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ABSTRACT
Hoffmann’s reflex (the H-reflex) is an electrically-induced reflex that is analogous to the mechanically-induced stretch reflex controlled by the spinal cord. The most common measurements performed concerns the electrical response of the soleus muscle to electrical stimulation in the tibial nerve. The response is induced by a discharge occurring in a motoneuron. The latency time of the H-reflex for the soleus muscle amounts to 30–40 ms. An increase in the strength of the stimulus induces a direct response from the muscle, i.e. the M-wave. The latency time of the M-wave amounts to 4–5 ms. A sport training may affect the parameters of the H-reflex. The Hmax/Mmax ratio is the highest among persons engaged in endurance sports and the lowest among those practising speed and strength sports. A decreased amplitude of the H-reflex characterises the level of the central fatigue, while a decrease in the M-wave amplitude is attributed to the peripheral fatigue. Usually, a decrease in Hmax/Mmax ratio is observed post-exercise. Different times of recovery were reported in the literature. No clear quantitative laws have yet been established that govern the course of the reflex as a result of fatigue. The H-reflex still remains within the scope of the interests of kinesiology as a valuable source of information about the reflex functions in the human motor system.

Key words: H-reflex, M-wave, central fatigue, peripheral fatigue, electrical stimulation
induces a response from the motor (efferent) fibres of the nerve, which in turn induces a response from the muscle, i.e. the M-wave (1). The latency time of the M-wave amounts to 4–5 ms. A further increase in the current will lead to an increase in the amplitude of the M-wave up to the maximal value; whereas the H-reflex decreases until it disappears completely. The main cause for this phenomenon is the antidromic wave (1*), which is formed through a stimulation performed with a high current that travels along the nerve fibres toward the spinal cord and causes a collision with the stimulus that induces the H-reflex. As a result, the H-reflex disappears. Based on these phenomena, the recruitment curve of the H-reflex and the M-wave can be drawn, as is presented in Figure 2.

A further increase in the intensity of the stimulus may also induce what is referred to as the F-wave, at a latency that is similar to that of the H-reflex. The F-wave occurs as a secondary response to the volley of antidromic action potential in the activated motor nerves.

The recruitment curve is most frequently used to analyse the maximal amplitude of the M-wave (Mmax), which represents the activation of the motor pool, i.e., a maximal stimulation of the muscle. The M-wave can also be used to determine the level of the patient’s peripheral fatigue [8]. Another parameter that can be useful for the analysis is the maximal amplitude of the H-reflex (Hmax), which may help to assess the number of motoneurons that have been activated by means of the reflex under a set of given conditions. The amplitude of the H-reflex characterises the level of the patient’s central fatigue [9]. In turn, the ratio of these two parameters (Hmax/Mmax) indicates the proportion between the motoneurons that can be activated by means of the reflex and the total number of neurons in the motor pool. In addition to the aforementioned parameters which can be determined based on the recruitment curve, other frequently analysed parameters include the latency time [10]. In the literature, the latency time is usually measured from the artefact of the stimulus to the deflection from the baseline [11]. However, the point at which the deflection from the baseline occurs is usually difficult to establish. As one example, Mazur-Różycka et al. [12] measured the latency time first from the artefact of the stimulus (A) to the point at which the M-wave crosses the baseline (B), and then from the H-reflex (C) to the baseline (the blue line at 0, see Figure 3).

**Measurement of the H-reflex**

The activity of the soleus muscle is determined using an EMG, usually with two bipolar surface electrodes located about 2 cm from each other, as SENIAM (Surface ElectroMyoGraphy for the Non-Invasive Assessment of Muscles) recommends.

Before the electrodes can be placed on the muscle, the skin should be shaved, exfoliated, and washed with a disinfectant. Any impedance between the electrodes should not exceed 5 kΩ. The grounding electrode is usu-
 ally placed on the head of the fibula. To elicit the H-reflex and the M-wave, the tibial nerve is then stimulated in the popliteal fossa. Usually, a 1-ms square-wave stimulus pulse is delivered [12, 13]. In order to obtain the recruitment curves for the H-reflex and the M-wave, the current is systematically increased by 1.2–2.5 mA every 5–8 s until the H-reflex disappears, after which time it is increased by 5–10 mA until the Mmax is reached. Some researchers [14] prefer to increase the impulse by 0.05 or 0.10 MT (the threshold intensity for inducing an M-wave). However, this requires the threshold to be determined first.

During the stimulation, the cathode (1.5 × 1.5 cm) is placed at the stimulation site in the popliteal fossa (Figure 4), and the anode (5.0 × 8.0 cm) is placed over the patella.

Measurement position

One factor that should be taken into special consideration is the patient’s position during the measurement, which may significantly affect the parameters of the H-reflex [15]. Therefore, the angles at the hips, knees and ankle joints, as well as the position of the head, and the audio and visual stimuli must be standardised for this measurement. The H-reflex is usually measured with the patient in a sitting or lying position [16–18]. However, some researchers have also used a standing position [19]. Kimura [20] states that a lying position (0° flexion at the hip joint, 30° flexion at the knee joint, and 30° plantar flexion at the ankle joint) will help to keep the muscles of the lower leg relaxed. Research has also shown that a plantar flexion of the ankle joint will increase the excitation of the motor pool for the soleus muscle; whereas a dorsiflexed ankle joint will impede the motor pool [21]. The amplitude of the H-reflex can also be affected by the tonic neck reflexes [22], which is why the head should be supported during the measurement.

Despite this, the literature remains inconclusive on what measurement position is the most suitable for the assessment of the H-reflex. Measurements of the excitability of the soleus muscle are variously taken in a prone position [18, 23], supine [24], sitting [25], or a standing position [26], as well as in a standing position while wearing unstable footwear [27]. This study involved measurements in two positions (a standing position with an equal load on both legs and a prone position). However, previous studies found that when a standing position was used instead of a lying one, the amplitude of the H-reflex either decreased [3, 28] or remained the same [29]. A higher amplitude of the H-index (Hmax) was observed in a lying position than in a standing one, which is consistent with studies conducted by other authors [30]. Kim et al. [19] observed a lower ratio of the Hmax and Mmax (Hmax/Mmax) in a standing position (under a load on both one leg and on two legs) than in a lying position. This effect was also confirmed in the first stage of this study. Furthermore, research has observed changes in the amplitude of the M-wave which so far have not been clearly confirmed under resting conditions [19, 31].

The results of this study confirm those obtained in a study by Takahara et al. [31], in which all of the measured parameters (Hmax, Mmax, and Hmax/Mmax) were significantly lower in a standing position than in a prone one. However, it has been speculated that the above measurement could not have been conducted until the Mmax was reached, which may have been affected by a high current in the final stage of the research that caused the patients’ discomfort.

The excitability of the motoneurons may change under different conditions, depending on spinal and supraspinal factors. The effect of these factors is considered as one of the main causes for the decrease in the H-reflex amplitude in the soleus muscle when the patient is standing or walking, as this decrease takes place through a presynaptic inhibition [32]. Other sources of H-reflex inhibition can include changes to the entry points of the peripheral muscle receptors of the feet or the receptors of the ankle joint [33, 34]. The literature also indicates that swaying has an effect on the amplitude of the H-reflex when measurements are conducted in a standing position. The differences in such amplitudes reached as much as 14% [35]. Furthermore, studies have indicated that a decrease in the Hmax/Mmax ratio in the soleus muscle (by about 12%) occurs when the patient is bent forward, compared to a backward bend in a standing position [36]. The research results provided in the literature clearly indicate that the measurement position has a considerable effect on the parameters of the H-reflex, and prove that a standing position is not suitable for the measurements. This is especially true for those
measurements conducted after exercise, when the patient may find it difficult to maintain a stable (unchanging) position during the subsequent measurements due to fatigue.

It seems that the most comfortable position for the patient during the measurement of the H-reflex in the soleus muscle is the prone position, with the head resting against a special depression in the couch, and the upper limbs aligned symmetrically, parallel to the trunk.

Applications of the Hoffman’s reflex measurement

The M-wave can be induced in any muscle in which a nerve is available for stimulation. However, inducing the H-reflex in many muscles is either impossible or is very difficult. The most commonly assessed muscles of the lower limbs that display the H-reflex are the soleus muscle [37–40] and the gastrocnemius muscle [5, 41, 42]. While the H-reflex is very difficult to observe in the upper limbs, some researchers have shown that it can be induced for the flexor carpi radialis muscle [43–47] and the extensor carpi radialis muscle [43, 46].

Many factors can affect the parameters of the H-reflex. Among them are the patient’s gender [48], age [49, 50], measurement position [25, 51], muscle tension [52], body temperature [53] and the anthropometric parameters [11, 54]. The highest changes in the H-reflex parameters were observed in patients over the age of 40 years. Due to differences in their body build, measurements conducted in women require a higher current to induce the H-reflex, which may cause discomfort to the patients. Furthermore, the latency time of the H-reflex is longer in men than it is in women, primarily due to the length of the lower limbs. Additionally, Murata et al. [23] suggest that among women, the Hmax/Mmax ratio can be more variable, for instance due to the menstrual cycle. A significant positive correlation between the latency time and the lower limb length has also been confirmed [11].

The H-reflex is frequently measured to assess the monosynaptic reflex in, among others, stroke patients [47] and healthy persons who do not engage in sport [39, 55]. Researchers have also observed that sport training may affect the parameters of the H-reflex; hence, a growing number of studies in the literature are being conducted among athletes engaged in endurance sports [37], as well as in speed and strength sports [5, 41]. For example, Casabona et al. [41] compared the H-reflex in the soleus and gastrocnemius muscles between persons engaged in speed and strength sports (sprinting and volleyball) and persons not engaged in a sport. They observed that the mean Hmax/Mmax ratio was lower among the former group than among the latter one, which was caused by a lower amplitude of the H-reflex. Maffiuletti et al. [37] compared persons who were engaged in speed and strength sports with persons engaged in endurance sports, and with persons not engaged in a sport. They observed that the Hmax/Mmax ratio was the highest among the persons engaged in endurance sports and was the lowest among the persons engaged in speed and strength sports.

Other studies have investigated changes in the amplitude of the H-reflex during various types of contractions of the soleus muscle [56, 57]. In one study, Duclay and Martin [58] obtained the lowest value of the Hmax/Mmax ratio during the eccentric contraction; whereas the isometric and concentric contractions showed a similar ratio. The effect of different types of training on the amplitude of the H-reflex has also been researched. Aagaard et al. [7] analysed the amplitude of the H-reflex following a 14-week programme of endurance training. They observed a 20% increase in the amplitude of the H-reflex following the training. Furthermore, Vila-Chá et al. [59] compared the effect of a 3-week strength training and endurance training programme. They found that the amplitude of the H-reflex for the soleus muscle increased significantly among those persons who participated in strength training. However, no such increase was observed among the persons who participated in endurance training. Further attempts have been made to analyse the parameters of the H-reflex during a drop jump from a particular height among persons of different ages [40, 60, 61]. Other studies have analysed the changes in the amplitude of the H-reflex during different times of day. No daily changes were observed for the responses of the flexor carpi radialis muscle [44–46]. On the other hand, the soleus muscle showed a significant increase in the amplitude of the H-reflex after 12 hours [45]. This indicates that future research on the H-reflex in the soleus muscle should be conducted under the same conditions and at the same time of day for all of the participants.

As was mentioned above, the M-wave can be used to determine the level of the patient’s peripheral fatigue [8], which is defined as a post-exercise reduction in the ability of muscles to create power or strength [62, 63]. Peripheral fatigue builds up gradually during exercise [64], and depends on the duration and intensity of the exercise [65]. Moreover, during short, intense exercise, the amplitude of the M-wave decreases. This effect may be caused by a decrease in the sodium and potassium ion gradients between the membranes due to the activation of the sodium-potassium pump. During long-term exercise, changes in the course of the M-wave are minute, which suggests that the excitability of the sarcolemma has an insignificant role in limiting the efficiency of such activity. Froyd et al. [66] showed that during exercises of different intensities, the neuromuscular functions decreased during the first 40% of the duration of the exercise, and then gradually returned between 1–2 minutes after the exercise. Froyd et al. confirmed the results obtained by other authors [67, 68] and suggested that measurements of the muscle functions should be conducted directly after exercise. However,
some other studies have recommended conducting measurements during breaks of 3–10 minutes between periods of exercise [69] or between 2–4 minutes after the exercise [70].

The analysis of the literature showed that the maximal amplitude of the H-reflex during rest amounts to about 50–60% of the maximal amplitude of the M-wave for the soleus muscle [16, 52], and to 25% for the gastrocnemius muscle [51]. Maffiuletti et al. [37] conducted a study on the excitability of the soleus muscle among persons who engaged in endurance sports, persons who engaged in speed and strength sports, and persons who did not engage in a sport. They showed that the amplitude of the H-reflex was the highest among those persons who engaged in endurance sports (4.15 ± 2.99 mV) and was the lowest among those who engaged in speed and strength sports (2.37 ± 0.98 mV). Also, the mean amplitude of the M-wave was the highest among the persons who engaged in speed and strength sports (6.86 ± 3.57 mV) and the lowest among those who engaged in endurance sports (6.24 ± 4.45 mV). No significant differences were found between the values of the analysed parameters within the individual groups of persons. However, a statistically significant difference in the Hmax/Mmax ratio occurred between the persons who engaged in endurance sports and those who engaged in speed and strength sports. The amplitude of the H-reflex among the persons who did not engage in a sport amounted to 5.70 ± 2.50 mV [71]. The Hmax/Mmax for this group amounted to about 45% [71] or 51% [72], although some studies reported a value of about 70% [30]. Some authors also reported that the H/M ratio decreased after exercise [73, 74]. However, in most studies, either the MVC test [74–76] or the jump up on an inclined surface test [40] were used as the exercise that the participants were asked to perform.

The parameters of the H-reflex change significantly as a result of physical exercise. Usually, no changes in the amplitude of the M-wave following exercise are observed compared to the measurements taken during rest [8, 77]. However, some studies report that long periods of exercise with a low strength of contraction can affect the amplitude of the M-wave [78, 79]. In these cases, the amplitude decreased directly after the exercise and then quickly returned to its resting values 10 minutes afterwards [80].

The literature also widely discusses changes in the amplitude of the H-reflex after various types of exercise [81]. For instance, a 30-minute walk on a treadmill was shown to cause a short-term decrease in the amplitude of the H-reflex among healthy adults [82]. Phadke et al. [83] also observed the effect of a 20-minute walk on the decrease in the amplitude of the H-reflex due to the presynaptic inhibition. Studies also show that the amplitude of the H-reflex may return to its resting values as quickly as a minute following exercises on a cycloergometer [57].

**Conclusions**

It is surprising that, despite the 100-year history of research that has been performed on the H-reflex, no clear quantitative laws have yet been established that govern the course of the reflex as a result of fatigue. The studies have often provided contradictory results. The reason for this can be assumed to stem from the presynaptic inhibition, which depends to a great extent on the different research conditions. There are also many unexpected external factors that can affect the H-reflex, such as the phase of the menstrual cycle in women, the position of the patient’s head during the measurement, or other movements performed by the patients. Perhaps the affinity between the H-reflex and the stretch reflex is only qualitative, since in the case of the former (in contrast to the latter) an electrical stimulus activates the afferent as well as the efferent pathways. Antidromic waves appear and cause echoes. Therefore, the observed response of the motoneuron is not as simple or as obvious as in the stretch reflex. All these facts indicate that this phenomenon requires further research. Nonetheless, the H-reflex still remains within the scope of the interests of kinesiology as a valuable source of information about the reflex functions in the human motor system. The parameters of the H-reflex constitute potential indicators that could help researchers to differentiate between the overlapping effects of central and peripheral fatigue.

**References**


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**Correspondence address**
Jan Gajewski
Akademia Wychowani Fizycznego
Józefa Piłsudskiego
ul. Marymoncka 34
00-968 Warszawa, Poland
e-mail: jan.gajewski@awf.edu.pl
TWO AEROBIC EXERCISE PROGRAMS IN MANAGEMENT OF BACK PAIN AMONG MIDDLE-AGED OBESE WOMEN: A RANDOMIZED CONTROLLED STUDY

ABSTRACT

**Purpose.** Back pain is a frequent symptom in the obese. The purpose of the study was to compare the effects of two training programs on the reduction of back pain among obese women. **Methods.** The study included 30 obese women who reported back pain within 3 months preceding enrollment. The subjects were randomly allocated to endurance or endurance/resistance physical exercise. The intensity of the exercise was adjusted to 50–80% of HRmax. Back pain intensity, muscle strength of knee flexors and extensors, body balance and body composition were measured before and after training. **Results.** Both the endurance and endurance/resistance training exerted positive effect on back pain ($p < 0.05$). Similarly, in both training groups the significant increase in the strength of knee flexors and marked reduction of body fatness ($p < 0.001$ for all) were documented. However, the interventions’ efficacies in selected groups did not differ. **Conclusions.** Both endurance and combined endurance/resistance training exert positive effect in decreasing back pain and improving functional fitness of obese women. Therefore, both forms of training may be recommended for individuals dealing with the abovementioned problems.

Key words: aerobic exercise, back pain, obesity

Introduction

Most back pain-related problems are non-specific [1, 2], and a small percentage (5 to 10%) of people suffering from back pain develops chronic pain. Heavy physical strain, repetitive lifting, age, gender, smoking, static positioning, previous history of pain, physical fitness, and genetics have also been well-documented risk factors for back pain [3]. Hue et al. has also reported on different spinal pathology-associated problems in obese persons [4].

The relation between obesity and functional impairment of the spine, secondary to weakness and stiffness of muscles, leading to back pain while performing such daily activities as standing up, walking, getting up, and running was already observed [5–8]. A significant positive association between Body Mass Index (BMI) and risk of low back pain was found in analyses adjusted for age, education, work status, physical activity at work and in leisure time, smoking, blood pressure, and serum lipid levels [9]. Also Payne et al. [10] indicated that physical fitness (muscle strength and endurance) and participating in physical activity were significantly higher among people with no history of low back pain than among those who suffered from this condition.

The multitude of potential causes of back pain inspires research on various forms of its prevention and treatment. Regular physical exercise and good mental health both have a protective effect. Physical exercise helps to keep the musculoskeletal system in shape and maintain psychological well-being [11]. Physical exercises may, in some aspects, be particularly important for women. Groessl et al. observed that exercising women had larger decreases in depression and pain and larger increases in energy than men [12].

The issues related to the rehabilitation of the spine were also studied by Demirel et al. [13], Sorensen et al. [14], and Lewandowski et al. [15], who suggested that physical exercise accompanied by other therapeutic methods, e.g. education or physiotherapy, can markedly reduce the demand for pharmacotherapy. As noted by Oldervoll et al. [16], increased body awareness is one of the consequences of programs designed to promote physical fitness, which may be of therapeutic importance in the treatment of every type of pain [17]. On the other hand, some authors have failed to find any effect of physical exercise on musculoskeletal pain [18–20]. Still, it is difficult to determine which specific components are the most important for back pain reduction.
Grønningsæter et al. [18] did not find any correlation between pain reduction and increased aerobic fitness. This suggests that aerobic fitness has no important role in musculoskeletal pain management. On the other hand, Larivière et al. [21] claim that poor aerobic fitness is an important factor in the development of musculoskeletal pain. To the best of our knowledge, there are no studies comparing two different training programs aimed at reducing back pain in obese women.

The purpose of the present study was to compare the effects of two aerobic training programs on reduction in back pain among obese women. One exercise program was aimed exclusively at improving cardiovascular fitness (aerobic fitness), whereas the other was designed to improve both muscle strength and fitness. Thanks to the anticipated stronger effect of resistance exercise on muscle tone, it was possible to assume that this training program will be more effective in improving the functional ability of obese women than endurance exercise. Furthermore, strengthening the muscles should help reduce back pain.

Material and methods

Informed written consent was obtained from all subjects, and the study was approved by the Ethics Committee of Poznan University of Medical Sciences, registered as case no. 1077/12 with supplement (no. 753/13). The privacy rights of human subjects were observed. The study was carried out in accordance with the revised Declaration of Helsinki of 1975 and the Uniform Requirements for Manuscripts Submitted to Biomedical Journals. The study included 30 subjects aged 37 to 62 years (mean 49.8). We identified women who had reported obesity (BMI above 30 kg/m²) and had incidence of back pain during the last 3 months prior to the beginning of study (Table 1). The participants were randomly assigned to Group E – with endurance intervention (N = 15) or Group M – mixed, endurance with resistance exercises (N = 15).

Measurements

Measurements of muscle strength of the knee flexors and extensors were taken on a UPR-02 A/S chair with Moment II by Sumer software (Sumer, Opole, Poland) [22, 23]. The study was performed in a sitting position, with stabilization of the thighs and trunk. Isometric knee extension torque was measured in both settings, with a knee joint angle of 90° (0° full extension) and a hip angle of 85° (0° supine position).

Balance was measured by having the subject stand on one leg with eyes open (balance with feet fixed). The subject stood on one leg for as long as she could, or until she was told to stop. Timing started when the foot was lifted, and stopped when the foot was placed on the ground, a hand touched a chair/table, the foot moved, or 30 seconds have passed.

Fat mass (%) was determined by impedance analysis using a Bodystat analyzer (1500 MDD; Bodystat, Isle of Man, UK).

Procedure

The 3-month intervention consisted of a physical exercise program including 3 sessions of training per week (on Mondays, Wednesdays, and Fridays). A total of 36 training sessions were carried out in each group. Training was performed under the supervision of a qualified fitness instructor and at least one investigator in a professional training room. Subjects were divided randomly into two groups (E – endurance and M – mixed) based on the type of training. Group E underwent endurance training on cycle ergometers (Schwinn Evolution, Schwinn Bicycle Company®, Boulder, Colorado, USA). Training sessions consisted of a 5-minute warm-up (stretching exercises) of low intensity (50–60% of maximum heart rate); 45-minute training, at an intensity between 50–80% of maximum heart rate; 5-minute cycling without load, and 5-minute closing stretching and breathing exercises of low intensity. Group M underwent endurance–resistance training which consisted of

<table>
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<th>Max.</th>
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BMI – body mass index
a 5-minute warm-up (stretching exercises) of low intensity (50–60% of maximum heart rate), a resistance component, an endurance component, cycling without load, and closing exercises. The resistance component involved 20 minutes of resistance exercise with a neck barbell and stability ball. To allow muscle power to regenerate, the resistance component was variable and repeated regularly every week. On Mondays, upper limb exercises were performed with a neck barbell; Wednesday sessions involved spine-stabilizing exercises, deep muscle strengthening exercises, and balance-adjusting exercises with a stability ball; on Fridays, lower limb exercises with a neck barbell were carried out. The exercises were repeated in series. The number of repetitions of each exercise in the series was dependent on the subjects' muscle strength and was equal to the number of repetitions performed correctly. The number of repetitions was systematically increased with increasing subjects' muscle strength. Between the series of resistance exercises, 10–15 second regeneration pauses were taken, during which subjects performed isometric exercises. Directly after the resistance exercises, subjects underwent 25 minutes of endurance exercise on cycle ergometers (Schwinn Evolution, Schwinn Bicycle Company®, Boulder, Colorado, USA) of intensity between 50–80% of maximum heart rate, 5 minutes of cycling without load, and 5 minutes of closing stretching and breathing exercises of low intensity. Heart rate during training was monitored with a Suunto Fitness Solution® device. Both training programs were comparable in exercise volume, and varied only in the nature of the effort.

Statistical analysis

Statistical analyses were performed using Statistica 10 software (StatSoft Inc., Krakow, Poland) and statistical significance was defined as \( p < 0.05 \). ANOVA was used to determine the significance of differences between groups E and M, and for the analysis of variation between pre-test and post-test results. The analysis with two levels of the first factor (within-subject factor: "training" – pre-test, post-test) and two levels of the second factor (between-subject factor: "group" – endurance or endurance/resistance training) was performed. For interaction effects, the \( \eta^2 \) (\( \eta^2 \)) effect size was calculated. \( \eta^2 \) can be defined as the proportion of variance associated with or accounted for by each of the main effects, interactions, and error in an ANOVA study. It was also used to calculate the power of significant effects. Pearson chi-square statistics were used to identify the potential differences between the kinds of training and changes in back pain.

Results

Changes in the well-being of the studied women represented important response to training. Both types of training, endurance and endurance/resistance, exerted beneficial effect on back pain (\( p < 0.05 \)). Similarly, in both training groups the significant increase in the strength of knee flexors and marked reduction in body fatness (\( p < 0.001 \) for all) was documented. However, the interventions’ efficacies in selected groups did not differ. As many as 70% of women participating in the training reported a lack of pain during the three months of the program, and 30% still complained of back pain (Table 2).

Neither of the two types of training caused significant changes in the strength of knee joint extensors (Figure 1 and 2). Furthermore, we did not observe significant intergroup differences with regard to this variable. In contrast, the significant (\( p < 0.01 \)) increase in the strength of knee flexors (Figures 3 and 4) was documented in both training groups (\( F = 23.30, p = 0.001, \eta^2 = 0.45 \) for the left, and \( F = 18.48, p = 0.001, \eta^2 = 0.39 \) for the right leg). Therefore, the effect of the training proved to be strong but limited to muscles which are usually considered as weaker, i.e. the knee flexors rather than the extensors.

Participants from groups E and M did not differ significantly in terms of training-induced changes. No significant results of the training were documented in body balance measured during the single stance test. The time of standing on both left (Figure 5) and right (Figure 6) leg did not change significantly in response to either training regimen. Moreover, we did not observe significant differences in body balance response to endurance and endurance/resistance training.

The fact that participation in both training programs was reflected by marked reduction in body fatness (\( F = 25.90, p = 0.001, \eta^2 = 0.48 \)) and BMI (\( F = 33.12, p = 0.001, \eta^2 = 0.55 \)) should be considered positive, as baseline analysis of body composition revealed high values of this parameter in the studied women. However, the results of the training in groups E and M proved equally positive (Figure 7 and 8).

<table>
<thead>
<tr>
<th>Group</th>
<th>Pre</th>
<th>Post</th>
<th>Chi²</th>
<th>( p )</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pain</td>
<td>Lack of pain</td>
<td>Pain</td>
<td>Lack of pain</td>
</tr>
<tr>
<td>Group E (N = 15)</td>
<td>100% (N = 15)</td>
<td>0% (N = 0)</td>
<td>66.7% (N = 10)</td>
<td>33.3% (N = 5)</td>
</tr>
<tr>
<td>Group M (N = 15)</td>
<td>100% (N = 15)</td>
<td>0% (N = 0)</td>
<td>73.3% (N = 11)</td>
<td>26.7% (N = 4)</td>
</tr>
<tr>
<td>Total</td>
<td>100% (N = 30)</td>
<td>0% (N = 0)</td>
<td>70.0% (N = 21)</td>
<td>30.0% (N = 9)</td>
</tr>
<tr>
<td>( p )</td>
<td>( p &gt; 0.05 )</td>
<td>( p &gt; 0.05 )</td>
<td>( p &gt; 0.05 )</td>
<td>( p &gt; 0.05 )</td>
</tr>
</tbody>
</table>
Figure 1. Changes in the muscle strength of the left knee extensors among women from “E” and “M” groups

Figure 2. Changes in the muscle strength of the right knee extensors among women from “E” and “M” groups

Figure 3. Changes in the muscle strength of the left knee flexors among women from “E” and “M” groups

Figure 4. Changes in the muscle strength of the right knee flexors among women from “E” and “M” groups

Figure 5. Changes in the body balance on left leg among women from “E” and “M” groups

Figure 6. Changes in the body balance on right leg among women from “E” and “M” groups
Additional information was obtained by the use of multiple regression analysis. Because of the multifactorial determinants of back pain, attempts to introduce all measured variables to the regression equation were being undertaken. The most optimal model built to measure changes in back pain includes 9 variables, but only changes in these variables “the body balance on left leg before training”, “pain on the left side before training”, “BMI before training”, “changing in strength of the right knee flexor after training” are, though rather small, statistically significant (Table 3). Correlation of changes in the dependent variable (pain) with the observed independent variables is small, on the verge of statistical significance (R = 0.842, F = 2.98, R² = 0.709, p = 0.045).

Discussion

Our findings raise hopes for better functioning of obese women with concomitant back pain. Although we expected significant differences between the effects of both training regimens on subjectively assessed back pain in women from groups E and M, marked improvement documented in most participants from both groups should be considered as a highly positive finding. We did not confirm the hypothesis that endurance training combined with resistance exercise exerts more favorable effects on functional fitness and reduction in back pain than purely endurance training. Nevertheless, women from groups E and M obtained higher well-being scores, better fitness and lower body fatness. It should be regarded as a positive determinant of their health [24]. As shown by Brown et al. [25], each reduction of body weight is associated with lower risk of headaches, back pain, difficulty in sleeping, as well as with higher scores in physical functioning and general health. On the other hand, high values of body mass index and prevalence of emotional problems may predispose women to both acute and chronic low back pain [26], and participation in physical exercise exerts positive effect in terms of stress reduction. The role of physical activity in mitigating back pain risk is shown to be considerable in the overweight and obese populations [27, 28].

Table 3. Most appropriate multiple regression model for the disappearance of back pain (Δ) among all women trainees.

<table>
<thead>
<tr>
<th>Source</th>
<th>B</th>
<th>SEB</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constants</td>
<td>0.85</td>
<td>1.21</td>
<td>0.498</td>
</tr>
<tr>
<td>Body balance on left leg before training</td>
<td>0.02</td>
<td>0.01</td>
<td>0.011</td>
</tr>
<tr>
<td>Changing after training of the right knee extensor strength</td>
<td>0.01</td>
<td>0.01</td>
<td>0.134</td>
</tr>
<tr>
<td>Left knee extensor strength before training</td>
<td>0.01</td>
<td>0.01</td>
<td>0.409</td>
</tr>
<tr>
<td>Pain on the left side before training</td>
<td>0.75</td>
<td>0.28</td>
<td>0.023</td>
</tr>
<tr>
<td>BMI before training</td>
<td>0.16</td>
<td>0.06</td>
<td>0.019</td>
</tr>
<tr>
<td>Fat% before training</td>
<td>0.09</td>
<td>0.05</td>
<td>0.107</td>
</tr>
<tr>
<td>Changing after training of the right knee flexor strength</td>
<td>0.03</td>
<td>0.01</td>
<td>0.021</td>
</tr>
<tr>
<td>Right knee extensor strength before training</td>
<td>0.01</td>
<td>0.01</td>
<td>0.080</td>
</tr>
<tr>
<td>Changing after training of the left knee flexor strength before training</td>
<td>0.01</td>
<td>0.01</td>
<td>0.153</td>
</tr>
</tbody>
</table>

R = 0.842, F = 2.98, R² = 0.709 p = 0.045

BMI – body mass index, SEB – standard error of coefficient, B – Beta coefficient
Therefore, the fact that 33.3% of overweight women from group E and 26.7% from group M declared the back pain had disappeared should be considered a positive effect of both types of training. However, the participation in the exercise programs might not have been the only factor that induced such positive changes among obese women. The increase of muscle strength in exercising women constitutes potential biological rationale for such interpretation. The changes were especially pronounced in the case of relatively weaker muscle groups, i.e. the knee flexors ($F = 14.34, p = 0.001, \eta^2 = 0.26$ for the left, and $F = 11.78, p = 0.001$ for the right leg). This is a very positive effect of the training since the imbalance between flexor and extensor strength can lead to improper muscle tonus, incorrect positioning of the lower limbs, and consequently pelvis and spine [29, 30]. Therefore, increased strength of these weaker muscles should be considered positive as it can be reflected by lower intensity of back pain. Dystonia muscle strength and concomitant disorders of balance can additionally predispose to decreased levels of everyday physical activity in obese individuals and be associated with back pain. Although we did not observe direct improvement of static balance, this aspect of functional fitness should be included in future experiments.

Taking into account the improvement of the frame of mind among obese women with back pain, we assumed that the proposed programs of training should enhance a reduction in body weight. The findings of Shiri et al. indicate that both obesity and a low level of physical activity are independent low back pain risk factors [31]. They suggest that a moderate level of physical activity is recommended for the prevention of low back pain, especially in obese individuals. Therefore, reduction in body fat was included among the endpoints of the present study. Although some researchers put into question the association between overweight, weight reduction, and back pain reduction. Garzillo and Garzillo [32] revealed a possible association between obesity and low back pain only in the upper quintile of obesity, and Brooks et al. [33] confirmed no evidence of a temporal relationship between changes in weight and low back pain. Nevertheless, our findings suggest that reduction in body weight is associated with decreased prevalence of back pain. Also Heuch et al. [9] observed a significant positive association between BMI and low back pain risk. Weight reduction is associated with decrease in low back pain [24]. The loss of every kilogram of body weight translates into lower load on the lower limbs and spine. This in turn facilitates maintaining correct posture during various activities of daily living.

Conclusions

It is to conclude that both endurance training and combined endurance/resistance training exert a positive effect leading to decreased back pain and improved functional fitness of obese women. Therefore, both forms of training may be recommended for individuals affected by the abovementioned problems.

Authors contribution

JM and JK conceived the study, made substantial contribution to its design, performed the statistical analysis and drafted the manuscript. DS and MR participated in the design of the study and helped to draft the manuscript and carried out the data acquisition. JW, WO and RS critically revised the manuscript for important intellectual content. PB and EM coordinated the study and critically revised the manuscript for important intellectual content. All authors have read and approved the final manuscript.

Statement of Interests

The authors report no personal or funding interests. All authors declare no actual or potential conflict of interest including any financial, personal or other relationships with other people or organizations within three years of beginning the submitted work that could inappropriately influence, or be perceived to influence, their work.

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Disclosures

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**Correspondence address**
Damian Skrypnik
Department of Internal Medicine, Metabolic Disorders and Hypertension
Poznan University of Medical Sciences
ul. Szamarzewskiego 84
60-569 Poznan, Poland
e-mail: damian.skrypnik@gmail.com
VERBAL INSTRUCTIONS ON LEARNING THE FRONT-CRAWL: EMPHASIZING A SINGLE COMPONENT OR THE INTERACTION BETWEEN COMPONENTS?

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MARIA TERESA DA SILVA PINTO MARQUES-DAHI*, FLAVIO HENRIQUE BASTOS†, ULYSSES OKADA DE ARAUJO†, CINTHYA WALTER‡, ANDREA MICHELE FREUDENHEIM†

† School of Physical Education and Sport, University of São Paulo, São Paulo, Brazil
‡ Federal University of Maranhão, São Luís, Brazil

ABSTRACT

Purpose. In Front-Crawl swimming stroke, the interaction between two of its components, i.e. arm stroke and breathing, affects the performance of the motor skill as a whole and therefore can be considered a critical aspect of the skill. The purpose of our study was to investigate if a verbal instruction emphasizing this interaction could lead to learning gains when provided along with video demonstrations.

Methods. Participants (children) were randomly assigned to three experimental groups according to the type of verbal instruction provided. Component and Interaction groups received their specific instructions along with video demonstrations of a model execution of the Front-Crawl. The Control group watched the same video, but received no further instruction concerning the movement pattern. In the Acquisition phase (AQ) all groups performed 160 trials (organized in 4 sessions) of the task that consisted in swimming 8 meters the Front-crawl at a comfortable velocity. To assess learning gains, a retention test (RT) and a transfer test (TR) were carried out one week after the end of the AQ.

Results. Regarding RT and TR, the one-way ANOVA on the movement pattern score showed a significant difference between groups, with post-hoc tests revealing that the Interaction group achieved higher score than the Control group.

Conclusions. The results reveal that enhancing aspects of a video demonstration with verbal instruction improves learning gains of the Front-crawl in children. Additionally, the results suggest that providing verbal instructions about the interaction between stroke and breathing might promote learning gains, compared to providing instructions about the stroke component individually.

Key words: motor learning, swimming, observational learning, verbal cues, ecological validity

Introduction

Efficient performance in Front-Crawl swimming has been associated with the pattern of interaction between the action of the arms in skilled swimmers [1]. The importance given to this pattern of interaction is due to the fact that it modifies the ability to produce propulsion and, therefore, a swimmer’s efficient forward movement [2]. Although the arm stroke is the most investigated component of the Front-Crawl, since it produces about 90% of the swimming propulsion [3, 4], when considering the learning process it is essential to take other components into account [5]. A beginner, still refining their movement pattern, performs relatively inefficient body movements that generate more hydrodynamic resistance compared to an experienced swimmer [6].

In addition to emphasizing aspects that have the potential to produce hydrodynamic resistance, considering that the other components, besides the arm stroke, can also emphasize effects that one component has on another one, i.e. interdependence between them. For example, breathing can affect arm stroke efficiency [7–9]. In less skilled swimmers, breathing affects the relationship between the arms increasing the discontinuity of the forward movement [8, 9]. Furthermore, breathing can modify the timing [7], as well as the symmetry between arm strokes [8] in less proficient swimmers. Thus, considering the importance of the stroke to produce propulsion, the interdependence between arm strokes and breathing is a determinant factor of the swimming performance. In this sense, one could argue that the learning of the Front-Crawl could be enhanced by the use of instructions highlighting the interaction between these two components. Moreover, if the aim of an instruction is to convey information about ‘what to do’ and ‘how to do it’ [10], critical elements should be included to guide the learner towards an optimal movement pattern. In the case of the Front-Crawl, although breathing and arm strokes can be clearly identified as important components because of their contribution to performance (as shown above), it is not clear how they should be addressed during the learning phase is taking place. In other words, although their importance and interdependence is hard to question when it comes to performance, it is not clear whether the interaction between them is a critical element worth highlighting when the motor skill ‘Front-Crawl’ is being learned.

Studies investigating the effect of verbal instructions on the learning of complex motor skills are scarce. Regarding the effect an instruction emphasizing interac-
tion can have in the learning of a motor skill, Masser [11] conducted an experiment to investigate the effects of two verbal instructions (cues) on the learning of the forward roll. Two groups received either of the two cues: ‘forehead on knees’ or ‘keep yourself in a tight ball’. Both groups practiced the motor skill for three weeks and were tested two months after the end of an acquisition period (retention test). The group receiving the cue considering the interaction between two body parts (‘forehead on knees’) showed superior performance in the retention test. In a study carried out by Wulf and Weigelt [12], participants learned how to perform oscillatory movements on a ski simulator. Specifically, the task involved moving the platform of the ski simulator rhythmically as far as possible left and right. The results indicated that the group receiving verbal instruction about the mechanical principles of the skill (the moment one should apply force on the platform to maximize performance) showed lower movement amplitude (worse performance) than the group without this instruction. The authors concluded that providing verbal instruction about mechanical principles of the skill considered difficult to verbalize can be detrimental to learning. In this sense, in order to be effective, a verbal instruction should not only highlight the critical aspect of the skill being learned, but also be structured in a way that is meaningful to the learners.

The aim of the present study was to investigate whether a verbal instruction emphasizing the critical aspect of the Front-crawl – i.e. the interaction between arm stroke and breathing – could lead to learning gains when provided along with video demonstrations. Specifically, the verbal instruction emphasizing the component ‘stroke’ was given to the Component group and the verbal instruction emphasizing the interaction between the components ‘stroke’ and ‘breathing’ (i.e. the moment during the stroke cycle in which the two components can be meaningfully linked together) was given to the Interaction group. Both groups received these instructions in addition to watching a video demonstration of the model task execution. Control group watched the same video, but received no further instruction concerning the movement pattern that characterizes the Front-Crawl.

Considering the interdependence between the components ‘stroke’ and ‘breathing’, we expected to observe better learning (retention and transfer) of the movement pattern for the Interaction group. Furthermore, we expected that both groups receiving verbal instruction (Interaction and Component), in addition to the video demonstration, would show better learning (retention and transfer) of the movement pattern than the group receiving only the video demonstration (Control group).

Material and methods

Participants

An invitation to participate in the research was published in a local newspaper of Atibaia city – State of São Paulo – and in leaflets distributed to private and public schools. We employed the following inclusion criteria: chronological age between 12 and 13 years, no prior experience with the task, and ability to perform basic aquatic skills: buoyancy, submersion and blow bubbles with the whole face in the water – respiratory control [13]. Reporting fear of water was an exclusion criterion. Out of the group of 90 children attending the initial meeting, 53 agreed to participate, but only 21 took part in the study submitting consent forms signed by their parents. There was only one dropout during the study, totaling 20 participants (8 boys and 12 girls, mean age = 12 years old, SD = 0.63) – Figure 1. The study was approved by the local Ethics Committee of the School of Physical Education and Sport – University of São Paulo.

Task and procedures

Participants were randomly assigned to three experimental groups, according to the verbal instruction provided. The Component group received instruction emphasizing only the ‘arm stroke’ component: ‘push the water back with your hand’. This verbal instruction was the same employed by Freudenheim et al. [14].

The verbal instruction provided to the Interaction group based on the one received by the Component group, but emphasized the interaction between ‘stroke’ and ‘breathing’. Specifically, the moment in the stroke cycle...
in which breathing should take place was added to the previous instruction: ‘push the water back with your hand and, at the end of the arm stroke, turn your face to breathe’. Participants allocated in the Control group did not receive any verbal instruction concerning the movement pattern. It is important to clarify that the instructions mentioned above were provided in Portuguese using ordinary expressions.

All groups, including the Control group, watched a video that showed a model execution of the Front-Crawl Stroke. This procedure was adopted considering the evidence supporting that verbal instruction combined with demonstration leads to more learning gains than when provided alone [15–18].

The experiment consisted of four phases: Entry Test (ET), Acquisition phase (AQ), Retention Test (RT) and Transfer Test (TR). Each AQ and test trials consisted in leaving an underwater platform, swimming 8 meters using the Front-Crawl at a comfortable velocity, and finishing the trial touching the edge of the pool. Participants performed all AQ and test trials individually, and were recorded performing the task with a camera Sony Cyber-Shot DSC-H9 (640 × 480 @30Hz) positioned laterally to the direction of the forward movement.

Before starting the ET, all participants were familiarized with the research environment by swimming freely from the starting platform to the edge of the pool three times. The ET consisted of five trials in which the participants were told to swim using the Front-Crawl – ‘as they knew it’ – without watching the video demonstration. This procedure aimed to ensure that all participants were in a similar condition before starting the experiment. The AQ consisted of four practice sessions (AQ1, AQ2, AQ3, and AQ4), ranging from two to three times a week, according to the availability of each participant. Each session comprised eight sets of five trials, with twenty seconds of interval between the trials and two minutes between the sets. In the AQ all groups performed a total of 160 practice trials.

Before starting each practice session, participants completed three trials of familiarization as described above, and then the video demonstration was shown three times. The verbal instructions for the Component and Interaction groups were provided at the beginning of each AQ session, between the video presentations and in the interval before each set of trials. At the end of each AQ session the Borg Scale of Perceived Exertion was applied to verify the fatigue level of the participants. Participants in the Interaction and Component groups were also asked to complete an attention questionnaire at the end of each session in which they answered ‘yes’ or ‘no’ to the question whether they had paid attention to the instructions provided. After the last practice session (AQ4), participants were instructed not to practice the task for a week. The RT, performed after this one-week interval, consisted of 10 trials with the same procedures as in the AQ but without any verbal instruction concerning the movement pattern or video demonstration. Before the test, participants were asked to recall the verbal instructions and video demonstrations provided in the AQ to perform the Front-Crawl. The TR began fifteen minutes after the end of the RT and followed the RT procedures, with no verbal instruction or demonstration provided. However, in the TR all participants were asked to swim as fast as possible in each trial, performing two sets of five trials and resting for one minute between the trials and five minutes between the sets. After the TR, participants’ height and weight were measured.

**Measures**

The score regarding the movement pattern (Score) and the time needed to complete the task were the dependent measures of interest. The Score was obtained from a Front-Crawl Stroke checklist [19]. The referred checklist includes an additional item that allows the evaluation of the head position, and removes items related to water entry, buoyancy and movement combinations from the originally proposed checklist. These changes aimed a better evaluation of the Front-Crawl stroke by minimizing items related to water adaptation. Arm propulsion and arm recovery were also merged in one new item that evaluates arm actions. Therefore, the checklist used in this study appraises the actions of five components of the Front-Crawl: body position, head position, breathing, arm actions and leg actions.

The recordings of the third and fourth stroke cycle of each trial were analyzed according to the checklist. Each Front-Crawl component was assessed and rated on a scale rating ranging from 1 to 5, corresponding to the least efficient movement pattern and the most efficient movement pattern, respectively. The percentage of occurrence of each rating, in each block, was multiplied by its corresponding relative ratio, from one to five, resulting in 5 values, one for each component. The Score of each participant, varying from a minimum of 100 to a maximum of 500, was produced by the sum of these 5 values, per block of trials.

All recorded trials were analyzed by one swimming coach expert using the above mentioned checklist. To evaluate intra-observer reliability, the expert reassessed all the ET trials one month after the first assessment. Reliability was measured with the Inter-Observer Agreement procedure – IOA – resulting in an agreement of 0.90.

The time needed to complete the task was registered by the experimenter with a digital chronometer, beginning when the participant left the starting platform and finishing when they reached the edge of the pool.

**Data analysis**

Homogeneity of variance (Levene’s test) and sphericity (Mauchly’s test) were verified before performing all analyses. One-way ANOVAs with repeated measures were performed for both dependent measures, for each
group and block (sessions) of the AQ (AQ1-AQ4) to verify performance improvements in practice. One-way ANOVAs were also performed for the anthropometric measures and for both dependent measures to compare groups in each test (ET, RT and TR). Sequential t-tests with False Discovery Rate correction [20] were employed as post hoc tests. Significance level was set at $\alpha = 0.05$.

The Borg Scale of Perceived Exertion data did not meet the assumptions for parametric analysis and the Kruskal-Wallis tests were carried out to verify the differences in perceived exertion. Data were organized, analyzed and plotted using R, a language and environment for statistical computing [21].

**Results**

**Complementary measures**

With respect to the attention questionnaire, all participants of the Component and Interaction groups reported paying attention to the verbal instructions provided.

No differences between groups were detected in perceived exertion (Borg Scale of Perceived Exertion) in any experimental phases, indicating comparable fatigue for all groups. Additionally, no differences between groups were found regarding height or weight, indicating that those anthropometric measures were similar for all groups.

**Movement Pattern**

No differences were found between groups in the ET, $F(2,17) = 0.06$, $p > 0.05$, $\eta^2 < 0.01$, indicating equivalent movement pattern at the beginning of the experiment for all groups (Figure 2).

With respect to the AQ, no differences were detected between blocks of trials in the Component or the Control group, $F(4, 24) = 1.98$, $p > 0.05$, $\eta^2 = 0.18$ and $F(4, 20) = 2.4$, $p > 0.05$, $\eta^2 = 0.20$, respectively. Conversely, a difference between blocks was detected in the Interaction group, $F(4, 24) = 9.12$, $p < 0.05$, $\eta^2 = 0.39$. The post hoc test revealed a lower Score in the first block compared to all the remaining blocks, indicating that participants in the Interaction group enhanced their performance in the AQ. As shown in Figure 3, throughout the AQ, the Interaction group ceased receiving ‘1’ (the lowest rating in the movement pattern checklist), reduced the percentage of ‘2’ and ‘3’ and increased the percentage of ‘4’ and ‘5’, suggesting a distinctive improvement in the movement pattern for this group compared to both Control and Component groups.

With regard to the RT, one-way ANOVA on the Score found a significant difference between groups, $F(2, 17) = 3.72$, $p < 0.05$, $\eta^2 = 0.30$, with post hoc tests revealing that the Interaction group achieved higher Score than the Control group. As can be seen in Figure 3, the Interaction group showed a lower percentage of low and intermediate ratings (‘1’, ‘2’ and ‘3’) and a greater percentage of higher ratings (‘4’ and ‘5’) compared to the other groups. Similar results were found for the TR. Specifically, a difference between groups was found, $F(2, 17) = 4.49$, $p < 0.05$, $\eta^2 = 0.34$, and post hoc tests indicated that the Interaction group achieved higher Score than the Control group. Despite the lack of statistical significance between the Score in the RT and the TR (Figure 2), a qualitative comparison between the Interaction and the Component groups reveals that the Component group showed a greater percentage of lower ratings compared to the Interaction group (Figure 3), which suggests a better movement pattern of the participants in the Interaction group.
Time to complete the task

With respect to the ET, one-way ANOVA found no differences between groups in the time needed to complete the task, $F(2, 17) = 0.11, p > 0.05, \eta^2 = 0.01$, indicating that all participants began the experiment swimming with similar efficiency. With regard to the AQ, repeated measures ANOVA found no differences in the time needed to complete the task for the component and Interaction groups, $F(4, 24) = 2.13, p > 0.05, \eta^2 = 0.06$ and $F(4, 24) = 1.04, p > 0.05, \eta^2 = 0.01$, respectively. A difference between blocks was found for the control group, $F(4, 20) = 5.29, p < 0.05, \eta^2 = 0.13$, but the post hoc test was unable to locate the differences. Although the Interaction group showed better performance compared to both Control and Component groups in the RT and TR tests (Figure 4), one-way ANOVA found no differences between groups regarding the time needed to complete the task.

Discussion

The present study aimed to investigate whether verbal instructions focusing on different elements of the Front-crawl would affect the learning of the motor skill. The study was based upon two premises: (1) a verbal instruction provided along with demonstrations of the motor skill being learned is more efficient if constituted by critical elements of this motor skill; (2) the interdependence between breathing and stroke can be considered a critical element of the Front-crawl, given the effect the former has on the latter [7–9]. Thus, we expected to observe better learning of the movement pattern (retention and transfer) in the group receiving instruction about the interaction between those two components (stroke and breathing) compared to receiving the instruction focusing on the stroke component alone. Furthermore, we expected that receiving verbal instruction, in addition to the video demonstration, would lead to better learning compared to receiving the video demonstration only (Control group).

Anthropometric measurements and the Borg Scale of Perceived Exertion indicate that the possible effects of the independent variable cannot be attributed to sample heterogeneity or differences in the effort required by each specific condition.

With regard to the AQ, results indicate that providing verbal instructions focusing on different elements of the Front-Crawl did not affect the acquisition process since there was no difference between groups during this phase. However, participants of the Interaction group improved their movement pattern between the first and last session of the AQ, which was not observed in the other groups. This improvement underscores the increasing number of higher ratings obtained by the Interaction group, while the other groups, despite performing the same number of trials, obtained lower ratings during the AQ.

With regard to the RT and TR tests, the results indicate that providing verbal instruction focusing on the interaction between arm stroke and breathing brings learning gains compared to the presentation of the video demonstration only. Most studies investigating the relationship between demonstration and motor performance adopted Bandura’s Social Learning Theory [22], which suggests that learners form a cognitive representation of a motor skill through observing a model, and that this representation subsequently guide their motor performance. However, our results indicate that the demonstration itself does not suffice to form this cognitive representation of the Front-Crawl. Specifically, the group receiving only the video demonstration showed no improvement in performance during the AQ phase, maintaining the same level of performance during the RT and TR tests. An explanation for this result is that participants failed to extract the relevant information from the model to benefit in practice. Our findings corroborate previous studies investigating the effects of providing verbal instructions and demonstrations which showed that demonstration combined with verbal instruction leads to better learning than when provided separately [15–18].

The combined use of instruction and demonstration as a way of guiding learners to an optimal motor performance was shown to benefit the learner only when part of what is being learned is already in the learner’s repertoire [10]. Our results do not corroborate with this statement, since all participants of the present study had no previous experience with the experimental task (Front-Crawl) and those who received demonstration associated with verbal instruction showed learning gains. One explanation for this incongruence is that the tasks
used in previous studies [12, 23, 24] had a lower degree of complexity compared to the Front-Crawl. In this sense, it is reasonable to suppose that as task complexity increases, also the need of information to guide the learner to key aspects of the skill increases.

The verbal instruction provided to the Interaction group was longer than the one provided to the Component group. In this sense, one could argue that this could overload the learner’s attentional resources, especially in the initial phase of learning [12]. However, our results do not give support to this interpretation, since the participants in the Interaction group not only did not show any impairment at the beginning of the AQ compared to the other groups, but improved their movement pattern during the AQ phase, which was not observed for the other groups.

With respect to our prediction that the effectiveness of the instruction would depend on whether critical aspects of the motor skill being learned are included [11, 25], the lack of statistical difference between the Component and Interaction groups fails to strongly support this hypothesis. Nevertheless, a descriptive analysis of the ratings obtained by those groups – during the AQ and both tests – suggests that the group receiving instruction about the interaction between stroke and breathing showed qualitatively superior movement pattern compared to the one receiving instruction about the stroke component only. Additionally, inferential analysis indicated that the groups completed the task within similar time, both during the AQ and in the RT and TR tests. Nevertheless, descriptive results indicate that the Instruction group needed less time to complete the task in the TR and RT tests, which suggests that the qualitatively better movement pattern was also the more efficient in the displacement of the swimmer. Considered together, these results do not rule out the hypothesis that instructions including critical aspects of the motor skills benefits learning, especially those with interdependence between the components, as is the case of the Front-Crawl. This issue, in this sense, remains open and should be tackled in future studies.

Conclusions

The results of this study clearly indicate that enhancing aspects of a video demonstration with a verbal instruction improves learning of the Front-Crawl in children, compared to providing video demonstration only. Additionally, there were indications that providing verbal instructions about the interaction between the components of stroke and breathing might promote better learning gains compared to the instructions about the stroke component alone.

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**Correspondence address**
Maria Teresa da Silva Pinto Marques-Dahi
Laboratório de Comportamento Motor
Escola de Educação Física e Esporte
Universidade de São Paulo
Av. Prof. Mello Moraes, 65, Cidade Universitária
São Paulo, Brazil
e-mail: marquesef@usp.br
THE DIFFERENCES IN FAT ACCUMULATION AND DISTRIBUTION IN FEMALE STUDENTS ACCORDING TO THEIR LEVEL OF ACTIVITY

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ALEKSANDRA STACHOŃ*, JADWIGA PIETRASZEWKA, ANNA BURDUKIEWICZ, JUSTYNA ANDRZEJEWSKA
University School of Physical Education, Wrocław, Poland

ABSTRACT
Purpose. The appropriate percentage of body fat is essential for women’s health and biological condition. Both accumulation of fat and distribution pattern of adipose tissue are connected with health risk, which justifies the investigation and permanent monitoring of their diversity in different sub-populations. The aim of the study was to evaluate the percentage of body fat and its distribution in female students representing different physical activity levels.

Methods. Fat proportion was estimated with use of classic anthropometric method and bioelectrical impedance analysis (BIA). The distribution of subcutaneous fat was calculated including waist and hip circumferences, and extremities and trunk skinfolds. The participants’ level of physical activity was determined according to the IPAQ questionnaire.

Results. Analysis showed that female students with medium level of physical activity had 26.5 ± 5.1% of total body fat estimated by BIA, whereas in the most active females almost 3% lower total body fat values were common. The bioelectrical impedance analysis indicated about 8% higher body fat content than classic anthropometry. Examined skinfolds revealed a tendency to decrease with increasing physical activity. The distribution pattern of subcutaneous fat varied according to level of activity.

Conclusions. The study showed that estimation of fat content in young women differed depending on the applied method and the level of physical activity. We emphasize the need to select adequate reference data for measurement methods and consider the level of physical activity during fat percentage assessment. Another conclusion is that the high level of physical activity is connected with masculinization of subcutaneous fat pattern, both in extremities/trunk fat proportion and waist/hip proportion.

Key words: adiposity, BMI, WHR, skinfolds, body composition, female, physical activity

Introduction

Adiposity is conditioned by polygenic inheritance that causes high susceptibility to external factors among which diet and physical activity seem to be crucial. Maintaining an appropriate amount of body fat as well as distribution of fat tissue is important for one’s good health and fitness [1–4]. During medical examination excessive fatness is diagnosed mainly on the base of body mass index (BMI), whereas a previous study showed that diagnostic values of the index varies in different subpopulations [5]. It is worth to noticed that frequencies of adiposity assessment connected with medical examination is not adapted to the dynamics of real changes in body composition. Moreover, the development of modern imaging techniques, allowing evaluation of visceral fat, diverted scientist’s attention from subcutaneous fatness.

However, some studies report the connection between the pattern of subcutaneous adiposity and health risk, which justifies the investigation of factors related to distribution of subcutaneous fat [1, 6]. The connection between adipose tissue, biological condition and physical activity is multifarious and based on many various mechanisms [7].

The study of Kruschitz et al. [8] proved there are differences in subcutaneous fat patterns between young athletes and non-athletes. The abovementioned findings suggest that compared to BMI levels, subcutaneous fat patterns are a more accurate way of discriminating between young athletes and non-athletes. In women, the upper back and arms compartment were the best sites to discriminate between athletes and non-athletes [8]. Subcutaneous fat topography was also proven to be associated with decreased aerobic capacity [9].

The purpose of the study was to prove that higher level of physical activity is connected not only with decreased total body fat and subcutaneous fat, but also with a different subcutaneous fat distribution expressed by the extremity to trunk skinfold ratio. We assumed that highly active women are characterized by stronger reduction in subcutaneous fat in the extremities compared to the trunk, which can be explained by greater activity of the extremities than the trunk during sport exercises as well as by the fact that trunk fatness constitutes fat storage that secures fertility in women. The second aim of the study was to check the diagnostic value of widely used indexes BMI and WHR in a group of women with different level of physical activity.
Material and methods

Participants

The survey contains results from cross-sectional anthropological measurements as well as a questionnaire study conducted among first-year female students (N = 255) of the University School of Physical Education in Wroclaw, Poland (Faculty of Physical Education N = 176; Faculty of Sport N = 45), and the Medical University in Wroclaw (Faculty of Health Sciences – studies in nursing N = 34). All the students who gave their informed consent were included in the study. The questionnaire study enabled the authors to excluded females which were on slimming or other special diets. Mean age of the examined women was 20.0 ± 1.0 years. All students underwent medical examination before they participated in the study and were recognized as healthy. The study was approved by the appropriate Ethics Committee. Females were informed of the benefits and risks of the investigation and were given an explanation of their own data.

Measurements and procedure

The anthropometric measurements were performed using the Martin-Saller method [10]. Body height (B–v) was measured with an anthropometer and circumferences with an anthropometric tape (to the nearest 0.1 cm; Siber Hegner Machinery Ltd., UK), skinfold thickness with a Tanner/Whitehouse skinfold caliper (Holtein, UK, with 0.2 mm graduation). Body mass was measured with an electronic weighing scale (to the nearest 0.1 kg). Body fat estimation was performed with a BIA-101 Anniversary Sport Edition analyzer (Akern, Italy) in the standard conditions recommended by the producer. Tissue analysis was performed using the Bodygram 1.3.1. software package with the Akern analyzer.

The results of anthropometric measurements enabled the authors to assess body composition using the classic anthropometric method. Fat mass (FM) and fat free mass (FFM) proportions were estimated on the basis of Slaughter–Lohman–Boileau regression equation for body fat in females as follows [11]:

\[
\text{Fat} (\%) = 1.33^* (\text{triceps skinfold} + \text{subscapular skinfold}) - 0.013^* (\text{triceps skinfold} + \text{subscapular skinfold})^2 - 2.5
\]

The massiveness of body build and type of fat distribution around the waist and hip were estimated, according to WHO recommendations, on the basis of Body Mass Index (BMI) and Waist-Hip Ratio (WHR) [12, 13]. The distribution of subcutaneous fat between the extremities and trunk was also estimated on the base of subcutaneous fat distribution index. Values below 100 mean predominance of trunk fatness, and the smaller the values of this index, the larger the difference between subcutaneous adiposity of trunk and extremities.

\[
\text{Subcutaneous fat distribution index} = \frac{(\text{triceps skinfold} + \text{calf skinfold})}{(\text{subscapular skinfold} + \text{suprailiac skinfold})} \cdot 100
\]

The participants’ level of physical activity was determined using a shorter form of the International Physical Activity Questionnaire (IPAQ, Polish version) [14]. According to the protocol, participants were previously divided into groups with different level of physical activity (minimally active, HEPA active = health enhancing physical activity) [14, 15]. With regard to the high percentage of women involved in competitive sport and a wide range of MET-min/week that characterized the examined group of female students, we decided to divide HEPA active women into: medium active group (1500–3000 MET-min/week; N = 76) and highly active group (more than 3000 MET-min/week; N = 90). Minimally active group consisted of 49 females.

Statistical analysis

Means and standard deviations (SD) of the measured characteristics in the three groups of women were calculated. The compatibility of distribution of the analyzed data with normal distributions was checked with the Shapiro–Wilk test. Levene’s test was used to check the homogeneity of variances. In order to investigate the differences between groups of women with various levels of physical activity, parametric statistical tests (ANOVA, post-hoc Scheffe test) and nonparametric tests (Kruskal–Wallis test, nonparametric test for multiple comparisons) were used. Statistical significance was set at p < 0.05. Statistical analyses were carried out with the StatSoft® Statistica 12 software. The obtained results were presented in charts using Microsoft® Office Excel 2003.

Results

The analyzed groups of women characterized by various levels of physical activity did not differ in age (ANOVA; F = 1.57; p = 0.2096), body height (ANOVA; F = 1.18; p = 0.3102), BMI and WHR (Table 1). The women’s average body height (B–v) amounted to 168.1 ± 6.5 cm, the mean BMI was 21.5 ± 2.3 kg/m². The majority of women (87%) had normal body weight according to BMI categories (WHO). The mean WHR was 0.735 ± 0.058, which is a correct value for young women.

Although the groups of women did not vary significantly in body mass (ANOVA; F = 1.11; p = 0.3312), the average body mass tends to increase as the level of activity increases: 59.3 kg in minimally active, 59.7 kg in medium active and 61.2 kg in highly active.

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### Table 1. Body Mass Index and Waist-Hip Ratio in groups of women with various levels of physical activity

<table>
<thead>
<tr>
<th>Index</th>
<th>minimally active</th>
<th>medium active</th>
<th>highly active</th>
<th>ANOVA</th>
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<tbody>
<tr>
<td>BMI [kg/m²]</td>
<td>21.6 ± 2.5</td>
<td>21.7 ± 2.2</td>
<td>21.6 ± 2.5</td>
<td>0.05</td>
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<tr>
<td>WHR</td>
<td>0.73 ± 0.05</td>
<td>0.73 ± 0.04</td>
<td>0.74 ± 0.07</td>
<td>1.19</td>
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</table>

### Table 2. The thickness of skinfolds and body composition in groups of women with various levels of physical activity

#### Skinfolds (mm)

| Skinfolds          | minimally active | medium active | highly active | F/H**   | p       |
|--------------------|------------------|---------------|---------------|---------|
| Subscapular        | 11.9 ± 3.7       | 10.8 ± 3.0    | 9.3 ± 2.4     | 6.20*   | 0.0024  |
| Triceps            | 11.6 ± 3.5       | 9.9 ± 3.9     | 8.2 ± 2.9     | 26.25** | 0.0000  |
| Abdomen            | 15.3 ± 4.4       | 13.5 ± 4.8    | 11.4 ± 4.1    | 4.39*   | 0.0135  |
| Suprailiac         | 12.0 ± 4.6       | 11.9 ± 4.9    | 10.2 ± 3.5    | 8.61*   | 0.0135  |
| Calf               | 10.0 ± 3.5       | 8.4 ± 3.0     | 7.1 ± 2.6     | 14.88*  | 0.0000  |

#### Body composition (skinfolds thickness)

| Body composition | minimally active | medium active | highly active | F/H**   | p       |
|------------------|------------------|---------------|---------------|---------|
| FFM (%)          | 80.9 ± 4.4       | 81.4 ± 4.9    | 83.5 ± 3.9    | 7.26*   | 0.0009  |
| FM (%)           | 19.1 ± 4.4       | 18.6 ± 4.9    | 16.5 ± 3.9    | 7.26*   | 0.0009  |

#### Body composition (BIA)

| Body composition | minimally active | medium active | highly active | F/H**   | p       |
|------------------|------------------|---------------|---------------|---------|
| FFM (%)          | 72.6 ± 5.3       | 73.3 ± 5.0    | 75.3 ± 5.2    | 5.61*   | 0.0042  |
| FM (%)           | 27.4 ± 5.3       | 26.7 ± 5.0    | 24.7 ± 5.2    | 5.61*   | 0.0042  |

* ANOVA, ** Kruskal–Wallis test

Women declaring the highest physical activity level were characterized by the lowest subcutaneous fatness. They had the slimmest subscapular skinfold, triceps skinfold, suprailiac and abdomen skinfolds and calf skinfold (Table 2). All the examined skinfolds revealed a tendency to decrease as physical activity increases (Table 2). The differences in subcutaneous fatness between women declaring a medium physical activity and women declaring the highest activity level amounted to 2–4 mm. Detailed post-hoc test results are presented in Table 3.

Subcutaneous fat distribution index (SFDI) revealed a wide range of variability of fat distribution between the trunk and the extremities (Figure 1; min = 36.2; max = 195.2). In the majority of examined female students, the subcutaneous fat tissue of the extremities was lower than the subcutaneous fat tissue of the trunk, which is showed by SFDI values < 100 (Figure 1). In minimally active, medium active and highly active group this index differs significantly (Figure 2; Kruskal–Wallis test H =17.825; p =0.0001). The differences were most visible in minimally active women, while the highly active women displayed similar fat pattern as medium active group (Figure 2). HEPA active groups (medium and high level of activity) had on the average about 20% slimmer skinfolds in the extremities than in their trunk, whereas minimally active women mostly had similar skinfolds in the trunk and the extremities (SFDI = 95.7).

The average body fat content according to BIA in all examined women amounted to 26.1% ± 5.2%. Body fat (FM), estimated both on the basis of regression equations and BIA, also decreased as the level of physical activity increased (Table 2). Women who were the least active had 2.6% more fat mass than the vigorously active women who using classic anthropometry, and 2.7% more when using BIA (Table 2).

Women characterized by the highest level of physical activity were most muscular, i.e. they had more fat free mass than the others. Detailed post-hoc test results are presented in Table 3. Individual values of fat content estimated with BIA were higher than values estimated with classic anthropometry. The differences between these two methods were similar in all groups of women (8.3% in the group of the most active women, 8.1% in the less active, and 8.2% in the least active women).

### Discussion

The multiplicity of body fat estimation methods with their varied reference values often causes confusion. Although there is a proven moderate concordance between results obtained with different methods, concrete results obtained with the use of these methods vary [16–18]. Frisch claims, without referring to any particular measurement method, that more than...
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26–28% of body fat may negatively influence the reproductive ability of young women [19]. Jeukendrup and Gleeson classified > 30% body fat content in women as overweight [20].

In the present study, according to bioelectrical impedance analysis, young women had an average of 26.1% ± 5.2% body fat. The fat content in women varied significantly depending on the level of their physical activity. Less active women had little more than 27% body fat, whereas the most active women had almost 3% less fat. Applying BIA in their study, Lukaski et al. [21] estimated body fat in American women at 25.1%, whereas it amounted to 26.05% in young Polish women examined by Major-Gołuch et al. [22]. The body fat content estimation in Polish women obtained with the use of DXA method was slightly higher (32.05%) [22]. In a South African study, healthy active women were shown to have 29.5% of body fat with the use of the DXA method, but 28.4% with the use of the near infrared reactance method [16], whereas resistance-trained women from the same study had 10% less body fat and 5.5% less body fat, respectively [16]. Scientists from the Czech Republic showed that elite female players in five different sports games were characterized by 20–21% of fat mass in BIA 2000 M estimation [23], whereas in the study of Buśko and Lipińska female volleyball players had about 29% body fat according to BIA with use of Tanita TBF-300 [24]. According to Lugito et al., female and male students with low-moderate activity had a higher risk of obesity compared to students with high activity [25]. Friedl et al. revealed a 2% decrease in body fat content after a few weeks of combat training in women [26], whereas Gutin et al. proved that the lower adipose tissue level was mainly connected with the frequency of vigor-

<table>
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<td>Subscapular skinfold* (mm)</td>
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<td>Triceps skinfold** (mm)</td>
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<td>Abdomen skinfold* (mm)</td>
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<td>Suprailiac skinfold** (mm)</td>
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<td>Calf skinfold* (mm)</td>
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<td>FFM (skinfolds)* (%)</td>
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<td>FFM (BIA)* (%)</td>
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<td>FM (BIA)* (%)</td>
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* Scheffe’s test, ** Wilcoxon rank sum tests for multiple comparisons
Athletes doing some sports were characterized by a higher content of body fat, as compared with active but not trained women [31].

Despite the differences in body fat content between more active and less active female students, they did not differ significantly in the aspects of body massiveness (BMI) and shape (WHR). This proved that the mentioned indices are not appropriate tools to estimate fat content in this group of women. It was probably caused by some diversification of the aforementioned features in the studied group. The vast majority of subjects (90%) had normal weight according to WHO [12]. Fewer than 3% of women had WHR values outside the range of 0.7–0.8, which means that they had correct body fat distribution between the waist and hips for their sex and age [13]. The use of body weight and BMI as a diagnostic tool for overweight and obesity has been previously criticized, particularly in athletic populations [32]. Unlike in the female students in the present study, the increasing BMI values together with the decreasing level of physical activity were found in middle-aged adults [28, 33]. Choi et al. indicated a protective role of increased physical activity in women whose body weight increases during the midlife years [34].

The evaluation of fat distribution on the basis of the subcutaneous fat distribution index revealed that the subcutaneous fatness pattern in the trunk and the extremities strongly depends on the level of physical activity. We noticed that a high level of physical activity mainly reduces fat accumulation in the extremities, because trunk fatness constitutes fat storage that secures fertility in women. However, with regard to WHR, it is worth mentioning that there is a slight tendency toward increased android fatness in the most active women, which means that the very high level of physical activity promote the reduction in fat accumulation in the place specific for women, i.e. the hips. Trichopoulou et al. indicated earlier that WHR values strongly depended on the level of physical activity in males, but not in females, which was probably caused by the hormonal influence [35].

The subcutaneous fat distribution index revealed a wide range of variability of fat distribution between the trunk and the extremities. In the majority of examined female students the subcutaneous fat tissue of the extremities was lower than the subcutaneous fat tissue of the trunk. Values of SFDI less than 100 mean predominance of trunk fatness, and the smaller the values of this index, the larger the difference between subcutaneous adiposity of the trunk and the extremities. The mentioned tendency can be interpreted as masculinization of subcutaneous fat pattern [36]. In previous studies females were characterized by thicker extremities skinfolds comparing to males, whereas the thickness of trunk skinfolds were similar in both sexes [37].

In this study the pattern of subcutaneous fat distribution among trunk and extremities depends on the level of activity. The differences between trunk and extremities skinfolds were more visible in HEPA women (me-
dium and highly active). Their subcutaneous fat distribution index (about 77–78) was lower than in minimally active group (about 95), which made their fatness pattern masculinized [38]. As it was proven in our previous study, the subcutaneous fat distribution index is about 50–60 in male athletes [38].

Conclusions

The results of the present study showed that estimation of fat content differed depending on the applied method and the level of physical activity. Therefore we emphasize that during body fat content analysis one should pay attention to using appropriate reference values adequate to the applied method and measurement device. The fat content estimated by bioelectrical impedance analysis is about 8% higher than the body fat content estimated on the basis of anthropometric measurements of skinfolds. On the basis of BIA method we showed that female students from the University School of Physical Education and Medical University were characterized by average amount of 26.1% ± 5.2% body fat, whereas in the most active females about 3% lower values of total body fat, comparing to minimally active group, were common. We also showed that the commonly used in medical practice indexes estimating fatness (BMI, WHR) are not appropriate tools for evaluation of fat tissue in this group of women. We also concluded that high level of physical activity is connected with masculinization of the subcutaneous fat pattern, both in extremities/trunk fat ratio and waist/hip ratio. Reduction in fat accumulation in the extremities is more visible because trunk fatness constitutes fat storage securing women’s fertility.

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Correspondence address
Aleksandra Stachon
Zakład Antropologii Fizycznej
Akademia Wychowania Fizycznego
al. I.J. Paderewskiego 35
51-612 Wrocław, Poland
e-mail: aleksandra.stachon@awf.wroc.pl


Differential Contribution of Reaction Time and Movement Velocity to the Agility Performance Reflects Sport-Specific Demands

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ERIKA ZEMKOVÁ
Department of Sports Kinanthropology, Faculty of Physical Education and Sports, Comenius University in Bratislava, Slovakia

ABSTRACT

Purpose. This study estimates the contribution of reaction time and movement velocity to the reactive agility time while covering varied distances. Methods. A total of 95 athletes of karate, hockeyball and soccer participated in a simple reaction, two choice reaction, step initiation and reactive agility test. Results. Agility time was significantly better in karate-kumite than karate-kata practitioners when covering a distance of 0.8 m (8.2%, \( p = 0.045 \)), better in hockeyball players than goalies when covering a distance of 1.6 m (10.9%, \( p = 0.028 \)) and better in soccer players than goalies when covering a distance of 3.2 m (14.2%, \( p = 0.009 \)). Movement velocity to agility time contributed to a lesser degree in the case of karate-kata competitors, hockeyball and soccer players (33.5%, 28.3%, and 19.9% respectively) than the karate-kumite competitors, hockeyball and soccer goalies (44.2%, 42.7%, and 39.4% respectively). Furthermore, both simple and two choice reaction times were highly related to the agility time when covering distances of 0.8 m, 1.6 m, and 3.2 m (\( r \) in range from 0.72 to 0.88). Movement velocity also significantly correlated with the agility time in the test with a distance of 0.8 m (\( r = 0.76 \)) but not with longer movement distances of 1.6 (\( r = 0.61 \)) and 3.2 m (\( r = 0.52 \)). Conclusions. Reaction time and movement velocity differentially contribute to the agility time in athletes of varied specializations. This reflects their specific demands on agility skills, and therefore should be addressed in agility testing in order to identify an athlete’s weakness.

Key words: reactive agility, reaction, step initiation, testing

Introduction

For many years, agility was classified as the ability to execute rapid movements and the capacity to stop and restart quickly. As a result, the majority of agility research was devoted to pre-planned and change-of-direction speed tests. Eventually, agility tests that combined change of direction speed and cognitive measures were developed. These reactive agility tests also included anticipation and decision-making components in response to the movements of a tester. Sheppard et al. [1] discovered that the reactive agility test differentiated between players of varied performance levels in Australian football, but traditional closed skill sprint and sprint with direction change tests did not. As a result, agility has been redefined as a rapid whole-body movement, with change of velocity or direction in response to a stimulus [2]. This definition implies three information-processing stages: stimulus perception, response selection, and movement execution.

The first two components of agility performance can be indirectly estimated by measuring the simple and multi-choice reaction time. Reaction time figures prominently in the open skills required in many sports (e.g., boxing, ice-hockey). Take baseball, for example. The entire trajectory of a pitch in baseball might measure only 400 ms and the bat swing may take 120 ms to execute. Thus, if a batter takes an extra 100 ms to detect the speed and trajectory of the pitch, this could severely limit the chance of successful contact [3]. Equally, processing delays in a sprinter or goalie may significantly impact their performance. An individual who has the ability to minimize such delays has an advantage in events such as the 100-m dash or when catching a ball.

Decision time strongly influences total reactive agility time, therefore it is important to address perceptual skills in agility testing and training. Young and Willey [4] discovered that of the three components that make up the total time, decision time had the highest correlation (\( r = 0.77, p = 0.00 \)) with the total time. This correlation with total time was greater than for the response movement time (\( r = 0.59 \)) or tester time (\( r = 0.37 \)), indicating that decision time is the most influential of the test components for explaining the variability in total time. The decision time component within the reactive test condition also revealed that highly-skilled players made significantly faster decisions than the lesser skilled players [5]. Also, as the results of Gabbett and Benton [6] demonstrate, decision and movement times in the reactive agility test were quicker in more highly skilled players, without compromising response accuracy. Similarly, Serpell et al. [7] revealed a significant difference in mean time in the sport-specific reactive agility test (RAT) between the elite group and the subelite group of the rugby league. Performance differences on the RAT were attributed to differences in perceptual skills and/or reaction ability. The review of Paul et al. [8] showed that decision-making and perceptual factors are often propositioned as
discriminant factors; however, the underlying mechanisms are relatively unknown.

The third component of agility performance is movement execution. To evaluate the speed of step initiation, one can perform simple or two-choice stepping reaction test to visual stimuli. The test begins with the subject standing on two mats placed in front of a light signal. When the light is activated, the subject performs two steps towards mats placed 60–70 cm apart and marked with tape on the floor. The time from foot-off (onset of unloading) and foot contact time (from foot-off to foot-contact) is recorded. However, due to problematic issues in reproducing the task, plus a lack of acceptable precision when compared to accurate laboratory tests, the practicality of using the visually-triggered step initiation test is limited, especially when quantifying slight changes in performance of individuals and small groups [9]. Therefore, it is preferable to utilise the diagnostic system based on a precise analogue velocity sensor with a sampling rate of 100 Hz to measure the velocity of step initiation. This measurement is more reliable and better equipped to distinguish between individuals of different ages and levels of physical fitness [10]. Since there is a significant relationship \( r = 0.837 \) between the foot contact time (from foot-off to foot-contact) and the maximal velocity of the step, such measurement may be a viable alternative to the previous test.

Performance in the change of direction test more strongly correlates with acceleration speed than with maximum running speed [11–13]. Therefore, stronger correlation may be assumed between maximal step velocity and agility time over a shorter than longer distance. Recently, Sayers [14] reported that measuring change of direction speed over a distance of 1 m provides an effective compromise between test reliability and the need to discriminate change of direction ability from high-speed linear running ability. The proportionally weaker correlations between high-speed linear running ability and change of direction speed measures for distance \( \leq 1 \) m suggest that the distance over which change of direction speed is measured currently (\( \geq 5 \) m) may be too long.

Our experience also showed that athletes prefer distances shorter than 5 m, for instance soccer players 3.2 m, badminton, basketball and hockeyball players 1.6 m, and karate and tae-kwon-do practitioners 0.8 m, when testing agility skills [15]. It is likely that acceleration and deceleration phases determine the agility performance more over shorter than longer distances. However, the reactive agility test only provides information on agility time (AT) which includes both reaction time (RT) and movement time (MT). From a practical perspective, estimating the contribution of these two components to the agility performance may provide additional relevant data for groups of athletes with diverse demands on decision-making and movement velocity. Such information on both reaction and movement times may be useful when designing training programs specifically focused on the improvement of weak components in agility performance. To address this issue, we estimated the contribution of simple reaction time, two-choice reaction time and step initiation velocity to the reactive agility time, while covering different distances in athletes of varied specializations.

### Material and methods

#### Participants

Six groups of athletes volunteered to participate in the study (Table 1). They were required to be active in selected sports. They each had over 10 years’ experience in particular sports with at least 7 years’ experience in a competition. Those who met the inclusion criteria were allocated to the study. Approximately 77% of the athletes enrolled in the selected sports clubs participated. They were asked to avoid any strenuous exercise for the duration of the study. All participants were informed of the procedures and main purpose of the study. The procedures presented were in accordance with the ethical standards on human experimentation as stated in the Helsinki Declaration.

#### Experimental procedure

Prior to the study, participants attended a familiarization session during which the testing conditions were explained and trial sets carried out. Participants were encouraged to practice the measurement procedure beforehand in order to eliminate unfamiliarity with the exercise. Then they performed four tests in no particular order as follows:

In the Reaction Tests, participants were required to respond to either one visual stimulus (simple reaction

### Table 1. Characteristics of groups of athletes (Mean ± SD)

<table>
<thead>
<tr>
<th>Groups of athletes</th>
<th>n (1)</th>
<th>Age (years)</th>
<th>Height (cm)</th>
<th>Weight (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Karate-kata practitioners</td>
<td>14</td>
<td>20.3 ± 2.2</td>
<td>171.8 ± 4.6</td>
<td>64.5 ± 7.9</td>
</tr>
<tr>
<td>Karate-kumite practitioners</td>
<td>22</td>
<td>21.5 ± 3.6</td>
<td>174.5 ± 7.3</td>
<td>70.3 ± 6.5</td>
</tr>
<tr>
<td>Hockeyball goalies</td>
<td>6</td>
<td>23.8 ± 3.5</td>
<td>177.7 ± 5.7</td>
<td>74.9 ± 6.7</td>
</tr>
<tr>
<td>Hockeyball players</td>
<td>17</td>
<td>22.8 ± 3.1</td>
<td>178.6 ± 6.4</td>
<td>72.6 ± 5.7</td>
</tr>
<tr>
<td>Soccer goalies</td>
<td>9</td>
<td>24.1 ± 4.7</td>
<td>178.1 ± 6.3</td>
<td>76.0 ± 7.7</td>
</tr>
<tr>
<td>Soccer players</td>
<td>27</td>
<td>21.9 ± 2.9</td>
<td>174.6 ± 5.1</td>
<td>69.5 ± 6.3</td>
</tr>
</tbody>
</table>
time) or two visual stimuli in the form of a circle, square, triangle or cross (2-choice reaction time) positioned on mats on the floor. The mats had to be touched in accordance with the stimulus on the screen. Participants were instructed to keep their legs as close as possible to the mats in order to eliminate the influence of their leg movements on the outcome. They performed three trials of 40 responses in each test. Data from the best trial of simple RT and 2-choice RT were selected for analysis.

Reaction times were measured using a diagnostic system FiTRO Reaction Check (FiTRONic, Slovakia) that consists of two mats connected by means of an interface to a computer. A special software measures the time the subject requires to accomplish leg contact with the mat corresponding to the stimulus on the screen. Software enables storage, analysis and extensive reporting of the data.

In the Step Initiation Test, participants performed voluntary steps in their own time. A device (described below) was anchored to the wall and tethered by a nylon rope to the ankle of the subject. The participant was instructed to perform, as quickly as possible, the steps while pulling the nylon tether of the device. Data from the best of 3 trials were utilised for analysis.

Movement velocity of the step was measured using the computer based system FiTRO Dyne Premium (FiTRONic, Slovakia) that consists of a sensor unit based on a precise encoder mechanically coupled with a reel. While pulling the tether (connected to the ankle of the subject) the reel rotates and measures velocity. Signals from a sensor unit are conveyed to the computer by means of a UsB cable. Comprehensive software allows the collection, calculation and on-line display of the basic biomechanical parameters involved in exercise. In this study, only maximal step velocity was utilised for analysis. Previous studies showed that intraclass correlation coefficient (ICC) was high for maximal step velocity and moderate for mean velocity in the acceleration phase as well as for maximal and mean acceleration [10]. In the same way, the standard error of measurement (SEM) was low for maximal step velocity and greater for the remaining parameters. Taking these findings into account, maximal velocity of the step initiation, as the most reliable parameter, was used for analysis in the present study.

Data analysis was performed using the statistical program SPSS for Windows version 18.0 (SPSS, Inc., Chi-
The calculation of the sample size was conducted with \( \alpha = 0.05 \) (5% change of type I error) and \( 1 - \beta = 0.80 \) (power 80%) and using the results from our preliminary studies that identified variations in agility time between athletes of different sports. This provides a sample size of 16 for this study. However, the sample size in three groups was below this limit, as the inclusion criteria required participants to be active in a particular sport. Therefore, the statistical power for a group of size \( n \) ranged from 0.74 to 0.80. To compensate for the lower power and to estimate the magnitude of the differences across these groups, the effect size (ES) was calculated. Where statistical significance was not established, retrospective power calculations were performed to identify the power associated with the comparisons in question. Power calculations were performed on variables which showed a moderate effect size difference between these groups. The power for each level of comparison was calculated for a given difference between two mean values and the group sample sizes, and the standard deviation for each group mean. Sample sizes were calculated for each group, to provide the estimated sizes required to show a significant difference between groups in variables of simple RT, two-choice RT, maximal step velocity, and agility time.

One way analysis of variance (ANOVA) was used to estimate significant between-group differences in simple RT, two-choice RT, maximal step velocity, and agility time. The level for statistical significance was set at \( p < 0.05 \). Where the results of ANOVA indicated significant F-ratios between groups, the Scheffé test was applied post hoc to determine in which groups the differences occurred. Sex data, determined to be normally distributed, were analyzed in previous studies using the independent samples t-test and showed no significant differences in agility time between men and women. Nevertheless, only male athletes were selected for the present study. This was because longer movement distances were used in this study in comparison with the original version of the agility test, which could lead to different physiological responses and consequently affect the outcome in female and male athletes. Additionally, correlations between agility time and variables of simple RT, two-choice RT, and maximal step velocity were assessed by calculating Pearson’s product moment (r). Data on reaction times, movement velocity, and agility time for all examined groups are presented as the mean ± the standard deviation (SD).

Results

Results in karate-kata and karate-kumite practitioners are shown in Figures 1 a–d. Simple RT was significantly better in karate-kumite practitioners than in karate-kata ones (19.6%, \( p = 0.048; \text{ES} = 0.75 \)) and two-choice RT (10.3%, \( p = 0.031; \text{ES} = 0.93 \)). On the other hand, agility time with a movement distance of 1.6 m between the subject and the mats was significantly better in karate-kumite practitioners than in karate-kata ones (8.2%, \( p = 0.045; \text{ES} = 0.85 \)). However, maximal step velocity did not differ significantly between these groups (3.3%, \( p = 0.233; \text{ES} < 0.2 \)).

Results in hockeyball goalies and players are shown in Figures 2 a–d. Goalies achieved significantly better values than players in both simple RT (7.9%, \( p = 0.048; \text{ES} = 0.75 \)) and two-choice RT (10.3%, \( p = 0.031; \text{ES} = 0.93 \)). On the other hand, agility time with a movement distance of 1.6 m between the subject and the mats was significantly better in players than in goalies (10.9%, \( p = 0.028; \text{ES} = 0.99 \)). Also, maximal step velocity was significantly higher in players than in goalies (13.8%, \( p = 0.017; \text{ES} > 1.0 \)).

Results in soccer goalies and players are shown in Figures 3 a–d. Goalies surpassed players in both simple RT (10.3%, \( p = 0.034; \text{ES} = 0.85 \)) and two-choice RT (12.0%, \( p = 0.024; \text{ES} = 0.96 \)). However, agility time with a movement distance of 3.2 m between the subject and the mats was significantly better in players than in goalies (14.2%, \( p = 0.009; \text{ES} > 1.0 \)). The maximal step velocity was also significantly higher in players than in goalies (16.8%, \( p = 0.007; \text{ES} > 1.0 \)).

Further analysis showed that simple RT, two-choice RT, and maximal step velocity were highly related to
agility time in the test with a shorter movement distance of 0.8 m ($r = 0.82$, $p < 0.01$; $r = 0.88$, $p < 0.01$; $r = 0.76$, $p < 0.05$). While simple RT and two-choice RT also strongly correlated with agility time in the test with longer movement distances of 1.6 m ($r = 0.76$, $p < 0.05$; $r = 0.72$, $p < 0.05$) and 3.2 m ($r = 0.79$, $p < 0.05$; $r = 0.75$, $p < 0.05$), there still remains considerable variation in the factors that contribute to performance over each movement distance. There were no significant relations of maximal step velocity to agility time in the tests with movement distances of 1.6 m ($r = 0.61$) and 3.2 m ($r = 0.52$). Therefore, other factors very likely contributed to performance, namely change of direction running velocity and anaerobic/aerobic capacity, when responding to 20 stimuli over a distance of 1.6 m and 10 stimuli over a distance of 3.2 m.

These findings may be corroborated by a higher Agility Index found in karate-kumite than karate-kata practitioners (on average 0.442 and 0.335, respectively) (Figure 4a). Similarly, a higher Agility Index was identified in hockeyball and soccer goalies (on average 0.427 and 0.394, respectively) than in hockeyball and soccer players (on average 0.283 and 0.199, respectively) (Figure 4b).

Figure 2. Simple reaction time (a), two-choice reaction time (b), maximal step velocity (c), and reactive agility time in hockeyball goalies and players (d) ($^*p < 0.05$)

Figure 3. Simple reaction time (a), two-choice reaction time (b), maximal step velocity (c), and reactive agility time in soccer goalies and players (d) ($^*p < 0.05$, $^{**}p < 0.01$)

Figure 4. The Agility Index in karate-kumite and karate-kata practitioners (a) and players and goalies of hockeyball and soccer (b)
Discussion

Although covering the same total distance, the protocols used in the present study involved more multiple direction changes over a short distance (40 × 0.8 m) compared to those designed for longer distances (20 × 1.6 m and 10 × 3.2 m). Results confirmed our assumption that the strength of the associations between maximal step velocity and agility time decrease when the latter is measured over longer distances. Relative speed of the first acceleration step appears to be an important component in determining change of direction ability over short distances [14]. This is consistent with previous studies that reported acceleration as an important aspect in agility and change of direction movement [2, 17–19]. However, the ability to decelerate CoM rapidly is also a key component of change of direction ability [14]. When undertaking a 180° change of direction test, deceleration movement times are extremely variable within and between individuals, particularly when compared with acceleration movement times [14]. Accordingly, the change of direction tests evaluate an athlete's ability to rapidly decelerate and reaccelerate in the new direction. When longer distances are covered, the total running time contains both change of direction ability and straight-line sprinting. In addition to this, agility tests include also perceptual and decision making components. Thus, breaking down the agility performance into two distinct phases is warranted. Recently, Sekulic et al. [20] reported that calculating stop'n'go change of direction speed to stop'n'go reactive-agility test ratio may allow strength and conditioning coaches to indirectly determine the perceptual and reaction capacities of their athletes. In the present study, higher Agility Indexes indicate the use of both sensory and motor components in athlete's performance, whereas their lower values signify the predominant contribution of motor abilities to agility performance. On the basis of our research, players may require varied agility skill training utilising motor abilities rather than sensory functions, as the longer distances appear more reliant on change of direction running velocity and anaerobic/aerobic capabilities. On the other hand, our results also identified the importance of cognitive factors in reactive agility performance for goalies and karate-kumite practitioners and suggest that specific methods may be required for training and testing of reactive agility and change of direction speed.

Taking into account the competition area in karate, the distance of 0.8 m between contact mats was used for the agility test, which identified better simple and two-choice reaction times in karate-kumite than the karate-kata practitioners. This very likely contributed to enhanced agility performance, as there were no significant differences in movement velocity between these groups. The contribution of movement time to the agility time was 33.5% in karate-kata practitioners and 44.2% in karate-kumite ones.

These results are in accordance with previous findings, in which individual differences in each component of the Agility Test were estimated [21]. In subject 1, multi-choice reaction time accounted for 64% of the agility time. However, in subject 2, multi-choice reaction time accounted for only 43% of the agility time. Interestingly, subject 1, with both longer simple and multi-choice reaction times, was able to achieve better agility times than subject 2. This was probably due to the fact that the participant initiated his/her foot responses more rapidly than his/her counterparts. This individual was in fact an elite karate-kata competitor, who does not respond to any stimuli but must be able to cover a short distance very quickly. Thus, it may be assumed that this result reflects a sport-specific adaptation. In contrast, despite better simple and multi-choice reaction times in subject 2, he/she was not able to transfer this capability into improved agility performance. These findings indicate that individual differences in agility time (RT + MT) are greater (about 26%) than in simple and multi-choice reaction times (18% and 9%, respectively).

In the present study, faster simple and two-choice reactions were found in hockeyball goalies than players when covering a distance of 1.6 m and in soccer goalies than players when covering a longer distance of 3.2 m. In contrast, higher maximal step velocity was recorded in hockeyball players than goalies. These differences were even more pronounced between soccer players and goalies. Higher movement time most likely contributed to better agility time in both hockeyball and soccer players than goalies. The contribution of movement time to the agility time was lower in players of hockeyball (28.3%) and soccer (19.9%) than goalies of hockeyball (42.7%) and soccer (39.4%).

Similarly, the changes in each component of agility performance following exercise or long-term systematic training can be evaluated. One study evaluated the effect of soccer match induced fatigue on neuromuscular performance [22]. After the first 45 min of the game, only dynamic balance with eyes closed was impaired, and ground contact time increased. A further increase was observed after the second period of the game. Along with dynamic balance with eyes open, agility performance (in the test with shorter – 0.8 m distance between mats) was also affected. On the other hand, there were no significant pre-post match changes in static balance, agility time (in the test with longer – 1.5 m distance between mats), speed of the step initiation and the soccer kick, height of the squat and counter movement jump. These findings indicate that fatigue impairs cognitive functions more than motor functions in highly skilled soccer players.

Another study compared the effect of 6 weeks of training consisting of reaction tasks similar to game situations on wobble boards (experimental group 1) and on a stable surface (experimental group 2) on neuromus-
cular performance in basketball players [23]. Following the training, there were no significant changes in simple and multi-choice reaction times when fingers were close to the buttons. However, a significantly shorter agility time was identified when subjects were required to move to the contact mats. Maximal velocity of step initiation also significantly improved after the training. This faster movement execution most probably contributed to the enhancement of agility performance. This assumption was corroborated by a significant correlation (r = 0.78) between the reduction in agility time and an increase in maximal velocity of step initiation after the training. Also of interest was the additional finding that the improvement in agility performance in older players (21 years on average) was greater than in their younger, less experienced counterparts (15 years on average). These results may be attributed to more rapid feedback control of movement execution, i.e. as the experience level increased with practice, the movement time decreased.

These findings indicate that assessment of simple and multi-choice reaction times, as well as movement time or movement velocity may provide additional information on individual differences in sensory and motor contribution to the agility performance. This would enhance differentiation of athletes with varied demands on agility skills, plus improve the evaluation of the efficiency of agility training.

Conclusions

The present study highlighted differential contributions of reaction time and step velocity to the agility time, depending upon a movement distance. It appears that cognitive and motor skills are better in karate-ku-mite than karate-kata practitioners, when only stepping reactions are required. In the case of longer distances, better agility time was found in players than in goalies of soccer and hockeyball. While the motor component of agility performance seems to be predominant in players in terms of faster movement execution, in goalies it is the sensory component allowing faster decision making. Hence, the agility test complemented with measurements of simple and multi-choice reaction times, and movement time or movement velocity provides additional information on agility performance in athletes with diverse demands on their agility skills. This differential contribution of reaction time and movement velocity to the agility performance should be addressed in agility testing in order to identify an athlete’s weakness.

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*Correspondence address*
Erika Zemková
Department of Sports Kinanthropology
Faculty of Physical Education and Sports
Comenius University in Bratislava
Nábr. arm. gen. L. Svobodu 9
814 69 Bratislava, Slovakia
e-mail: erika.zemkova@uniba.sk
EFFECTS OF AN ELEVEN-WEEK PILATES EXERCISE PROGRAM ON PROGRESSIVE-SPEED WALKING CAPACITY IN SEDENTARY YOUNG WOMEN: A PILOT STUDY

ALAN QUEIROZ RODRIGUES¹, FÁBIO MENDONÇA MARTINS¹, ALEXANDRE CARVALHO BARBOSA² *, PEDRO SCHEIDT FIGUEIREDO¹, MÁRCIA OLIVEIRA LIMA¹, EDGAR RAMOS VIEIRA³

¹ Department of Physical Therapy, Federal University of Jequitinhonha and Mucuri Valleys, Diamantina, Brazil
² Department of Physical Therapy, Federal University of Juiz de Fora, Governador Valadares, Brazil
³ Department of Physical Therapy, Florida International University, Miami, USA

ABSTRACT

Purpose. To assess the effects of an 11-week Pilates exercise program on the functional capacity of young sedentary women.

Methods. Ten subjects underwent the shuttle walking test. A portable metabolic system was used during the shuttle walking test to measure the maximum heart rate and VO₂ max. The heart rate recovery and the predicted maximal heart rate were also assessed.

Results. The findings showed increased walking distance, maximum heart rate and heart rate recovery after completing the protocol. The peak of VO₂ was not significantly different but showed a tendency to increase, being significantly correlated with the covered distance. Conclusions. The current results suggest that Pilates exercises significantly improve walking functional capacity.

Key words: heart rate, functional capacity, peak of VO₂, recovery

Introduction

Pilates exercises are performed on a mat or using Pilates equipment to assist the subject to practice the exercises properly [1]. Pilates exercises include controlled breathing, concentration, and precision of the movement, tightening the core muscles including the abdominals, the lumbar multifidus and the pelvic floor muscles. The core muscles are responsible for static and dynamic stabilization, and are associated with breath control [2, 3]. The core muscles support the diaphragmatic function by activating the abdominals, and helping to increase lung volume and capacity [4].

A recent review found contradictory or inconclusive results on the effects of Pilates exercise on pain, quality of life and lower extremity endurance in women [3]. On the other hand, another review found strong evidence to support the use of Pilates exercises to improve flexibility and dynamic balance [5]. Recent studies found increased muscular endurance among subjects who started to practice Pilates exercises compared to inactive subjects and with subjects who maintained their normal activity routine [6, 7]. Also, some improvements in lower limb strength and muscle endurance were found in older adults and patients with fibromyalgia [8, 9]. Nevertheless, the effectiveness of Pilates exercises on increasing progressive-speed walking capacity needs to be further evaluated. Cardiopulmonary exercise (e.g. fast walking) capacity can be used for exercise prescription [10]. The shuttle walking test can be used to evaluate the functional walking capacity of healthy and unhealthy subjects [11, 12]. This low-cost/easily administered test imposes a cardiopulmonary challenge; the information on change in walking speed is communicated to the participants using an audio signal for progressive effort to assess their functional walking capacity [10–13].

Pilates exercises are often used by health professionals (e.g. physical therapists) to treat patients, but further studies are needed to evaluate the benefits claimed by Pilates himself, including its potential effects on functional walking capacity [14]. Therefore, the aim of the study was to assess the effects of an 11-week Pilates exercise program on the functional capacity of young sedentary women. The hypothesis was that the Pilates exercises would increase the functional capacity of young sedentary women.

Material and methods

Participants

A sample of ten healthy but sedentary young women participated in this study (Table 1). Subjects were recruited through public call at the city of Diamantina, Minas Gerais, Brazil. Inclusion criteria were: age between 18 and 21 years of age, weight between 50 and 70 kg, International Physical Activity Questionnaire – IPAQ [15] score classification as inactive or minimally active (sedentary lifestyle). The subjects were assessed by a trained physical therapist, and the exclusion criteria were: leg

* Corresponding author.
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Table 1. Participants' characteristics

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Mean ± SD</th>
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<tbody>
<tr>
<td>Age (years)</td>
<td>23 ± 2</td>
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<tr>
<td>Height (cm)</td>
<td>163 ± 6</td>
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<tr>
<td>Weight (kg)</td>
<td>62 ± 13</td>
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<td>Body mass index (kg/m²)</td>
<td>23 ± 4</td>
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<tr>
<td>Resting Heart Rate (bpm)</td>
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</table>

Figure 1. Pilates method exercises: (1) initial position, (2) final position; (A) the cat, (B) the bridge, (C) the hundred, (D) Monkey, (E) Standing on Floor, (F) Arms up and down

length discrepancy, pregnancy, ankylosing spondylitis, shoulder impingement, paresthesia, and absence of tendon reflexes. The local ethics committee for human research approved the study protocol, and all subjects signed an informed consent form prior to participation (Protocol 531.995/CEP-UFVJM).

Figure 2. Pilates method exercises: (1) initial position, (2) final position; (A) Climb a Tree, (B) Leg Extension, (D) Step Down, (E) Swan Front
Procedures

The following sequence of Pilates exercises was performed twice a week, in non-consecutive days (~45 minutes/session), during the 11-week protocol (22 sessions): Mat Pilates: “the cat”, “the bridge” and “the hundred”. Exercises on the Cadillac (Pilates exercise equipment): “Monkey” and “Standing on Floor”; on the Reformer: “Arms up and down” (Figure 1); on the Chair: “Step Down” and “Swan Front”; on the Barrel: “Climb a Tree” and “Leg Extension” (Figure 2). All the exercises were performed using the basic Pilates breathing technique that consists of (1) deep exhalation through the mouth – with the lips slightly pursed, (2) inhalation through the nose before the movement and (3) deep exhalation through the mouth – with the lips slightly pursed – during the movement [1].

Outcome measurements

The shuttle walking test was performed in a 10 m course marked by two cones placed 0.5 m from each end point. Participants went from walking to running around the 10 m course according to the speed communicated by an audio signal. The initial walking cadence was 0.5 m/s increased by 0.17 m/s each minute. The cadence increment was always indicated by a triple audio signal. All tests were administered by the same trained physical therapist and all explanations were standardized.

The shuttle walking test was interrupted when participants became unable to maintain the required speed due to dyspnea or fatigue, or if the subject failed to complete the course within the specified time twice. The therapists approached the subject with a chair and recorded the total distance walked. The number of turns was counted, and a digital chronometer AK71® (AKS0®, St. Leopoldo, RS, Brazil) was used to measure the time. The reduction in heart rate (heart rate recovery) during a 1-minute long rest immediately after completion of the test was recorded [16], and the predicted maximal heart rate was calculated as 220 minus age (in years). A portable metabolic system (VO2000®, MedGraphics®, St. Paul, MN, USA) including a metabolic unit, a battery pack, a harness, a heart rate monitor, a face mask, and a breathing valve was used during the shuttle walking test to measure the peak heart rate and peak of VO2 [17].

The reference values for the shuttle walking test in women is largely explained by gender, age and BMI using the following equation [10]: $SWT_{\text{pred}} = 1449.7 - (11.7 \times \text{age}) + (241.9 \times \text{gender}) - (5.7 \times \text{BMI})$; where male gender = 1 and female gender = 0. Based on the sample demographics, the $SWT_{\text{pred}}$ was 1049 m.

Statistical analysis

BioEstat 5.3 software (Belém, PA, Brazil) was used for statistical analyses. Descriptive statistics were calculated for the participants’ characteristics. The Shapiro-Wilk test was performed to evaluate the Gaussian distribution of the data. Paired $t$-tests were used to compare differences between assessments (before vs. after). Correlations were calculated using Pearson’s correlation coefficient. All were conducted with a significance level set at $\alpha = 0.05$.

Results

Figure 3 shows the increased walking distance after completing the Pilates exercise program (mean difference 95% CI = 29 to 167 m, $p = 0.005$). The peak heart rate also increased after completing the Pilates exercise program (180 ± 17 bpm before vs. 194 ± 10 bpm after, mean difference 95% CI = 5 to 22, $p = 0.003$), and the heart rate recovery increased from 27 ± 12 bpm before to 42 ± 12 bpm after (mean difference 95% CI = 0.7 to 29, $p = 0.021$).

Peak VO2 tended to increase, but the differences were not statistically significant (30 ± 4 mL/kg/min before vs. 32 ± 4 mL/kg/min after). Peak VO2 was also significantly correlated with covered distance ($r = 0.63$, $p = 0.048$, 95% CI = 0.01 to 0.90).

Discussion

There were no adverse effects and all subjects stated no difficulties and a very satisfying experience in completing the Pilates exercise program. There was an improvement in heart rate recovery after the Pilates exercises protocol. Faster heart rate recovery was also found in aerobically trained subjects [18, 19]. Type of exercise is an important determinant of the post-exercise autonomic recovery and also of the effects of interaction between sympathetic withdrawal and parasympathetic activation [20]. On the other hand, a recent study found no difference between cardiac autonomic recovery after continuous and intermittent maximal exercise [21].

Guimarães et al. [22] assessed heart failure patients randomly assigned to either a 16-week Pilates exercise...
program or conventional cardiac rehabilitation and, consistently with the trends observed in this study, they found increased ventilation, peak VO$_2$ and O$_2$ saturation only for the Pilates exercise group. Jürgensen et al. [23] reported that healthy subjects reached 78% of their maximal predicted heart rate when performing the shuttle walking test, while Probst et al. [10] reported that subjects reached 99% of their maximal predicted heart rate. Similarly to the latter, in the current study, subjects reached 98% of their maximal predicted heart rate. Additionally, heart rate recovery was found to be faster in groups with progressive training load, independently of the VO$_{2\text{max}}$ level [24].

Pilates exercises characteristics might be beneficial to pulmonary function and functional capacity [4]. The increased recruitment of the abdominal, gluteal and lumbar muscles and breathing technique results in increased blood flow and O$_2$ consumption. Aerobic training atten-tense levels (as opposed to moderate) also increases heart rate recovery [25]. However, the Pilates exercises prescribed during the 11-week protocol were not an intense routine, as classified by the participants. The findings showed changes in heart rate recovery due to a moderate level of Pilates exercise. Another important finding is that the subjects progressively needed less time to complete the exercise sequence. Until the 6th week, the average time to complete the sequence was 45 minutes; afterwards the average time was 35 minutes.

Some limitations of this study can be addressed. The sample size of the current study was small, so larger studies are encouraged including the evaluations of different populations and people with different demographics because we only assessed young sedentary women. Also, more parameters need to be assessed including gait characteristics and muscle activation. Furthermore, a control group would strengthen the design of future studies. However, the significantly longer distance covered after the intervention would strengthen the design of future studies. The study compared breast cancer subjects to reach the predicted shuttle walking test distance in the functional walking capacity. subjects were closer to the predicted shuttle walking test distance in the functional walking capacity. However, the significantly longer distance covered after the intervention would strengthen the design of future studies.

**Conclusions**

Pilates exercises may significantly improve walking functional capacity including walking distance/speed, peak heart rate and heart rate recovery (cardiopulmonary function).

**References**


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Correspondence address
Alexandre Barbosa
Campus JK - Diamantina/MG
Rodovia MGT 367 - Km 583, n° 5000
Alto da Jacuba CEP 39100-000, Brazil
e-mail: alexandre.barbosa@ufjf.edu.br
ABSTRACT
Purpose. The purpose of this study was to compare the inter-joint coordination during sit-to-stand (STD) and stand-to-sit (SIT) execution between healthy people and people with low back pain.
Methods. Fifteen healthy adults (age = 45.14 ± 5.18 years) and fifteen age-matched (age = 46.17 ± 8.26 years) people with chronic low back pain were selected voluntarily. They performed three repetitions of STD and SIT movement patterns in their preferred pace. Motion analysis system was used for measuring 3-dimensional (3D) angular displacement of hip, knee and ankle joints during execution of movement patterns. Decomposition indices were analysed and were compared between two groups through Hotelling T² Multivariate Analysis of Variance (MANOVA) and follow-up Analysis of Variance (ANOVA).
Results. The results showed that there is a significant difference (T² = 18.32, F₁₄,₅ = 8.33, p < 0.05) between the groups on decomposition indices. The ANOVA follow-up results showed that there are significant differences between two groups on decomposition indices of the whole pattern of STD (F₁,₁₈ = 7.96, p < 0.05), whole pattern of SIT (F₁,₁₈ = 5.37, p < 0.05), the first-half phase of STD (F₁,₁₈ = 7.26, p < 0.05) and the first-half phase of SIT (F₁,₁₈ = 6.33, p < 0.05).
Conclusions. People with low back pain have dis-coordination in the function of different body parts, and results in pausing of one segment while the other segment moves independently. This knowledge may help in the development of rehabilitation strategies for movement in this population.

Key words: decomposition index, inter-joint coordination, low back pain

Introduction
Low back pain [LBP] is common in many developed countries [1–4]. According to a national survey in the UK [1] it is reported that 40% of adults have experienced back pain lasting more than one day in the previous 12 months. In addition, it is reported that 15% of people with back pain said they were in pain throughout the year. The European Union Commission study [2] in 2007 reported that 67 million people of the European countries had experienced pain in their lower or upper back in the previous week. Strine and Hootman [3], based on the 2002 National Health Interview Survey in the USA comprising adults over 18 years, reported that 34 million people suffered from low back pain. Fernández-de-las-Peñas et al. [4] in a recent report on Spanish population reported that 1-year prevalence of low back pain in adults over 16 years was approximately 20%.

Low back pain has physical, psychological, social and economic consequences for the individual. It is believed that adults with low back pain exhibit more psychological distress, engage in more risky health behaviours than adults without back pain [3] and are more likely to experience depression and other physical complaints such as arthritis and osteoporosis [4, 5].

Some surveys reported that in the UK 12.5% of all sick days were found to be related to low back disorders. In Sweden it is estimated that 13.5% of sick days were the result of lower back problems [6]. The economic cost of back pain on society in the Netherlands has been estimated to be 1.7% of the gross national product [7]. In another survey in the UK it is reported that the direct health care cost of back pain in 1998 was 1632 million, of which approximately 35% relates to services provided in the private sector [8].

Physical and behavioural consequences of low back pain are interrelated so that behavioural changes often are accompanied with physical limitations in painful regions. In a severe level of back pain, it can result in movement disability that ultimately may lead to sufferers avoiding their daily activities or occupations in the short or long term [9]. Since mechanical stressors in the workplace are the most important cause of low back incidence in the developed countries and its manifestations are physical complaints in different forms such as back ache, back pain, muscle soreness, muscle stiffness and limited joint range of motion due to pain [10].

Keefe and Block [11] labelled the pain behaviours in low back persons into 4 categories including guarding, bracing, rubbing and grimacing, which were later expanded by McDaniel et al. [12] into 8 categories including guarding, bracing, grimacing, sighing, rigidity, self-stimulation, passive and active rubbing.

Guarding is one of the observable features of pain behaviours that has attracted the attention of scien-
tists investigating low back pain. Keefe and Block [11] defined guarding as abnormal stiff, interrupted, or rigid movement while moving from one position to another. This behaviour is observable in movements such as sitting, standing, reclining, walking or other movement patterns that require shifting from one position to another. McDaniel et al. [12] later revised the original characteristics that were defined by Keefe and Block. They assumed that the guarding cannot occur during a stationary position such as sitting, standing and reclining. They included other features in their definition for guarding which were hesitation in the execution of movement that was different from movement undertaken at a slow velocity. Guarding that is considered to be an adaptive mechanism in response to acute pain in people with low back pain [13] is accompanied with increased muscle activity during flexion-extension tasks and walking [14–17] and restricted optimal trunk movement [18, 19]. These two guarding features that are known as muscle stiffness and joint rigidity are responsible for stabilising the spine via changes in the reflex control of trunk muscles [20].

Coordination between different body parts or muscle groups is necessary in order to control the multi-joint movement in a fluent manner. This synergy [21] might be deteriorated by factors such as pain, muscle stiffness, decreased joint range of motion [22, 23] and neurological problems [24] which may eventually result in the lack of coordination between different body parts. Silfies et al. [22] demonstrated that in a standing reach task lumbar-pelvic coordination was more separated in time and more variable in people with chronic low back pain compared to healthy participants. This lack of coordination was attributed to freezing the motion of the lumbar spine in the subjects with low back pain [21, 22, 25] in contrast to healthy people who simultaneously moved their lumbar spine and pelvis in the same direction during trunk bending [26].

Previous studies [23, 25] have shown that inter-joint coordination is altered in the lumbar spine and hips during sit-to-stand (STD) and stand-to-sit (SIT) in people with LBP. The method used to compute joint coordination in these studies was the relative phase, quantified by subtracting the phase angle (inverse tangent of angular velocity relative/angular displacement) of one joint from the other [29]. Positive or negative values of relative phase represent the earlier onset, or delay of movement, in one joint relative to other joint. For example, if relative phase between hip to lumbar spine is negative, the hip movement is delayed until after onset of the lumbar spine movement. Relative phase is an indicator of positional changes in coordination of two joints rather than a time parameter of joint coordination. An alternative method for representing joint coordination is the decomposition index. This is defined as an index of dis-coordination between two segments in terms of smooth or hesitant movement on the basis of timing [24]. It shows whilst one segment is moving another segment is stopping. This index is applicable for studying the pain behaviours such as hesitation in guarding behaviour.

There are no previous studies which have investigated joint motion based on the decomposition index in a population with low back pain, thus the aim of this study was to compare movement coordination between the lumbar spine and hip joints using this method in participants with and without low back pain.

**Material and methods**

**Participants**

Fifteen adult (age = 46.17 ± 8.28 years) subjects (male = 7, female = 8) with chronic low back pain and 15 age-matched (age = 45.14 ± 5.18) asymptomatic healthy people (male = 7, female = 8) were selected voluntarily. All subjects completed an informed consent form, the Recent Physical Activity Questionnaire (RPAQ) and the Visual Analog Scale (VAS) prior to participation in this study. They suffered from chronic pains in low back area and were inactive in the past year according to their responses in questionnaires. The Research Committee of the University approved all stages of study.

**Instrument**

An 8-camera motion analysis system (Simi motion, co) was used to calculate angular displacement during STD and SIT according to a standard protocol. For the purpose of this study only lumbar spine and thigh markers were analysed for calculating movement coordination. Markers were placed on the body on the second sacral vertebra (S2), right and left Anterior Superi or Iliac Spine (ASIS). Right and left thigh wands and markers were placed nearly 15 cm above the patella.

**Procedure**

Information about the execution of movement patterns was presented verbally. Participants performed three repetitions of STD and SIT according to their preferred speed without using their hands. They stood in front of adjustable chair (30–40 cm height) with neither armrest nor backrest. The height of the chair was adjusted so that the knee angle in the sitting position was 90° regardless of the person’s height. The movement was started from a sitting position then was progressed to a standing position to complete one repetition of STD movement. After a few seconds (2–3 seconds) the movement was continued from a standing position and finished in a sitting position to complete one repetition of SIT movement. This sequence was repeated 3 times in a row. Figure 1 depicts the whole sequence and two phases of STD and SIT that are segmented according to the muscle power and type of muscle contraction in the lumbar spine. In the first phase of both STD and...
SIT, the eccentric contraction and negative power are produced, whereas in the second phase of STD and SIT the concentric contraction and positive power are produced [25].

**Data analysis**

**Inter-joint coordination**

Angular velocities of hip and lumbar spine joints were computed through dividing of angular displacement (degree) of flexion-extension (frontal) axis to time (second). The instantaneous velocity was computed for each frame number in order to acquire the detailed changes in movement sequence. Decomposition index values as indicators of inter-joint coordination were the percentage of STD and SIT time during which movement was decomposed. A joint was considered to pause when its angular velocity dropped below 5º/s [24]. Average decomposition index values (%) were calculated for the lumbar-hip joint pair in each phase of STD, SIT and whole STD and SIT when one joint was moving while the other joint paused.

**Statistical analysis**

Descriptive statistics include mean and standard deviation. Hotelling’s T^2 MANOVA test was used to compare movement coordination between healthy and patient groups. If the results were significant, follow-up ANOVA tests were used to find the between-group differences in decomposition indices of STD and SIT and their phases. Confidence interval value was set at 95% and two-sided.

**Results**

Figure 2 demonstrates the mean decomposition index changes in different phases of STD and SIT. According to the results, decomposition index changed differently between two groups so that for low back pain persons’ decomposition indices of the first-half phase were higher than the second-half phase in STD and SIT, but for healthy group the second-half phase had higher score than the first-half phase for both STD and SIT.

The Hotelling T^2 test result showed that there is a significant difference (T^2 = 18.32, F_{14, 5} = 8.33, p < 0.05) in decomposition indices between the low back pain group and the healthy one. ANOVA follow-up results showed that there are significant differences between the two groups for decomposition indices of whole pattern of STD (F_{1, 28} = 7.96, p < 0.05), whole pattern of SIT (F_{1, 28} = 5.37, p < 0.05), the first-half phase of STD (F_{1, 28} = 7.26, p < 0.05) and the first-half phase of SIT (F_{1, 28} = 6.33, p < 0.05). Low back pain people had significantly higher decomposition indices relative to healthy group in whole STD (21.16 vs. 15.35), whole SIT (22.18 vs. 18.95), the first-half of STD (21.35 vs. 16.04), and the first-half of SIT (23.04 vs. 13.18).

**Discussion**

The aim of this study was to examine the effects of chronic low back pain on movement coordination in the lumbar spine and hip joints during two functional movement abilities including STD and SIT. Our findings showed that there were significant differences between low back pain people and healthy ones in decomposition indices of STD, SIT and the first-half phases of STD and SIT. These findings are indicative of the lack of synergy between movements of two joints that move independently due to lack of coordination. On the other hand, while the hip joint flexed lumbar joint paused and vice versa. These findings also support the findings of previous studies about the incidence of hesitation due to pain in low back pain people [11, 12].

Silfies et al. [22] showed that lumbar-pelvic coordination was more separated in time and more variable in people with chronic low back pain. Shum et al. [23] have demonstrated that low back pain people showed
different lumbar-hip coordination relative to healthy people. In fact, the contribution of the lumbar spine in STD and SIT movements was reduced due to immobility in these joints induced to protect the spine against pain. Shum et al. [25] in another study have revealed that muscle moment reduction in the lumbar spine in the sagittal plane is the reason why STD and SIT strategies change in low back pain people. They minimise the trunk motion and thereby reduce the muscle moment on the joint that in turn changes inter-joint coordination. Another study [30] showed a decreased power flow from the pelvis to the lower limbs in low back pain people during STD. The present findings also showed dis-coordination of joints due to pausing of one joint whilst the other joint is moving.

The method of current study was different from previous studies [22, 25] that measured inter-joint coordination through relative phase as an indicator of phase difference between paired-joints such as hip and lumbar spine joints. Relative phase is an indicator of positional changes in coordination (leading or lagging joint into degree) rather than time parameter (pausing one joint for a millisecond). In fact, guarding behaviour as a form of muscle stiffness or joint freezing [14–20] that is observable in low back pain people resulted in limitation in trunk or thigh movements and it led to inter-joint dis-coordination.

The additional data analysis of decomposition index of the lumbar and hip joints showed different contribution of them in inducing dis-coordination in healthy and low back pain groups. In healthy group the pausing percentage in the lumbar and hip joints in entire movements were 77% and 22%, respectively (lumbar to hip ratio: 3.5), whereas in low back pain group the pausing percentage for lumbar and hip joints were 60% and 42%, respectively (lumbar to hip ratio:1.42). Thus, the hip joint slightly (25% less than in healthy people) contributed to body weight transfer in low back pain people. These findings are important as they show to what extent a hesitant movement is shared between two different body parts so that STD and SIT could be executed.

In addition, as Figure 2 shows that the decomposition index for low back pain people in different phases of STD and SIT are different – in the first-half of STD and SIT they demonstrated more pausing than in the second-half. This pattern was different in healthy people who showed more pausing in the second-half of STD and SIT. Shum et al. [25] revealed that muscle powers are different in different phases of STD and SIT, namely in the first-half phase the muscle work is negative because the type of muscular contraction is eccentric. It seems that keeping the trunk upright during seat-off phase to peak lumbar spine flexion (a, b and c in Figure 1) due to painful condition deteriorates inter-joint coordination by reducing the fluent motion and converting it into a hesitant movement. Again during SIT movement, the type of muscle contraction in first-half phase is eccentric that will interrupt the joints’ synergy which caused more pausing during movement execution.

Reduction in the angular velocity of both lumbar and hip joints during STD and SIT have been demonstrated in previous studies [23, 31] and were explained as a preventive mechanism against pain that is caused by muscle contraction and high levels of acceleration. Difficulty in transferring the muscle force from the pelvis to the lower limbs causes an interruption in the execution of closed kinetic chain that in turn is responsible for transferring the force from the upper to lower body parts [30]. These findings suggest that reducing angular velocity in the lumbar spine is helpful to reduce the angular moment between two joints and subsequently prevents the risk of losing balance. But reducing it beyond the normal values relative to hip movement is a preventive mechanism that is observable in low back pain people that could change the mechanics of movement into hesitant behaviours. Thus, in rehabilitation programmes of low back pain, emphasising on a constant and fluent motion and prevention from hesitant movement reduce the pressure on the lumbar spine through efficient utilisation of the hip in coordination with the lumbar spine by means of a closed kinetic chain.

Future studies should investigate the possible mechanisms of hesitation behaviours through electromyography [EMG] study to confirm the biomechanical findings that have been revealed in the present study. In conclusion, low back pain causes dis-coordination in the function of different body parts and results in pausing in one segment while the other segment moves independently. Therapeutic exercises that emphasise coordinative movement of the pelvis and the hip joints could reduce dis-coordination due to freezing in movement segments.

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HUMAN MOVEMENT

M. Shafizadeh, Movement coordination during Sit-to-Stand in low back pain people


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Correspondence address: Mohsen Shafizadeh
Academy of Sport and Physical Activity
Faculty of Health and Wellbeing
Sheffield Hallam University
Sheffield, UK, S10 2BP
e-mail: m.shafizadeh@shu.ac.uk
THE INFLUENCE OF ENERGY BOOST AND SPRINGBLADE FOOTWEAR ON THE KINETICS AND KINEMATICS OF RUNNING

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JONATHAN SINCLAIR1*, STEPHANIE DILLON2
1 Centre for Applied Sport and Exercise Sciences, School of Sport and Wellbeing, College of Health and Wellbeing, University of Central Lancashire, Preston, Lancashire, United Kingdom
2 International Institute of Nutritional Sciences and Applied Food Safety Studies, School of Sport and Wellbeing, College of Health and Wellbeing, University of Central Lancashire, Preston, Lancashire, United Kingdom

ABSTRACT
Purpose. The aim of the current study was to comparatively examine the effects of energy return, spring and conventional footwear on the kinetics and kinematics of running. Methods. Twelve male runners ran over an embedded force platform at 4.0 m · s⁻¹ in the three footwear conditions. Lower limb kinematics were collected using an 8 camera motion capture system and tibial accelerations were obtained using an accelerometer. Differences in kinetic and kinematic parameters between footwear were examined using one-way repeated measures ANOVA. Results. The results showed that there were no significant differences in kinetic parameters between footwear. However, it was shown that spring footwear were associated with significantly greater angles of peak eversion (–12.49°) and tibial internal rotation (13.09°) in comparison to the conventional footwear (eversion = –10.52° & tibial internal rotation = 10.84°). Conclusions. Therefore, the findings from the current investigation indicate that spring footwear may place runners at increased risk from excessive ankle eversion/tibial internal rotation.

Key words: footwear, biomechanics, running

Introduction
Recreational distance running is known to mediate a number of physiological benefits [1]. However, despite this, runners are also known to be highly susceptible to chronic injuries [2], with an incidence rate of around 70% over the course of one year [3]. A number of intrinsic and extrinsic risk factors have been associated with the aetiology of running injuries, such as mileage, previous injury, number of years of training, training characteristics, running mechanics, surface and footwear [4]. The most common chronic injuries associated with distance running are iliotibial band syndrome, tibial stress fractures, patellofemoral pain, Achilles tendinitis, and plantar fasciitis [4].

A large range of preventative/treatment modalities have therefore been explored, such as modifications to training schedules [5–7], stretching regimens [8–10], warm ups/cool downs [11], external supports [12], orthoses [13, 14] and footwear [15] in an attempt to mitigate the high risk of injury in runners. A key preventative modality is to select running shoes with appropriate mechanical midsole characteristics, which can influence the biomechanical mechanisms linked to the aetiology of injury. The properties of running shoe midsoles have therefore been proposed as a mechanism by which chronic injuries can be managed [16].

Energy return has become a contemporary topic in footwear biomechanics literature [17–19]. The first energy return footwear utilized a thermoplastic polyurethane midsole which is designed to reduce energy loss in comparison to traditional ethylene-vinyl acetate footwear midsoles. There has been only one study which has examined biomechanics of running in these footwear. Sinclair et al. [17] investigated the effects of conventional and energy return footwear on the kinetics and kinematics of running. Their results showed that the conventional running footwear with an ethylene-vinyl acetate footwear midsole were associated with significantly reduced tibial accelerations and peak eversion angles in comparison to energy return. In addition, a further footwear design has also been introduced, which also claims to increase energy return via 16 curved springs designed to store and release energy. Currently, there is no published information regarding the biomechanics of the spring footwear. However, given the high incidence of chronic pathologies in runners and the popularity of these new footwear models, research of this nature would be of both practical and clinical significance.

Therefore, the aim of the current study was to comparatively examine the effects of energy return, spring and conventional footwear on the kinetics and kinematics of running. Given the high rate of chronic pathologies in runners, a study of this nature may give key information to runners and clinicians with regards to the selection of footwear for the reduction of injury.

* Corresponding author.
Material and methods

Participants

Twelve male participants volunteered to take part in the current investigation. The mean ± SD characteristics of the participants were: age 23.59 ± 2.00 years, height 177.05 ± 4.58 cm and body mass 77.54 ± 5.47 kg. All were free from musculoskeletal pathology at the time of data collection and provided written informed consent. The procedure utilized for this investigation was approved by the University ethical committee in accordance with the principles outlined in the Declaration of Helsinki.

Procedure

The runners completed five successful trials in which they ran through a 22 m walkway at an average velocity of 4.0 m·s⁻¹ in each of the three running shoe conditions. The participants struck a piezoelectric force platform (Kistler Instruments) embedded into the middle of the laboratory with their right foot [20]. The force platform data was collected with a frequency of 1000 Hz. Running velocity was controlled using timing gates (SmartSpeed Ltd UK) and a maximum deviation of 5% from the pre-determined velocity was allowed. Three-dimensional (3D) kinematic information from the stance phase of the running cycle were obtained using an eight-camera motion capture system (Qualisys Medical AB, Goteburg, Sweden) with a capture frequency of 250 Hz. To prevent any sequence effects, the order in which participants performed in each footwear condition was counterbalanced. Each footwear condition had four participants who received it first, second and last. The stance phase was delineated as the duration over which > 20 N of vertical force was applied to the force platform.

To quantify lower extremity joint kinematics in all three planes of rotation, the calibrated anatomical systems technique was utilized [21]. Retroreflective markers (19 mm) were positioned unilaterally allowing the right foot, shank and thigh to be defined. The foot was defined via the 1st and 5th metatarsal heads, medial and lateral malleoli and tracked using the calcaneus, 1st metatarsal and 5th metatarsal heads. The shank was defined via the medial and lateral malleoli and medial and lateral femoral epicondyles and tracked using a cluster positioned onto the shank. The thigh was defined via the medial and lateral malleoli and the hip joint centre and tracked using a cluster positioned onto the thigh. To define the pelvis additional markers were positioned onto the anterior (ASIS) and posterior (PSIS) superior iliac spines, and this segment was tracked using the same markers. The hip joint centre was determined using a regression equation that uses the positions of the ASIS markers [22]. The centers of the ankle and knee joints were delineated as the mid-point between the malleoli and femoral epicondyle markers [23, 24]. Static calibration trials were obtained allowing for the anatomical markers to be referenced in relation to the tracking markers/ clusters. The Z (transverse) axis was oriented vertically from the distal segment end to the proximal segment end. The Y (coronal) axis was oriented in the segment from posterior to anterior. Finally, the X (sagittal) axis orientation was determined using the right hand rule and was oriented from medial to lateral.

To quantify tibial accelerations an accelerometer (Biometrics ACL 300, Gwent UK), sampling at 1000 Hz was utilized. The accelerometer was attached onto a piece of lightweight carbon-fibre material using the protocol outlined by Sinclair et al. [25], and strapped securely to the distal anterio-medial aspect of the tibia in alignment with its longitudinal axis 0.08 m above the medial malleolus [26].

Footwear

The footwear used during this study consisted of conventional footwear (New Balance 1260 v2), energy return (Adidas energy boost) and spring (Adidas spring-blade drive 2) footwear, (shoe size 8–10 in UK men’s sizes).

Processing

Trials were processed in Qualisys Track Manager in order to identify anatomical and tracking markers, then exported as C3D files. Kinematic parameters were quantified using Visual 3-D (C-Motion Inc, Gaithersburg, USA) after marker data was smoothed using a low-pass Butterworth 4th order zero-lag filter at a cut off frequency of 12 Hz. Kinematics of the hip, knee, ankle and tibial segment were quantified using an XYZ cardan sequence of rotations (where X is flexion-extension; Y is ab-adduction and Z is internal-external rotation). 3D kinematic measures from the hip, knee, ankle and tibia which were extracted for statistical analysis were 1) angle at footstrike, 2) angle at toe-off, 3) peak angle during stance and 4) relative range of motion (ROM) from footstrike to peak angle.

From the force platform vertical force parameters of impact peak, time to impact peak, average loading rate and instantaneous loading rate were calculated. The impact peak was taken as the vertical ground reaction force peak that occurred early in the stance phase. The average loading rate was calculated by dividing the impact peak by the duration over which the impact peak occurred whereas instantaneous loading rate was calculated as the maximum increase between adjacent data points [16]. The acceleration signal was filtered with a 60Hz low-pass Butterworth 4th order zero-lag filter. Peak tibial acceleration was defined as the highest positive acceleration peak measured during the stance phase. Tibial acceleration slope was quantified by dividing the
peak tibial acceleration magnitude by the duration over which the acceleration occurred, whereas tibial acceleration instantaneous loading rate was calculated as the maximum increase in tibial acceleration between adjacent data points [16].

All of the aforementioned kinetic and kinematic parameters were extracted from each of the five trials and the data was then averaged within subjects for statistical analysis. Hip, knee and ankle joint kinematic curves were time normalized to stance and were ensemble averaged across subjects for graphical purposes.

Statistical analysis

Means and standard deviations were calculated for each outcome measure for all footwear conditions. Differences in kinetic and kinematic parameters between footwear were examined using one-way repeated measures ANOVAs, with significance accepted at the $p < 0.05$ level. Effect sizes were calculated using partial eta² ($\eta^2$), with $\eta^2 = 0.2$ considered small, $\eta^2 = 0.5$ considered medium and $\eta^2 = 0.8$ considered large. Post-hoc pairwise comparisons were conducted on all significant main effects. The data was screened for normality using a Shapiro–Wilk which confirmed that the normality assumption was met. All statistical actions were conducted using SPSS v22.0 (SPSS Inc., Chicago, USA).

Results

Kinetics

Table 1 presents the kinetic parameters obtained as a function of the different experimental footwear.

The results show that there were no differences ($p > 0.05$) between footwear were found for any of the kinetic parameters.

Kinematics

Tables 2–5 and figures 1–2 presents the 3D kinematic parameters obtained as a function of the different experimental footwear.

| Table 1. Kinetic and tibial acceleration parameters as a function of footwear |
|------------------|------------------|------------------|
|                  | Conventional | Energy return | Spring |
|                  | Mean  | SD    | Mean  | SD      | Mean  | SD      |
| Impact peak (N/kg) | 17.58  | 6.10  | 17.86  | 6.28    | 18.32  | 6.16    |
| Time to impact peak(s) | 0.03  | 0.01  | 0.03  | 0.01    | 0.03  | 0.01    |
| Load rate (N/kg/s) | 678.23 | 74.04 | 653.63 | 91.27   | 669.36 | 133.84  |
| Instantaneous load rate (N/kg/s) | 1102.82 | 196.37 | 1287.51 | 373.67 | 1438.55 | 435.65 |
| Peak tibial acceleration (g) | 6.60  | 2.47  | 7.03  | 2.79    | 7.53  | 2.75    |
| Time to peak tibial acceleration (s) | 0.05  | 0.03  | 0.04  | 0.03    | 0.05  | 0.03    |
| Tibial acceleration slope (g/s) | 242.28 | 145.69 | 225.71 | 112.99  | 241.17 | 154.88  |
| Tibial acceleration instantaneous slope (g/s) | 709.67 | 353.88 | 659.42 | 290.16  | 720.26 | 298.88  |

| Table 2. Hip joint kinematic parameters as a function of footwear |
|------------------|------------------|------------------|
|                  | Conventional | Energy return | Spring |
|                  | Mean  | SD    | Mean  | SD      | Mean  | SD      |
| Sagittal plane (+ = flexion & – = extension) |
| Angle at footstrike | 23.79  | 7.67  | 27.02  | 10.07   | 24.03  | 6.43    |
| Angle at toe-off | −17.40 | 9.25  | −15.24 | 11.11   | −17.21 | 8.95    |
| Peak angle | 24.95  | 6.80  | 27.41  | 9.94    | 24.78  | 6.56    |
| ROM | 1.16  | 2.26  | 0.39  | 0.77    | 0.76  | 0.76    |
| Coronal plane (+ = adduction & – = abduction) |
| Angle at footstrike | 0.78  | 3.62  | 1.00  | 2.39    | 1.65  | 4.56    |
| Angle at toe-off | −3.88 | 5.25  | −4.08 | 4.15    | −4.01 | 4.68    |
| Peak angle | 7.31  | 4.36  | 7.14  | 3.42    | 7.61  | 3.33    |
| ROM | 6.53  | 2.46  | 6.14  | 1.68    | 5.96  | 3.17    |
| Transverse plane (+ = internal & – = external) |
| Angle at footstrike | −11.40  | 6.55  | −12.52 | 7.90    | −12.76 | 8.29    |
| Angle at toe-off | −9.89  | 9.78  | −8.80 | 9.87    | −8.58 | 10.73   |
| Peak angle | −18.16 | 6.77  | −17.88 | 7.00    | −17.63 | 7.20    |
| ROM | 6.76  | 5.86  | 5.36  | 4.33    | 4.86  | 3.59    |
Table 3. Knee joint kinematic parameters as a function of footwear

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<td></td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
</tr>
<tr>
<td>Sagittal plane (+ = flexion &amp; – = extension)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Angle at footstrike</td>
<td>9.81</td>
<td>8.76</td>
<td>10.04</td>
</tr>
<tr>
<td>Angle at toe-off</td>
<td>14.05</td>
<td>8.02</td>
<td>12.91</td>
</tr>
<tr>
<td>Peak angle</td>
<td>37.98</td>
<td>5.27</td>
<td>35.56</td>
</tr>
<tr>
<td>ROM</td>
<td>28.17</td>
<td>8.24</td>
<td>25.52</td>
</tr>
<tr>
<td>Coronal plane (+ = adduction &amp; – = abduction)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Angle at footstrike</td>
<td>−0.61</td>
<td>7.16</td>
<td>−0.25</td>
</tr>
<tr>
<td>Angle at toe-off</td>
<td>−3.26</td>
<td>4.08</td>
<td>−2.52</td>
</tr>
<tr>
<td>Peak angle</td>
<td>−7.77</td>
<td>7.32</td>
<td>−6.87</td>
</tr>
<tr>
<td>ROM</td>
<td>7.16</td>
<td>3.68</td>
<td>6.62</td>
</tr>
<tr>
<td>Transverse plane (+ = internal &amp; – = external)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Angle at footstrike</td>
<td>−2.13</td>
<td>6.37</td>
<td>−0.86</td>
</tr>
<tr>
<td>Angle at toe-off</td>
<td>−1.72</td>
<td>5.76</td>
<td>−1.74</td>
</tr>
<tr>
<td>Peak angle</td>
<td>11.05</td>
<td>5.76</td>
<td>11.36</td>
</tr>
<tr>
<td>ROM</td>
<td>13.17</td>
<td>6.24</td>
<td>12.23</td>
</tr>
</tbody>
</table>

Table 4. Ankle joint kinematic parameters as a function of footwear

<table>
<thead>
<tr>
<th></th>
<th>Conventional</th>
<th>Energy return</th>
<th>Spring</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
</tr>
<tr>
<td>Sagittal plane (+ = dorsiflexion &amp; – = plantarflexion)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Angle at footstrike</td>
<td>4.75</td>
<td>12.26</td>
<td>3.48</td>
</tr>
<tr>
<td>Angle at toe-off</td>
<td>−23.70</td>
<td>5.42</td>
<td>−20.91</td>
</tr>
<tr>
<td>Peak angle</td>
<td>19.29</td>
<td>5.39</td>
<td>18.56</td>
</tr>
<tr>
<td>ROM</td>
<td>14.53</td>
<td>7.91</td>
<td>15.08</td>
</tr>
<tr>
<td>Coronal plane (+ = inversion &amp; – = eversion)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Angle at footstrike</td>
<td>0.75</td>
<td>4.99</td>
<td>0.29</td>
</tr>
<tr>
<td>Angle at toe-off</td>
<td>3.75</td>
<td>4.76</td>
<td>1.63</td>
</tr>
<tr>
<td>Peak angle</td>
<td>−10.52</td>
<td>7.01</td>
<td>−11.17</td>
</tr>
<tr>
<td>ROM</td>
<td>11.27</td>
<td>3.80</td>
<td>11.46</td>
</tr>
<tr>
<td>Transverse plane (+ = external &amp; – = internal)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Angle at footstrike</td>
<td>−10.83</td>
<td>5.14</td>
<td>−10.72</td>
</tr>
<tr>
<td>Angle at toe-off</td>
<td>−5.60</td>
<td>6.83</td>
<td>−6.41</td>
</tr>
<tr>
<td>Peak angle</td>
<td>−0.95</td>
<td>3.97</td>
<td>−0.38</td>
</tr>
<tr>
<td>ROM</td>
<td>9.88</td>
<td>2.54</td>
<td>10.34</td>
</tr>
</tbody>
</table>

Table 5. Tibial internal rotation parameters as a function of footwear

<table>
<thead>
<tr>
<th></th>
<th>Conventional</th>
<th>Energy return</th>
<th>Spring</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
</tr>
<tr>
<td>Transverse plane (+ = internal &amp; – = external)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Angle at footstrike</td>
<td>3.29</td>
<td>7.18</td>
<td>3.82</td>
</tr>
<tr>
<td>Angle at toe-off</td>
<td>1.87</td>
<td>7.86</td>
<td>3.50</td>
</tr>
<tr>
<td>Peak angle</td>
<td>10.84</td>
<td>7.16</td>
<td>11.27</td>
</tr>
<tr>
<td>ROM</td>
<td>7.55</td>
<td>2.98</td>
<td>7.44</td>
</tr>
</tbody>
</table>
Hip

No differences ($p > 0.05$) in hip joint kinematics were found between footwear.

Knee

No differences ($p > 0.05$) in knee joint kinematics were found between footwear.

Ankle

In the coronal plane a main effect ($p < 0.05, \eta^2 = 0.45$) was shown for the angle at footstrike. Post-hoc analysis revealed that the eversion was significantly greater in the spring footwear compared to the conventional and energy return conditions. A main effect ($p < 0.05, \eta^2 = 0.71$) was also shown for the angle at toe-off. Post-hoc analysis revealed that the inversion was significantly reduced in the spring footwear compared to the conventional condition. Finally a main effect ($p < 0.05, \eta^2 = 0.41$) was found for the angle of peak eversion. Post-hoc analysis revealed that the angle of eversion was significantly greater in the spring footwear compared to the conventional condition.

Tibia

A main effect ($p < 0.05, \eta^2 = 0.36$) was shown for the angle at footstrike. Post-hoc analysis revealed that the internal rotation was significantly greater in the spring
footwear compared to the conventional and energy return conditions. A main effect \( (p < 0.05, \text{effect size } = 0.54) \) was also shown for the angle at toe-off. Post-hoc analysis revealed that internal rotation was significantly greater in the spring footwear compared to the conventional condition. Finally, a main effect \( (p < 0.05, \text{effect size } = 0.45) \) was found for the angle of peak internal rotation. Post-hoc analysis revealed that the angle of peak internal rotation was significantly greater in the spring footwear compared to the conventional condition.

**Discussion**

The aim of this work was to determine the influence of energy return, spring, and conventional running footwear on the kinetics and kinematics of running. To the authors' knowledge, this study represents the first to comparatively examine the biomechanical effects of running in energy return and spring footwear.

The first key observation from the current investigation is that no significant differences in impact kinetics were shown between any of the experimental footwear. This finding is interesting in light of the vastly different midsole characteristics between the three footwear conditions and shows that different materials can have the same impact attenuating properties. This finding disagrees with the findings of Sinclair et al. [5] who demonstrated that conventional running shoes were associated with reduced tibial accelerations compared to energy return footwear. Therefore, importantly based on the findings from this study, it appears that the experimental footwear used in this research does not appear to affect runner's susceptibility to impact-related chronic disorders.

That the peak angle of eversion and tibial internal rotation were significantly greater in spring footwear compared to conventional running shoes is also an important observation. It is proposed that this finding relates to the lack of medial support in the spring footwear in relation to the conventional running shoes, meaning that their mechanical characteristics are unable to physically restrain the coronal plane motion of the ankle and associated inward rotation of the tibia. This observation may have clinical significance as increased eversion and tibial internal rotation parameters have been linked to the aetiology of chronic injuries [27]. Therefore, the current investigation indicates that spring footwear may place runners at increased risk from chronic injuries in comparison to conventional running shoes.

A potential drawback of this study is that it investigated only the kinetics and 3D kinematics of running. This procedure represents a useful practice when investigating the effects of different footwear on running biomechanics. However, the mechanical characteristics of the energy return and spring footwear are designed specifically to increase energy return from the midsole and reduce the metabolic requirements of running. Therefore, in addition to the current work, future research should seek to determine whether these footwear can influence the metabolic cost of running.

**Conclusions**

In conclusion, the present investigation adds to the current knowledge by providing a comprehensive evaluation of both kinetic and kinematic parameters when running in energy return, conventional, and spring footwear. Firstly, the current study demonstrated that despite the infinitely different midsole characteristics of the three footwear conditions and the manufacturers' claims, there were no differences in impact attenuation. Secondly, the current study showed that the peak angles of eversion and tibial internal rotation were significantly larger in spring in comparison to conventional footwear. Therefore, the findings from the current investigation indicate that spring footwear may place runners at increased risk from chronic injury related to excessive ankle eversion/tibial internal rotation.

**References**

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HUMAN MOVEMENT

J. Sinclair, S. Dillon, Effects of energy and spring footwear


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Correspondence address
Jonathan Sinclair
Centre for Applied Sport Exercise and Nutritional Sciences
School of Sport and Wellbeing
College of Health and Wellbeing
University of Central Lancashire
Preston, Lancashire
UK, PR1 2HE
e-mail: jksinclair@uclan.ac.uk
EVALUATION OF LATERALITY IN THE SNOWBOARD BASIC POSITION

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MICHAIŁ STANISZEWSKI¹*, PRZEMYSŁAW ZYBKO¹, IDA WISZOMIRSKA²
¹ Faculty of Physical Education, Józef Piłsudski University of Physical Education, Warsaw, Poland
² Faculty of Rehabilitation, Józef Piłsudski University of Physical Education, Warsaw, Poland

ABSTRACT

Purpose. Snowboarding requires a lateral positioning of the body. Moreover, a person must continuously control their balance and use this in order to manoeuvre on the slope applying properly pressure on the lower limb closest to the nose of the board (the leading leg). The present study is an attempt to determine the interdependencies between side preference while snowboarding and laterality when performing other tasks. The dynamic stability in the neutral standing position, as well as in the lateral positions (left or right) was also evaluated.

Methods. The survey participants (100 active snowboarders) answered a set of questions concerning laterality while carrying out basic everyday tasks and while doing sports. The respondents were divided into two groups based on their preferred leading side in snowboarding. Additionally, in the case of 34 people, muscle torques values of the lower limbs were measured under static conditions and the postural stability was evaluated using AccuSway AMTI platform and Biodex Balance System platform.

Results. Over 90% of the participants declared right-handedness and right-footedness. However, with regard to snowboarding, only 66% indicated their right leg as leading. No significant dependence was found between the directional stance on the board and the leading hand, dominant leg, or leading eye. The stability measurements revealed statistically significant differences between the neutral stance and the lateral positioning.

Conclusions. Based on the study results, it may be assumed that the declared directional stance on the snowboard is not contingent on the person’s basic laterality, and that the lateral stance on the board significantly affects the posture control.

Key words: biomechanics, posture control, muscle torques, leading lower limb

Introduction

The combination of three fundamental elements – board’s design, the snowboarder's stance and riding technique – determines a snowboarder’s performance. However, all of them require an asymmetrical lateral positioning of the body with regard to the slide's direction, and turning is then controlled by leaning outward on the board's edges in the direction of the desired turn. The most difficult element when learning to snowboard is how to control posture. The sideways stance (in snowboarding known as the basic position) on the board is not a natural position for human locomotion, and because the lower limbs are bound, their role in posture control is limited. The direction impulse which results in taking a turn starts when the snowboarder puts their weight on one edge of the board to make it change direction. Therefore, in order to do it, the snowboarder must unbalance themselves in a controlled way and lean into the direction of the intended turn. Stability is maintained during the turn due to the occurrence of an inertial force – which is characterised by the same velocity and magnitude, but is in the opposite direction to the centripetal force. The value of the inertial force, commonly referred to as the centrifugal force, cancels out the forces which might overturn the snowboarder, and is directly proportional to the square of the rider’s velocity and inversely proportional to the curve's radius. In order to stay on the curved path, the snowboarder must lean at a proper angle into the turn maintaining the body’s centre of gravity in the centre of the curve – for a greater velocity or a smaller turn radius, the lean angle must be greater [1, 2].

Snowboarding is positively linked with constant balancing. Standing on the board is conditioned by the rider’s ability to keep posture control, whilst a turn is executed due to conscious unbalancing. The snowboarder’s stability is affected by the size of the base of support; the position of the centre of pressure (COP); the person’s body mass; and the direction of the gravitational force [3, 4]. Furthermore, posture control during the slide is affected by the velocity and momentum of the counteracting forces. It is worth noting that the balance control necessary to make a turn requires the rider to lean in the sagittal (anterior/posterior) plane while their head must face the slide’s direction, which occurs in the frontal (medial/lateral) plane.

In winter sports such as snowboarding and skiing, posture control is an element that can be assessed in relation to many different aspects [5]. For instance, Platzer et al. [6] evaluated the one-legged stance among members of the Austria national snowboarding team using

* Corresponding author.
the Biodex Balance System platform. The authors monitored changes in their posture control during successive stages of training and related the gathered data to the specificity of the given competition, combined with the number of points accumulated in the World Cup. In another study, Noé and Paillard [7] evaluated the posture control of amateur skiers and members of the national skiing team. The subjects were evaluated both while wearing skiing boots and without them. Their results showed that in the measurements without boots the amateurs had better posture control than the professionals. In turn, the national team members had far better results when tested in skiing boots, which proves the long-lasting effects of wearing them on their balancing capabilities. Still, this sort of compensation phenomenon occurred only under conditions characteristic of the practiced sport.

In the proper snowboarding technique, the slide trajectory is determined by putting more pressure on the lower limb positioned closer to the nose of the board – the so-called ‘leading leg’ [8]. For beginners, determining the leading limb is essential to an efficient learning process; whereas the reversed slide (with the opposite limb in front) is taught at a later stage of training due to its difficulty. The ability to ride freely with either leg in front requires many days of practice, and attests to a certain level of the snowboarder’s proficiency. The asymmetry of snowboarding is significantly displayed when freestyle techniques are performed. McAlpine et al. [9] point out that when landing after the flight phase, the pressure on the rear leg is significantly greater than on the limb in the front. After taking into consideration some other additional factors, the authors validate the assumption that, from the perspective of sliding technique and biomechanics, the lower limbs should be assessed separately when determining laterality.

Laterality occurs naturally in the course of human development and applies to several different functions of the human body. The inclination for the organs located on either the left or right side to perform given tasks is comprehensively described in literature. However, basic analyses of functional laterality tend to focus on determining the dominant upper and lower limb when performing basic everyday chores and motor activities, such as kicking a ball or writing. The differentiation between dominant side and non-dominant one may also apply to other functions, such as hearing, seeing or brain functions, and generally plays a role in the choice of the best limb to carry out a given task or when rotating the body [10]. Additionally, some researchers have pointed out the differences between each side with regard to: the ranges of motion in specific joints [11, 12], the discrepancies in the anatomy and biomechanical functions of body parts based on the preferred side [13–16] or the differentiation in lateralisation factors stemming from the gender of the study participants [17].

Since at present there are no papers which analyse the relationship between the laterality associated with the choice of the leading lower limb in snowboarding and the person’s functional laterality, this paper will attempt to establish whether there is such a connection, and determine the influence of the snowboarder’s laterality on their body stability.

Material and methods

The study population included 100 participants who were randomly chosen from a snowboarding course consisting of 46 females (21 ± 4 years old) and 54 males (22 ± 3 years old). The participants were asked questions in the form of a survey concerning their laterality while performing basic everyday chores and sports activities. The dominant upper limb was determined based on the respondents’ statements concerning one-handed throwing. Whereas the laterality of the lower limb was not so easy to determine. We needed to take into account many activities involving the use of the lower limbs in human life. Based on this, the laterality in four tasks was determined: ball kicking, one-legged bouncing off the ground after a running start, one-legged stance and the declaration of their leading leg during snowboarding ride (the leg at the front of the snowboard). Additionally, the respondents were asked about their preferred side while looking through one eye and their favoured rotation direction when jumping with both feet with a 360 degree spin. Next, the respondents were divided into two groups based on their leading leg in snowboard stance. Moreover, 34 people participating in a snowboarding instructor’s course (16 females, aged 22 ± 1 year old, mean body mass: 59 ± 7 kg and mean height: 170 ± 7 cm; and 18 males aged 22 ± 3 years old, body mass: 80 ± 7 kg and mean height: 182 ± 6 cm) underwent an assessment of their body stability and an evaluation of the muscle torque in their lower limbs. All of the respondents were informed about the research protocol and were acquainted with the requirements and conditions of the experiment. Also, each participant personally signed an informed consent form prior to participating in the research study, and was notified of their right to leave the experiment without any consequences. The study was approved by the Scientific Research Ethics Committee.

To evaluate the laterality of strength between front and rear leg on the snowboard, measurements of the muscle torques of the flexors and extensors in both knee joints and plantar flexors in both ankle joints were taken under isometric conditions. The participants were examined on a Biodex System 3 Pro machine (USA) in a sitting position with a stabilized torso and their knees bent at 90°.
To evaluate the laterality of posture control between front and rear leg on the snowboard, measurements of the static stability were tested on the AccuSway AMTI (USA) stabilographic platform with a stable floor. Testing protocols were performed with the subjects’ eyes open and closed in one-legged stances. The path length of the COP was used for comparison of the stability between legs.

Dynamic stability measurements were performed using the Biodex Balance System (USA) platform. Three testing protocols were carried out at the 8th level of instability (scale of platform settings), with each protocol consisted of 3 trials – each lasting 20 seconds with a 10-second interval between the trials. A Postural Stability Test (PST) was performed with biofeedback, requiring the participant to stand straight in front of the screen and to stand sideways with their head facing the screen (mimicking the snowboarding stance, Figure 1). For the analysis of the results, the Overall Stability Index (OSI) was used.

The registered data was statistically analysed using STATISTICA (a data analysis software system), Version 10 by StatSoft, Inc. (2011). In order to establish the conformity of the analysed dispersion matrix to a normal distribution, the Shapiro–Wilk test was utilised. The statistical significance of the dependencies between all of the lateralisation parameters was then calculated using the Spearman correlation coefficient. As to postural stability on the unstable Biodex platform, the significance of the determined differences after logarithmisation was checked using the analysis of variance (ANOVA) method. When statistically significant differences were reported, a post-hoc test was performed (Fisher’s LSD test of the lowest significant differences). The evaluation of the differences in the static postural stability parameters (AMTI platform) and the torque values between the leading and the non-leading limb was performed using the non-parametric Mann-Whitney U test. For all the tests, the significance level was set at $p < 0.05$.

**Results**

Among the surveyed snowboarders, the overwhelming majority (over 90%) declared themselves to be right-handed when throwing and right-footed when kicking a ball. These two parameters determine whether the person is considered right handed or left handed and right footed or left footed, respectively. Thus, these parameters decidedly correlate with each other (Table 1). Moreover analysis showed that 72% of the respondents bounced off the ground from their left lower limb and 28% from their right one when jumping forward on one leg combined with a running start. The data re-

### Table 1. Laterality declared by the participants of the survey while performing certain everyday life and sports activities

<table>
<thead>
<tr>
<th>Dominant side</th>
<th>One-handed throwing</th>
<th>Kicking a ball</th>
<th>Bouncing off the ground</th>
<th>One-legged stance</th>
<th>Seeing with one eye</th>
<th>360° rotation jump</th>
<th>Leading leg on a board</th>
</tr>
</thead>
<tbody>
<tr>
<td>Left</td>
<td>8%</td>
<td>11%</td>
<td>72%</td>
<td>46%</td>
<td>42%</td>
<td>59%</td>
<td>34%</td>
</tr>
<tr>
<td>Right</td>
<td>92%</td>
<td>89%</td>
<td>28%</td>
<td>54%</td>
<td>58%</td>
<td>41%</td>
<td>66%</td>
</tr>
</tbody>
</table>

* statistically significant interdependency between one-handed throwing and kicking a ball; ($p < 0.001, r = 0.60$)
* statistically significant reverse interdependency between kicking a ball and bouncing off the ground; ($p < 0.001, r = 0.35$)
* statistically significant interdependency between bouncing off the ground and 360 rotation jump; ($p = 0.003, r = 0.29$)
garding ball kicking and one-legged bouncing off the ground are the only ones to show a negative correlation. This observation indicates a proportionally inverse dependence, i.e. where people kick a ball with their right foot but bounce off the ground using their left limb, and vice versa. The statements concerning bouncing off the ground and aerial rotation correlated. However, no compelling relationship between the direction of the snowboarding stance and the other discussed laterализation parameters in everyday life was established. In the study group, 68% subjects said that they ride on snowboard with the right foot in front (in snowboarding known as the 'goofy' stance) and 32% with the left foot in front (known as the 'regular' stance).

As was to be expected, the majority of respondents were right-handed and right-footed; hence, analysis of the interdependency between the right/left lower limb positioned at the front of the snowboard and the laterализation factors would have been unjustified (i.e. if we were to discuss the results in this way, the significant correlation would only exist in the case of people snowboarding with the right side to the front). Therefore, the interdependencies were not analysed in terms of the left/right axis, but instead with regard to the dominant side of the front/rear lower limb on the board plane while performing a given motion (Table 2). Assuming this approach to be the right one, no significant interdependencies were found between the dominant side while snowboarding and the laterализation parameters for the everyday human activities.

Moreover, static muscle torques were measured for the knee flexors and extensors and the ankle plantar flexors. Data for the left and right lower limbs was collected; however, in the course of a further comparative analysis the data was calculated only for the anterior/posterior position on the board (Figure 2). A closely corresponding set of values was calculated for each function, and these were not differentiated with regard to the muscle torque of the lower limb depending on the direction of the stance on the board.

In evaluating the measurement results of the one leg stance on the AMTI platform, the same division was utilized for the front/rear leg. Table 3 shows the values for the centre of pressure path length. Considerably higher ($p < 0.001$) values of the parameters were reported when the test was performed with the subjects’ eyes closed; but

![Figure 2. Mean ± SD values of the muscle torques under static conditions for the knee flexors and extensors, and ankle plantar flexors of the front and rear lower limbs on the board](image)

![Figure 3. Mean ± SD value of the overall stability index (OSI) in the neutral standing position heading front and with the left and right side to the front](image)

<table>
<thead>
<tr>
<th>Protocol</th>
<th>Front leg</th>
<th>Rear leg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eyes open</td>
<td>Path length (cm)</td>
<td>37.52 ± 11.95</td>
</tr>
<tr>
<td>Eyes closed</td>
<td>Path length (cm)</td>
<td>101.48*** ± 35.17</td>
</tr>
</tbody>
</table>

*** values significantly higher ($p < 0.001$) than with eyes open

### Table 2. Interdependency between the leading leg on the board (the one at the front) and the declared laterality while performing other tasks

<table>
<thead>
<tr>
<th>Leg on a board</th>
<th>One-handed throwing</th>
<th>Kicking a ball</th>
<th>Bouncing off the ground</th>
<th>One-legged stance</th>
<th>Looking with one eye open</th>
<th>360° rotation jump</th>
</tr>
</thead>
<tbody>
<tr>
<td>Front</td>
<td>55%</td>
<td>55%</td>
<td>51%</td>
<td>60%</td>
<td>49%</td>
<td>57%</td>
</tr>
<tr>
<td>Rear</td>
<td>45%</td>
<td>45%</td>
<td>49%</td>
<td>40%</td>
<td>51%</td>
<td>43%</td>
</tr>
</tbody>
</table>

### Table 3. Mean ± SD values of the COP path length during the postural stability test on one leg on the AMTI platform in regard to the lower limb’s position on the board – at the front and at the back
no statistically significant differences in the postural stability parameters were found between the front and rear leading leg on the board.

The dynamic postural stability was evaluated using the Biodex Balance System platform. The subjects were given the task of keeping their balance on the dynamic platform with their eyes open while visually controlling the COP deviation on the biofeedback screen. The first testing protocol was performed in a neutral position—with the subject standing in front of the screen. The subsequent two protocols required the subjects to stand with either their right or left side to the front, while their face was directed at the screen, i.e. in a head position similar to the snowboarding stance. The overall stability index (OSI) values for all the trials are presented in Figure 3. It should be noted that the postural stability values obtained for lateral/directional stance are higher (and are statistically significant at \( p < 0.001 \)) than the values recorded in the neutral position.

Discussion

Eighty seven out of 100 participants were characterised by right-sidedness, i.e. their right hand was dominant while performing manipulative motor activities and their right leg was dominant as the swinging limb when kicking a ball. 6% of the respondents were decidedly left-sided; while 5% showed signs of Type I cross-lateralisation (right handed/left footed). In the case of two subjects, Type II cross-lateralisation was established (left handed/right footed). The occurrence of these four basic laterality models within the hand-foot system established during this study corresponds to the data gathered for the overall European population by other authors [14, 18].

Based on the visuospatial study of laterality in volleyball players and rowers conducted by Giglia et al. [19], the researchers proved that differences between the right and left side are only present in the case of the top-notch professionals. However, the lateralization results gathered from ski carving turns by Vaverka and Vodickova [20] showed that when the preferred lower limb is also the outer leg, it affects efficacy of a turn. Their study of laterality during symmetrical ski turns showed that the functional preference of the lower limb can affect the execution of a turn, even in the case of professional skiers. Furthermore, Jandová and Chárousek [21] performed an evaluation of ski runners and demonstrated that even for motions such as a two-step glide (V2 Alternate), which is symmetrical, the kick off will be performed quicker and in a shorter time by the dominant leg. The practical meaning of this is that when training, the ski runners should focus on improving their explosive power, especially in the case of the non-dominant leg.

Danielsson [11] analysed the lateralisation parameters among proficient snowboarders and compared the data with the results of people who did not train snowboarding. He did not find any differences with regard to the ranges of motions within the main joints or the right and the left side. The only meaningful interdependencies were noted when he analysed the strength of the lower limbs and the hip circumference. The author highlighted the fact that the snowboarders he evaluated presented a higher muscle strength value in the leg placed toward the rear end of the board. This may be because the back leg functions as a support and is bounced off while performing most of the elements of snowboarding freestyle techniques.

Our study indicates the lack of a significant relationship between the selected parameters in regard to the declared laterality and the directionality of the stance while snowboarding. The muscle torque values under static conditions and the postural stability parameters also did not differentiate the limbs based on their position on the board. It is worth mentioning that the stability evaluation was performed on the participants who were experienced snowboarders taking part in an snowboard instructor course. Therefore, it may be assumed that the lack of a consequential difference in the stability results between the front limb and the rear limb results is a consequence of the riders’ skills and their frequent shifting in stance direction while performing this sport. Executing freestyle elements of snowboarding and free-riding techniques often results in a forced bi-lateralisation, which could have affected the symmetry distribution of the stability factors. To verify this hypothesis, further studies will need to evaluate people who do not ride on regular basis and participants of a snowboarding course for beginners utilizing the same protocols as in the present study.

As a rule, in order to maintain the proper posture and posture control, the entire motor system is involved in the execution of a given task, which means that various groups of muscles undergo a concomitant strain [22, 23]. Snowboarding requires constant activity of these muscles under conditions of a relative dynamic stability and the learning process encompasses sets of exercises and activities aimed at increasing/improving the balance kinesiology while riding a snowboard. Physical exercises done under conditions where balance is disrupted result not only in the enhancement of postural stability, but also affect the muscles and build up strength. Myer et al. [24] indicated that a training protocol including balancing exercises is just as effective as plyometric training in terms of strengthening the muscles and overall fitness [25]. Similarly, Gorman et al. [26] and Lynn et al. [27] conducted separate experiments, and both demonstrated the multi-dimensional efficacy of training that included balancing exercises for the entire body and incorporated the muscle strength of the lower limbs, and not simply training that included only equilibrium components.

The present study has showed notable differences in the postural stability between a neutral standing posi-
tion and the same position but with head facing sideways (similar to the directional snowboarding stance). Nonetheless, the available literature does not provide sufficient accounts of studies that describe the stability parameters in the case of snowboarders, and which evaluate the effects of snowboarding courses on changes in the components of posture control.

Conclusions

Considering the results of the study, the stance direction on the snowboard (i.e. declaring the so-called ‘leading leg’) is yet another completely independent functional laterality element. What is more, the lateral positioning on the board with the rider’s face simultaneously turned toward the direction of the slide poses a considerable difficulty in keeping posture control. With this conclusion in mind, a further study is planned which would be specifically designed to evaluate the stability of the body in people who are just beginning their adventure with snowboarding. Such a study would also assess how this sort of training affects the postural stability parameters.

References


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*Correspondence address*
Michał Staniszewski
Zakład Sportów Wodnych i Zimowych
Akademia Wychowania Fizycznego
Józef Piłsudskiego
ul. Marymoncka 34
00-968 Warszawa 45, Poland
e-mail: michal.staniszewski@awf.edu.pl
ABSTRACT

Purpose. The aim of this study was to examine the relationship between impulsiveness and tactical performance of U-15 youth soccer players.

Methods. The sample comprised 100 U-15 youth soccer players. Impulsiveness and tactical performance were assessed using the Continuous Performance Test-II (cPT-II) and the System of Tactical Assessment in Soccer (FUT-SAT), respectively. FUT-SAT enables evaluation of ten core tactical principles of soccer game: (i) penetration; (ii) offensive coverage; (iii) depth mobility; (iv) width and length; (v) offensive unity; (vi) delay; (vii) defensive coverage; (viii) balance; (ix) concentration; and (x) defensive unity. Impulsiveness values were obtained using the Omission and Commission Error analysis. Tactical performance values were obtained through the Game Tactical Performance Index (GTPI), Offensive Tactical Performance Index (OTPI) and Defensive Tactical Performance Index (DTPI). The Kolmogorov–Smirnov test and Spearman's Correlation one were performed (\(p < 0.05\)) through SPSS, v. 22.

Results. We observed a positive correlation between impulsiveness and GTPI (\(\rho = 0.226; p = 0.018\)).

Conclusions. It is concluded that impulsiveness is related to tactical performance of U-15 youth soccer players.

Key words: soccer, impulsiveness, tactical performance

Introduction

Tactical performance in soccer and the cognitive processes related to decision-making have been associated with the efficiency of game actions, and consequently with sport expertise [1, 2]. Tactical performance can be defined as the result of individual and collective actions performed in the game [3]. Thus, the knowledge about tactical domain must be examined through the assessment of both individual performance and players' interactions, as well as the factors which may affect these interactions [4, 5].

One of these factors that may influence the performance of players and have been associated with players' behaviour is impulsiveness. Impulsiveness can be defined as the tendency to inhibit responses to a lesser extent than in most people before taking an action [6]. Previous studies involving impulsiveness and motor behaviour identified differences among people due to response inhibition in a determined task [7–10].

In this respect, investigations have examined impulsiveness in sports. In one of these investigations, Svebak and Kerr [11] examined the relationship between impulsiveness and sport preference in an Australian sample. They found that people engaged in explosive sports (e.g. soccer) obtained higher scores on impulsiveness measures than people who prefer an endurance sport. Recently, in a study involving team sports, Lage et al. [12] investigated the relationship between impulsiveness and technical performance of handball players. They found that high scores on impulsiveness (i.e. more impulsive people) produce errors in game responses. Although some cases of impulsiveness are related to negative factors, there is no unanimity regarding its effect in sports responses.

Therefore, studies related to physical and technical variables present in literature advance with studies that investigate the influences of impulsiveness in sports. However, studies involving tactical components are scarce and this variable demands further attention, as the quick action responses might directly influence the tactical response and consequently team performance [12, 13]. Thus, the aim of this study was to examine the relationship between impulsiveness and tactical performance of U-15 youth soccer players.

Material and methods

Sample

The sample comprised 100 U-15 youth soccer players from soccer clubs and schools from the state of Minas Gerais (Brazil) who performed 6,640 tactical actions. The inclusion criteria were: (i) players from clubs and soccer schools must participate in regular training sessions, at least three times a week; (ii) they must participate in competitions at regional level.

* Corresponding author.
<table>
<thead>
<tr>
<th>Categories</th>
<th>Sub-Categories</th>
<th>Variables</th>
<th>Definitions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Offensive</td>
<td>Penetration</td>
<td>Movement of player with the ball towards the goal line.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Offensive Coverage</td>
<td>Offensive supports to the player with the ball.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Depth Mobility</td>
<td>Movement of players between the last defender and goal line.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Width and Length</td>
<td>Movement of players to extend and use the effective play-space.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Offensive Unity</td>
<td>Movement of the last line of defenders towards the offensive midfield, in order to support offensive actions of the teammates.</td>
<td></td>
</tr>
<tr>
<td>Tactical Principles</td>
<td>Delay</td>
<td>Actions to slow down the opponent’s attempt to move forward with the ball.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Defensive Coverage</td>
<td>Positioning of off-ball defenders behind the “delay” player, providing defensive support.</td>
<td></td>
</tr>
<tr>
<td>Defensive</td>
<td>Balance</td>
<td>Positioning of off-ball defenders in reaction to movements of attackers, trying to achieve the numerical stability or superiority in the opposition relationship.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Concentration</td>
<td>Positioning of off-ball defenders to occupy vital spaces and protect the scoring area.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Defensive Unity</td>
<td>Positioning of off-ball defenders to reduce the effective play-space of the opponents.</td>
<td></td>
</tr>
</tbody>
</table>

Figure 1. Ten core tactical principles of soccer [14]

Figure 2. The Macro-Category Observation and Macro-Category Outcome of FUT-SAT [14]
Instruments for data collection

As a means to assess the tactical performance, the System of Tactical Assessment in Soccer (FUT-SAT) [14] was used. This system enables the evaluation of tactical actions according to ten core tactical principles of soccer, as shown in Figure 1.

The FUT-SAT comprises two macro-categories (Figure 2). The Macro-CATEGORY Observation refers to aspects that can be assessed in the instrument. The Macro-CATEGORY Outcome refers to results provided by the instrument.

Regarding the assessment of impulsiveness, the Continuous Performance Test (CPT-II) was used [15]. This instrument is performed via computer and enables evaluation of processes related to vigilance, response inhibition, signal detection, and other aspects of performance, among them, attentional and motor impulsiveness.

Ethical procedures

This research was approved by the Research Ethics Committee from Universidade Federal de Viçosa, Brazil (Ref. N. 132/2012/CEPH) and meets the norms established by the National Health Council (CNS 466/2012) and by the Declaration of Helsinki (1996). To participate in this research, players and parents/tutors were previously contacted and provided with the information about research procedures and thereafter they signed an informed consent. Data collection began after parents/tutors had authorized players to participate in the research. Players were free to withdraw from the study at any moment.

Data collection procedures

In order to assess tactical actions, the FUT-SAT field test (GK+3 vs. 3+GK) was conducted. The structure of the test consists of a small-sided game (playing area is 36 m long by 27 m wide) in which players are divided into two teams, each with 3 outfield players and a goalkeeper, who wear numbered vests. Players are asked to play for four minutes according to the rules of soccer, except for the offside rule. Prior to the start of the test, players are given 30 seconds to familiarize with the activity. The field tests were filmed and recorded on a digital camera (Sony HDR-XR100). Video footage was introduced in digital format in a laptop (POSITIVO Premium 4A015RX8T) via USB cable and converted into AVI format through Format Factory Video Converter software. For video processing and analysis, Soccer Analyser® software was used. The Soccer Analyser® software enables assessment of the tactical actions performed by participants, as it is possible to calculate the Tactical Performance Index (TPI) of each soccer player using the following formula:

\[
\text{Tactical Performance Index (TPI)} = \frac{\sum \text{tactical actions}}{\text{number of tactical actions}}
\]

In order to assess impulsiveness, the Continuous Performance Test (CPT-II) was used. The test consists in a task in which letters show up randomly and alternately in the centre of computer screen (in this study a POSITIVO Premium 4A015RX8T laptop computer was used). The players sitting in front of the computer screen in a quiet room have to press the spacebar on the computer keyboard when letters appear, except when the letter “X” appears. In this case, the participants should not press the spacebar. The duration of test was fourteen minutes. We used two main scores measured in this test: (i) Omission Errors, which indicates the number of times that the stimuli (non-X letters) appeared and the player did not respond to it. This variable is related to the attentional impulsiveness; and (ii) Commission Errors, which indicates the number of times the player responded when the letter X appeared on the screen. This variable is related to the motor impulsiveness.

Statistical analysis

Initially, descriptive analyses were conducted (means and standard deviations). Tactical performance data were obtained using the Tactical Performance Indexes (TPI) in each game phase: (i) Offensive Tactical Performance Index (OTPI), (ii) Defensive Tactical Performance Index (DTPI), and for both phases of play: (iii) Game Tactical Performance Index (GTPI).

With respect to impulsiveness data, the measures used to analyse participants’ performance were the number of Omission Errors (when the subject omits responses) and Commission Errors (when the subjects give inappropriate responses).

The Kolmogorov–Smirnov normality test was used to verify data distribution. To verify the relation between tactical and impulsiveness measures, Spearman’s Correlation Test was used. For statistical procedures, SPSS (Statistical Package for Social Sciences) v. 22 was used.

Test-retest reliability of the observations was measured using Cohen’s Kappa test. Analyses were verified through the reassessment of 1,260 tactical actions, i.e. 18.97% of the sample, a higher value than that indicated by literature (10%) [16]. Two observers participated in the procedure respecting a three-week interval for reanalysis, thus avoiding task familiarity issues [17]. Values of intra-observer reliability were between 0.885 (SE = 0.009) and 0.929 (SE = 0.009), while values of inter-observer reliability were between 0.847 (SE = 0.033) and 0.958 (SE = 0.014). These values are defined by literature as “almost perfect” [18].
Results

Table 1 presents the correlation between the CPT measures (Omission Errors and Commission Errors) and the Tactical Performance Indexes (Offensive, Defensive, and Game). Positive correlation was observed between CPT Commission and GTPI (rho = 0.226; p = 0.018).

For the remaining cases, no significant correlations were found.

Table 1. Correlation between the CPT measures and Tactical Performance Indexes

<table>
<thead>
<tr>
<th>Measures</th>
<th>OTPI</th>
<th>DTPI</th>
<th>GTPI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Omission Errors</td>
<td>rho</td>
<td>p</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.054</td>
<td>0.579</td>
<td>0.018*</td>
</tr>
<tr>
<td></td>
<td>-0.150</td>
<td>0.119</td>
<td>0.905</td>
</tr>
<tr>
<td>Commission Errors</td>
<td>rho</td>
<td>p</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.165</td>
<td>0.086</td>
<td>0.226</td>
</tr>
<tr>
<td></td>
<td>0.030</td>
<td>0.753</td>
<td></td>
</tr>
</tbody>
</table>

* significant correlation at p < 0.05

Discussion

Assessment of cognitive processes and how these processes affect the performance have received some attention in recent years. However, specific studies that assess the influence of impulsiveness in soccer (mainly in tactical aspects) are scarce. Accordingly, the aim of this study was to examine the relationship between impulsiveness and tactical performance of U-15 youth soccer players.

Results displayed positive correlation between impulsiveness and Game Tactical Performance Index (GTPI). Players who committed more errors by commission (i.e. executed quicker decisions and consequently more mistakes) have displayed higher tactical performance than others. These data suggest that impulsive players may present higher scores of tactical performance compared to less impulsive players.

In this respect, a pioneer investigation conducted by Vestberg et al. [19] suggested that specific cognitive processes predict the success of soccer players. When discussing their findings, the authors suggest that what is demanded of a “successful player” is not only quickness of decisions during actions, but also quick inhibition of planned decisions. In this context, this research corroborates with findings from other studies which demonstrated that more impulsive people showed more accuracy than less impulsive people when the time available for decision-making is extremely short [6, 20].

Although game accuracy aspects might decrease as the time set to perform actions decreases, the results of this research suggest that high tactical performance is positively related with quick responses. Errors by commission are related with quickness in motor responses [15] and it seems to be a positive factor for tactical demands, whereas game success depends on risk choices even when mistakes are made. Thus, players’ behaviour should be guided by the need to perform tactical principles within the shortest possible time, once tactical management efficiency is closely related to response quickness such as space creation that may influence other game demands [21, 22].

Therefore, in learning/training process, the efficient execution of tactical principles is related to quick game responses. Accordingly, such responses might be influenced by impulsiveness. However, there are few studies investigating the role of impulsiveness in soccer tactical performance. Thus, we suggest further investigation regarding impulsiveness in different samples, age groups and expertise level to better understand its role in soccer.

Conclusions

1. We concluded that motor impulsiveness was related to tactical performance of U-15 youth soccer players. Players that are more impulsive presented higher tactical performance in the game.
2. The attentional impulsiveness did not show correlation to tactical performance of U-15 youth soccer players.
3. This study furthers the knowledge about players’ impulsiveness and how it is related to the tactical domain in soccer. However, more research is necessary.

Acknowledgements

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References


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14. Authors are obliged to cooperate with the editorial staff: native speaker, HM editor and proofreaders (language and statistical data) in order to eliminate ambiguities and errors. In case of no response to the editorial observations within a week, the author's consent for introduction of the suggested changes is taken for granted.

15. Authors should list all the people or institutions that contributed to the article preparation factually, financially or technically.

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20. The original version of the journal is its paper issue.

Sszczegółowe zasady przygotowania artykułu do Human Movement

1. Redakcja przyjmuje prace wyłącznie w języku angielskim.

2. Tekst prac empirycznych wraz ze streszczeniem, rycinami i tabelami nie powinien przekraczać 20, a prac przeglądowych – 30 stron znormalizowanych formatu A4 (ok. 1800 znaków ze spacjami na stronie). Strony powinny być numerowane.

3. Artykuł należy przygotować w edytorze tekstu Microsoft Word według następujących zasad:
   - krótkie pisma: Times New Roman, 12 pkt;
   - interpunkt: 1,5;
   - tekst wyjustowany;
   - tytuł zapisany pogrubionym krojem pisma, wyodrębniony.
4. The main title page should contain the following:
   - The article's title
   - A shortened title of the article (up to 40 characters in length including spaces), which will be placed in the running head
   - The name and surname of the author(s) with their affiliations written in the following way: the name of the university, city name, country name. For example: The University of Physical Education, Wrocław, Poland
   - Address for correspondence (author's name, address, e-mail address and phone number)
5. The second page should contain:
   - The title of the article
   - An abstract of approximately 200 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 ethical 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.

4. Strona tytułowa powinna zawierać:
   - tytuł pracy w języku angielskim;
   - skrócony tytuł artykułu w języku angielskim (do 40 znaków ze spacjami), który zostanie umieszczony w żywej paginie;
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   - tytuł artykułu;
   - streszczenie w języku angielskim (około 200 wyrazów) składające się z następujących części: Purpose, Methods, Results, Conclusions;
   - 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**

Prezentowanie wyników powinno być logiczne i spójne oraz ściśle powiązane z danymi zamieszczanymi 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.
Conclusions
In presenting any conclusions, it is important to remember 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.

Bibliography
The bibliography should be composed of the article's citations and be arranged and numbered in the order in which they appear in the text, not alphabetically. Referenced sources from literature should indicate the page number and enclose it in square brackets, e.g., Bouchard et al. [23].

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Bibliographic citations of journal articles should include: the author's (or authors') surname, first name initial, article title, abbreviated journal title, year, volume or number, page number, doi, for example:


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