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Dancing as non-pharmacological treatment for healthy aging in the COVID-19 era; a gerontological perspective

PATRYCJA RĄGLEWSKA[1], VIDA DEMARIN[2]

Abstract
Findings reveal a strong correlation between physical activity and cardiorespiratory fitness, the nervous system, psycho-motor skills, vascular aging, mood, cognition, and the overall quality of life as a result of a regular non-pharmacological treatment. Among many types and modes of physical activities dancing seems superior thanks to the widest spectrum of its impact on the body, including not only physical (fitness endurance, muscle strengthening, flexibility), but also psychological (cognition) and even social needs (satisfying the need of closeness, reducing the sense of loneliness). In view of the above, we summarize current knowledge on the connection between healthy ageing and dancing, which should be especially recommended for older people (>60 y).

KEYWORDS: COVID-19, dancing, physical activity in gerontology.

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Introduction

There is conclusive evidence that classical medicine including surgery and pharmacological treatment in certain cases may be indispensable during the aging process; however, any non-pharmacological treatment that does not disrupt normal bodily function is of interest, provided it can be effective in the prevention or management of disease. This is especially valuable when positive effects are observed in terms of cardiorespiratory fitness [16], the nervous system [21], psycho-motor skills [8], vascular aging [18], mood, cognition and the overall quality of life [11] as a result of regular non-pharmacological treatment. One spectacular example is dancing, which is especially recommended for older people (>60 y) [7] proving to be superior to fitness exercise [17] thanks to the widest spectrum of its impact on the body, including not only physical (fitness endurance, muscle strengthening, flexibility), but also psychological (cognition) and even social needs (satisfying the need of closeness, reducing the sense of loneliness).

Biological aging

Processes that influence biological aging might be divided into two classes as innate functions that decline/change over time and those affected by damage-related factors. These adaptations are accompanied by vascular and neurological changes that compromise muscle function [5]. A challenge in the study of aging is to determine whether the deterioration of muscle and nervous system functions is attributed to aging *per se* or rather whether is a consequence of disease and lifestyle. Unfortunately, among numerous factors aging itself is the essential risk factor for neurodegenerative diseases, including Parkinson's disease (PD), Alzheimer's disease (AD), dementia and increased sensitivity to sudden pathophysiological episodes, such as stroke. However, focusing on AD as the main cause of dementia, about

33% of all AD cases worldwide could be attributed to seven risk factors, including smoking, diabetes, hypertension, obesity, low education, physical inactivity and depression, with the largest proportion of AD cases attributable to physical inactivity [13]. Thus, among other things physical activity is regarded as one of the most significant non-pharmacological treatments against rapid, pathological and unfavourable symptoms of neurological aging [20]. For instance, Voss et al. first demonstrated the existence of exercise-induced functional plasticity in large-scale brain systems in the aging brain [22].

Muscles and nervous tissues are functionally connected, and thus an exercising person who usually focuses on training muscles also needs to be aware that during exercise the nervous system is trained as well. Moreover, maintaining cognition in older age is more likely in physically active people than in those who are physically inactive. In 2003 Verghese et al. reported in the NEJM that leisure activities, reading, playing musical instruments, playing board games and dancing are associated with a reduced risk of dementia [21].

Muscle must be lifelong trained

Aging is associated with changes in muscles that contribute to the age-related decline in peak aerobic and anaerobic power. Additionally, age-related alterations in muscle metabolism, including mitochondrial capacity and insulin sensitivity, are apparent. That is important in the view of the fact that muscle health is a decisive factor against physical frailty and determines maintenance of metabolic health until the limit of chronological age. The role of exercise against aging is well documented; however, more details need to be discussed concerning the intensity, frequency, volume and type of physical activity (exercise) as most suitable for people above >60 y and which thus could be especially recommended.

First of all, exercise can be classified into the three following subclasses: resistance, endurance and patterned movements, where only endurance and resistance exercise have a significant influence on the muscle phenotype, while patterned movement exercises concern essentially a motor program in the central nervous system, resulting in almost imperceptible biochemical changes in muscles.

While in the case of resistance exercise the primary acute response is connected with an increase of protein synthesis, in the case of endurance exercise the primary acute response leads to increased levels of slow contractile and regulatory proteins, decreased levels of glycolytic enzymes, increased levels of oxidative enzymes, increased mitochondrial mass and a decrease in the fast-fiber area. Those processes become especially important in view of the fact that in healthy people aged 60-71 yr the maximal oxygen uptake (VO_2max) adapts to aerobic exercise to the same relative extent as in young people and this adaptation is independent of age, gender and the level of fitness at the beginning of training [9].

Most ballroom dances (formal social dancing in couples) such as Standard dances: slow waltz, tango, foxtrot, and Latin dances: rumba and cha-cha, are characterized by their impact on the aerobic metabolic system, which makes them especially suitable for people over 60 years old. During slow to moderate endurance exercise, two essential intracellular signals triggering muscle adaptation may be distinguished: first, a progressive increase in the AMP : ATP ratio and second, an increase of free Ca^{2+} in myocytes [6]. Since most adaptations can be compounded by training-induced ischaemia, this additionally draws attention to a crucial AMPK role in stimulating both vasculogenesis and angiogenesis in exercised muscles [14]. However, aerobic processes do not decline as strongly during aging as muscle strength does; thus, resistance exercises need to be focused on as an essential part of the exercise regimen for older >60 y.

Why is resistance exercise important during aging?

Resistance exercise is any form of exercise that causes muscular contraction at external resistance. Several subtypes can be distinguished: eccentric, concentric, dynamic, static exercises and others. During dancing all subtypes can be observed. However, the phenotypes of prognosed hypertrophy and increased bone density can be expected only as a result of systematic and progressive activity of adequate intensity, weekly frequency, duration of each programmed bout, causing adaptation of the body according to the overload principle. Even a single bout of resistance exercise brings a 50% increase of protein synthesis at 4 h and 115% at 24 h. However, these data refers to young men [10]. In older >60 y persons we do not observe true hypertrophy, but rather slower sarcopenia and muscle decline.

In the enhanced protein synthesis observed after a resistance exercise, mTOR plays a pivotal role. The mTOR pathway is a specific response of skeletal muscles to resistance exercise, nutritional or environmental stimuli; however, the decisive variable is activation through the regular and adequate intensity of exercise. Thus, regular resistance exercise and an adequate choice of intensity are essential for all physically active people, but especially for adults >60 y, as a crucial factor stimulating intracellular muscle protein synthesis and maintaining adaptation to exercise bouts as changing environmental conditions.

Which style of dance is most suitable for older people?

Among the many dance styles and techniques contemporary dance can be especially dedicated and recommended for adults >60 y, as it represents a combination of aerobic and resistance exercise, but is still characterized by its impact on the aerobic metabolic system [19]. However, for the elderly there may be some bodily movement restrictions associated with age-associated changes in the labyrinth, skeletal muscle and joint functioning limitations in the context of the necessary floor practice including rolling, shifting, sliding, travelling, transferring weight, etc.

Dancing is most commonly accompanied by music. Regardless of age and musical expertise, people relatively easily synchronize their body movements to rhythmic music [15]. It should be emphasized that the necessity of coordinating bodily movements to the music rhythm is a positive challenge for people >60 y, especially for their nervous system. Effectiveness of rhythmic music-based interventions on cognitive functioning and motricity especially in neurological populations are being evaluated and adjusted to improve health and well-being [12].

Dance therapy

In the process of prevention and treatment of various illnesses common in elderly people, art therapy plays a significant role. The concept of art therapy (Latin *ars* – art and Greek *therapeia* – care, treatment) involves treatment through art. Although this form of therapy is only reimbursed as a health service in psychiatry, it is increasingly often chosen by therapists and coaches as one of the more effective actions delaying ageing. Therefore, it is a method suitable not only for diseased individuals, but also for healthy people aiming to improve their physical and mental health.

Art therapy does not only involve the use of visual art techniques, as it was the case at the beginning of its heyday. Apart from the visual art aspect, art therapy includes also music therapy and dance therapy. Art therapy is often a part of occupational therapy, which is defined as a continuous therapeutic activity using music, art or movement, carried out in order to rehabilitate a patient or maintain physical and mental fitness of participants. These activities can be performed individually or in groups and involve passive or active participation.

Art therapy in the form of music therapy and dance therapy allows the patient to focus on his or her relation with himself or herself and help build relations with others.

Apart from its relaxing effect, the therapeutic effect of music therapy on the nervous, motor, respiratory, circulatory, digestive and urogenital systems has been confirmed. Rhythm and tune used in music therapy activities positively affect body motor functions and imagination by improving thinking processes. Music therapy is based on listening to music, singing and – the patients' favourite – dancing.

In the case of elderly people the selection of music pieces plays a considerable role. The type of music used affects the emotions of dancers. Each type of dance therapy positively affects the mental and physical condition of the dancing person, stimulating the body and mind to reach the state of balance. When used in people with multiple chronic diseases of the nervous system "dance therapy has become not only an important area of specialised activity in the field of the Polish medicine, rehabilitation and education, but also an opportunity to treat dance art and music as prevention and a panacea for the threats of the modern world. In view of the popularity of art therapy we should bear in mind the ethical rule of *primum non nocere*, which should accompany every therapeutic activity".

Dance is a therapy which improves the mood through the effect of body movement, thus increasing the vitality and reducing the risk of depression, which is very common in elderly people.

However, some effects of dancing are vague and rather intuitive; even though contemporary medicine defines human beings in a biopsychosocial pattern after George Engel [3], since some ailments cannot be treated successfully by biological means, this activity by itself may be not enough. Frecska and Luna went even further and proposed a modified, extended paradigm: the biopsycho-socio-spiritual model [4]. According to WHO, "there is no health without mental health" [23]. Among the many inconveniences of aging loneliness is trully troublesome and there is strong evidence showing that it is a significant factor affecting well-being during aging [24]. For this reason, social behavior and activities such as dance take on an entirely new context for older people feeling lonely, since attending dance activities (classes, workshops, meetings) promotes the creation of social bonds and fosters microcommunities for those sharing the interest, which may counteracts the feeling of loneliness.

Moreover, it seems helpful to recognize that the state of art creation is a process that brings the human being closer to the inner element of the psyche. Delving into the moment of dancing provides the following impression.

When a dancer gives in to impulses and even pre-impulses (since Barba from Odin Theatret calls the Scandinavian term *Sats*), takes off the technique, style and all the learned roles from the foreground and immerses himself/herself in the place of vulnerability. This is when he/she takes off (disarms) one mask after another and faces himself/herself internally, not identified with anyone or anything, free from any judgment and view, aware of the inner needs, unrestricted by any rules, allowing the movement of consciousness in the structures of the imagination, realizing dreams, independent and distant. It may be assumed that at this moment the dancer is deeply immersing himself/herself in the inner element of their psyche. It makes dance, in some circumstances, a viable psychotherapeutic treatment and is defined by the American Dance Therapy Association (ADTA) as "the psychotherapeutic use of movement to promote emotional, social, cognitive, and physical integration of the individual, for the purpose of improving health and well-being" [1]. Results suggest that the Dance Movement Therapy (DMT) even decreases depression and anxiety and improves the overall quality of life and enhances interpersonal and cognitive skills [5]. Moreover, other more specific and non-specific psychotherapeutic mechanisms are connected to dance techniques including mirroring, non-verbal metaphors, movement analysis, imaginative techniques, meditative techniques, focusing and introspection, which all stimulate the nervous system in a non-pharmacological way [2].

Our limited knowledge concerning the relevance of dance as a commonly available and non-expensive non-pharmacological treatment may be broadened by a striking convergence between the effect of dancing and specific and non-specific health benefits and the interconnection between the body, the mind and the healing power of dance, thus supporting healthcare systems [8]. It makes dance a unique possibility of influencing the basically almost the entire human body architecture regardless of age and thus it needs to attract our attention also in the COVID-19 era.

Conflict of interests

The authors declare no conflict of interest.

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Effects of morning and afternoon high-intensity interval training (HIIT) on testosterone, cortisol and testosterone/cortisol ratio response in active men

ABDOSSALEH ZAR[1,2], FATEMEH AHMADI[2], PETER KRUSTRUP[3], RICARDO J. FERNANDES[4,5]

Abstract

Introduction. The time of exercise (morning and afternoon) can lead to changes in hormonal responses and exercise performance. Aim of Study. The current study aimed to investigate the effects of morning vs afternoon high-intensity interval training (HIIT) on testosterone (T), cortisol (C) and the testosterone/cortisol (T/C) ratio in active men. Material and Methods. Eleven active male students (aged: 19.0 ± 1.0 yrs., height: 177.5 ± 9.0 cm, weight: 70.6 ± 8.3 kg and BMI: 22.19 ± 1.88 kg/m^2) completed two trials of the 40-m maximal shuttle run test (which incorporates 5 × 40 m shuttle sprints with 30 s between the start of each sprint), with seven days between the trials. All the trials were conducted indoors. Blood samples were taken before and immediately after each exercise session from the antecubital vein by repetitive venous puncture in a sitting position. Results. Data evidenced that the T concentration increased after HIIT in the afternoon (pre: 9.86 ± 0.42 vs post: 10.3. ± 0.61, P = 0.02). The significant difference was observed between pre-tests (T: 10.4 ± ± 0.67 vs 9.86 ± 0.42, P = 0.009; C: 898.38 ± 199.51 vs 355.53 ± 92.95, P = 0.001; T/C ratio: 0.012 ± 0.002 vs 0.03 ± 0.012, P = 0.001) and also post-test (T: 10.68 ± 0.53 vs 10.3. ± 0.61, P = 0.01; C: 990.64 ± ± 293.07 vs 452.73 ± 307.34, P = 0.001; T/C ratio: 0.011 ± 0.003 vs 0.056 ± 0.065, P = 0.04). Conclusions. It seems that performing high-intensity interval training (HIIT) in the afternoon may be more suitable in terms of the level of anabolic processes.

KEYWORDS: high-intensity interval training (HIIT), testosterone, cortisol, testosterone/cortisol ratio.

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Introduction

Scientific evidence shows that physical exercise plays a key role in improving hormonal function [27], that its long-term practice has beneficial effects on the body physiological functioning [19] and that acute physiological responses to exercise differ depending on the activity type [9]. However, exercising at different times of the day has different consequences depending on the exercise type and duration, and on hormone adaptation [14]. Also, there are differences in physical performance for exercise performed in the morning and evening, which is the reason why these factors should be considered by athletes, coaches and scientists [25]. Although physical exercise has many beneficial effects, it can also act as a stressor, with several indicators being proposed for its diagnosis (e.g. the testosterone/cortisol ratio) [5]. Testosterone is a sex hormone that is produced and secreted in men's testicular cells, with an important anabolic effect on muscle tissue development and growth [33]. Cortisol is a glucocorticoid secreted from the adrenal cortex in the adrenal glands, playing a key role in protein degradation and preventing muscle building [6]. Since testosterone and cortisol are anabolic and catabolic hormones, respectively [5], their ratio is used to indicate anabolic/catabolic balance and it is influenced by exercise intensity and duration.

The testosterone/cortisol ratio decreases as a result of high-intensity training and regular participation in competitive events, indicating physiological stress [29]. In healthy men it was found that testosterone concentration increases after submaximal and maximal endurance training concurrently with a cortisol concentration increase after maximal exertion and a decrease after submaximal training, with the testosterone/cortisol ratio being higher for submaximal comparing to maximal exercise [26]. A decrease in cortisol concentration was observed only in the first analysis immediately after exercise compared to the pre-exercise measurement, while in subsequent measurements an increase in cortisol level was noted. The authors conclude that the results of this study showed that repeated short periods of high intensity exercise in both a thermoneutral and moderately hot environment resulted in no significant differences in testosterone or cortisol response. Moreover, no significant differences in recovery after exercise were observed between the two environments [14].

High-intensity interval training (HIIT) is a form of interval training, a cardiovascular exercise strategy alternating short periods of intense anaerobic exercise with less intense recovery periods, until the athlete is too exhausted to continue. Though there is no universal HIIT session duration, these intense workouts typically last under 30 minutes, with times varying based on the participant's current fitness level. The general prescription for interval training is to employ 3- to 5-minute work bouts with an interval to rest. This type of training may not be safe, tolerable or practical for many individuals [8, 24]. In fact, in the last decades some studies have shown that high-intensity interval exercise can accelerate skeletal muscle metabolism adaptations, with sport physiologists implementing it in training programmes [17]. However, since the circadian rhythm effect on training outputs is still scarcely known, we have aimed to evaluate the effect of time of performance of high-intensity interval exercise (morning vs afternoon) on testosterone and cortisol variations and their respective ratio.

Material and Methods

Subjects

Eleven healthy men with a sedentary lifestyle (19.81 ± ± 0.98 years old, 177.9 ± 5.0 cm of height, 70.6 ± 8.3 kg of body mass, 22.2 ± 1.9 kg/m^2 of BMI and 14.4 ± 4.0% of body fat) volunteered to participate. The inclusion criteria were that the subjects did not have infectious, respiratory or cardiovascular diseases or diabetes, and did not use drugs, supplements, consume alcohol or smoke. The study was performed in accordance with the Declaration of Helsinki and approved by the Research Ethics Committee of the host University (ethics code: IR.MIAU.REC.1396.102).

Study design

Two weeks before starting the experiments the participants were asked to complete medical history and exercise readiness questionnaires (PAR-Q) and those who had abnormal conditions were excluded from the study [22]. Then, demographic measurements were taken, with the subject's weight and height measured using a scale and a Seca 700 height measuring tape (700, Seca, Hamburg, Germany), while body composition and body fat percentage were measured using a bioelectrical impedance device (Boca X1, Medigate, Korea).

The participants performed a familiarization session and then the high-intensity interval exercise was performed on two distinct days separated by a week washout period. In that period (and 24 h before) the participants were asked to refrain from any extra high intensity exercise and not to consume caffeinated beverages (they were allowed to drink water ad libitum during the run). Each participant's heart rate was monitored during all the exercise sessions using a heart rate monitor (FT4, Polar Electro, Finland).

HIIT occurred in the morning (8:30 to 9:30) and in the afternoon (15:00 to 16:00), consisting of a short burst of high-intensity activity followed by a brief low-intensity activity [12]. All the participants were allowed to warm up for 5 min before starting the exercise. The subjects were asked to complete five repetitions of a 40-m shuttle run with a 30-s interval between the start of each sprint, i.e. recovery time between sprints was 30 s minus the time taken to complete the previous sprint. The subjects ran between two lines placed 20 m apart with the start/finish line placed at the midpoint of the course. On instruction, each participant sprinted 10 m from the start/finish line to the end of the course, turned 180°, sprinted 20 m to the other end of the course, turned 180°, and sprinted 10 m back through the start/finish line. For all the tests, sprints were initiated from a line 50 cm behind the start line to prevent false triggering of the first timing gate. The subjects were instructed to place at least one foot over the line at the end of each shuttle, the adherence to which was monitored to ensure full compliance (Figure 1). During each trial the subjects were verbally encouraged to give a maximal effort [23]. Average exercise intensity and maximum heart rate at all the exercise sessions were measured using the Polar FT4 device.

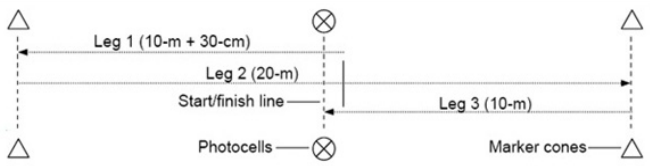

Figure 1. Schematic illustration of the 40-m maximal shuttle run test

Blood samples were taken before (PRE) and immediately after (POST) each exercise session from the antecubital vein by repetitive venous puncture in the sitting position. To separate serum, the blood was allowed to clot at room temperature and then it was centrifuged at 3500 g for 20 min. The serum was drawn off and stored at −70°C for subsequent analysis of testosterone and cortisol levels. The testosterone concentration was measured using ELISA kits made by Monobind, USA (Kit Lot No. EIA-.37K4I6). The kit sensitivity was 576.0 picograms, equivalent to a testosterone concentration of 0.0576 ng/ml. The ELISA kits made by DBC Corporation, Canada (Lot No. 161380) were used to measure serum cortisol concentration. The kit sensitivity was 0.4 micrograms per decilitre (calibrator range: 0.5-60 µg/dl). The ELISA kits were analysed based on the protocol given by the manufacturer. The kits were read using ELISA readers (Awareness Technology Inc., USA). The intra-assay and inter-assay coefficients of variation were as follows: testosterone 10.22%, 5.60%; cortisol 4.50%, 9.49%.

Statistical analysis

In this study the minimum, maximum, and the 25th and 75th quartiles were used as descriptive statistics. The normal distribution of data was examined using the Shapiro–Wilk test. The Wilcoxon signed-rank test was used to compare pre- and post-test measurements, as well as the differences between morning and afternoon. The significance level was considered to be $P < 0.05$ and all the analyses were performed using the SPSS version 17 software.

Results

Testosterone

The results showed that testosterone concentration increased significantly only after HIIT in the afternoon

Table 1. Findings for changes in testosterone, cortisol and T/C ratio in the morning and afternoon

Variable	Time of training	Test	Mean ± SD	quartiles		(a)	(b)	(c)
				25th	75th	P	P	P
Testosterone (nmol/L)	morning	pre-test	10.4 ± 0.67	9.708	10.748	0.09	0.009*	0.01*
		post-test	10.68 ± 0.53	10.68 ± 0.53	10.748			
	afternoon	pre-test	9.86 ± 0.42	9.361	10.401	0.02*		
		post-test	10.3. ± 0.61	9.708	10.748			
Cortisol (nmol/L)	morning	pre-test	898.38 ± 199.51	721.103	1120.827	0.23	0.001*	0.001*
		post-test	990.64 ± 293.07	697.655	1263.724			
	afternoon	pre-test	355.53 ± 92.95	327.172	411.586	0.27		
		post-test	452.73 ± 307.34	136.827	806.620			
T/C ratio	morning	pre-test	0.012 ± 0.002	0.010	0.013	0.79	0.001*	0.04*
		post-test	0.011 ± 0.003	0.008	0.015			
	afternoon	pre-test	0.03 ± 0.012	0.024	0.030	0.16		
		post-test	0.056 ± 0.075	0.013	0.075			

Note: T/C ratio – testosterone/cortisol ratio

(a) comparison of pre-tests and post-tests of each activity; (b) comparison of pre-tests in the morning and afternoon; (c) comparison of post--tests in the morning and afternoon

* significance difference of $P < 0.05$

(P = 0.02), while there was a tendency for an increase in the morning (P = 0.09) (Table 1; Part a). Significant differences in testosterone concentrations were observed when comparing pre-tests in the morning and afternoon (P = 0.009) (Table 1; Part b). Significant differences in testosterone concentrations were observed when comparing post-test results in the morning and afternoon (P = 0.01) (Table 1; Part c).

Cortisol

Cortisol concentration tended to increase in the morning (P = 0.23) and afternoon (P = 0.27) after HIIT (Table 1; Part a). Significant differences in cortisol concentrations were observed when comparing pre-test results in the morning and afternoon (P = 0.001) (Table 1; Part b). Significant differences in cortisol concentrations were also observed when comparing post-test results in the morning and afternoon (P = 0.001) (Table 1; Part c).

Testosterone/cortisol ratio

The testosterone/cortisol ratio tended to decrease in the morning (P = 0.79) and to increase in the afternoon (P = 0.16) after HIIT (Table 1; Part a). Significant differences in the testosterone/cortisol ratio were observed when comparing pre-test results in the morning and afternoon (P = 0.001) (Table 1; Part b). The differences in the testosterone/cortisol ratio were also significant when comparing post-test results in the morning and afternoon (P = 0.04) (Table 1; Part c).

Maximum heart rate and peak heart rate

The results also showed a significant difference in activity intensity between morning (85.1 ± 4.0% of maximum heart rate) and afternoon (88.9 ± 4.5% of maximum heart rate) (P = 0.008). However, no significant difference was observed in peak heart rate (195.1 ± 7.2 bpm in the morning vs 195.0 ± 8.3 bpm in the afternoon; P = 0.98).

Discussion

This study found that testosterone concentration increased after HIIT in the afternoon. This is consistent with the results of a number of studies reporting increased testosterone levels after HIIT [13, 18, 20]. Results of a study in obese and overweight children showed a significant increase in testosterone concentration after HIIT [20]. Another study demonstrated that testosterone level significantly increased in response to a single session of HIIT and high-volume training in young athletes [16]. Additionally, it was also indicated that HIIT induced an increase in testosterone level in triathletes/cyclists [23]. In sedentary older men, total testosterone and free testosterone levels were significantly increased as a result of HIIT [11]. In endurance-trained males HIIT caused a significant increase in free testosterone concentration [9]. In turn, in recreationally trained males and females a significant increase was observed in testosterone levels after HIIT compared to pre-exercise concentrations [18].

Conversely, some studies have reported decreases or no change in testosterone concentration after HIIT [1, 13, 28]. These results are not consistent with the findings of this study. The difference in the results can be attributed to the time and duration of training [28], sport level of participants [1], as well as differences in the study protocols [13]. For example, in well-trained young cyclists a decrease was observed in total testosterone and free testosterone levels following four weeks of HIIT [28]. Another study in women showed non-significant changes in testosterone after HIIT [1]. In male master's athletes, a non-significant change was observed in total testosterone and a small increase in free testosterone level following HIIT [13].

Another finding of this study was that testosterone, cortisol and the testosterone/cortisol ratio changes in the morning were not statistically significant. Other studies have shown non-significant changes in testosterone, cortisol and the testosterone/cortisol ratio, in line with the current study. For example, in male master's athletes a non-significant change was observed in total testosterone and only a small increase in free testosterone following HIIT [13]. Another study found non-significant changes in testosterone level after HIIT in women [1]. Another study in young athletes showed a non-significant increase in cortisol and the testosterone/cortisol ratio after HIIT [16].

Conversely, some studies have reported significant changes in testosterone, cortisol and the testosterone/cortisol ratio after HIIT. These results are not consistent with the findings of this study [11, 16, 20, 31]. The difference in the reported results can be attributed to the time and duration of training [16, 20], sport level of participants [11, 20] and differences in the study protocols [16, 20, 31]. For example, total testosterone and free testosterone levels were significantly increased as a result of HIIT in sedentary older men [11]. A significant increase in testosterone and significant decreases in cortisol concentration and the testosterone/cortisol ratio was observed after HIIT in obese and overweight children [20]. In young athlete's testosterone level significantly increased as a result of HIIT training [16]. In triathletes/cyclists, HIIT induced increases in testosterone and the testosterone/cortisol ratio, and a decrease in cortisol level [31]. In well-trained male cyclists cortisol concentration increased significantly as a result of HIIT [21]. In turn, in endurance-trained males HIIT caused a significant increase in free testosterone [9]. In recreationally trained males and females significant increases in testosterone and cortisol were observed post-HIIT compared to pre-HIIT concentrations. Additionally, the testosterone/cortisol ratio was significantly reduced compared to pre-HIIT values [18]. In overweight adults, significant decreases in cortisol levels and significant increases in the testosterone/cortisol ratio were recorded in the HIIT group [30]. Various studies have shown that exercise intensity is one of the factors that can increase testosterone levels.

Although no difference was found in peak heart rate between morning and afternoon training sessions in this study, a significant difference was found in exercise intensity (based on average heart rate) between morning and afternoon. Average heart rate was higher in the afternoon than in the morning, which may significantly increase the testosterone concentration in the afternoon. This difference in average heart rate between morning and afternoon training was also reported in another study [2]. Catecholamine stimulates the Leydig cells in the testes and the secretion of testosterone following intense exercise activity [9]. Nevertheless, the findings showed that HIIT can dramatically increase concentrations of adrenaline and noradrenaline [21]. Hormone changes (e.g. testosterone) are variable and may depend on the exercise paradigm (resistance vs aerobic), the exercise intensity, the study population (young vs older men) and/or the catecholamine concentration [3, 10, 15].

On the other hand, as reported, testosterone increases may acutely influence the central nervous system (e.g. mood, behaviour, aggression, cognition), substrate metabolisms (e.g. glycogen and amino acid metabolism) and neuromuscular electrophysiological-contractile properties [4].

The training intensity therefore reverses the cortisol response to training. An increase in the concentration of this hormone in the current study can be attributed to the high-intensity exercise protocol, but the short intervals of the exercise may explain the non-significance of this increase. The reason for the difference in the results can be attributed to exercise duration [11], the subjects [13, 20, 28] and gender [1]. In the current study, although HIIT increased the testosterone/cortisol ratio, the increase in the afternoon was not statistically significant. The testosterone/cortisol ratio was used as an indicator of the physiological pressure response to exercise and as an indicator of anabolic/catabolic balance [29]. The higher this ratio in the afternoon, the more superior the anabolic metabolism after HIIT in the afternoon. Wilk et al. [32] indicated that the highest testosterone values may occur during exercise or at any other time when no measurement was taken.

In summary, in the current study HIIT significantly increased testosterone concentrations only in the afternoon. Significantly higher testosterone and cortisol concentrations in the morning compared to the levels in the afternoon may be attributed to the normal secretion rhythms of these hormones [7]. However, the testosterone/cortisol ratio was higher in the afternoon than in the morning, which is probably due to lower cortisol concentrations in the afternoon. A lower cortisol concentration and a higher testosterone/cortisol ratio in the afternoon therefore show a favourable anabolic-catabolic balance in the afternoon. Consequently, HIIT should ideally be performed in the afternoon due to the favourable anabolic-catabolic balance. Since HIIT simulates the successive sprints that are part of most exercise activities, the time of these activities should be considered by athletes, coaches and developers of academic and non-academic sports programmes when implementing such programmes. Lack of control diet/exercise/bedtime patterns during the study are some of the limitations of the present study. It seems that performing HIIT in the afternoon may be more suitable in terms of the level of anabolic processes. However, further studies are needed to measure these hormones at consecutive intervals during recovery to generalise these findings to the entire population and to better explain them.

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Conflict of Interests

The authors declare no conflict of interest.

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Strength training combined with high-intensity interval aerobic training in young adults' body composition

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Abstract
Introduction. **Although health-enhancing effects of physical activity are well-reported, a high rate of physical inactivity worldwide is still observed. Additionally, the most effective method for weight control and/or weight loss is still unknown. In this sense, analyzing whether strength training could be useful when combined with high-intensity aerobic interval training to improve body composition is important to provide further knowledge of the effects of combined strength and aerobic training in young adults.** Aim of Study. **The purpose of the study was to compare the effects of high-intensity interval aerobic training (HIIT) with a combined strength training followed by HIIT (ST+HIIT) on body composition of young adults.** Material and Methods. **Eighteen college students (age 24.83 ± 6.60 years, body mass 70.05 ± 14.26 kg, height 1.72 ± 0.08 m) were subjected to two different training programs for 8 weeks: high-intensity interval aerobic training (n = 9), or strength training combined with high-intensity interval aerobic training in the same session (n = 9). Anthropometric variables were assessed.** Results. **After eight weeks significant differences were found in body fat mass (p = 0.01; ES = 1.11), waist circumference (p = 0.04; ES = 0.82) and hip circumference (p = 0.04; ES = 0.82) with a large effect size in the ST+HIIT group. A large decrease in fat-free mass was found in the HIIT group (p = 0.04; ES = 0.80).** Conclusions. **These findings suggest that strength training should be added to high-intensity interval aerobic training to improve body composition in adults by reducing body fat after 8 weeks. Performing HIIT seems to contribute to the loss of fat-free mass. These outcomes might be important for physical fitness professionals and researchers, providing further understanding of the dose-response effects of combined strength and aerobic training in young adults.**

KEYWORDS: exercise, morphology, body fat, HIIT, health.

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Introduction

Although health-enhancing effects of physical activity are well-reported, a high rate of physical inactivity worldwide is still observed [14]. The current global exercise recommendations suggest a moderate-intensity physical activity (for a total of 150 to 300 minutes per week) or vigorous-intensity physical activity (for a total of 75 to 150 minutes per week) to produce substantial benefits in physical fitness and health [7]. Unfortunately, recent studies reported that most of the global population does not meet the suggested physical activity levels [14, 17], which results in overweight in around 38.5% of men and 39.2% of women [28]. In the last decade, most exercise programs aimed to provide weight loss, mainly body fat, through continuous moderate-intensity exercise (e.g. walking, running) [25, 27]. Nevertheless, some authors have recently reported that both high-intensity interval aerobic training and moderate-intensity continuous training produce positive adaptations in physical conditioning, weight loss and body composition

[2, 4]. Interestingly, some researchers provided evidence that high-intensity interval training seems to induce favorable metabolic adaptations similar to those induced by continuous exercise of lower intensity and longer duration in both healthy and clinical populations [1, 13]. However, the most effective method for weight control and/or weight loss has not yet been reported [27]. In this sense, alternative training programs are still being studied. Wewege et al. [27] reported that performing interval training in running produces better results in the body composition of young adults than cycling. Additionally, regardless of the training method used, evidence revealed greater exercise effectiveness when intensity levels are higher [9]. Moreover, Tjønna et al. [24] compared the effects of high-intensity interval aerobic training with those of moderate-intensity continuous aerobic training, reporting a significant decrease in total body mass, fat mass and visceral fat from high-intensity interval training, while continuous training induced no significant improvements. Nevertheless, difficulty in performing and maintaining high-intensity exercise for an extended period in the sedentary population was also shown [15]. It should be mentioned that high and/or moderate intensity training combined with strength training may be complementary training to prevent or reduce obesity [11]. Although strength training has been considered as a useful approach to fat mass loss [21], recent findings reported greater effectiveness in terms of body composition improvement when using aerobic training combined with strength training compared to aerobic exercise or strength training alone [3]. High-intensity interval training has increasingly emerged as an alternative for enhancing cardiorespiratory fitness, but also improving body composition by reducing body fat mass [11, 27]. However, most studies have focused on high-intensity interval training in trained or experienced young adults and measured only physical and physiological variables (e.g. maximal strength, endurance performance, oxygen kinetics, heart rate response, energy expenditure) [4, 12]. To the best of our knowledge, scarce studies have analyzed the combination of high-intensity interval training with strength training in overweight and young adults [18]. From this point of view, it is important to understand if the effects of strength training combined with high-intensity aerobic interval training could be beneficial to the body composition. Thus, the purpose of this study was to compare the effects of 8-week high-intensity interval aerobic training with a combined strength training followed by high-intensity interval aerobic training on the body composition of young adults. The established hypothesis was that combined high-intensity interval aerobic and strength training may induce body composition improvements through a potential increase in fat-free mass.

Material and Methods

Evidence suggests that higher intensity levels of exercise can be an effective option to enhance cardiorespiratory fitness and to improve body composition by reducing body fat mass [5, 8]. This seems to be important in a world population which tends to be inactive and prone to develop diseases [14]. However, can the effects of strength training combined with high-intensity interval training be helpful to improve body composition? For this, a randomized controlled trial was developed to compare 8 weeks of high-intensity interval aerobic training (HIIT) and a combination of strength training plus interval aerobic training (ST+HIIT).

Participants

Eighteen college students (mean ± SD) age: 24.83 ± ± 6.60 years; body mass: 70.05 ± 14.26 kg; height: 1.72 ± 0.08 m, took part in this study and voluntarily provided their written informed consent. The subjects were randomly divided into two study groups, one of the groups performed high-intensity interval aerobic training (HIIT) and the other performed a combined strength and high-intensity interval aerobic training in the same session (ST+HIIT). Each individual was asked to report any previous illness, injury or any other physical issue that would hinder their performance and they were included in the study on condition they were healthy and injury-free. Criteria of exclusion from the study included evidence of any medical or orthopedic problem and a self-reported issue that would endanger their health. All the subjects gave their written informed consent before participation. For the entire sample participation in a minimum of 14 of the 16 sessions was required to be included in the analysis. The study was approved by the University of Beira Interior ethics committee (under project M7145, March 2016) and was conducted according to the Declaration of Helsinki.

Procedures

Before the experiments two weeks of familiarization to procedures was allowed to all the subjects. During these two weeks each subject was able to experiment with aerobic training intensities and strength training exercises. During that time the subjects were taught about the proper technique for each training exercise and any of their questions were properly answered to clear any doubts. Clear instructions concerning the importance of adequate nutrition were also delivered.

All the subjects were evaluated before and after the implementation of each training program. To assess different variables, each subject went to the laboratory where the evaluations were performed on a specific day. No strenuous effort was permitted within 48 hours before any evaluation. These evaluations were applied in the week preceding the beginning of the training program and in the week after the end of the training program. Each subject remained in a resting position for 5 minutes before resting heart rate measurements. Then the resting heart rate was measured, followed by body composition and perimeters. Body mass, percentage of fat mass, fat-free mass and body water were measured using an electronic scale (Tanita Body Composition Analyzer BC-418, Illinois, USA). The measurements were taken based on standard procedures [20]. To complement the anthropometric evaluation, hip and waist circumferences were also assessed. To avoid typical errors in the measurement of these variables, each perimeter was measured 3 times and the mean value was considered for further analysis. The intraclass correlation coefficient of the values found exceeded 0.95 for hip circumference and 0.97 for waist circumference. The resting heart rate was monitored using a voltage meter (Tensoval Duo Control, Heidenheim, Germany) in a relaxed and seated position after resting for 5 minutes. Each subject was evaluated 3 times (intraclass correlation coefficient greater than 0.97) and the mean value was used to estimate the maximal heart rate (HRmax). To determine interval training intensities, Tanaka's equation [22] was used to obtain the estimated HRmax:

$$\text{HRmax} = 208 - (0.7 \times \text{age})$$

To determine the intensity of strength training, each subject in the ST+HIIT group was evaluated regarding maximal dynamic strength (1 maximum repetition, 1RM). For this purpose a progressive test was implemented until the maximal load was reached. Each subject started with an external load that was believed to be lifted only once at maximal effort. Following a 3-5 minute resting period another repetition was performed after adding some load. This was repeated until the maximum load was reached. No more than 5 attempts were allowed [6]. The determination of the 1RM load was made 1 week before the other assessments.

Both groups, HIIT and ST+HIIT, trained twice a week for 8 weeks. The HIIT group performed an aerobic interval treadmill training and the ST+HIIT group performed a strength training followed by the same aerobic training as the HIIT group. Each interval training session lasted for 25 minutes of running on a treadmill per session. Each workout was started with a slight warm-up (30% to 50% of estimated HRmax) for 5 minutes to prepare the body for physical exertion. Then the intensity increased to 75-95% estimated HRmax for 2 minutes, and then it dropped to 50% of the estimated HRmax for 2 minutes. These cycles of high and low intensities were performed until the 20 minutes of training were completed. It is important to point out that the higher intensities were progressively increased by 5% every two weeks, starting at 75% of estimated HRmax. Aerobic training was performed by the HIIT group as well as the ST+HIIT group – in the latter case it was 10 minutes after performing strength training. The strength training included 4 exercises in the following order: bench press, leg press, lat pull down and shoulder press. In the first week the load was settled as 50% of 1RM and then it was increased by 5% each week. Two minutes of rest were allowed between the sets and exercises. Then after 5 minutes of rest the same aerobic interval training was performed. The same researcher performed data collection, anthropometric assessments and training programs. No dropout occurred in the present study. There were no injuries resulting from the implementation of the training programs. A more detailed analysis of the strength training design can be found in Table 1.

Table 1. Strength training design

Weeks	Sets	Repetitions	Intensity
1	3	12	50% 1RM
2	3	12	55% 1RM
3	3	10	60% 1RM
4	3	10	65% 1RM
5	3	8	70% 1RM
6	3	8	75% 1RM
7	3	6	80% 1RM
8	3	6	85% 1RM

Note: RM – maximum repetition

Statistical analysis

Statistical analyses were performed using the Statistical Package for Social Sciences (SPSS) v.24.0® for Windows. Standard statistical procedures were selected for the calculation of means, standard deviations (SD) and 95%

confidence limits. The normality of all distributions was verified by the Shapiro–Wilks test and parametric statistical analysis was adopted. The independent t-test was used to identify the existence of differences between the groups in pre-training and post-training periods. To analyze the effect of training from pre- to post-training in each group the t-test for repeated measures was used. Changes from pre- to post-training were calculated (in %) and compared between the groups using paired t-test analysis. The level of significance of $p \leq 0.05$ was assumed for the rejection of the null hypothesis. The G*Power 3.0.10 program for Windows (University of Kiel, Germany) was used to calculate the magnitude of the effect (ES) between the pre- and post-training moments and to compare the groups at each moment. A value of 0.2 was considered small, 0.5 medium and 0.8 high [10].

Results

At the baseline there were no differences between the experimental groups regarding the age, body composition and anthropometric measures ($p < 0.05$; ES < 0.40). After the 8-week intervention period, body composition has significantly improved in the ST+HIIT group as shown in Table 2. Changes from pre- to post-training momentum reported statistically significant differences in anthropometric measures, specifically body fat, waist circumference and hip circumference with a large effect size in the ST+HIIT group. Even though there were no significant differences in fat-free mass, a small increase in the ST+HIIT group was found after the 8-week intervention period. The outcomes from the HIIT group only presented a significant decrease in the fat-free mass, with a large effect size. Although the HIIT group showed no significant differences in the other variables,

Table 2. Paired t-test analysis (Mean ± SD and confidence interval 95%)

Variables	Group	Pre-training	Post-training	p-value	ES
BM	HIIT	66.97 ± 17.46 (53.55, 80.38)	66.16 ± 16.49 (53.48, 78.83)	0.18	0.49
	ST+HIIT	73.13 ± 10.30 (65.21, 81.05)	72.22 ± 9.78 (64.70, 79.74)	0.13	0.56
BMI	HIIT	22.55 ± 4.40 (19.17, 25.92)	22.33 ± 4.23 (19.08, 25.58)	0.26	0.40
	ST+HIIT	24.18 ± 2.20 (22.49, 25.88)	23.88 ± 1.92 (22.40, 25.36)	0.16	0.52
FM%	HIIT	21.90 ± 8.16 (15.63, 28.17)	22.69 ± 8.96 (15.80, 29.58)	0.21	0.45
	ST+HIIT	24.08 ± 8.97 (17.18, 30.97)	22.80 ± 9.21 (15.72, 29.88)	0.03*	0.90
FM	HIIT	15.04 ± 8.12 (8.80, 21.29)	15.38 ± 8.54 (8.82, 21.95)	0.40	0.29
	ST+HIIT	17.44 ± 6.06 (12.79, 22.10)	16.29 ± 6.00 (11.68, 20.90)	0.01*	1.11
FFM	HIIT	51.64 ± 12.44 (42.08, 61.21)	50.51 ± 11.56 (41.63, 59.40)	0.04*	0.80
	ST+HIIT	55.72 ± 11.13 (47.17, 64.28)	55.93 ± 11.06 (47.43, 64.44)	0.72	0.12
BW	HIIT	39.27 ± 9.75 (31.77, 46.76)	38.53 ± 9.22 (31.44, 45.62)	0.07	0.69
	ST+HIIT	40.80 ± 8.14 (34.54, 47.74)	40.96 ± 8.10 (34.73, 47.18)	0.72	0.12
VF	HIIT	2.67 ± 2.87 (0.46, 4.87)	2.56 ± 2.92 (0.31, 4.80)	0.35	0.33
	ST+HIIT	3.44 ± 1.81 (2.05, 4.84)	3.00 ± 1.22 (2.06, 3.94)	0.10	0.61
WC	HIIT	77.39 ± 13.83 (66.76, 88.02)	76.11 ± 11.08 (67.59, 84.63)	0.31	0.36
	ST+HIIT	83.28 ± 8.51 (76.74, 89.82)	81.39 ±7.19 (75.86, 86.92)	0.04*	0.82
HP	HIIT	100.33 ± 9.11 (93.33, 107.34)	97.78 ± 7.05 (92.36, 103.20)	0.12	0.58
	ST+HIIT	102.72 ± 6.41 (97.79, 107.65)	100.33 ± 5.22 (96.32, 104.35)	0.04*	0.82

Note: BM (kg) – body mass; BMI (kg/m^2) – body mass index; FM% (kg) – fat mass in percentage; FM (kg) – fat mass; FFM (kg) – fat-free mass; BW (kg) – body water; VF (units) – visceral fat; WC (cm) – waist circumference; HP (cm) – hip circumference. Pre-corresponding to the baseline values, post- corresponding to the values after 8-weeks of training. ST+HIIT – combined strength and high-intensity interval aerobic training; HIIT – high-intensity interval aerobic training

* p-value < 0.05

it was possible to verify a decrease in the values of hip circumference, waist circumference and body mass (Table 2).

When comparing the changes obtained with the training programs between the groups, significant differences were found in fat mass, with a considerable loss in the ST+HIIT group (Figure 1). Despite no statistically significant differences recorded in the other variables, a moderate effect size between the groups in terms of visceral fat (decreased for ST+HIIT) and a large effect in terms of body water and fat-free mass (decreased for HIIT) were observed.

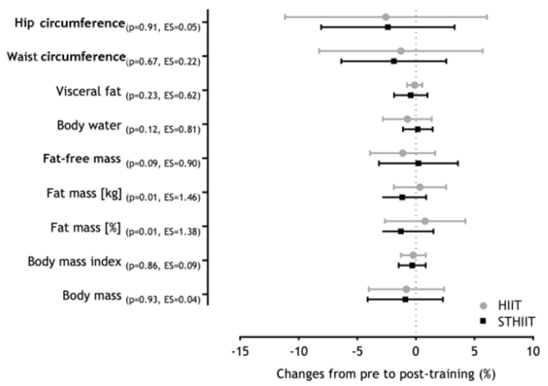

Figure 1. Changes from pre- to post-training

Discussion

The purpose of the study was to compare the effects of high-intensity interval aerobic training (HIIT) with strength training followed by HIIT (ST+HIIT) in the body composition of young adults. A significant improvement of body composition was reported in the combined strength and high-intensity interval aerobic training group after 8 weeks of intervention. These results corroborate the hypothesis that combined strength training and aerobic high-intensity interval training induces body composition improvements. Despite the changes in body fat mass, the fat-free mass did not change in the ST+HIIT subjects. This fact might be explained by the short duration of the training protocol (8 weeks) that could not be enough to elicit significant improvement in lean mass. Nevertheless, this period of intervention in ST+HIIT was sufficient to significantly improve other anthropometric variables, specifically hip and waist circumferences. These findings are consistent with previous studies [12, 19], where the authors observed no significant changes in lean mass after a 6- or 4-week intervention period of high-intensity interval training, respectively [12, 19]. Curiously, a significant decrease in fat-free mass was shown after the HIIT intervention. These results could be explained either by a possible demotivation associated with HIIT, negatively influencing the quality of the workout, or by the non-existence of an adequate stimulus for enhancing fat-free mass, such as the phenomenon of muscle hypertrophy [5]. High-intensity interval training has emerged as an efficient alternative to conventional training methods due to its effects on different variables and populations [8, 23]. It is considered as an interesting time-efficient method to the improvement in physical conditioning, weight loss and body composition [2, 4]. Remarkably, the present study reported significant improvements in fat mass (–6.6%), waist circumference (–2.3%) and hip circumference (–2.4%) in the ST+HIIT group after the 8-week intervention. To support our findings a recent meta-analysis showed that a short-term intervention of high-intensity exercise training can improve body fat (~2 kg) and waist circumference (~3 cm) in adults [27]. The limited time available is stated to be an obstacle for many adults to practice physical activity [26], thus an intense exercise method with less demand for time may provide an appropriate strategy to produce modest improvements in the body composition. Interestingly, the absence of a significant difference in visceral fat was reported in both experimental groups. In contrast, a meta-analysis [25] examining the effects of exercise and caloric restriction on visceral adipose tissue loss found that exercise is related to a 6.1% decrease in visceral fat, regardless of a lack of a reduction in body weight. In the meta-analysis 84% of the studies applied a long-term intervention (≥12 weeks). A possible mechanism underlying these distinct effects on visceral effects could also be related to the duration of the intervention period, which in our study was a short-term intervention. In order to provide a possible answer to the question of the study, according to the obtained results the strength component seems to be a boost for the high-intensity interval aerobic training, assisting to improve the body composition in young adults after the 8-week intervention. This important fact could be an update to previous evidence. Kessler et al. [16] in their systematic review study concluded that a short-term HIIT protocol (≤10 weeks) was slightly useful in providing significant modifications in anthropometric variables. Moreover, combining strength and high-intensity interval aerobic training seems to be more effective than high-intensity aerobic training alone to achieve body fat loss and perimeters improving body composition in young adults. Our data provide interestingly dose-response effects of exercise-related with body composition. Notwithstanding the interesting findings revealed in our study, some limitations should be acknowledged: (i) the number of subjects was relatively low, where adding more participants could have provided more statistical differences in body composition parameters; (ii) our study is a two-group pre-test and post-test design without a control group, which may limit the generalizability of our results; (iii) the absence of subcutaneous adiposity fold measures and also nutrition parameters; (iv) the non-existence of a group without any training intervention, which could facilitate a comparison of experimental groups with a control group. For future investigations a large and prospective study could be interesting to establish the best HIIT protocols for decreasing visceral fat (i.e. another component of body composition), or even to introduce physical fitness parameters to measure in both training programs.

Conclusions

Our data suggest that an 8-week program of combined strength and high-intensity interval aerobic training (ST+HIIT) significantly improved the body composition of young adults when properly supervised. Differences in body fat (percentage and absolute values), waist and hip circumferences were found in ST+HIIT, while a significant decrease in fat-free mass of HIIT was reported. Specifically, the outcomes of the present study provided information concerning the effects of combined strength and high-intensity interval aerobic training with favorable changes in the body composition of young adults.

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Conflict of Interests

The authors declare no conflict of interest.

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The effect of physical fitness and physical activity level on memory storage of Italian pre-adolescent secondary school students

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Abstract
Introduction. Physical activity could enhance some psychological functions, and it is crucial for the growth of individuals. Aim of Study. The present investigation aimed at testing pre-adolescent students' memory functions to understand whether physical activity and physical fitness can increase memory storage. Material and Methods. A battery of physical tests (MOTORFIT) and questionnaire (PAQ-C, RSES – self-esteem) were administered to identify the physical and psychological characteristic of the students. A Free Recall Memory Test was performed by the children in order to assess their memory skills. In the memory test, participants had to memorize as many words as possible from a list of 20 words presented. Participants had to write down as many words as possible in two different times, 100 seconds after the presentation (e.g., immediate recall) of the 20 words and after 12 minutes (e.g., delayed recall). Results. The results showed an effect of physical fitness but did not show an effect of physical activity level. In particular, results highlight that students with high physical fitness are able to remember more words than pre-adolescent with low physical fitness. Conclusions. Our results provide evidence that physical practice could lead to an enhancement of memory functions.

KEYWORDS: schoolchildren, physical education, delayed recall, immediate recall, reactivation stage.

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Introduction

Physical activity and related physical fitness are essential for individuals' physiological and psychological development [14, 15, 24, 33, 44, 45]. However, in our society the, level of sedentary lifestyle across countries is increasing. For instance, children spend much time playing computer games and/or watching television [6, 13, 22, 29, 36, 41]. This behaviour could lead to a deterioration of physical fitness that could consequently bring to a decrement of general wellness and well-being [12]. In the last years, much research has been focused on the modulatory effects of physical exercise on cognitive functions in childhood and late adulthood [9, 11, 14, 15, 18, 37, 40, 42]. Specifically, researchers have focused their attention on the relation between physical activity and physical fitness on cognitive functions and academic achievement. Some scholars have tried to summarize the results through meta-analyses and systematic reviews [2, 3, 8, 16, 27, 35]. The outcomes were relatively similar across the investigations. All reviews and meta-analyses highlighted a positive relationship between physical activity and cognitive functioning. However, the authors reported that these effects are small and inconsistent, probably due to some research design limitations.

Furthermore, according to these reviews and meta-analyses, not all cognitive functions are affected by physical activity in the same way. For instance, a meta-analysis conducted on children by Sibley and Etnier [35] showed a positive relationship between physical exercise and perceptual skills except for memory capacities. A more recent systematic review of Donnelly et al. [8], where both single bout and intervention increased cognitive functioning measured through attentional paradigms (i.e., D2 attentional test, Stroop Task) and academic achievement. These results were supported by another systematic review performed by Rasberry et al. [27], which highlighted that physical activity could have a neutral or positive effect on cognitive skills. However, recent independent investigations (e.g. [33]) failed to find a strong relationship between cognitive functioning and physical activity. Specifically, an intervention study by Russo et al. [33] confirmed that physical activity could affect cognitive functioning differently.

In summary, according to the reviews and meta--analyses mentioned above, the results in this domain are usually weak, and the effects are small or moderate. Thus, further research is needed to understand the phenomena thoroughly. Furthermore, the investigations were often focused on primary school children instead of pre-adolescents and adolescents. Moreover, when considering the relevance of this age for the development of most motor and cognitive abilities, the positive effect of physical activity should be further investigated to understand the potential development of physical training that consequently can be useful in improving motor and cognitive skills.

This experiment focused on the relationship between physical fitness and physical activity levels on memory capacity in a large sample of pre-adolescent children. Memory skills are fundamental in the learning process because during school lessons, children should hold information in their memory and recall it when necessary. This interest was motivated by the lack of systematic works on the modulatory effect of physical activity and memory functions [26, 35]. To test memory functions, a similar experimental paradigm was used by Pesce et al. [26], Russo et al. [32], and Coles and Tomporowsky [5]. Instead, physical fitness was assessed through a physical test battery (MOTORFIT test battery) [25]. Because of the possibility that some children should have higher physical fitness but low physical activity level, the results of the physical tests were controlled through the Physical Activity Questionnaires – children (PAQ-C [17]). Moreover, we controlled the effect of self-esteem (RSES) [30] because it could influence these performances. Specifically, according to some investigations, it is possible to consider that physical activity could indirectly affect cognitive functioning through self-esteem [10, 31, 38].

Thus, in this experiment we assumed that students with high physical fitness and high physical activity level should have better memory capacity than pre-adolescents with low physical fitness and low physical activity. Furthermore, we controlled the age effect, dividing the sample into three different levels of age, and controlled self-esteem's role in memory performance. In the former case, we expected a possible increment of memory performance with increasing age. In the latter case, if self-esteem influenced memory performance, we expected better results in participants with high self-esteem than those with low self-esteem.

Methods

Participants

Students of a middle school located in Rimini (an Emilia Romagna County – Italy) were recruited. Specifically, they were 93 (47 females) students with an average age of 12.21, SD = 0.93 y.o. (female: 12.17, SD = 0.96 y.o.; male: 12.30, SD = 0.89 y.o.). In order to analyze the age effect, students were divided into three groups according to their age. Three age groups (G) were created. The G1 group was composed of 25 (15 females) participants of 11 y.o., G2 was formed by 30 pre-adolescents (15 females) of 12 y.o. and G3 was composed of 38 students (17 females, 13 and 14 y.o.).

Moreover, participants were sorted according to the median of Physical Activity Questionnaire (PAQ-C) [17] score, the Self-Esteem Questionnaire (RSES) [30] score and according to the score obtained in the Physical Fitness tests (MOTORFIT. See Section: *Physical tests and Physical Activity Questionnaire*) (25).

The Physical Activity Questionnaire median was 2.68 points. Thus, the sample was divided into High Physically Active (HPA) students and Low Physically Active (LPA) students. Seventy-four students (26 females) were highly physically active, while 76 (50 females) formed the LPA groups. The median of the Rosenberg questionnaire was 31 points. Participants were divided according to the median of the sample in the High Self-Esteem Group (HSEG) and the Low Self-Esteem Group (LSEG). Seventy-four pre-adolescents (34 females) formed the LSEG, while 75 pre-adolescents (42 females) composed the HSEG.

The study obtained approval by the ethics committee from the Local Bioethics committee. In addition, parents and pre-adolescents were informed about the experiment and signed the informed consent form.

Physical tests and Physical Activity Questionnaire

Participants performed the MOTORFIT physical battery test [25]. The tests administered included the 10 m shuttle run, the Cooper, the sit-up, the long jump and the flexibility test. We excluded the local muscle endurance for the upper limb due to the lack of suitable equipment. In the 10 m shuttle run test, participants had to run 5 meters at their maximum speed in 10 repetitions. In the Cooper test, participants had to run continuously for 12 minutes, trying to cover as much distance as possible. In the sit-up test, participants performed as many sit-ups as they could in 30 seconds. In the stationary long jump test, participants had to perform a horizontal jump from a stationary position. Instead, in the flexibility test participants in the sitting position with the inferior limbs extended had to try to reach or go over the toes with their hands.

The Physical Activity Questionnaire for Children (PAQ-C) was filled to understand the level of physical activity for each participant. Through a series of questions, the PAQ-C questionnaire provides an estimation of participants' physical activity levels. In this questionnaire participants reported performance of the activity/ies in the previous week and the time spent on it. If participants were sick, the questionnaire was removed.

Regarding the Physical Fitness Test (MOTORFIT test), we assigned a dummy value (i.e., 0 or 1) for each participant. If they performed better than the MOTORFIT [24] guideline average of that particular test, we assigned the value of 1; if they performed below the average of that specific test, we assigned the value of 0.

The sum of each score was calculated, and the Physical Fitness Index (PFI) was created. Thus, the sample was divided according to the median of PFI scores in High and Low PFIs (HPFI and LPFI, respectively). The High PFI group was composed of 66 participants (36 females), while in the Low PFI group there were 84 (40 females) students.

Rosenberg self-esteem questionnaire

The self-esteem (RSES [30]) questionnaire is a valid instrument developed by Rosenberg in 1966. Participants are asked to respond to ten questions concerning their perception of themselves on a 4-point Likert scale.

Free Memory Recall Test

Memory skills were tested through the Free Recall Memory Test [21], previously adapted and used by Pesce et al. [26] and Cole and Tomporowsky [5]. One hundred and fifty-six words were chosen according to their imaginable and concreteness indexes. Specifically, according to the Normative list of Paivio [23], words with an index of over 6.40 for both these indices were selected. A total of 177 words were selected to be suitable for the experiment. Afterwards, through the MATLAB software (MathWorks, version 2018a), the randomization of the words previously selected was performed, and three lists with the first 20 items were selected (Figure 1). With teachers, we discussed the lists of the words created. Thus, only one list was chosen. The experiment was programmed in Open Sesame (https://osdoc.cogsci.nl/ [20]), and the words were projected on the whiteboard of the classroom. They were black coloured with a height of 10 cm. The height of the words was determined according to the best visual angle. The students were seated at a variable distance. However, the height of the letters was sufficient for every participant to see adequately the words projected. Students had normal or corrected vision during and before the experiment. A series of 5 words were presented to explain the task and examine whether the participants were able to read the words projected.

The words were randomly presented. After 100 seconds, the last word was presented. The students could write down the word (immediate recall) on a blank piece of paper and after 12 minutes (delayed recall) on another blank piece of paper provided by the researchers/teachers. Participants had 120 seconds to write down the words. For each correct word reported on the blank sheet of paper, we assigned 1 point, also the words with plural and grammatical errors.

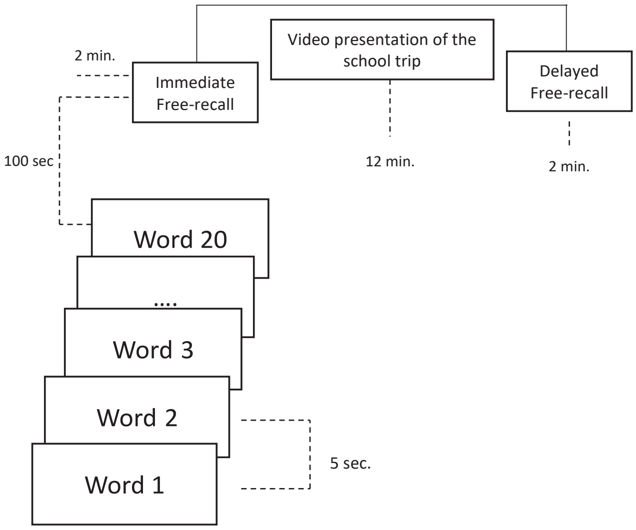

Figure 1. The scheme shows the procedure of the free-recall memory test. Modified figure on the basis of Pesce et al. [26]

General procedure

All the tests were performed during class hours and under the supervision of the physical education teacher and at least one researcher. Each student performed all the tests and the questionnaire in the same week. They filled the questionnaires (PAQ-C and RSES) and performed the Free Recall Memory Test in the classroom before moving into the gym, where they performed the physical strength and endurance tests, in this order.

Physical tests procedure

The MOTORFIT tests [25] were performed in the following way. Each class carried out the MOTORFIT tests during their physical education hours. Due to the organizational and time problems, each class performed the Cooper test together. The other tests, such as the long jump, the sit-up and the speed test, were performed individually.

Data analysis

Statistical analysis was conducted using the R Studio software (version 1.1.463, www.rstudio.com) [34].

A linear mixed-effects model was created with the "lme4" package [1] to analyze the memory skills of children. The dependent variable was the number of words recalled in each session. The independent variables were PFI (2 levels, HPFI and LPFI), PA (2 levels, HPA and LPA), Self-Esteem (HSEG, LSEG), Session (2 levels, Immediate Recall (IR) and Delayed Recall (DR) and Age Group (3 levels, G1, G2 and G3). When necessary for multiple comparisons, the Tukey post-hoc analysis was performed. Step-wise regression analysis was employed in order to find the final regression model. In order to reduce the non-normality of data, the score of the memory test was rank transformed.

Moreover, in order to check the linear mixed-effects regression, we conducted a MANOVA analysis following Pesce et al. [26]. The dependent variables were the scores of Immediate and Delayed Recall Sessions. The independent variables were PFI (2 levels, HPFI and LPFI), PA (2 levels, HPA and LPA), Self-Esteem (HSEG, LSEG) and Age Group (3 levels, G1, G2 and G3). When necessary, ANOVA post-hoc analysis was performed to analyze the possible differences between the groups.

Results

Step-wise regression revealed that a single factor PFI was significant (F(1, 90) = 7.64, $p = 0.007$) where HPFI remembered more words than LPFI (M = 11.14, SE = 0.31 words vs M = 10.11, SE = 0.29 words) (Figure 2). Also the single factor PA was significant (F(1, 90) = 5.94, $p = 0.02$). The LPA group performed slightly better than the HPA group (M = 10.88, SE = 0.29 words vs M = 10.20, SE = 0.31 words) (Figure 3). The Self-Esteem, Age Group and Session factors were non-significant ($F < 2.81$, $p > 0.05$).

MANOVA analysis revealed a significant main effect of PFI (F(1, 87) = 3.29, DPillai = 0.07, $p = 0.04$) as well as a significant single factor PA (F(1, 87) = 2.53, DPillai = 0.08, $p = 0.03$). Single factors Self-Esteem and Age Group were non-significant ($F < 1.79$, $p > 0.05$).

Post-hoc ANOVA analysis for the Immediate Recall Session revealed that PFI was significant (F(1, 90) = 6.44, $p = 0.01$), the performance of HPFI was better than LPFI (M = 11.08, SE = 0.42 words vs M = 9.96, SE = 0.37 words). In turn, a trend toward significance for a single factor PA emerged (F(1, 90) = 3.19, $p = 0.08$). LPA showed a better performance than HPA (M = 10.62, SE = 0.39 vs M = 10.23, SE 0.41 words).

Post-hoc ANOVA analysis on the Delayed Recall Session revealed no differences between HPFI and LPFI groups (F(1, 90) = 1.60, $p > 0.05$), while PA single factor was significant (F(1, 90) = 6.88, $p = 0.01$). In particular,

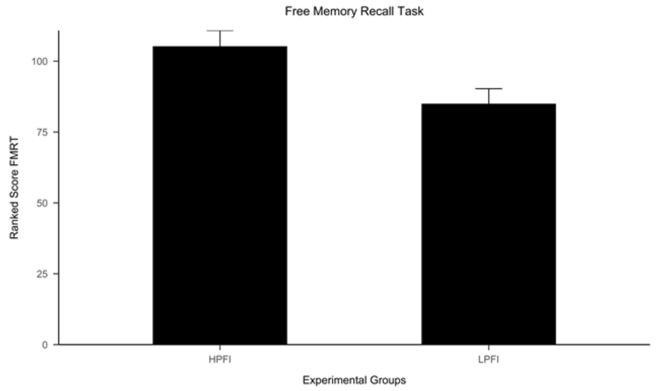

Figure 2. Significant differences ($p < 0.05$) between HPFI and LPFI in the Free Memory Recall Task

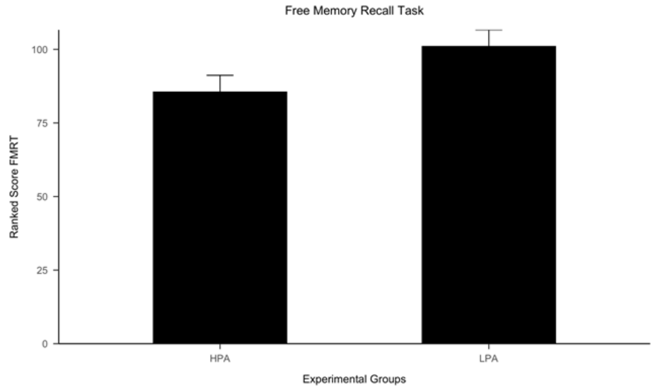

Figure 3. Significant differences ($p < 0.05$) between HPA and LPA groups in the Free Memory Recall Task

LPA performed better than HPA (M = 11.15, SE = 0.45 words vs M = 10.15, SE = 0.47 words).

Discussion

The effects of physical activity on cognitive functioning have been extensively studied throughout the years due to the great importance that can bring the development of an excellent physical education lesson. Thus, it can be transformed as a teachers' tool for the students' psychophysiological development [8].

Despite the benefit of these results, that should be considered for the development of the individual's physiological and psychological traits. In our society, the level of sedentary lifestyle is increasing, leading to some problematic issues. For instance, the risk of incurring some pathologies and decrementing our children's cognitive functions will be increasing [19, 43]. Thus, to avoid these issues, if well planned, physical education could be a low-cost instrument to employ to enhance well-being in our society.

In this experiment, we aimed at investigating the role of physical fitness and physical activity on memory functions in a large sample of pre-adolescent children. In particular, we tested the memory skills through the Free Recall Memory Test [5].

The Free Recall Memory Test analyzed both short-term and long-term memory. Participants had to remember a series of words immediately after their presentation (100 seconds) and after 12 minutes. The PAQ-C questionnaire [17] and the MOTORFIT test battery [25] were involved in analyzing the physical activity level and physical fitness of pre-adolescents, respectively. Furthermore, we controlled two confounding factors: self-esteem and age.

Overall, our results highlight the effect of physical fitness on memory skills, where pre-adolescents with high physical fitness performed better than students with low physical fitness. However, a no-interactive effect with the Session factor emerged. At the same time, results concerning physical activity showed an opposite effect, where the pre-adolescent participants who reported to be less physically active had a slightly higher performance compared to the students who reported to be more physically active. Furthermore, the analysis indicated that self-esteem did not influence performance actively. Thus, our results provide evidence that regular physical activity practice could enhance memory skills, and these results could extend the research of Pesce et al. [26]. Indeed, in contrast to Pesce et al. [26], our attention was focused on chronic exercise instead of the acute effect of physical exercise.

However, we found a discrepancy between physical activity and physical fitness. It is important to remember that the former is usually referred to as any bodily movement that requires energy expenditure, whereas the latter refers to a general state of well-being that brings a low risk of premature disease development and which participate in a plethora of physical activities [12]. Thus, it is possible that pre-adolescent children may incorrectly report the time spent in physical activity or even when the pre-adolescents reported it correctly, the activities performed during the day could not increase the general physical fitness. In the latter case, it is possible that the intensity of physical activities does not influence physical fitness; thus, if this is true, high-intensity exercises should be promoted.

Conclusions

According to the above-mentioned reviews, physical activity can enhance cognitive skills such as attention and perceptual skills. Moreover, it could improve academic achievements [28].

Instead, the studies focused on memory abilities are relatively controversial, and not all the investigations were able to find better children's memory skills improved by an increase in daily physical activity [35]. On the other hand, Pesce et al. [26] found that high-intensity physical activity and a single bout of activity can help to increase the memory skills of the children. In this study, we provided evidence that physical fitness can improve the memory function of children. Our results are in line with the results reported by Pesce et al. [26]. Together with their results, it may be assumed that physical fitness and chronic exercise may have a positive effect on short-term memory skills. Furthermore, our results are similar to the findings of Chaddock et al. [4]. A neuroscience study reported better memory performance for high physically fit children than less physically active ones. Moreover, the results highlighted that physical activity could modify the brain structure, increasing the hippocampus volume (for a review concerning the role of physical activity in the modification of brain structure, see [7]).

However, our results are in contrast with a recent investigation [32], where the positive relationship between physical activity and memory function was not found. Nevertheless, according to the authors, there are important limitations affecting the research that could lead to result inconsistency.

Furthermore, our research indicated an important discrepancy between physical fitness and physical activity level. Thus, to better understand this discrepancy, researchers should monitor both direct and reported measures. For instance, physical activity could be monitored through accelerometers [39] to understand better the effect of physical activity level on cognitive functions.

In conclusion, sport/physical activities could enhance some psychological aspects of pre-adolescents. The results are quite relevant for subsequent studies, where both cognitive abilities and psychological characteristics of the children should be taken into account. Furthermore, teachers should consider these results to employ physical education as a tool for other school subjects. For instance, physical education lessons could help students in memorizing poems and/or mathematical multiplication tables. To do that, teachers could create games or relay races that should be performed at high intensity. At the same time, participants during these exercises have to memorize a fair amount of information that should be recalled in the following exercise. In this way, children's aerobic fitness, general strength and cognitive functioning should be increased.

However, this research is not free of limitations; particular importance has to be given to the motivational aspects in the task and how to control them. Specifically, it is difficult to understand whether the students were more motivated to perform at their best; thus, in future research, their motivation should be analysed [21].

Future studies

Further investigations are required to gain insight into how physical activity could influence the cognitive aspects. It is possible to propose different physical activities to understand which activity could better enhance the participants' mental functions. Moreover, different cognitive and psychological tests should be necessary to examine all the components in depth. Again, in future studies it is recommended to better understand the effect of chronic physical activity according to different physical activities practised (e.g., open and closed skills activities), or to the teaching methods adopted by teachers (e.g. inductive and deductive methods). This could allow us to understand how physical education lessons should be planned and which teaching methods should be adopted by teachers in order to enhance cognitive functioning.

Another possible future investigation is to investigate within a longitudinal study how physical activity affects cognitive functioning at different stages of maturity, such as in adolescence and when the maturation is complete.

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Reliability of kinematic parameters of power snatch from recreationally-trained weightlifters

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Abstract
Introduction. The Olympic weightlifting movements (snatch, clean and jerk) and their variations (snatch and clean deadlift, high pull, etc.) have been widely used in order to improve performance in many sports, but there are no normative data, nor data on reliability of kinematic parameters for power snatch from recreational weightlifters. Aim of Study. This study aimed to quantify the reliability and the minimal detectable change of kinematic parameters from bar displacement during a power snatch movement in non-professional (i.e., recreationally trained) weightlifters. Material and Methods. Sixteen healthy (13 male), trained, but non-competitive weightlifters, volunteered to participate in this study. Each volunteer performed 2 power snatches at 60% of their RM. The barbell path was recorded using a high-speed camera and the data was processed off-line to obtain barbell position coordinates. Elapsed time to complete the movement, trunk and knee position at catching, the kinematic parameters from horizontal and vertical bar displacements, vertical velocity and acceleration were obtained for each of the 5 movement phases (1st pull, transition, 2nd pull, turnover and drop). Descriptive data, intraclass coefficient correlation (ICC) and minimal detectable change (MDC) from each studied variable were obtained and presented. Results. Our results indicated low to excellent reliability for studied variables, with the initial phases of the lift (i.e., 1st pull, transition and 2nd pull) displaying better reliability, while the later phases of the movement (turnover and drop) exhibited poorer reliability for a majority of variables. Conclusions.The presented data, with a comprehensive description of normative data obtained from the power snatch of recreational weightlifters could help coaches to evaluate power snatch performance as a conditioning tool for recreational athletes.

KEYWORDS: kinematics, biomechanics, Olympic weightlifting, explosive force.

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Introduction

The Olympic weightlifting movements (snatch, clean and jerk) and their variations (snatch and clean deadlift, high pull, etc.) have been widely used in order to improve performance in many sports [2, 12, 22] and in functional fitness programs [25]. Although it requires a long time to acquire the necessary skills to perform the movements with a proper technique, this modality of training has been shown to be effective in improving lower limb power, speed and agility [20].

Olympic weightlifting training (OWT) has gained increased popularity in recent years, especially among recreational fitness enthusiasts, influenced by the growing popularity of mixed modality training (MMT) [6, 15, 18], and the evidence of its safety for non-professional people [21]. Yet, future studies should aim to evaluate long-term effects of weightlifting interventions on the cardiovascular and hemodynamic system [21]. Notably, the increase of adherence to OWT by recreational athletes is a challenge for coaches, since professional weightlifters have a more complete understanding of the athletic lifestyle [21], including awareness that a proper movement technique may promote better performance and ensure safety.

The use of kinematic data is proposed as an effective, safe and low-cost method to guide weightlifting training programs for professional and recreational weightlifters [5, 11, 24]. Data from the barbell displacement, obtained through video capture and their analysis with appropriate software have been widely used to improve the snatch technique [5, 16, 24]. Nevertheless, studies investigating the reliability and the minimal detectable change (MDC) from power snatch kinematics are scarce, even though these statistical parameters (i.e., reliability and MDC) are usually a part of a larger investigative study [23]. Notwithstanding, knowledge of reliability and MDC from kinematic parameters obtained from power snatch of non-professional weightlifters could guide coaches and sport scientists to monitor the effect of OWT routines.

In this context, the present study aimed to quantify the reliability and the MDC of kinematic parameters from bar displacement during a power snatch movement in non-professional (i.e., recreationally trained) weightlifters.

Methods

Experimental approach to the problem

To obtain normative data of kinematic parameters, describing both joint position (knee and hip) and barbell displacement parameters from a power snatch executed by non-professional weightlifters.

Sample

Sixteen healthy volunteers (13 male) participated in this study (age: 25 ± 3 years; height: 172.7 ± 7 cm; body mass: 81.6 ± 10.8 kg; power snatch: 80.8 ± 10.6 kg) and with at least 1 year of experience in Olympic weightlifting, training at least 3 times a week, but without competitive purposes. All participants were informed about the objectives and gave their informed written consent to participate in the study, which was approved by the local research ethics committee (protocol #: 3.425.388).

Procedures

Each volunteer performed two repetitions of a power snatch at 60% of the one repetition maximum (1RM) reported by each volunteer. The self-reported 1RM was based on the best performance at a standard 1RM test (i.e., 3-6 attempts with a 3- to 5-minute interval between each attempt) obtained in their last (~4 week) training cycle. A minimum interval of 2 minutes was given between attempts. The 60% of 1RM was chosen, because it was used in a previous study involving the kinematic analysis [9] and since it corresponds to a load that can confidently be lifted for multiple repetitions, as is often prescribed in MMT programs.

The volunteers were instructed to follow the training routine one day before the data recording, but avoiding any excessive volume. Before the data recording, volunteers carried out a dynamic warm-up consisting by dynamic stretches, 15 power snatch trials with a weighted barbell (20 kg) only, 10 trials with 30% of 1RM, and 5 trials with 60% of 1RM. The power snatch attempts were recorded using a high-speed GoPro® Hero 5 Black (GoPro Inc., USA) digital camera operating at 60 Hz. The camera was placed 5 m from the volunteers and perpendicular to the right side of the sagittal plane. Aiming to obtain the two-dimensional position coordinates of the barbell path in the sagittal plane, the right end was tracked to obtain the position coordinates. The tracking of the barbell path was analyzed using the Kinovea® v0.8.26 software (www.kinovea.org).

A standard box (height = 0.60 m) was used as the reference to calibrate the barbell position coordinates and the coordinate origin was set at the start position of the barbell. With respect to the axes, the data was adjusted as the positive and negative values of the x-axis representing the forward and backward motions of the barbell, respectively, while the positive values of the y-axis represent the vertical upward motions of the barbell. There was no guarantee that the barbell movement would be symmetric. However, the right barbell end was analyzed as the representative point of the barbell trajectory in the present study, as indicated by Nagao et al. [17].

The coordinate values were smoothed using a recursive fourth-order low-pass Butterworth filter at 6 Hz, as used by Kipp and Harris [14]. To obtain the data on barbell kinematics, the lift phases from the power snatch were defined according to the barbell trajectory as described previously [8, 14, 17]: 1) the 1st pull phase (from the start position to the most backward position, when the knees achieve or are close to the maximum extension for the first time); 2) the transition phase (from the end of the first 1st pull phase until the maximum knee flexion, where the volunteer adopts the power position); 3) the 2nd pull phase (from the end of the transition to the peak vertical velocity of the barbell); 4) the turnover phase (from the end of the second pull phase to the maximum height of the barbell path); and 5) the drop phase (from the end of the turnover phase to the catch position).

The elapsed time to complete the movement (i.e., from the start position to the catch position) was recorded, together with the elapsed time to complete each studied phase of movement (i.e., 1st pull, transition, 2nd pull, turnover, drop). The elapsed time in each phase was also normalized by the total time to complete the movement. The trunk and knee angles were measured at the catch position. The horizontal and vertical barbell displacements were recorded for each phase. The horizontal displacement was also measured as done by Winchester et al. [24], obtaining DxL (the horizontal displacement from the most forward position to the catch position), DxT (the horizontal displacement from the start position to the catch position), Dx2 (the horizontal displacement from the start position to the beginning of the 2nd position) and DxV (the horizontal displacement from the 2nd pull position to the most forward position). Mean and peak vertical velocity ($m \cdot s^{-1}$) and vertical acceleration ($m \cdot s^{-2}$) were also recorded from each phase.

Statistical analysis

Descriptive data from each studied variable (joint angle at the catch, elapsed time, barbell displacement, mean and peak velocity and acceleration) are reported as means and the respective 95% confidence interval [95% CI], standard deviation, minimum, maximum, median and 25 and 75 percentiles. The reliability of the kinematic parameters was determined from the ICCs by means of the two-way model (ICC2,1 – a two-way repeated-measures analysis of variance) [19]. The reliability was defined as 'excellent' for ICC values between 0.80 and 1.00, 'good' between 0.60 and 0.80, and 'low' when <0.60, as proposed by Shrout and Fleiss [19]. The ICC and the respective 95% CI were recorded. The error in an individual's score at 1 point in time was estimated by multiplying the standard error of mean (SEM) by the z value for the 90% and 95% confidence level (z value = 1.64 and 1.96 for 90% and 95%, respectively). This value was then multiplied by the square root of 2 (accounting for the measurement error on 2 test sessions) to estimate the MDC at the 90% and 95% confidence levels.

Results

All the recorded attempts were successful. The analysis of knee angle at the catch position demonstrated good reliability (ICC = 0.77 [0.48-0.91]), while for the trunk angle the reliability was low (ICC = 0.59 [0.16--0.82]). The mean angle for the knee flexion was 77.33º and the MDC90 and MDC95 were 10.27º and 12.27º, respectively. For the trunk angle the mean angle was 78.36º and the MDC90 and MDC95 were 7.60º and 9.09º, respectively (Table 1).

The analysis of the duration of each snatch phase indicated a low to excellent reliability. The duration of the 1st pull was the phase with the greatest reliability (ICC = 0.90 [0.76-0.96]) and the drop phase exhibited the lowest reliability (ICC = 0.50 [0.05-0.78]), for the 2nd pull, transition and turnover phases the ICC [95% CI] was 0.86 [0.66-0.95], 0.64 [0.26-0.85] and 0.63 [0.25-0.84]. The total time demanded to complete the task exhibited an excellent reliability (ICC = 0.82 [0.57--0.93]) (Figure 1). When normalized, the demanded time in each phase also ranged from low to excellent (Figure 1).

The mean of total time demanded to complete the power snatch was 1.49 seconds [95% CI = 1.43-1.55] and the MDC90 and MDC95 were 0.18 and 0.22 seconds, and 38.70% [36.48-40.93] of this time was spent in the 1st pull, 7.82 [7.09-8.55] in transition, 16.87 [14.79-18.95] in 2nd pull, 29.83 [27.52-32.14] in turnover and 6.77 [4.95-8.59] in the drop phase. The MDC90 and MDC95 of each phase are presented in Table 1.

The kinematic analysis was based on horizontal (Table 2, Figure 2) and vertical bar displacement parameters (Tables 3-5, Figures 2-4). A greater horizontal bar displacement was observed at the 2nd pull (0.10 m [0.09-0.12]) and turnover phases (0.14 m [0.12-0.15]), and the MDC90 and MCD95 of these were 0.046, 0.055 and 0.06, 0.07 m, respectively. DxL (0.17 m [0.16--0.18]) and DxV (0.10 m [0.09-0.12]) also exhibited horizontal bar displacement of min. 10 cm. The MDC90 and MDC95 ranged from 0.01/0.02 m for the transition phase to 0.09/0.11 m for DxT. All the studied kinematic data from horizontal bar displacement are presented in Table 2. The ICC for horizontal bar displacement ranged from low (ICC = 0.05 [–0.44-0.50]) for the 1st pull, good for transition (ICC = 0.74 [0.44-0.89]), the 2nd pull (ICC = 0.79 [0.52-0.92]), DxT (ICC = 0.73 [0.41-0.89]) and Dx2 (ICC = 0.72 [0.40-0.88]), while

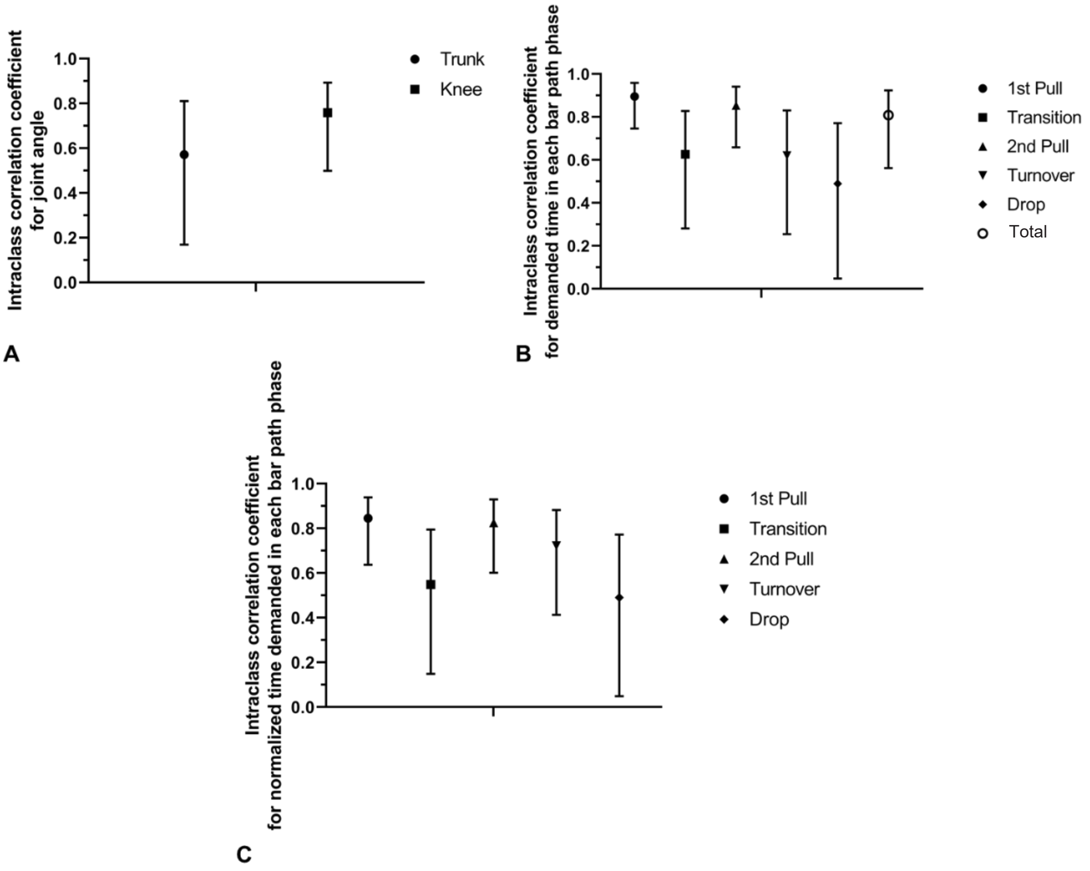

Figure 1. Intraclass correlation coefficient and its respective 95% confidence intervals between power snatch attempts. (A) Trunk and knee angles at the catching the bar; (B) Duration of each phase; (C) Percentual duration of each phase of power snatch

Table 1. Descriptive parameters for trunk and knees angles at catching, and the duration (in seconds and normalized [%]) of each phase of power snatch attempts

Angle at catching the bar										
Variable/ Phase	Attempt	Mean	95% CI	SD	Min	Max	Median	25-75 Percentile	MDC90	MDC95
Trunk	first	77.22	74.07-80.37	6.33	67.00	94.00	75.50	72.00-82.00	10.27	12.27
	second	77.44	73.68-81.20	7.55	68.00	93.00	77.00	71.00-82.00		
	grouped	77.33	75.00-79.65	6.87	67.00	94.00	76.00	72.00-82.00		
Knee	first	78.28	74.40-82.16	7.80	64.00	90.00	78.50	75.00-85.00	7.60	9.09
	second	78.44	75.51-81.38	5.90	68.00	88.00	79.00	74.00-83.00		
	grouped	78.36	76.05-80.67	6.82	64.00	90.00	78.50	74.50-84.00		
Duration of phase (s)										
1st Pull	first	0.59	0.51-0.67	0.16	0.32	1.13	0.56	0.53-0.63	0.12	0.14
	second	0.59	0.50-0.68	0.17	0.30	1.12	0.61	0.48-0.65		
	grouped	0.59	0.53-0.65	0.17	0.30	1.13	0.57	0.53-0.64		

Transition	first	0.12	0.10-0.14	0.03	0.08	0.18	0.12	0.10-0.13	0.06	0.07
	second	0.12	0.09-0.14	0.05	0.07	0.22	0.10	0.08-0.13		
	grouped	0.12	0.10-0.30	0.04	0.07	0.22	0.10	0.08-0.13		
2nd Pull	first	0.24	0.20-0.28	0.08	0.13	0.47	0.23	0.18-0.30	0.07	0.08
	second	0.26	0.22-0.30	0.08	0.12	0.47	0.27	0.18-0.32		
	grouped	0.25	0.22-0.28	0.08	0.12	0.47	0.25	0.18-0.31		
Turnover	first	0.45	0.40-0.51	0.11	0.32	0.70	0.42	0.37-0.52	0.13	0.16
	second	0.44	0.39-0.48	0.09	0.33	0.62	0.41	0.37-0.47		
	grouped	0.44	0.41-0.48	0.09	0.32	0.70	0.41	0.37-0.51		
Drop	first	0.10	0.06-0.14	0.09	0.00	0.27	0.12	0.00-0.17	0.14	0.16
	second	0.10	0.06-0.14	0.08	0.00	0.23	0.10	0.03-0.17		
	grouped	0.10	0.06-0.14	0.08	0.00	0.23	0.10	0.03-0.17		
Total	first	1.49	1.40-1.58	0.18	1.27	2.05	1.44	1.38-1.57	0.18	0.22
	second	1.49	1.39-1.58	0.19	1.20	2.05	1.45	1.38-1.58		
	grouped	1.49	1.43-1.55	0.18	1.20	2.05	1.45	1.38-1.58		
Duration of phase (%)										
1st Pull	First	38.69	35.48-41.91	6.46	23.75	54.84	38.74	35.79-41.56	5.87	7.02
	Second	38.72	35.29-42.15	6.89	23.08	54.03	38.80	34.02-42.27		
	Grouped	38.70	36.48-40.93	6.58	23.08	54.84	38.74	35.28-41.91		
Transition	First	8.04	7.06-9.01	1.96	4.85	11.76	8.29	6.32-9.41	3.31	3.96
	Second	7.60	6.41-8.78	2.38	4.21	13.40	7.00	6.17-9.20		
	Grouped	7.82	7.09-8.55	2.15	4.21	13.40	7.41	6.29-9.29		
2nd Pull	First	16.25	13.20-19.30	6.13	9.41	35.00	15.03	10.87-19.59	6.63	7.92
	Second	17.49	14.38-20.60	6.25	8.05	35.90	17.07	14.29-19.59		
	Grouped	16.87	14.79-18.95	6.14	8.05	35.90	16.20	12.72-19.59		
Turnover	First	30.35	26.67-34.03	7.40	17.74	41.75	28.50	25.00-38.82	8.16	9.76
	Second	29.32	26.15-32.48	6.37	18.55	40.48	29.51	25.00-31.82		
	Grouped	29.83	27.52-32.14	6.82	17.74	41.75	28.72	25.00-36.46		
Drop	First	6.66	3.86-9.46	5.63	0.00	17.39	7.16	0.00-9.57	8.76	10.47
	Second	6.88	4.26-9.49	5.25	0.00	14.29	7.45	1.61-10.87		
	Grouped	6.77	4.95-8.59	5.37	0.00	17.39	7.45	0.81-10.75		

it was excellent for DxV (ICC = 0.84 [0.62-0.94]). The ICC values and its respective 95% CI are presented in Figure 2A.

The total vertical bar displacement (from the ground to the catch position) was 1.47 m [1.43-1.51], the reliability was excellent (ICC = 0.94 [0.84-0.98]) and with a small MDC90 (0.07 m) and MDC95 (0.08 m). The height of the 1st pull was 0.35 m [0.32-0.38], with an excellent reliability (ICC = 0.88 [0.71-0.95]) and small MDC90 (0.06 m) and MDC95 (0.07 m). The unique parameter obtained from the vertical bar displacement with low reliability was the turnover (ICC = 0.57 [0.15-0.81]), with 0.45 m [0.42-0.48] of mean displacement and MDC90 (0.14 m) and MDC95 (0.16 m) corresponding

Table 2. Descriptive parameters from horizontal displacement of the bar for each phase of power snatch attempts

Horizontal displacement (m)										
Variable/ Phase	Attempt	Mean	95% CI	SD	Min	Max	Median	25-75 Percentile	MDC90	MDC95
1st Pull	first	0.03	0.02-0.03	0.01	0.02	0.05	0.03	0.02-0.04	0.03	0.04
	second	0.03	0.02-0.04	0.02	0.01	0.09	0.03	0.03-0.04		
	grouped	0.03	0.03-0.04	0.01	0.01	0.09	0.03	0.02-0.04		
Transition	first	0.02	0.01-0.03	0.01	0.00	0.05	0.02	0.01-0.03	0.01	0.02
	second	0.02	0.01-0.02	0.01	0.00	0.04	0.02	0.01-0.03		
	grouped	0.02	0.02-0.03	0.01	0.00	0.05	0.02	0.01-0.03		
2nd Pull	first	0.11	0.08-0.12	0.04	0.06	0.23	0.09	0.08-0.13	0.046	0.055
	second	0.10	0.08-0.12	0.05	0.03	0.19	0.10	0.08-0.15		
	grouped	0.10	0.09-0.12	0.04	0.03	0.23	0.10	0.08-0.13		
Turnover	first	0.14	0.11-0.16	0.05	0.08	0.24	0.13	0.10-0.17	0.06	0.07
	second	0.14	0.12-0.16	0.04	0.07	0.20	0.14	0.11-0.17		
	grouped	0.14	0.12-0.15	0.04	0.07	0.24	0.12	0.10-0.17		
Drop	first	0.02	0.01-0.02	0.02	0.00	0.06	0.01	0.00-0.03	0.03	0.04
	second	0.02	0.01-0.02	0.02	0.00	0.05	0.01	0.00-0.03		
	grouped	0.02	0.01-0.02	0.02	0.00	0.06	0.01	0.00-0.03		
Dx2	first	–0.02	–0.036 - –0.006	0.03	–0.08	0.04	–0.02	–0.04-0.00	0.04	0.05
	second	–0.03	–0.05 - –0.01	0.04	–0.11	0.04	–0.03	–0.05-0.00		
	grouped	–0.02	–0.036 - –0.013	0.03	–0.11	0.04	–0.02	–0.05-0.00		
DxL	first	0.17	0.15-0.19	0.04	0.10	0.25	0.16	0.13-0.20	0.06	0.08
	second	0.17	0.15-0.19	0.03	0.12	0.24	0.17	0.14-0.20		
	grouped	0.17	0.16-0.18	0.04	0.10	0.25	0.16	0.14-0.20		
DxT	first	–0.05	–0.09 - –0.007	0.08	–0.21	0.09	–0.05	–0.08-0.03	0.09	0.11
	second	–0.06	–0.10 - –0.03	0.07	–0.19	0.08	–0.08	–0.12 - –0.02		
	grouped	–0.06	–0.08 - –0.03	0.08	–0.21	0.09	–0.05	–0.12 - –0.02		
DxV	first	0.10	0.08-0.13	0.05	0.01	0.23	0.09	0.07-0.13	0.045	0.054
	second	0.10	0.08-0.13	0.05	0.02	0.19	0.11	0.07-0.15		
	grouped	0.10	0.09-0.12	0.05	0.01	0.23	0.10	0.07-0.14		

to approximately 33.3% of mean displacement. Transition (ICC = 0.66 [0.30-0.86]), the 2nd pull (ICC = 0.78 [0.50-0.91]) and drop (ICC = 0.79 [0.44-0.93]) exhibited good reliability. Despite the good reliability, the MDC90 and MDC95 of transition, the 2nd pull and drop were relatively high, representing approximately 30 to 35% of the mean displacement of the 2nd pull (0.51 m) and more than 50% of mean displacement of the transition and drop phases (Table 3). The ICC [95% CI] of vertical bar displacement from each phase are presented in Figure 2B.

The mean and peak velocity from vertical bar displacement are presented in Table 4. The greater mean and peak velocity were achieved at the 2nd pull phase. The reliability was excellent (ICC ranging from 0.74 to 0.89 for mean velocity and 0.76 to 0.91 for peak

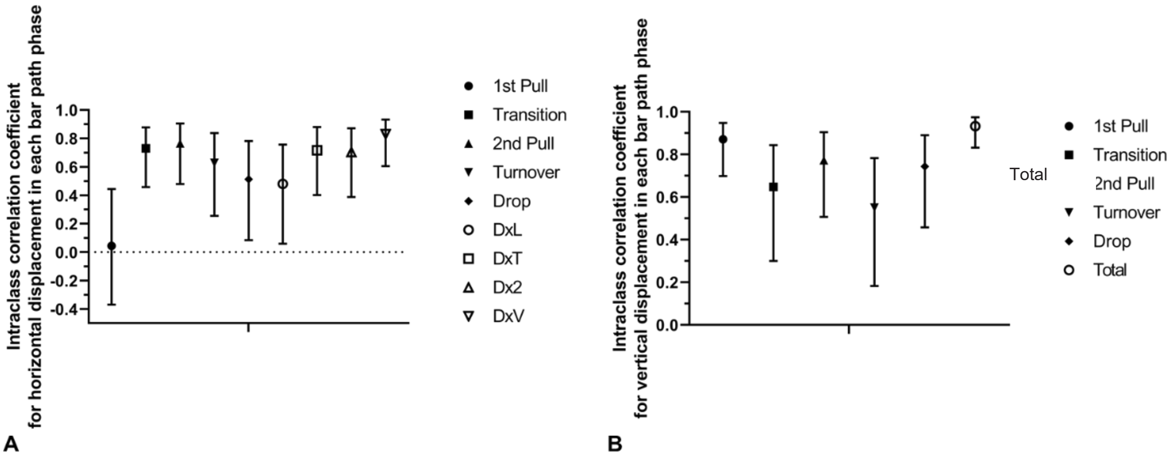

Figure 2. Intraclass correlation coefficient and its respective 95% confidence intervals between power snatch attempts. (A) Horizontal displacement in each phase of power snatch; (B) Vertical displacement in each phase of power snatch

Table 3. Descriptive parameters from vertical displacement of the bar for each phase of power snatch attempts

					Vertical displacement (m)					
Variable/ Phase	Attempt	Mean	95% CI	SD	Min	Max	Median	25-75 Percentile	MDC90	MDC95
1st Pull	first	0.36	0.32-0.39	0.07	0.15	0.43	0.37	0.34-0.41	0.06	0.07
	second	0.34	0.30-0.38	0.08	0.12	0.45	0.35	0.32-0.40		
	grouped	0.35	0.32-0.38	0.07	0.12	0.45	0.36	0.32-0.41		
Transition	first	0.17	0.14-0.19	0.06	0.09	0.27	0.15	0.12-0.23	0.08	0.09
	second	0.15	0.12-0.17	0.06	0.07	0.25	0.15	0.10-0.18		
	grouped	0.16	0.14-0.17	0.06	0.07	0.27	0.15	0.11-0.20		
2nd Pull	first	0.49	0.42-0.56	0.14	0.30	0.85	0.48	0.38-0.53	0.15	0.18
	second	0.53	0.46-0.60	0.14	0.28	0.90	0.53	0.45-0.57		
	grouped	0.51	0.47-0.56	0.14	0.28	0.90	0.50	0.43-0.57		
Turnover	first	0.46	0.42-0.49	0.07	0.32	0.62	0.47	0.40-0.51	0.14	0.16
	second	0.44	0.39-0.49	0.11	0.19	0.58	0.50	0.39-0.51		
	grouped	0.45	0.42-0.48	0.09	0.19	0.62	0.47	0.40-0.51		
Drop	first	0.01	0.001-0.01	0.01	0.00	0.05	0.00	0.00-0.01	0.02	0.02
	second	0.01	0.002-0.02	0.02	0.00	0.07	0.01	0.00-0.01		
	grouped	0.01	0.004-0.01	0.01	0.00	0.07	0.00	0.00-0.01		
Total	first	1.47	1.41-1.53	0.12	1.23	1.62	1.51	1.38-1.57	0.07	0.08
	second	1.47	1.40-1.53	0.12	1.25	1.65	1.50	1.36-1.56		
	grouped	1.47	1.43-1.51	0.12	1.23	1.65	1.50	1.36-1.56		

velocity) for all parameters, except for the mean and peak velocity from the turnover phase, which exhibited a low and good reliability (ICC = 0.34 [–0.15-0.70] mean velocity; ICC = 0.64 [0.26-0.85] peak velocity), and the drop phase, which exhibited a low reliability (ICC = 0.25 [–0.39-0.71] for peak velocity). Considering

Table 4. Descriptive parameters of mean and peak vertical velocity during vertical displacement of the bar for each phase of power snatch attempts

Mean velocity (m·s^{-1})										
Variable/ Phase	Attempt	Mean	95% CI	SD	Min	Max	Median	25-75 Percentile	MDC90	MDC95
1st Pull	first	0.64	0.57-0.71	0.14	0.27	0.84	0.66	0.57-0.74	0.21	0.25
	second	0.63	0.53-0.74	0.21	0.27	1.21	0.59	0.51-0.69		
	grouped	0.64	0.57-0.70	0.17	0.27	1.21	0.63	0.53-0.72		
Transition	first	1.38	1.20-1.55	0.36	0.70	1.98	1.39	1.19-1.66	0.28	0.34
	second	1.34	1.14-1.54	0.40	0.37	1.97	1.35	1.13-1.53		
	grouped	1.36	1.23-1.48	0.37	0.37	1.98	1.39	1.16-1.61		
2nd Pull	first	2.08	1.98-2.17	0.19	1.66	2.42	2.09	2.00-2.23	0.23	0.28
	second	2.09	1.97-2.21	0.24	1.51	2.46	2.07	1.96-2.26		
	grouped	2.08	2.00-2.15	0.21	1.51	2.46	2.07	1.97-2.23		
Turnover	first	1.00	0.91-1.09	0.18	0.70	1.25	1.01	0.83-1.18	0.40	0.48
	second	0.98	0.85-1.10	0.25	0.50	1.41	1.00	0.87-1.20		
	grouped	0.99	0.91-1.06	0.21	0.50	1.41	1.00	0.85-1.18		
Drop	first	–0.05	–0.08 - –0.02	0.06	–0.23	0.02	–0.05	–0.09-0.00	0.07	0.08
	second	–0.07	–0.10 - –0.03	0.07	–0.29	0.00	–0.05	–0.10 - –0.01		
	grouped	–0.06	–0.08 - –0.03	0.07	–0.29	0.00	–0.05	–0.10-0.00		
Peak velocity (m·s^{-1})										
1st Pull	first	1.20	1.03-1.36	0.33	0.42	1.74	1.22	1.05-1.48	0.24	0.28
	second	1.16	0.99-1.34	0.36	0.36	1.74	1.13	1.02-1.37		
	grouped	1.18	1.06-1.30	0.34	0.36	1.74	1.17	1.02-1.44		
Transition	first	1.59	1.40-1.77	0.38	0.82	2.22	1.57	1.36-1.82	0.37	0.44
	second	1.56	1.35-1.76	0.41	0.67	2.21	1.52	1.28-1.87		
	grouped	1.57	1.44-1.70	0.39	0.67	2.22	1.54	1.35-1.84		
2nd Pull	first	2.39	2.31-2.47	0.17	2.11	2.73	2.42	2.28-2.51	0.21	0.25
	second	2.42	2.31-2.51	0.20	2.05	2.83	2.42	2.26-2.56		
	grouped	2.40	2.34-2.46	0.18	2.05	2.83	2.42	2.27-2.51		
Turnover	first	2.34	2.24-2.44	0.20	1.91	2.74	2.40	2.22-2.46	0.33	0.39
	second	2.36	2.22-2.49	0.27	1.77	2.78	2.40	2.19-2.58		
	grouped	2.35	2.27-2.43	0.24	1.77	2.78	2.40	2.20-2.49		
Drop	first	–0.02	–0.03 - –0.01	0.03	–0.09	0.02	–0.02	–0.03-0.00	0.06	0.07
	second	–0.02	–0.04 - –0.01	0.03	–0.08	0.03	–0.02	–0.03-0.00		
	grouped	–0.02	–0.03 - –0.01	0.03	–0.09	0.03	–0.02	–0.03-0.00		

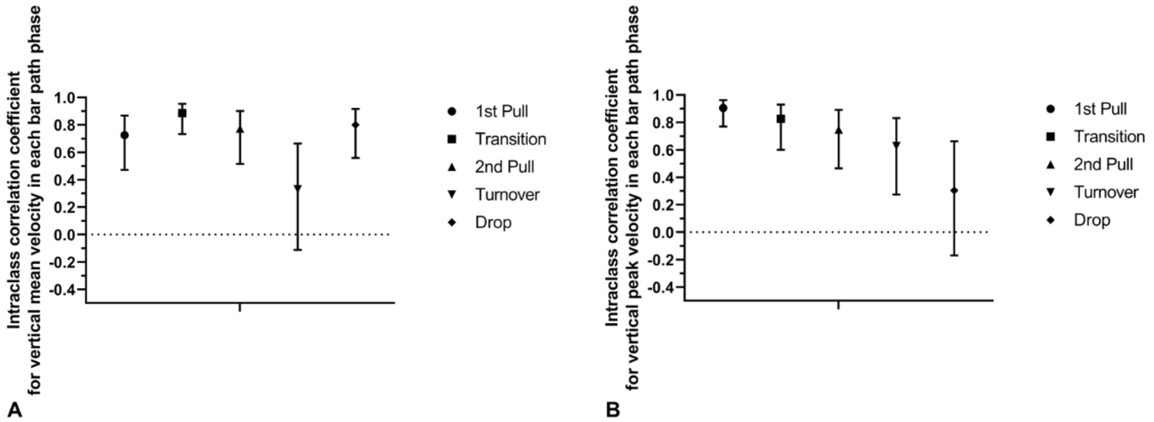

Figure 3. Intraclass correlation coefficient and its respective 95% confidence intervals between power snatch attempts. (A) Mean velocity in each phase of power snatch; (B) Peak velocity in each phase of power snatch

Table 5. Descriptive parameters from mean and peak acceleration during vertical displacement of the bar for each phase of power snatch attempts

Mean acceleration (m·s^{-2})										
Variable/ Phase	Attempt	Mean	95% CI	SD	Min	Max	Median	25-75 Percentile	MDC90	MDC95
1st Pull	first	1.96	1.62-2.30	0.69	0.29	3.17	2.04	1.70-2.45	0.59	0.71
	second	1.83	1.49-2.17	0.69	0.13	3.11	1.81	1.57-2.27		
	grouped	1.89	1.66-2.12	0.68	0.13	3.17	1.87	1.57-2.39		
Transition	first	3.23	2.67-3.79	1.13	1.37	5.08	3.55	2.12-4.13	1.36	1.62
	second	3.43	2.88-3.97	1.10	1.90	5.26	3.21	2.57-4.24		
	grouped	3.33	2.96-3.70	1.10	1.37	5.26	3.45	2.41-4.20		
2nd Pull	first	2.88	2.27-3.48	1.22	–0.49	4.32	3.04	2.10-3.70	1.91	2.28
	second	2.84	2.28-3.39	1.11	0.28	4.30	2.95	2.04-3.68		
	grouped	2.86	2.46-3.24	1.15	–0.49	4.32	3.03	2.07-3.69		
Turnover	first	–5.33	–5.93 - –4.73	1.21	–8.05	–3.46	–5.31	–5.86 - –4.64	1.60	1.91
	second	–5.50	–6.04 - –4.96	1.08	–7.80	–3.60	–5.54	–6.25 - –4.71		
	grouped	–5.41	–5.80 - –5.03	1.13	–8.05	–3.46	–5.36	–6.08 - –4.66		
Drop	first	–0.15	–0.33-0.03	0.36	–1.40	0.19	–0.02	–0.21-0.00	1.42	1.70
	second	0.04	–0.33-0.41	0.75	–1.65	1.38	0.00	–0.12-0.22		
	grouped	–0.05	–0.25-0.14	0.59	–1.65	1.38	0.00	–0.12-0.22		
peak acceleration (m·s^{-2})										
1st Pull	first	3.02	2.56-3.48	0.93	1.58	4.93	2.83	2.32-3.69	0.86	1.03
	second	2.97	2.39-3.54	1.16	1.06	5.52	2.90	2.35-3.32		
	grouped	2.99	2.64-3.34	1.03	1.06	5.52	2.85	2.33-3.53		
Transition	first	4.12	3.47-4.76	1.30	1.66	6.09	4.08	3.03-5.01	1.72	2.06
	second	4.35	3.69-5.01	1.33	2.28	7.06	4.35	3.25-5.19		
	grouped	4.23	3.80-4.67	1.30	1.66	7.06	4.20	3.16-5.17		

2nd Pull	first	4.98	4.33-5.62	1.31	2.41	6.78	4.90	3.78-6.28	1.30	1.55
	second	5.16	4.61-5.73	1.11	3.12	7.11	5.00	4.52-5.96		
	grouped	5.07	4.66-5.47	1.20	2.41	7.11	4.90	4.24-6.15		
Turnover	first	7.93	7.34-8.53	1.20	5.44	9.84	7.92	7.18-8.77	1.73	2.07
	second	8.42	7.89-8.96	1.08	6.03	10.10	8.68	7.79-9.06		
	grouped	8.18	7.79-8.57	1.15	5.44	10.10	8.36	7.42-9.04		
Drop	first	0.61	0.22-0.99	0.78	–0.55	2.68	0.36	0.00-1.00	1.63	1.95
	second	0.76	0.36-1.16	0.81	–1.03	2.17	0.76	0.00-1.29		
	grouped	0.68	0.42-0.95	0.79	–1.03	2.68	0.62	0.00-1.15		

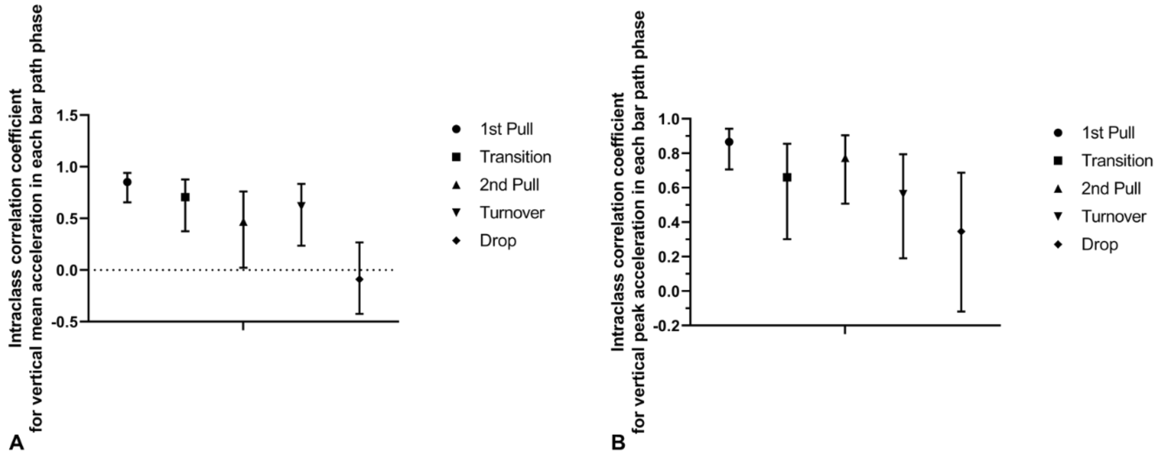

Figure 4. Intraclass correlation coefficient and its respective 95% confidence intervals between Power Snatch attempts. (A) Mean acceleration in each phase of power snatch; (B) Peak acceleration at each stage of the power snatch

the MDC from mean velocity, the values were relatively small for the transition and 2nd pull, while for peak velocity the relatively small MDC were observed for the 1st pull, transition, 2nd pull and turnover phases.

A greater mean acceleration was achieved at the transition phase, while a greater peak acceleration was achieved at the beginning of turnover phase. The reliability was excellent (ICC = 0.86 [0.66-0.95] for mean acceleration and 0.87 [0.69-0.95] for peak acceleration) only for 1st pull phase. Transition exhibited good reliability for both parameters (ICC = 0.72 [0.40-0.88] for mean acceleration and 0.67 [0.32-0.86] for peak acceleration), while the 2nd pull exhibited low reliability for mean acceleration (ICC = 0.48 [0.02-0.77]) and good reliability for peak acceleration (ICC= 0.78 [0.52--0.91]). Inversely, the turnover phase exhibited good reliability for mean acceleration (ICC = 0.63 [0.25--0.84]) and low reliability for peak acceleration (ICC = 0.58 [0.18-0.82]). Considering the MDC from mean and peak acceleration, the values were relatively greater for all phases.

Discussion

Identifying execution errors during sports gestures is essential to improve performance and reduce injury risk [3]. In this context it is necessary to know the “normal” movement pattern and the values within which the kinematic parameters of a given pattern are found, as well as the perspectives within which it is possible to modify these parameters. The present study collected kinematic data of the bar displacement during the performance of a power snatch by non-professional weightlifters, quantifying the values expected for each phase of this movement, which was inferred by the mean and 95% CI for each investigated variable. In addition, we inferred the reliability of these measures, as well as the perspective of MDC required for each parameter to achieve minimal clinical importance.

Our results showed the reliability ranging from low to excellent, depending on the studied variable (i.e., time of execution of each phase of the movement, horizontal and vertical bar displacement, velocity and acceleration of the bar) and the phase of the movement (i.e., 1st pull, transition, 2nd pull, turnover, drop). In general, the initial phases (i.e., 1st pull, transition, 2nd pull) of the power snatch movement showed better ICC values, while the worst values were identified in the final phases of the movement, especially the drop.

The 1st pull corresponds to the beginning of the Olympic weightlifter movements (i.e., clean and snatch) and is similar to the deadlift movement, which is commonly trained by OWT practitioners, whether competitors or not. In this way, this phase of the power snatch is highly trained and then it tends to be improved, leading to greater consistency, which may justify the higher ICC values and lower relative MDC values (i.e., considering the value of the MDC proportional to the mean of a variable). Additionally, the power snatch starts from a condition of inertia of the bar, while in the subsequent phases the bar is already in displacement and adjustments are inevitable, being directly dependent on the execution of the previous phase, which may contribute to worse ICC values and higher MDC values.

The duration of the movement as well as its each phase comprises the set of variables with the best reliability. In this context, it is noteworthy that the power snatch is characterized as explosive and, therefore, of short duration for its execution. Nevertheless, the average duration of the movement was 1.49 seconds (95% CI = = 1.43-1.55 seconds), time required to move the bar with the load referring to 60% of the PR at an average height of 1.47 meters (95% CI) = 1.43-1.51 meters), with an excellent ICC value (0.94 [0.84-0.98]).

It is important to emphasize that the height of the catch, used as a reference for the maximum height of the vertical bar displacement, showed excellent reproducibility, but the trunk and knee angles at the catching were on average 77.33º (95% CI = 75.00-79.65) for the trunk and 78.36º (95% CI = 76.05-80.67) for the knee, with ICC values between good (ICC = 0.77 [0.48-0.91] for the knee) and low (ICC = 0.59 [0.16-0.82] for the trunk). This fact indicates that these volunteers make effective adjustments in body position to fulfill the task objective with good reproducibility (i.e., moving the bar from the floor to an overhead position), thus suggesting that, despite their being non-professional weightlifters, the volunteers in this study exhibited a good body control to execute the movement. In this context, Ho et al. [11] suggested that investigations of the snatch technique should consider not only the variables related to bar displacement, but also those related to the subjects' body position.

From the biomechanical point-of-view vertical displacement is the largest, as a more efficient snatcher will be able to transition their body underneath the barbell with a shorter vertical pull [10, 13]. Therefore, adjustments in body position are an important aspect when considering technical quality in the snatch execution, as they are decisive in the bar path [11]. In this context, the reliability of horizontal bar displacement parameters DxT (ICC = 0.73 [0.41-0.89]), Dx2 (ICC = = 0.72 [0.40-0.88]) and DxV (ICC = 0.84 [0.62-0.94]) was good, with emphasis on reliability classified as excellent for the DxV parameter, measuring the horizontal bar displacement from the 2nd pull position to the most forward position [24].

Regarding movement duration, the transition phase is reported in several studies as important for a proper snatch technique [1, 4, 7, 8, 9, 11, 15]. In the present study we found that the duration of this phase is short, corresponding to approximately 0.12 seconds (95% CI = 0.10-0.30 seconds) or ~16.87% (95% CI = 14.79--18.95%) of all the time required for power snatch execution and with an ICC = 0.64 (0.26-0.85). The knowledge of the mean duration and its 95% CI can help to identify less effective patterns in this phase (i.e., the transition between the 1st and 2nd pull), which is reported as one of the main determinants in the success of a snatch [14], as will be discussed in more detail.

The velocity and acceleration parameters (mean and peak) are among the variables of greatest interest in studies investigating kinematic characteristics of snatch. In fact, these variables are decisive for power output, which in turn is essential for the successful task execution. In the present study we identified the highest mean and peak velocity values in the 2nd pull, while the highest mean and peak acceleration values were recorded in the transition and turnover phases, respectively. The observation of higher mean and peak velocity values is expected in the 2nd pull, which corresponds to a phase, which objective is to maximize bar velocity through a coordinated and explosive triple extension (i.e., hip, knee and plantar flexion), projecting the bar to an overhead position [4].

Identifying the highest mean acceleration values in the transition phase between the 1st and 2nd pull shows that the slowdown in the transition phase between the 1st and 2nd pull is one of the main determinants for success/failure of snatch attempts at maximum loads, as stated by Kipp and Harris [14]. Deceleration in this phase leads to lower mean acceleration values and will imply greater needs for acceleration in the subsequent phase (i.e., 2nd pull). It is important to note that in the present study submaximal loads were used, unlike the study of Kipp and Harris [14], who investigated maximum loads and squat snatch movements in competitive athletes.

Notwithstanding, maintaining the velocity of vertical bar displacement in the transition phase should be considered important also at submaximal loads, since decelerations will also demand greater velocity gains in the 2nd pull. Thus, a better maintenance of velocity in the transition phase will reduce the need to develop acceleration in the 2nd pull phase, making the movement more efficient. This can be advantageous when the objective is to perform multiple repetitions of the power snatch in the same set or within the same training session, as commonly used in many workouts of MMT programs.

It is worth mentioning that the ICC measurements indicated excellent reliability for mean and peak velocity (0.74 to 0.91) for the 1st pull, transition and 2nd pull. The turnover and drop phases presented lower reliability for mean and peak velocity, likely because they are predominantly phases of deceleration. In contrast, ICC values for peak acceleration were consistently high between the early phases (1st pull, transition and 2nd pull phases – ICC range = 0.67-0.87), while the later phases (transition and turnover) presented high ICC values for mean acceleration (ICC range = 0.63-0.72).

Conclusions

Summarizing the findings of the present study, recreational weightlifters with at least 1 year of training exhibited a good movement pattern, with good reliability at crucial phases of power snatch. The presented data, with a comprehensive description of normative data for power snatch obtained from recreational weightlifters, could help coaches to evaluate a range of people who use power snatches as a conditioning tool for other sports.

It is important to mention that the present study chose to analyze the power snatch instead of the squat snatch (i.e., full snatch, where the knee angle is less than 90°), since power snatch, typically performed with a lighter weight, as in this study (i.e., 60% of RM), allows greater barbell velocity, leading to greater barbell height, as well as the high squat catch position [22]. This higher catch position does not require the athlete to go into a full overhead squat position, which can be difficult to achieve for recreational weightlifters. Additionally, the power snatch catch position is similar to an athletic ready position (e.g., when preparing to or recovering from a jump), providing greater familiarity with the lift [22]. These aspects provide applicability of our results applicability in daily practice for a large number of weightlifting enthusiasts.

Conflict of Interests

The authors declare no conflict of interest.

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The influence of rest intervals following low-load countermovement jumps in athletes

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Abstract

Introduction. **A countermovement jump (CMJ) is a common explosive activity used to measure lower body power. Determining an optimal rest interval may be beneficial in creating a training program to improve performance.** Aim of Study. **To investigate the post-activation potentiation (PAP) effect of different low-load, high-intensity CMJs on subsequent bodyweight CMJs.** Material and Methods. **On four different occasions, 18 athletes (age: 19.61 ± 0.98 y; height: 177.69 ± ± 11.35 cm; mass: 80.22 ± 11.96 kg) completed one baseline CMJ followed by a series of low-load, high-intensity CMJs (0%, 10%, and 20% of their back squat one repetition maximum [1RM]) and one control condition without a CMJ (NJ). For each low-load intervention, participants completed 1 set of 6 CMJs, except NJ where participants stood for 20-seconds. Then, participants performed single CMJs at 8 different rest intervals following the experimental and control conditions. Three, 4 × 9 (condition [NJ, 0%, 10%, and 20%] × time [baseline, 0.5-min, 1-min, 2-min, 4-min, 6-min, 8-min, 10-min, and 12-min]), and three, 4 × 2 (condition × time [baseline and peak]) repeated measures analysis of variance were used to analyze jump height (JH), estimated power (eP), and flight time (FT) via a jump mat.** Results. **There were no protocol × time interactions. However, there was a significant ($p < 0.05$) main effect for time for FT, where FT was longer at 2-min than 10-min, and FT was longer at 4-min than 8-, 10-, and 12-min. Peak JH, eP, and FT values were all significantly greater than baseline.** Conclusions. **A single warm-up jump may enhance jump performance and other low-loads investigated in this study. The effectiveness of a low-load PAP response may be highly dependent upon the individuals. Thus, a greater focus on individualized PAP programming is needed.**

KEYWORDS: power, warm-up, post-activation potentiation, PAP.

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Introduction

Post-activation potentiation (PAP) is a phenomenon that occurs after performing a specific priming activity that may lead to a heightened ready state prior to performing a powerful movement [3, 6, 19, 28]. Therefore, PAP is considered to be a sport- or activity-specific extension of an otherwise general warm-up that can elicit supramaximal levels of explosive movement [3, 12, 15, 16, 30]. Although, the exact mechanisms underlying this phenomenon are not completely known, it is well documented that PAP is likely related to the contractile history of skeletal muscle [3, 13, 14, 22, 28, 29]. It has been suggested that phosphorylation of the myosin regulatory light chain (MRLC), excitability of the spinal cord reflex, and muscle spindle/presynaptic and postsynaptic changes are all potential factors that may enhance performance [3, 13, 14]. Thus, the specific contractile activity performed before an explosive task is likely to impact the likelihood of a PAP effect taking place.

Post-activation potentiating tasks are often performed by completing a brief bout of high- load, high-intensity movement prior to performing a bout of light, explosive activity [1, 18, 28, 29]. It has been suggested that performing high-loaded activities may induce fatigue [1, 3, 6, 18, 19, 28], thereby impacting subsequent performance. Despite this potential fatigue-effect, literature suggests the potentiation effect may outlast fatigue, and once this priming load-induced fatigue subsides, an increase in overall explosive performance may occur for a short period of time [29]. There is also evidence that negative loading (i.e., assisted exercise whereby the priming activity is performed with a load lighter than the performance load) can also induce a beneficial PAP effect on jumping, sprinting, and swinging motions [3, 6, 8, 19]. Therefore, both heavy and negative loading patterns may have beneficial effects on performance, there may be additional activity-specific stimuli with the ability to induce a PAP response. Heavy loading may induce fatigue and negative loading often requires specialized equipment that may not be practical in many strength and conditioning settings. Thus, a practical load and specific movement priming activity that does not result in significant fatigue, but can quickly induce.

PAP shortly after the priming activity, could be performed readily in the field. A practical non-fatiguing PAP application would be desirable to the strength and conditioning practitioner or athlete to possibly enhance acute explosive performance.

Rest interval prescription might be as important as load and intensity of the priming activity [5, 10, 20, 29]. At low-loads, a short rest interval 1- to 2-minutes (min) may be enough to augment subsequent explosive performance. For example, it has been reported that improvements in low-load, high intensity plyometric activity occurred following 2-minutes of rest [5]. In addition, Read et al. (2013) revealed as little as one-minute of rest led to a significant ($p < 0.05$) 2.2% increase explosive performance. Yet, excessive rest (10-min) at low-loads may be too long to observe any potentiating effect on jump performance (pre: 43.94 ± ± 5.28 cm; post: 44.70 ± 6.45 cm) [10]. Previous evidence suggests (6, 10, 20) that shorter rest intervals may be optimal to increase the likelihood of potentiation and ultimately performance. However, there is evidence that PAP responses may be highly individualized and that some individuals may peak early, while others late. Thus, there is a need to investigate a range of rest intervals at low-loads and high intensities to determine the optimal range.

Jump performance also appears to be elicited to a greater extent in those who have a higher degree of anaerobic training [17, 25]. In addition, there is evidence that individuals with higher absolute and relative strength may benefit from this phenomenon [6, 17]. Previous evidence [17] suggests that these individual differences may impact the time to peak performance around a PAP stimulus. For example, at high-load, high-intensity activity, individuals with a higher relative strength appear to potentiate closer to the PAP intervention, in comparison to those with a lower relative strength [17]. It is unknown if this same pattern of peak performance can be applied to a low-load, high-intensity sport-specific intervention such as the counter-movement jump (CMJ).

Although previous research has investigated the effect of low-load PAP protocols, these protocols differed in specific task, rest interval between PAP stimulus and performance, and individual training status [17]. Additional research is needed to determine an appropriate priming activity prescription to increase the likelihood of a PAP using a low-load priming activity across various loads and rest intervals for its effect on bodyweight (BW) CMJ performance in college-aged athletes.

Aim of Study

Therefore, the aim of the study was to determine whether different low-load (0%, 10%, and 20% of 1RM back squat) CMJ could induce PAP on subsequent BW CMJ across a 12-min rest interval range. Based on the findings of Chattong et al. [5] who reported a significant ($p < 0.05$) increase in jump height (post-intervention: 22.99 ± 3.35 in; pre-intervention: 22.69 ± 3.37) performance after a low-load intervention, it is hypothesized that there would be differences across conditions and time from baseline to one or more post-test jump performances and that group peak performance would likely occur closer to the potentiating stimulus, especially in those with higher levels of relative strength [3, 17].

Material and Methods

A mixed factor design investigated the influence of different low-load CMJs on subsequent bodyweight CMJ performance. On separate days, participants completed 1 maximal effort baseline CMJ. After 1-min of rest, participants performed either a control condition that included 20-s of standing without jumping, or 1 set of 6 CMJs. During the 1 set of 6 CMJs, participants jumped with only their BW (0%) or with 10% (10%)

or 20% (20%) of their back squat 1RM [5, 9]. The order of the conditions were randomized. Participants completed one CMJ at nine different time points for each of the following conditions (0.5-, 1-, 2-, 4-, 6-, 8-, 10-, and 12-min). Dependent variables analyzed included: CMJ height (JH), flight time (FT), estimated power output (eP). An a-priori power analysis to calculate sample size determined that in order to detect a significant effect size of 0.40, with an alpha of 0.05, and a power of 0.80, a minimum of 16 participants would be required. Potential significant effect size were calculated using investigations that measured similar variables [5, 6, 8, 20]. Twenty collegiate athletes from team sports such as football and men and women's basketball (FB, MBB, WBB, respectively) were recruited for this study. Two dropped out, resulting in a total of 18 athletes for our study (Table 1). Each participant demonstrated proper technique during the testing session to ensure the participant was able to safely perform the necessary exercises. Exclusionary criteria for participants included a history of any lower body musculoskeletal or orthopedic injuries within the last six months. There was no concern with women completing this exercise protocol while on their menstrual cycle [11], as research has shown it has no effect on jumping capabilities, nor significant differences of potentiation between men and women [29].

Table 1. Descriptive characteristics for anthropometrics and relative strength (rStrength) by sport

	Men's football	Men's basketball	Women's basketball
N	4	5	9
Age (y)	19.75 ± 0.96	20.60 ± 1.14	19.00 ± 0.00
Mass (kg)	82.04 ± 4.85	87.90 ± 13.81	75.14 ± 11.51
Height (cm)	176.85 ± 1.22	190.99 ±11.12	170.67 ± 6.73
Body fat (%)	9.95 ± 1.41	10.06 ± 5.87	22.94 ± 4.67
rStrength ($kg \cdot kg^{-1}$)	1.49 ± 0.20	1.13 ± 0.23	1.08 ± 0.24

Visit 1: Familiarization and one repetition maximum testing

All testing was completed in a strength and conditioning facility. Visit 1 consisted of familiarization and 1RM testing. First, each participant read and signed the institutionally approved informed consent document upon arrival to the facility; any questions were answered at this time. Then, a general warm up (GWU) was demonstrated for the participants to complete and use when instructed prior to the familiarization and intervention days: 10 jumping jacks, 10 BW squats, 5 walking knee hugs to full range of motion of plantar-flexion per leg, 5 forward lunges per leg, and 5 straight leg marches per leg [3, 15]. After the GWU, familiarization of CMJs were completed on the jump mat. Participants were instructed to begin in a standing and upright on the jump mat, with their arms above their head. Participants were instructed to stand on the jump mat. The investigated provided a countdown: "3.. 2.. 1.. Go!" On "Go", participants began to rapidly squat down to their self-selected depth by flexing the hip and knees while simultaneously swinging their arms down and behind their hips. Immediately following the downward/eccentric phase, participants explosively jumped, swinging their arms above their head (concentric phase). Two, 15-sec of rest periods were given between 3 jumps (18). Test-retest reliability was conducted of the jump mat for CMJ performance (JH, eP, and FT). Intraclass correlation coefficients (ICC) and 95% confidence intervals (CI) were calculated based on a mean-rating (k = 3), absolute-agreement, 2-way mixed-effects model (ICC = = 0.816-0.990, CI = 0.948 for jump mat JH; ICC = 0.966--0.998, CI = 0.991 for eP; and ICC = 0.824-0.989, CI = = 0.945 for FT). Intraclass correlation coefficient ranges demonstrated good to excellent agreement indicating a high degree of agreement utilizing the jump equipment for CMJ performance. Following the CMJs, 10-min [23] sitting recovery was provided. After the recovery period, 1RM testing began and proper technique of the back squat was evaluated at this time.

One repetition maximum (1RM) testing of lower body strength: back squat (BS)

Following the wash-out period, the 1RM testing protocol was implemented in order to determine the appropriate intervention loads. The National Strength and Conditioning Association has published a standardized method to measure a 1RM of the back squat exercise [12]. Comfort and McMahon [7] demonstrated paired sample t-test, and no significant differences occurred between two trials of 1RM back squat (ICC = 0.994, $p < 0.001$) and an excellent reliability (0.978). If the 1RM back squat was not attained within 5 sets, retesting was scheduled on a separate day. This completed the familiarization and baseline-testing day.

A standard Olympic barbell (20 kg), universal exercise power rack and safety bars was used during the 1RM back squat. For the low-load CMJ conditions, the load of a standard adjustable weighted vest (Mir Vest Inc., San Jose, CA) was individualized and adjusted to the appropriate weight for each loaded intervention (10% and 20%); weight vest was not worn during the no-load condition. Measurement of CMJ height, flight time and estimated power was determined by a jump mat (Swift Performance, Northbrook, IL) [21]. The equation to estimate power associated with the jump mat was the Harman formula:

$$\text{Estimated power (W)} = 21.2 \times \text{jump height (cm)} + \\ + 23.0 \times \text{body mass (kg)} - 1393$$

Visits 2-5

Upon arrival to the weight room, participants completed the GWU as done on day one. One-min after the GWU, one maximal effort baseline CMJ was completed prior to each PAP intervention. In addition to the three intervention conditions (0%, and 10%, and 20% of 1RM BS), participants completed a NJ condition. On this day, participants completed the GWU, 1-min of rest, one maximal CMJ, followed by standing for 20-sec (time of intervention and walking over to the jump mat), and then performed one post-CMJ at each time interval. All conditions were implemented in a randomized order (NJ, 0%, and 10%, and 20% of 1RM BS) by selecting conditions randomly from a basket.

Loaded countermovement jump, PAP intervention

The no-load or low-load, high-intensity CMJ exercise was instructed following the guidelines of the NSCA [12]. Participants began in an upright position, feet with shoulder width apart, with the weighted vest on and velcrowed. Each participant was instructed to use an arm swing and a self-selected depth during the eccentric phase throughout all 6 jumping reps, immediately followed by pushing off the ground to jump. The landing position was the same as the starting position. Each rep of the CMJ was immediately repeated until all 6 reps were completed in a plyometric fashion. After the 1 set was completed, one maximal effort CMJ was performed at 0.5-, 1-, 2-, 4-, 6-, 8-, 10-, and 12-min. Participants were sat during the resting periods. This completed a single visit. The following three sessions were conducted as the first except for the intervention condition implemented in a randomized order.

Three, 4 × 9 (condition [NJ, 0%, 10%, and 20%] × time [baseline, 0.5-min, 1-min, 2-min, 4-min, 6-min, 8-min, 10-min, and 12-min]) and three, 4 × 2 (condition × time [baseline and peak value]) repeated measures analysis of variance (ANOVA) was used to analyze JH, eP, and FT. Bonferroni-corrected dependent sample t-tests were completed where indicated by significant main effects. Greenhouse–Geisser corrections were applied when sphericity was not met according to Mauchly's test of sphericity. Partial eta squared (η_p^2) and Cohen's d (small × 0.20 to 0.49, medium = 0.50 to 0.79, and large = 0.80 and above) effect sizes were also calculated for each ANOVA and t-test, respectively. All confidence intervals were calculated at 95%. For all analyses, an a-priori alpha was set at 0.05 and all statistical analyses were performed using IBM Statistical Package for Social Sciences software (version 25.0, SPSS Inc. Chicago, Il, USA).

Results

Jump height (JH)

The 4 × 9 ANOVA revealed no significant ($p = 0.980$, $\eta_p^2 = 0.028$) condition × time interaction, main effect for condition ($p = 0.411$, $\eta_p^2 = 0.520$), or main effect for time ($p = 0.105$, $\eta_p^2 = 0.120$). Further analysis with a 4 × 2 ANOVA showed no significant ($p = 0.672$, $\eta_p^2 = 0.200$) condition × time interaction or main effect for condition ($p = 0.393$, $\eta_p^2 = 0.053$). There was, however, a main effect for time ($p < 0.001$, $\eta_p^2 = 0.801$), with pairwise comparisons revealing that peak JH values were significantly ($p < 0.001$) greater than baseline values (Table 2). The corresponding effect size (Cohen d) was 0.30, (CI: –0.36; 0.95).

Estimated power (eP)

The 4 × 9 ANOVA revealed no significant ($p = 0.594$, $\eta_p^2 = 0.034$) condition × time interaction, main effect for condition ($p = 0.230$, $\eta_p^2 = 0.084$), or main effect for time ($p = 0.118$, $\eta_p^2 = 0.112$). Further analysis with a 4 × 2 ANOVA showed no significant ($p = 0.673$, $\eta_p^2 = 0.018$) condition × time interaction or main effect for condition ($p = 0.228$, $\eta_p^2 = 0.081$). There was, however, a main effect for time ($p < 0.001$, $\eta_p^2 = 0.623$), with pairwise comparisons revealing that peak eP values were significantly ($p < 0.001$) greater than baseline values (Table 2). The corresponding effect size (Cohen d) was 0.21, (CI: –0.49; 0.90).

Flight time (FT)

The 4 × 9 ANOVA revealed no significant ($p = 0.652$, $\eta_p^2 = 0.037$) condition × time interaction or main effect for condition ($p = 0.253$, $\eta_p^2 = 0.076$). There was, however, a main effect for time ($p = 0.030$, $\eta_p^2 = 0.163$). Pairwise comparisons revealed that FT at 2-min was significantly ($p = 0.031$) greater than 10-min, and FT at 4-min was significantly greater than 8-min ($p = 0.031$), 10-min ($p < 0.001$) and 12-min ($p < 0.001$). Further analysis with a 4 × 2 ANOVA showed no significant ($p = 0.533$, $\eta_p^2 = 0.018$) condition × time interaction or main effect for condition ($p = 0.406$, $\eta_p^2 = 0.081$). There was, however, a main effect for time ($p < 0.001$, $\eta_p^2 =$ = 0.623), with pairwise comparisons revealing that peak FT values were significantly ($p < 0.001$) greater than baseline values (Table 2). The corresponding effect size (Cohen d) was 0.29 (CI: –0.36; 0.92).

Table 2. Jump height (JH), estimated power (eP), and flight time (FT), main effect for time

	JH	eP	FT
Base	44.44 ± 11.41	1366.46 ± 428.63	0.598 ± 0.08
0.5 min	44.44 ± 10.36	1383.86 ± 388.56	0.599 ± 0.08
1 min	45.12 ± 09.80	1394.32 ± 369.86	0.604 ± 0.07
2 min	45.51 ± 09.92	1406.81 ± 376.03	0.605 ± 0.08*
4 min	45.74 ± 10.56	1412.65 ± 385.09	$0.608 \pm 0.08^{*x}$
6 min	44.59 ± 09.90	1387.50 ± 377.07	0.599 ± 0.07
8 min	44.69 ± 09.81	1385.68 ± 376.80	0.598 ± 0.07
10 min	44.18 ± 10.25	1378.63 ± 381.47	0.596 ± 0.07
12 min	44.13 ± 09.90	1375.29 ± 367.58	0.596 ± 0.08
Peak	47.92 ± 11.86^	1455.71 ± 419.78^	0.621 ± 0.08^

Mean ± SD (s)
^ significantly ($p < 0.05$) greater than baseline; * significantly ($p < 0.05$) greater than 10-min; ^{x} significantly ($p < 0.05$) greater than 8-, 10-, and 12-min

Discussion

The purpose of this study was to investigate whether different low-load CJMs (0%, 10%, and 20% of 1RM) could induce PAP for subsequent CMJs. There were no differences in jump performance between conditions, including the NJ condition, at any time point. However, individual responses indicated that each subject's peak jump performance was greater than baseline, indicating that all subjects did in fact potentiate at unique time points. Therefore, it seems as though a combination of the GWU, baseline measurements, and a single-set of low-load jumps may have been enough to induce PAP for FT within close proximity (2- and 4-min). This rapid time-dependent change is supported by previous literature [3, 5] showing that potentiation likely appears and disappears quickly when the priming activity is not fatiguing, especially in stronger individuals [5, 8, 27].

The main finding of the present study was that although none of the low-load priming activities potentiated jump performance better than any of the other conditions, each subject did in fact experience their own individualized PAP effect (Figure 1). This finding is in line with previous research showing that PAP seems to be a highly individualized phenomenon [25, 26, 29]. Previous findings [3, 25, 29] have shown that the time to potentiation peak after an explosive priming activity is highly individualized and improvements in jump performance may begin as early as 1-min, but as late as 12-min after an intervention. It has also been reported that the differences in individual responses may be due to prescribed recovery intervals, volume, intensity, and strength level [17, 23, 24, 29]. The approach of recruiting skeletal muscle across the force-velocity spectrum to ultimately improve acute power output may rely greater on established neuromuscular pathways [2] and specific exercise prescription given for the priming activity (intensity and volume).

Highly trained individuals should have improved synchronization and recruitment patterns of the higher-order fibers, and therefore, should have the ability to recruit fibers faster or additional fibers overall [4, 12]. This may be an explanation for augmented jump performance for time, but not condition within the present study. Nevertheless, explosive priming activities appear to elicit a PAP response that is highly individualized, which suggests a trial-and-error approach might be needed to determine the optimal PAP stimulus on an individual basis rather than prescribed from mean responses.

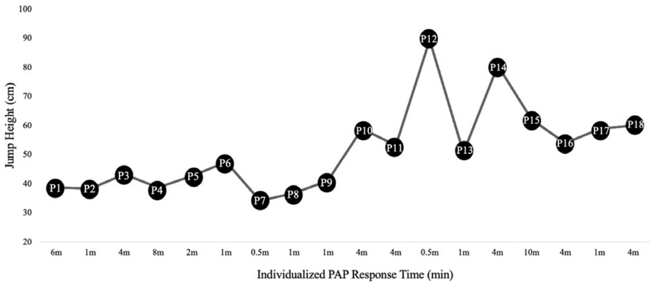

Figure 1. Individual responses by participant (P) for jump height (cm)

Note: m – minute

A time-dependent change in jump performance (FT) occurred, but that response was similar regardless of condition. Previous literature reported early jump performance improvements from 2- to 5-min post-priming activity following no- and low-load conditions [5, 8, 27], which is similar to the current study. Moreover, Chattong et al. [5], Cuenca- Fernández et al. [8], and Turner et al. [27] all had single recovery periods, 2-min, 5-min, and 4-min, respectively, and did not include other post-testing time points, meaning that it is possible potentiation could have occurred before or after these recovery time points. Despite a lack of improvement between no- and low-load conditions before the priming activity, the implemented GWU might have been sufficient stimulus to prime the skeletal muscle and nerves to augment overall performance, even minimally [5, 8]. Further suggesting, regardless of the load priming activity, PAP is highly individualized, and the stimuli might need to be individualized or a self-selected rest interval might be needed to augment a change between conditions for the current population.

The current sample of collegiately trained athletes were similar to those recruited in previous literature [5, 8, 27], suggesting the weighted conditions were not enough to elicit a physiological response that differed from a single baseline jump. Previous research has shown that stronger athletes can potentiate within a shorter period of time than weaker athletes [17, 25, 29]. Furthermore, stronger individuals may require a more intensive priming activity in order to stimulate a PAP response [17, 29]. Considering the athletes in the present study had an average BS 1RM of about 110 to 150% of their body mass, we did not have enough individuals to separate by relative strength into even "strong" or "weaker" categories to determine if there was a unique "strength" effect on the PAP response to the low-volume low-load priming activity used in the present study. Therefore, future studies should investigate whether athletes with different strength levels respond in unique patterns to such low-load protocols. Additionally, it is possible that the stronger athletes would have needed a more fatiguing stimulus in order to encourage PAP. Future research should determine whether a greater volume of low-load exercises could potentiate CMJ performance to a greater extent than in the present study. Despite the inability to compare individuals based on strength characteristics, the findings of the present study are reflective of what is common among team sport athletes. In team sports, athletes commonly have different relative strength levels, where some members are relatively stronger than other members of the same team. The data from current study indicates that there may be impact of relative strength on a PAP performance response. Thus, when utilizing PAP, the relative strength data lends evidence that coaches should assess PAP interventions based on the individual rather than the mean strength of the whole team.

Conclusions

The study demonstrated that individual subjects experienced a PAP effect, and that a GWU alone may be sufficient to stimulate PAP in some individuals. The findings of the present study lend evidence to the notion that a priming stimulus as simple as a GWU may be sufficient to stimulate a rapid PAP response, as most subjects potentiated within 2- to 4-min. Furthermore, there were moderate-to-large effects for peak FT, JH, and eP compared to baseline, indicating that the individualized PAP responses observed in this study likely could be a practical warm-up for jump performance. The results of the present study also provided support to the individualized nature of PAP responses and that individual prescriptions of varying volumes or intensities may be required to maximize effectiveness of a potentiation intervention. Thus, a specific prescription to elicit a PAP response is recommended and should be adjusted based on current status and training abilities to ensure optimal subsequent jump performance.

Although the purpose of this study was to investigate the effects of a single set of low-load jumps on subsequent BW jump performance, increasing the volume of jumps may have resulted in greater potentiation and future studies should investigate the effects of multiple sets of low-load jumps. Furthermore, the influence of relative strength should be investigated to determine whether relatively stronger or weaker individuals respond better to low-load, low-volume priming activities, which may help clarify how potentiation is elicited and best be prescribed.

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Assessment of respiratory function and aerobic capacity in postmenopausal women participating in water aerobics classes

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Abstract

Introduction. Respiratory function is subject to the aging process, similarly to that of multiple other systems. Regular aquatic exercise favors physical development, and improves circulation and respiration, as well as overall health. Aim of Study. The purpose of the study was to assess the impact of a 12-week training program involving water aerobics on respiratory system function and aerobic capacity in post-menopausal women. Material and Methods. The study included 30 women (21 in the study group, 9 controls). Women in the study group participated in supervised water aerobics classes, twice a week for 3 months. At the beginning and end of the study, all the women underwent a spirometry test and an exercise test by an ergometer. Results. An analysis of changes after the training program demonstrated a significant increase of the maximal aerobic capacity in the study group ($p < 0.05$). No significant changes were found in spirometry indicators (VC) or airflow parameters in the large and small airways (MEF_{75}, MEF_{50}) following a 12-week water aerobics program. Conclusions. The implemented training program for healthy postmenopausal women did not improve the spirometry indicators studied, and the observed aerobic capacity increase likely resulted from improved circulatory and metabolic performance that determines an individual's exercise tolerance and health.

KEYWORDS: spirometry, postmenopausal women, maximum oxygen uptake.

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Introduction

Health is a major component of the quality of life (QoL), especially in older individuals. In an aging society poor health and deteriorating QoL are major problems that interfere with an individual's functioning in the society. Maintenance of good health and QoL is the primary consideration for elderly individuals who undertake exercise [10].

Respiratory function, which is required for supplying oxygen to the muscles, is subject to the aging process, similar to that of multiple other systems. This process may have individually varying dynamics and health consequences and it is affected by multiple factors that may be beyond an individual's control. Lung aging results from physiological changes that occur in the body with age, the history of disease and environmental factors associated with lifestyle [22]. While total lung capacity (TLC) remains largely unchanged, residual volume (RV) increases, whereas vital capacity (VC) decreases with age. RV increases, while expiratory reserve volume (ERV) decreases in elderly patients. In (non-smoking) women older than 45 years peak expiratory flow (PEF) drops by approx. 2.5 mL/year. Forced expiratory volume in one second (FEV_1) decreases by 17.7 ± 1.4 mL/year on average in individuals aged 40-49, and by 37.1 ± ± 2.1 mL/year in those aged 60-79 [18].

In older age the metabolic cost of respiration increases both at rest and during exercise. This increases oxygen use, while its supply is restricted by lung aging, which in many cases leads to quick onset of dyspnea even with low-intensity exercise. In physically fit individuals this point moves towards greater exercise intensity [18].

Physical fitness is a product of multiple factors, including physiological, biochemical and psychological ones. Contributors to better fitness include good respiratory, circulatory and metabolic functions associated with muscular effort. Physical fitness changes as a result of training and is affected by an individual's sex and age. As women typically have a greater body fat percentage, smaller heart and lungs, as well as lower hemoglobin levels, their VO_2max is approximately 10-12% lower than that of men. Greater physical fitness allows one to perform the same work with the same load at a lower energy expense. One parameter used in the assessment of the body's aerobic capacity is the maximum oxygen uptake (VO_2max). VO_2max is largely determined by genetic factors and its most intensive development occurs by the age of 16 in girls and by the age of 20 in boys. The parameter then stabilizes until the age of 30, followed by a decrease by approx. 0.75% annually due to aging processes in the body. A rapid decrease, exceeding 20% per decade, is observed in individuals older than 70 years. The rate of this decrease depends on one's exercise levels and the VO_2max value achieved by the age of 25-30. The parameter increases with endurance training, by up to 10-30%. Regardless of age, the greatest gain is observed in individuals with a low physical fitness level who are then subjected to guided physical training. In individuals with a high aerobic capacity, the VO_2max increase with training may only reach several percent [1, 25].

Literature provides evidence for the positive impact of aquatic exercise on circulatory function [11, 12, 21]. If the chest is completely immersed in water during exercise, the work of respiratory muscles increases to overcome the resistance of water resulting from its density and hydrostatic pressure. Therefore, the impact of water aerobics training on the static and dynamic respiratory parameters occurs constantly, with the relevant spirometry parameters expected to change accordingly. Regular aquatic exercise favors physical development, improves circulation and respiration [4], as well as overall health [3, 26].

Aim of Study

The purpose of the present study was to determine the effectiveness of a 3-month training program involving water aerobics in terms of improvement of respiratory function and aerobic capacity in post-menopausal women participating in the program as compared to controls.

Material and Methods

Participants

Subjects were recruited by advertisements in local media and at educational events and were qualified to participate in the project based on medical history and cardiology tests. The following exclusion criteria were applied (presence of at least one of the factors listed below): diseases of the locomotor system preventing independent movement, giant obesity, active or post cancerous disease (ongoing radiation or chemotherapy treatment), liver diseases (ALT > 3 × borderline) except for liver disease, chronic kidney disease (eGFR < 30 mL/1.73 m^2/min), acute inflammation (CRP > 5 mg/dL), unstable ischaemic heart disease, after an ischaemic or haemorrhagic stroke (<6 months), post-STEMI (ST-elevation myocardial infarction) women with a drug-eluting stent implantation, NSTEMI (non-ST-elevation myocardial infarction) (<12 months), inherited metabolic disorders (phenylketonuria and galactosaemia), autoimmune diseases (an acute thyroiditis, celiac disease, systemic connective tissue disease, haemolytic anaemia, vitiligo, Addison's disease, hyperbilirubinaemia), non-specific enteritis (Crohn's disease and ulcerative colitis), psychological disorders, antibiotic therapy, steroid therapy (ongoing), drug and alcohol addiction (a daily consumption of more than 1 portion of alcohol).

The study included 52 women randomly assigned to the study group (n = 26) or the control group (n = 26). Randomization was performed by simple random allocation; all subjects' identifiers were sent to a person with no further relationship to the study, who performed the randomization blindly using a computer list. All subjects were Caucasian and specifically, belonged to the native Polish population from the Greater Poland region. The subjects were asked for the entire study period not to change their dietary habits and not to engage in any new physical activity beside that provided for in the study protocol. Individuals with chronic illnesses restricting their ability to engage in aquatic exercise or constituting a contraindication to spirometry were excluded from the study. Five women (study group) dropped out from the project due to non-completion of the minimum required number of training sessions. Seventeen women (control) withdrew during the study. Ultimately, the

Table 1. Participants' anthropometric characteristics

Group	Age (years)	Height (cm)	Weight – pre (kg)	Weight – post (kg)	Z	BMI – pre (kg/m²)	BMI – post (kg/m²)	Z
Study group (n = 21)	63.20 ± 4.72	158.05 ± 4.81	73.20 ± 22.11	72.01 ± 20.42	2.34*	28.93 ± 7.50	28.67 ± 7.22	1.73
Control group (n = 9)	64.07 ± 3.66	161.39 ± 6.58	74.81 ± 12.28	73.20 ± 12.01	1.96*	28.63 ± 3.83	28.12 ± 3.62	1.77

Data are presented as means ± standard deviations
* $p < 0.05$

analyses included 30 subjects (study group n = 21, control group n = 9). The groups were heterogeneous in terms of anthropometric characteristics, such as body weight, height and age (Table 1). All participants consented to participate in the study and were informed about its voluntary nature, objectives, benefits and course. The study was conducted in accordance with the Declaration of Helsinki and the National Statement and Human Research Ethics Guidelines, and approved by the IRB (Institute for Research in Biomedicine) at the Poznań University of Medical Sciences (2017-12-17; Ethics Approval Number 1224/17). The study was performed between April and October 2017 in an accredited endurance test laboratory of the Poznan University of Physical Education.

Anthropometric measurements, respiratory function and aerobic capacity testing

Anthropometric measurements and spirometry tests were performed twice, at the same time of day. The first tests were performed in January and the second – in June of the same year. Body weight and height was measured using a certified Radwag device (Radom, Poland), accurate to 0.01 kg for weight and 0.5 cm for height.

Pulmonary function test

Pulmonary function was evaluated by conventional spirometry using a spirometer (PDD-301/s, Piston, Budapest, Hungary). Direct evaluation was performed for lung volumes, capacities and flows through the procedures of Slow Vital Capacity (SVC) and Forced Vital Capacity (FVC) performed in this order at least three times each, in accordance with the standards of the American Thoracic Society (ATS) and the European Respiratory Society (ERS), with the patient in a seated position. Results were expressed as absolute values and as percentages of the reference predicted values from Pereira [16]. The SVC procedure was used to obtain vital capacity (VC). The FVC procedure allowed to determine forced expiratory volume in one second (FEV_1), FEV_1/FVC ratio, MEF_{75}, and MEF_{50} [16].

Aerobic capacity evaluation

Aerobic capacity was assessed with the modified Astrand–Ryhming protocol to predict VO_2max using a Kettler DX1 Pro ergometer (Ense-Parsit, Germany), while heart rate (HR) was monitored using a Polar A-5 pulse meter (Polar Electro Oy, Kernpele, Finland) [5]. The predicted VO_2max was read from the nomogram [1, 2] or accompanying tables [2] and multiplied by both the Astrand and the von Dobeln age correction factors. These two predictions in L/min were then converted to mL/kg/min [2, 5].

Training program

The project lasted for 3 months, with training sessions twice a week. Exercises were performed in deep water and participants wore flotation belts, with no contact with the bottom of the pool. The trainer was in the pool as well, clearly demonstrating each exercise. Various types of resistance equipment were used [27].

A single unit of training was 45 minutes long. It included in sequence: warm up exercises, cardio warm up, the main aerobic and strengthening portion, and cool down (Table 2). The training program comprising 24 units was developed based on water aerobics method guidelines and adjusted to the participants' level of ability. Heart rate was measured using the Polar A-5 pulse meter (Polar Electro Oy, Kernpele, Finland) [17, 19, 28].

Statistical analysis

Descriptive data were expressed as mean values and SD. Distribution normality was tested using the Shapiro–Wilk test. In order to calculate the significance of changes in the parameters studied, the nonparametric test of pairs by Wilcoxon was performed. The significance of differences between the study and control groups was calculated using the Mann–Whitney U-test. Spearman's rank analysis was applied to calculate correlation coefficients. Findings were considered statistically significant at $p < 0.05$. The obtained results were analyzed statistically using the Dell Inc. (2016) Dell Statistica 13 software (Tulsa, Oklahoma, USA).

Table 2. Water aerobics program

Week / equipment	Part of the class	Exercises	Intensity	Frequency
	warm up (5 min)	• walking in place • arm exercises in multiple planes		2 times per week
	cardio warm up (5 min)	• running in place • running in multiple directions • arm exercises with multiple hand positions • movement exercises in multiple directions		
(1) no equipment (2) long pool noodle (3) short pool noodle (4) BEtomic (5) aquadisc (6) gloves (7) cuffs (8) happy flower (9) big wave bells (10) punches	main portion aerobic/ strengthening (30 min) cool down (5 min)	• arm exercises in multiple directions and within different ranges (pushing, pulling) • leg exercises (single and double leg raises, jumps, jumping jacks, scissors, grounded, elevated) • coordination exercises • lying front and lying back exercises • position change exercises • stretching and relaxing exercises	40-50% HRR 40-50% HRR 50-60% HRR 50-60% HRR 50-60% HRR 60-65% HRR 60-65% HRR 60-65% HRR 65-70% HRR 65-70% HRR 65-70% HRR	

Results

The descriptive characteristics of the participants (study and control groups) are shown in Table 2. The circulatory and respiratory function and capacity parameters studied are given in Table 3. All the parameters studied were measured at the start of the training program and immediately after its completion, in line with measurement standards.

Table 3 shows changes in the parameters studied after the training program in the study group and in controls, as well as differences in the change rates between the two groups.

In both groups there was a decrease of body weight between the two tests ($p < 0.05$), without a significant change in BMI (Table 1). An intra-group analysis of changes after the training program demonstrated a significant increase of the maximal aerobic capacity in the study group ($p < 0.05$). No significant changes were found in spirometry indicators (VC) or airflow parameters in the large and small airways (MEF_{75}, MEF_{50}) following the 12-week water aerobics program (Table 3).

Spearman's R correlation analysis demonstrated a negative correlation between the post-training change in body

Table 3. Results of two exercise and spirometry tests for the study group and controls

Variable		Pre	Post	Z-value	Change
VO_2 max (mL/kg/min)	study group	30.69 ± 7.66	32.37 ± 7.81	2.80*	1.68 ± 2.56
	control group	27.31 ± 0.79	30.04 ± 5.80	1.48	2.73 ± 5.67
VC (L/min)	study group	2.88 ± 0.34	2.89 ± 0.38	1.50	0.22 ± 0.63
	control group	2.52 ± 0.44	2.52 ± 0.50	0.40	0.04 ± 0.21
FVC (L/min)	study group	2.82 ± 0.43	2.86 ± 0.42	0.23	0.05 ± 0.28
	control group	2.55 ± 0.42	2.72 ± 0.52	1.78	0.07 ± 0.08
FEV_1 (L/min)	study group	2.45 ± 0.34	2.41 ± 0.34	0.45	0.00 ± 0.18
	control group	2.21 ± 0.30	2.31 ± 0.42	0.31	0.02 ± 0.12
FVC/VC (L/min)	study group	85.74 ± 7.58	83.71 ± 4.82	0.68	–0.59 ± 7.71
	control group	86.70 ± 5.62	85.53 ± 8.11	0.94	–0.65 ± 7.87
MEF_{75} (L)	study group	5.50 ± 1.18	5.18 ± 1.02	1.48	0.16 ± 1.79
	control group	4.75 ± 0.59	5.36 ± 0.92	0.94	0.34 ± 0.95
MEF_{50} (L)	study group	3.63 ± 0.98	3.15 ± 0.72	1.48	–0.31 ± 0.72
	control group	3.60 ± 0.69	3.59 ± 0.88	0.94	–0.02 ± 0.44

Data are presented as means ± standard deviations

* $p < 0.05$

Table 4. Spearman's rank correlation coefficient for changes in selected anthropometric and spirometric parameters and changes in aerobic capacity in both groups

	ΔVO$_2$max study group	ΔVO$_2$max control group
Δ body weight	r = –5.5411 p = 0.0113*	r = 0.1000 p = 0.7980
Δ VC	r = –0.1000 p = 0.7227	r = –1.000
Δ VT	r = 0.0529 p = 0.8456	r = 0.3143 p = 0.5441
Δ FVC	r = –0.3029 p = 0.2541	r = –0.1429 p = 0.7872
Δ FEV$_1$	r = –0.1912 p = 0.4781	r = –0.3714 p = 0.4685
Δ FVC/VC	r = –0.0265 p = 0.9225	r = 0.4857 p = 0.3287
Δ MEF$_{75}$	r = –0.2265 p = 0.3990	r = –0.6000 p = 0.2080
Δ MEF$_{50}$	r = –0.0486 p = 0.8582	r = 0.4286 p = 0.3965

weight and the aerobic capacity in the study group only (Table 4).

Discussion

The purpose of the study was to evaluate the effectiveness of water aerobics training in terms of circulatory and respiratory function and aerobic capacity in healthy post-menopausal women. Endurance training improves respiratory system function by increasing chest mobility, respiratory muscle strength and the diffusing capacity of the lungs. This is associated with an increased ventilation to perfusion ratio and increased blood flow to the upper lungs. The strengthening of chest musculature with endurance training additionally contributes to better posture, as postural muscles are also strengthened. The respiration mechanism also becomes more economic, as the respiratory volumes increase while the respiratory rate decreases. In the present study no improvement of respiratory function was observed following a 12-week training program. The lack of effectiveness of aquatic training programs with a similar duration was already described by Janyacharoen et al., who found no change in the basic spirometry parameters (VC and FEV$_1$/VC) in their subjects [6].

The lack of statistically significant improvement in respiratory function is likely due to participants' good respiratory health. Out of the 30 women included in the project only 2 had moderate signs of restrictive disease. Spectacular improvements of VC and FEV$_1$/VC following aquatic exercise were described in patients with obstructive and restrictive lung disease. Literature includes a number of cases where respiratory function did improve with aquatic endurance training. In Jung et al. there was a significant improvement of spirometry parameters in patients with spinal cord injury [7]. Lung function in patients with cervical spinal cord injury is mainly impaired due to respiratory muscle weakness, while in patients with chronic obstructive pulmonary disease — due to airway obstruction. In their study Nolasco et al. demonstrated that vitamin D supplementation was associated with improved spirometry parameters in post-menopausal women, irrespectively of participation in a water aerobics training program [14]. Song and Kim also observed an improvement in spirometry parameters in a group of patients with a history of stroke, participating in aquatic exercise as part of their physical therapy [23].

The benefits of aquatic exercise are evidenced by multiple studies, including that by Nuttamonwarakul. The study showed that aquatic exercise resulted in improved blood glucose and lipid levels and reduced cardiovascular risk in older patients with type 2 diabetes [15]. Neiva demonstrated that training of the same duration as that applied in the present study leads to increased muscular strength, especially with regard to upper extremity muscles. It also reduced body fat content and systolic blood pressure [13]. In their study Sarojini et al. reported that this type of training improved muscle flexibility and overall physical fitness [20]. In literature, there are also reports on the effectiveness of such training in terms of changing participants' lean body mass, muscle mass, and body fat weight [9].

Findings by multiple authors warrant the conclusion that aquatic exercise does contribute to better physical fitness and function in participants of various ages [8, 24]. In most cases fitness levels were evaluated indirectly, through aerobic capacity measurement, simple walking tests or the Senior Fitness Test.

In the present study the participants' aerobic capacity values increased independently of any changes in body weight. Both in the study group and in controls there was a statistically significant decrease in body weight. Therefore, it is likely that neither body weight nor respiratory function was the main contributor to the observed significant increase in aerobic capacity among the women studied. These findings warrant the conclusion that the circulatory and respiratory fitness of healthy older women engaging in water aerobics is modified by circulatory and metabolic changes in the muscles.

Conclusions

Exercise contributes to better health and physical fitness in individuals of various ages and various fitness levels. The aging process undoubtedly contributes to a decrease of the body's functional reserve and affects exercise tolerance. Aquatic exercise is safer than other proposed forms of exercise that are performed on land, as the aquatic environment is load-reducing, which prevents injuries.The implemented training program for healthy post-menopausal women did not improve the spirometry indicators studied, while the observed aerobic capacity increase likely resulted from improved circulatory and metabolic performance that determines an individual's exercise tolerance and health. Presumably, greater benefits in terms of spirometry parameters could be expected after water aerobics training in individuals with reduced respiratory function. Therefore, further research should concentrate on the analysis of the impact of this form of training on the respiratory functions of people with respiratory failure caused of the aging process, COPD, emphysema or changes caused by SARS-CoV-2 virus infection.

The limitation of the study is a small sample size, especially in the control group. The duration of the project between April and October resulted in exclusions from the study, because women participated in additional physical activity beyond the one carried out in the research project.

Conflict of Interests

The authors declare no conflict of interest.

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Effect of Mulligan's mobilization with movement and eccentric exercises for lateral epicondylitis in recreational tennis players

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Abstract

Introduction. Recreational tennis players often have been documented to suffer from lateral epicondylitis (LE). There is a lack of evidence on the effects of Mulligan's mobilization with movement (MWM) and eccentric exercises in recreational tennis players with lateral epicondylitis. Aim of Study. To find the effect of Mulligan's MWM along with eccentric exercise on grip strength and functional disability in recreational tennis players for lateral epicondylitis. Material and Methods. Thirty subjects based on the inclusion criteria were recruited through referrals. The experimental group underwent Mulligan's MWM along with eccentric exercise and the control group intervention comprised solely of eccentric exercise program 3 sessions a week for 4 weeks. Grip strength using Hand Held Dynamometer and functional abilities using Patient Rated Tennis Elbow Evaluation (PRTEE) were measured. Data were analyzed using SPSS 16.0 with descriptive and inferential statistics at 5% level of significance. Results. Analysis demonstrated statistically significant improvements for both outcomes in both the experimental group and the control group. Improvements for both dependent variables were greater for the experimental group. Conclusions. The administration of Mulligan's MWM along with eccentric exercise was found to be more effective than eccentric exercise alone to increase grip strength and functional abilities in recreational tennis players with lateral epicondylitis.

KEYWORDS: lateral epicondylitis, mobilization, eccentric, mulligan, recreational tennis.

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Introduction

Tennis has become very popular in the past few years as a recreational sport/hobby [6]. Lateral epicondylitis can be a bothersome injury for a recreational tennis player. Recent studies suggest that the relevance and incidence of lateral epicondylitis in recreational tennis players are comparatively higher than in elite players [4, 11]. The probable reasons may be connected with the use of a flexed wrist position immediately before the ball impact [2] and/or the single-handed stroke used by recreational players associated with faulty mechanics, which adds up to increased extensor activity [23]. These faulty mechanics transmit excessive shock impact force from the racket to the elbow joint in such players [28]. When the pattern of muscle activation and joint mechanics were observed in both recreational and experienced players using kinematic data in combination with a computer model, substantial eccentric contractions of the extensor carpi were discovered. This is probably the reason for repetitive microtrauma leading to lateral epicondylitis [23]. The incidence of this condition was reported in 39.70% in a study of 500 tennis players indicating a "mis-hit" jerky shot with backspin [8] as one of the contributing factors to lateral epicondylitis. The risk is increased 3- to 4-fold in players who play about 2-3 hours per week [8, 20].

Many conservative treatment options in physiotherapy have been proposed for the rehabilitation of patients suffering from lateral epicondylitis. Nevertheless, the effectiveness of these treatments is largely unknown [10, 30] and remains somewhat of an enigma. The conservative physiotherapy treatment of lateral epicondylitis includes exercise, manipulation, massage, acupuncture, taping, ultrasound, orthotic devices, activity modification and rest [3]. Among all the manual therapies used around the globe, Mulligan's mobilization with movement (MWM) is presently acquiring tremendous recognition. The technique of Mulligan's MWM involves a glide or translation applied in a perpendicular direction towards the plane of the affected movement, which is being performed during the glide. This allows the painful joint to be moved freely without any pain or disablement [26]. On the other hand, eccentric exercise training focuses on braking or slowing down the elongation process of a muscle, which provides a challenge for the muscle leading to increased muscle strength, quicker healing and improved metabolic rate. Eccentric exercises are suggested to have beneficial effects in rehabilitating sportspersons, older adults, and patients by altering their muscle properties and performance [14].

An exceptional number of studies suggest the utilization of Mulligan's MWM as a remedial approach for this condition [9, 15]. Furthermore, for the same condition a good amount of studies have been performed on eccentric exercises as well [3]. No evidence is documented to date regarding the isolated application of such techniques in patients or individuals who play tennis as a recreational sports activity. A novel study is required to support and establish the clinical efficacy of these techniques for recreational tennis players with lateral epicondylitis. This study is aimed to investigate the effects of Mulligan's MWM on functional outcomes in recreational tennis players with lateral epicondylitis when compared with eccentric exercise.

The objective of the study was to find the efficacy of MWM along with eccentric exercise on grip strength, pain and functional disability in recreational tennis players with lateral epicondylitis.

The Null hypothesis was that there will be no significant difference in grip strength, pain and functional ability following MWM along with eccentric exercise in recreational tennis players with lateral epicondylitis. An alternative hypothesis stated that there will be a significant difference in grip strength, pain and functional ability following mobilization-with-movement along with eccentric exercise in recreational tennis players with lateral epicondylitis.

Material and Methods

This was a pre- and post-experimental study design. The study was approved by the institutional ethical committee (IEC). After obtaining the ethical clearance from the IEC, the study was conducted. The procedure of the study was explained and the interested participants were recruited after obtaining their written informed consent. Recreational tennis players from various tennis academies, hospitals and clinics around Bangalore were approached. Participants between 18 to 45 years of age were diagnosed with lateral epicondylitis based on positive Mill's test and Cozen's test, with symptoms persisting for more than 6 weeks with complaints of local tenderness distal to the common extensor origin at the elbow. In addition, the participants were required to have a full extension range of movement in the affected elbow as a requirement for the assessment and treatment purposes. Individuals with a history of recent trauma of upper limbs, elbow immobilization, administration of steroid injection in the past 6 months, recent administration of platelet-rich plasma containing growth factors, diagnosis of cervical radiculopathy, upper thoracic outlet syndrome, rheumatoid arthritis, myositis ossificans, carpal tunnel syndrome and which had taken physical therapy of any sort in the past 6 months were excluded from the study. Furthermore, individuals with any history of occupation-related pain were ruled out.

The sample size was estimated using the mean difference and SD of an outcome measure PRTEE from previous literature. With a mean difference of 42 and 26.2 with standard deviation of 15.1 and 21.7 for 2 groups, considering type 1 error at 0.05 and power of the study at 95%, the sample size was 27, with n1 = 13 and n2 = 14 [1, 25]. During the participant recruitment procedure 50 interested patients volunteered and were screened. A total of 30 participants were selected based on the inclusion and exclusion criteria. Thus the final sample size was 15 in each group. The mean duration of symptoms in the participants was around 3 months. After obtaining informed consent they were allocated to one of the two groups (experimental group and control group) using simple random sampling. The participants were unaware of their allocation to treatment groups. The socio-demographic data (name, age, sex, occupation, address) of the participants were obtained and recorded at baseline.

Assessment of pain and the level of disability/function was performed using PRTEE and pain-free grip strength was determined using a calibrated Jamar hand-held dynamometer. The recordings were done before commencing the treatment and then after the fourth week. PRTEE is a reliable, sensitive and reproducible tool to assess chronic tendinopathy in the tennis-playing population. The PRTEE scores in 78 tennis-playing LE patients showed excellent internal consistency and reliability (pain subscale = 0.94; function-specific activities subscale = 0.93; function usual activities = = 0.85) [24]. For the pain-free grip strength assessment the patient sat comfortably with the arm held at the side along with shoulder adduction and neutral rotation, the elbow flexed to 90 degrees [5], the forearm in a neutral position and the wrist between 0-30 degrees of extension and between 0-15 degrees ulnar deviation. The maximal grip readings (in kilograms) were noted with pain-free maximum contraction. The patient was encouraged to squeeze as tightly as possible for 3-5 seconds. More than one trial was provided and an average of 3 repetitions was recorded with a pause of about 15 seconds between each trial to avoid the possible effect of muscle fatigue.

The experimental group received Mulligan's MWM followed by eccentric exercise. For MWM the patient was in the supine position with the arm placed by the side with sufficient abduction to allow the therapist access to the medial side of the upper limb. The elbow was placed in full extension and the forearm in pronation. It was ensured that the participant had a reproducible aggravating action (comparable sign) before applying glide. Then, the patient was asked to grip a dumbbell during the glide. The stabilizing hand of the therapist was placed at the distal part of the arm, whereas the gliding hand was placed over the medial surface of the ulnar side just distal to the elbow joint line. While the patient started performing flexion and extension of the wrist, the therapist applied a laterally directed glide across the elbow joint. After the glide had ended; the patient had to release the grip. The glide was applied and sustained for approximately 30 seconds, during which the patient was asked to perform the previously painful movement up to 10 times. The process was repeated only if there was a substantial relief of pain during the application of the technique along with no latent pain immediately following the treatment technique [16]. It was done for three sets with a 30-second rest in between each set. After this therapy the patient took a rest for 15 minutes and then received eccentric exercise training.

For eccentric exercise the participant was seated in a chair with forearm support on the armrest/adjacent table in pronation with the wrist in full extension. The patient was instructed to slowly lower the dumbbell by flexing the wrist of the affected arm downwards for a count of 30. The weight of the dumbbell was initially 0.5 kg or 1 kg. With the uninvolved arm the wrist was returned to the starting position. Patients were given instructions to continue to perform the exercise even with mild discomfort and they could stop performing the exercise if their pain worsened or became disabling. Patients who could perform the exercise without minor discomfort/pain were allowed to add the load using free weights; this increment was based on the patient's 10 repetition maximum (RM). Each session included 3 sets of 10 repetitions; a 1-minute rest interval was given between each set [7]. The control group intervention comprised solely eccentric exercises for the wrist extensors. The application guidelines for the treatment were the same as those given for the experimental group. Both the groups received a total of 12 sessions divided into 3 times a week for a month.

Statistical analysis

The statistical analyses were performed using the SPSS 16.0 software for Windows. Descriptive and inferential statistical analysis was used. Significance was assessed at a 5% level. The paired t-test was used to find the significance between pre- and post-treatment measurement values of PRTEE and pain-free grip strength for the experimental group and control group. The unpaired t-test was used to compare the effectiveness between the groups.

Results

A total of 30 patients (21 men and 9 women) were recruited to this study. The mean age of the participants was 32.93 (SD = 7.30) in the experimental group and 31.80 (SD = 7.60) in the control group. The demographic details are summarized in Table 1. The baseline values of clinical and demographic variables for both groups were found to be similar (p = 0.66). A majority of the participants (65%) were office employees who work most of the time on computers/laptops.

The comparisons of improvements between the groups and within the group are shown in Table 2 whereas the figurative comparisons are presented in Figure 1 and

Table 1. Baseline characteristics of participants

Baseline characteristics	Experimental group (N = 15)	Control group (N = 15)
Age*	32.93 (7.30)	31.80 (7.60)
Male#	11 (73.33%)	10 (66.66%)
Female#	4 (26.66%)	5 (33.33%)
PRTEE*	66.00 (14.26)	64.86 (14.81)
Grip strength*	16.93 (3.26)	17.40 (2.29)

Note: PRTEE – Patient Rated Tennis Elbow Evaluation
Data presented as * Mean & Standard Deviation; # total number & %.

Table 2. Treatment effects within and between groups

Parameters	*Pre-test	*Post-test	Mean difference	#p-value
Experimental group				
Grip strength (kg)	16.93 ± 3.26	22.60 ± 2.55	33.49%	p < 0.05
PRTEE	66.00 ± 14.26	31.20 ± 8.40	52.72%	p < 0.05
Change in PRTEE subscales post-test	pain		50.48%	
	function (i) special activities		54.32%	
	function (ii) usual activities		56.31%	
Parameters	*Pre-test	*Post-test	Mean difference	#p-value
Control group				
Grip strength (kg)	17.40 ± 2.29	21.33 ± 2.12	22.58%	p < 0.05
PRTEE	64.86 ± 14.81	38.26 ± 9.46	41.01%	p < 0.05
Change in PRTEE subscales post-test	pain		43.34%	
	function (i) special activities		42.05%	
	function (ii) usual activities		37.19%	
Experimental group vs control group	PRTEE			p < 0.030
	Grip strength			p < 0.000

Data presented as *Mean & Standard Deviation; p is significant at p < 0.001

Figure 2.The intra-group comparison for PRTEE in the experimental group treated with MWM and eccentric exercise demonstrated a decrement of pain and functional disability scores by 52.72% with a t-value of 11.904 and p-value of 0.05, whereas the decrement in the control group treated with eccentric exercise alone was 41.01% with the t-value of 12.760 and p-value of 0.000. Thereafter, the inter-group comparison of PRTEE scores yielded a t-value of 2.228 and a p-value of 0.030. The intra-group comparison for pain-free grip strength in the experimental group treated with MWM and eccentric

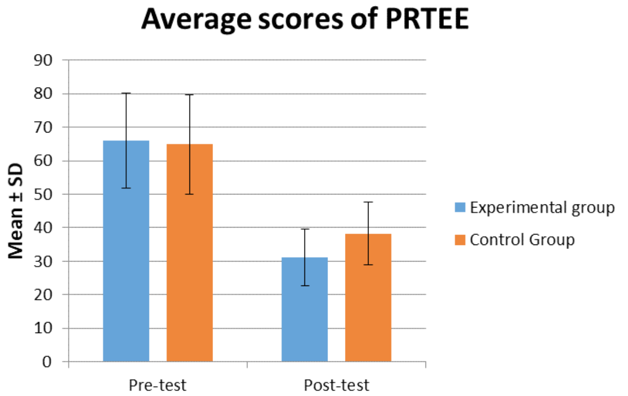

Figure 1. A comparison of pre-treatment and post-treatment scores of Patient-Rated Tennis Elbow Evaluation (PRTEE) between the two groups. The decrements in post-treatment scores indicate the decrement in patients' pain and level of disability

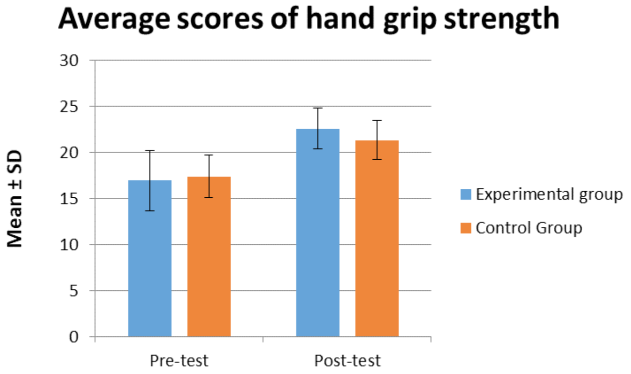

Figure 2. A comparison of pre-treatment and post-treatment scores of hand grip strength/dynamometry (HHD) between the two groups. The increment in post-treatment scores indicates the increment in patients' pain-free grip strength

exercise demonstrated increment of the grip strength by 33.49% with a t-value of 17.770 and p-value of 0.000, whereas the increment in the control group treated with eccentric exercise alone was 22.58% with the t-value of 15.840 and p-value of 0.000. Thereafter, the inter-group comparison of pain-free grip strength yielded a t-value of 4.290 and a p-value of 0.000. The in-depth look at the subscale scores of PRTEE showed that the experimental group achieved a 50.48% decrement in pain, a 54.32% improvement in special activities function and a 56.31% increment in usual activities function, whereas the control group achieved a 43.34% decrement in pain, a 42.05% improvement in special activities function and a 37.19% increment in usual activities function.

Discussion

The purpose of this study was to evaluate the effect of Mulligan's MWM and eccentric exercises on grip strength and functional disability in recreational tennis players. All 30 participants completed the 4-week training. Overall, the participants (> 95%) of both the experimental and control group demonstrated improvement in PRTEE and pain-free grip strength scores ($p < 0.05$). After analyzing the data between both groups it was found that the experimental group, which received MWM along with eccentric exercise, garnered statistically better outcomes ($p < 0.05$) than the control group, which received eccentric exercise alone; the p-values for PRTEE and pain-free grip strength were 0.030 and 0.000 respectively. Therefore, training with Mulligan's MWM and eccentric exercise resulted in better outcomes than eccentric exercise alone. Interestingly, other authors who applied Mulligan's MWM along with other treatment approaches have attained similar results. A study on the effects of MWM on grip strength, function and pain in LE found that MWM is a promising intervention for improving grip strength (hand grip dynamometer), function (PRTEE) and pain relief (VAS) [1]. A study on various physiotherapy regimens for LE concluded that Mulligan's MWM when applied with other therapeutic modalities such as ultrasound, eccentric and concentric exercises, showed positive gains in muscle strength [13]. Similarly, another study utilizing MWM techniques and cryotherapy demonstrated significant improvement in grip strength and functional performance in patients with lateral epicondylitis [22]. Another study evaluated the effects of an MWM treatment on tolerance to repeated applications showed initial hypoalgesic effects similar to spinal manipulations and concurrent sympathoexcitation in chronic LE with an improved pressure pain threshold and pain-free handgrip strength [18].

The % of the mean difference in the PRTEE score in the experimental group was 52.7%. MCID of around 37% from the baseline score was mentioned as 'much better' or 'completely recovered' for the PRTEE scores [21]. Hence the intervention with MWM and eccentric exercises were beneficial in improving the studied clinical manifestations.

The MCID for grip strength is 19.5% and in the present study MWM and eccentric exercise intervention showed 33.5% of the mean difference. This further signifies the effect of the combined techniques and their functional implications [12].

The mechanism behind Mulligan`s MWM may be neurophysiological, as it provides some tactile response along with compressive stimuli to soft tissues [29]. The afferent nerve activity resulting from these tactile or compressive stimuli may influence the spinal cord neurons inhibiting nocioperception and the motor neuron pool. Thus it may provide a way to retrain the spinal cord circuitry by allowing the patient to experience repetitive pain-free motion, which may help to switch off maladaptive spinal cord circuitry, re-establishing normal levels of nocioperception and motor neuron pool excitation [17]. This provides an alternative to the theories offered by Mulligan which place a positional fault or block of the joint as the source of the dysfunction in lateral epicondylitis [16]; Mulligan assumed that a repositioning of the joint accompanied by joint motion restores the positional fault of the joint [26].

Studies conducted previously on the utilization of eccentric exercises have well-established results regarding the improvement of grip strength in LE patients. Studies demonstrated similar results with eccentric exercise as concentric exercise for LE patients [7, 19]. A review suggested the incorporation of eccentric exercise as a multimodal therapy for chronic LE, which is supported by the present study as well [3]. Studies suggest that eccentric loading exercises assist with tendon injuries by stimulating the collagen cross-linkage bridge formation and its alignment, leading to improved tensile strength [27].

This study was conducted for 4 weeks and no further follow-ups were conducted. Another potential limitation might arise because of a few participants who had been using a tennis elbow brace for symptomatic relief before the treatment, which might have resulted in a bias. Since the participants recruited in the study suffered from the chronic stage, because of which they might have avoided functional activities with the affected limb. This possibly results in the weakness of neighboring muscles as well as the wrist flexors, elbow muscles, and shoulder muscles; therefore, no certain information was obtained on the effect of the neighboring weak muscles on the condition.

There is a warranted need for future RCTs with a larger sample size and tennis-specific return-to-sport rehabilitation, correction of the faulty techniques and exercise prescription. Also, the inclusion of radiological investigations such as ultrasound, MRI and EMG for diagnostic or prognostic information might provide data on physiological changes. Future studies may also be performed on occupational-based cohorts who encounter this condition while playing recreational tennis.

Conclusions

In this study both groups showed a significant response to the treatment protocol. However, a significant increase in functional ability and grip strength was obtained with Mulligan's MWM along with eccentric exercise with 12 sessions. Mulligan's MWM and eccentric exercise incorporated into multimodal treatment regimens can demonstrate multiplied improvements in lateral epicondylitis. Furthermore, the collaboration of the physiotherapist(-s) with sports trainer(-s) can help in preventing the occurrence and recurrence of this condition by focusing on proper stroke mechanics, sufficient warm-up exercises, appropriate racket weight, correct grip size, and sports specific exercise planning.

Conflict of Interests

The authors declare no conflict of interest.

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

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