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Contents

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EFFECTS OF ACUTE B-ALANINE SUPPLEMENTATION ON COUNTERMOVEMENT JUMP PERFORMANCE AFTER A 4X400 M RUNNING FATIGUE PROTOCOL: A RANDOMIZED, DOUBLE-BLIND, PLACEBO-CONTROLLED TRIAL

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Abstract:

This study aimed to examine the effect of acute beta-alanine (β-alanine) supplementation on jump performance after a strenuous fatigue protocol. Twelve healthy young men (age 21.4±0.5 years, body height 180.2±5.8 cm, body mass 76.6±9.2 kg) volunteered to participate in this randomized, double-blind, placebo-controlled trial. The experimental group ingested 3.2 g of β-alanine (separated into two 1.6 g dosages) mixed with 23 g of glucose, whereas the placebo group ingested two dosages containing 23 g of glucose. Following the supplementation intake, participants completed a jump protocol involving countermovement jump (CMJ) and four consecutive countermovement jumps (CMJ-4). Subsequently, a 4x400 m running fatigue protocol was carried out to produce fatigue. After the fatigue protocol, the same jumping tests were repeated, CMJ and CMJ-4, to evaluate the loss in jump height. The Mann-Whitney U test was used to analyze differences between the groups, whereas Wilcoxon signed-rank test was conducted to analyze differences within the groups with statistical significance set at $p<.05$. After β-alanine supplementation, no significant decrease in jump height was found in the experimental group in none of the tests after the fatigue protocol. Conversely, a significant decrease was noticed in the placebo group in CMJ but not in the CMJ-4 test. In conclusion, an acute β-alanine supplementation could attenuate jump height loss after the fatigue protocol. Therefore, athletes and coaches should consider acute β-alanine supplementation to attenuate sports performance decrease after high-intensity exercises in which muscle acidosis is highly increased.

Key words: *beta-alanine, countermovement jump, acute supplementation, sports performance*

Introduction

Beta-alanine (β-alanine) is a naturally occurring non-proteogenic beta-amino acid endogenously produced in the liver (Trexler, et al., 2015). The main reason for β-alanine ingestion is to increase muscle carnosine. It is essential to note that carnosine supplementation is not an efficient method for increasing muscle carnosine levels because it is metabolized before reaching skeletal muscle (Gardner, Illingworth, Kelleher, & Wood, 1991). On the other hand, β-alanine has been shown as the rate-limiting precursor to endogenous carnosine production, where this compound, combined with L-histidine, forms carnosine (Blancquaert, et al., 2017). Beta-alanine is obtained through diet by consuming foods such as poultry and meat (Trexler, et al., 2015), while the most common supplementation method is to ingest β-alanine in doses ranging from 1.6 to 6.4 g/day−1 (Saunders, et al., 2017; Saunders, Sale, Harris, & Sunderland, 2012; Stellingwerff, et al., 2012). In addition, β-alanine ingestion has been shown to increase muscle carnosine, regardless of diet or baseline carnosine levels (Stellingwerff, et al., 2012; Trexler, et al., 2015). Therefore, supplementation with β-alanine could be the most effective method to increase muscle carnosine levels.

The increase of muscle carnosine levels could play a key role in exercise. Intracellular acid-based regulation is considered the primary physiological role of carnosine. Improvement of intracellular buffer capacity causes fatigue delay and, therefore, prolongs exercise (Hobson, Saunders, Ball, Harris, & Sale, 2012). Intramuscular carnosine reduces muscle acidity, decreasing the large production of hydrogen ions (H+) (Cady, Jones, Lynn, & Newham, 1989). Increased concentration of H+ instigates a diminution of actin and myosin cross-bridge formation, which further causes a decrement in muscle contraction (Fabiato & Fabiato, 1978). This leads to a string of metabolic processes such as a decrease in force production and a fatigue increase (Dutka & Lamb, 2004). Therefore, muscle carnosine increase could influence power performance after a fatigue protocol. In addition, this supplement could also be susceptible to a placebo effect. Previously, other nutritional ergogenic aids have shown a placebo positive influence on sports performance (Hurst, et al., 2020).

Previous studies had shown improvements in performance tests after β-alanine ingestion when fatigue protocol was carried out, probably due to the aforementioned physiological explanations. Concretely, chronic (eight weeks) oral β-alanine ingestion has been shown to significantly improve power performance after a strenuous endurance exercise, as shown in Van Thienen et al. study on endurance-trained cyclists (Van Thienen, et al., 2009). In addition, in another study (Carpentier, Olbrechts, Vieillevoye, & Poortmans, 2015), after two months of β-alanine intake, there was a slight increase in power performance, measured as countermovement jumps (CMJ). However, athletes usually ingest β-alanine as a "pre-exercise" supplement (Gonzalez, Walsh, Ratamess, Kang, & Hoffman, 2011), and there is a lack of information concerning acute β-alanine intake in sports performance (Huerta Ojeda, Tapia Cerda, Poblete Salvatierra, Barahona-Fuentes, & Jorquera Aguilera, 2020). To the best of the authors' knowledge, there are only three studies carried out with only acute β-alanine ingestion on exercise performance with diverse results, where one obtained positive results (Huerta-Ojeda, et al., 2019), and the remaining two showed no effects (Bellinger & Minahan, 2016; Glenn, Smith, Moyen, Binns, & Gray, 2015) on exercise performance. Moreover, none of the previously mentioned studies using the acute β-alanine ingestion were carried out after a strenuous exercise protocol. To the best of the authors' knowledge, there is no research investigating the effects of the acute β-alanine ingestion on performance after a strenuous exercise. Therefore, the main objective of this study was to evaluate the effects of the acute β-alanine ingestion on performance after a strenuous fatigue protocol.

Methods

Participants

Twelve healthy, physically active students from the Faculty of Sport and Physical Education, University of Novi Sad (21.4±0.5 years, 180.2±5.8 cm, 76.6±9.2 kg) volunteered for the study. None of the participants in the study consumed any dietary supplements during the four weeks prior to the study kick-off, and none of them reported any musculoskeletal injury or disease. Volunteers signed a consent form to participate in the study after receiving a complete insight into the study protocol. Each participant obtained written guidelines, including detailed information about the test protocol, time frame, and responsibilities regarding the study.

Study design

This study was based on a randomized, double-blind, placebo-controlled, parallel design of evaluating the effects of acute β-alanine ingestion. The randomization was carried out by alternating group assignment of participants into either the placebo group (n=6) or the β-alanine group (n=6). The study was approved by the Ethical Committee of the Faculty of Sport and Physical Education in Novi Sad (46-06-01-2020-1) and conducted according to the principles of the Helsinki Declaration. This experiment was divided into three different roundups: the pre-study protocol, baseline, and experimental protocol (Fig. 1).

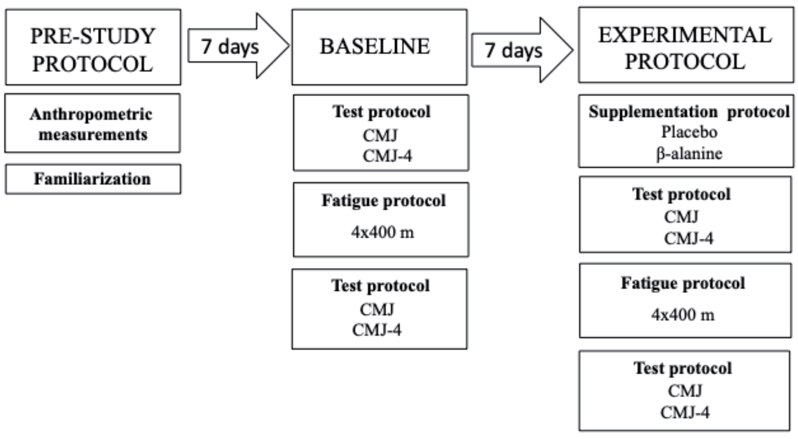

Figure 1. Study design. CMJ, countermovement jump; CMJ-4, four consecutive countermovement jumps.

The pre-study protocol was divided into two different phases. The purpose of the first phase was to obtain anthropometric measurements for all of the included participants in order to assess the homogeneity between the groups. Body mass (BM), body mass index (BMI), and body fat percentage (BF%) estimations were obtained using bioelectric impedance (model InBody 230), whereas the body height (BH) was calculated through a Seca SE213 stadiometer. The second phase of the pre-study protocol consisted of the familiarization of participants with the performance test of the study to minimize any potential learning influence on the subsequent tests.

At baseline, participants performed a standardized warm-up before any test was carried out. The warm-up consisted of five minutes of submaximal running followed by a previously established dynamic warm-up: high knee and foot walk, carioca, butt kicks, high skip, spiderman, lateral slide with floor touch, low skip + long jumps, and dynamic calf stretch (Stevanovic, et al., 2019). Following the warm-up, participants completed the countermovement jump (CMJ) and four consecutive countermovement jumps (CMJ-4). Jump heights were measured on a force plate (Just Jump System; Probotics, Huntsville, AL, US) and were executed with voluntary knee flexion and keeping the hands placed on the hips during all tests. Both tests were performed three times, with a 1-minute rest between the attempts, and only the highest result was used for the analysis. Subsequently, a fatigue protocol was performed to produce muscle tiredness in the participants. This protocol consisted of 4x400 meters running trials, interspersed with three minutes of recovery between the trials. After the fatigue protocol, the same jumping tests were repeated, CMJ and CMJ-4.

For the experimental protocol, each group ingested either a placebo or β-alanine supplementation four hours (the first dosage) and 45 minutes (the second dosage) before the warm-up. The β-alanine group ingested a total dosage of 3.2 mg/kg, as previously other authors used the same dosage (Gross, et al., 2014), and it was ingested at two different moments so as to reduce possible side effects (e.g., paresthesia). The β-alanine group ingested two dosages of 1.6 mg/kg of β-alanine mixed with 23 g of glucose, whereas the control group ingested two placebo dosages containing only 23 g of glucose. Both groups received the same amount of drink (500 ml) of similar color and smell. Beta-alanine and glucose powder were obtained from THE Nutrition®. After supplementation ingestion, volunteers carried out a warm-up and performed the same procedures as at baseline, i.e., the jump test, fatigue protocol, and repetition of jump tests.

Statistical analysis

All quantitative data were recorded into an Excel table and analyzed using Statistical Package for Social Sciences version 26.0 (SPSS Inc., Chicago, IL, USA). Data are presented as mean (M) ± standard deviation (SD). Given that the sample size of each group is lower than 10, non-parametric statistics were applied. Mann-Whitney U test was used for the differences between the groups and the Wilcoxon signed-rank test to analyze the differences within the groups between the pre- to post-test measurements. Statistical significance was set at $p<.05$.

Results

All the participants completed the intervention, and no side effects associated with supplementation were reported during the study. Participants completed all individual running trials in the range of 0:59–1:34 min, accumulating between 4.5–5.4 min of total high-intensity activity (four running trials in total). Since participants ingested the second dosage of supplement to the end of the performance measurements, the duration was less than two hours. Physical characteristics of the β-alanine group and control group were similar at baseline, with no significant differences in age, height, BM, BMI, or BF. Therefore, both groups were considered to be homogeneous. Table 1 displays the details concerning both groups' physical characteristics and body composition.

Table 1. Descriptive characteristics of β-alanine and control groups

Variable	β-alanine group (n=6)	Placebo group (n=6)	p value
Age (years)	20.9±2.9	22.0±2.9	.808
Body height (cm)	180.2±5.8	180.2±4.3	.748
Body mass (kg)	76.8±9.2	76.3±5.6	.873
BMI (kg/m^2)	23.5±1.7	23.5±1.1	.749
BF (%)	17.4±2.9	17.5±4.4	.873

Note. Data are expressed as mean ± standard deviation. BMI, body mass index; BF, body fat; kg, kilograms; cm, centimeters; m, meters; %, percentage; n, number of subjects; SD, standard deviation; p, statistical significance; bolded p values indicate statistical significance ($p<.05$).

Table 2. Jumping test performance data in baseline and after the experimental protocol

	Baseline					
	β-alanine group (n=6)			Placebo group (n=6)		
	Before	After	p value	Before	After	p value
CMJ (cm)	50.89±2.77	44.87±2.83	**.028**	58.58±6.90	52.17±7.20	**.028**
CMJ-4 (cm)	47.20±3.03	42.42±4.01	**.028**	51.92±5.71	46.52±7.06	**.046**
	Experimental protocol					
	β-alanine group (n=6)			Placebo group (n=6)		
	Before	After	p value	Before	After	p value
CMJ (cm)	49.15±4.20	46.86±3.20	.249	57.20±7.30	53.97±6.90	**.043**
CMJ-4 (cm)	44.73±2.75	42.42±2.30	.345	50.44±6.90	46.37±6.10	.075

Note. Data are expressed as mean ± standard deviation. CMJ, countermovement jump; CMJ-4, four consecutive countermovement jumps; bolded p values indicate statistical significance (p<.05).

CMJ and CMJ-4 were measured before and after the fatigue protocol in baseline and experimental protocol. In baseline, both the β-alanine and placebo groups significantly decreased their CMJ and CMJ-4 values after the fatigue protocol. In the experimental protocol, after the β-alanine supplementation, no significant decrease in height was found in none of the tests. Conversely, a significant decrease was noticed in the placebo group in CMJ but not in the CMJ-4 test. Jumping test values are depicted in Table 2.

Discussion and conclusions

This study was carried out to determine the effects of acute β-alanine supplementation on explosive strength tests after a strenuous exercise. None of the participants reported any side effects after ingestion of this ergogenic aid. The results revealed that the acute β-alanine supplementation provided positive effects on CMJ and CMJ-4 performance, attenuating the loss of jump height after the fatigue protocol. Moreover, the study results could have also been influenced by a possible placebo effect, as shown placebo's positive impact on the CMJ-4 performance.

The acute dosage of β-alanine was 3.2 g (separated into two 1.6 g dosages), and none of the participants suffered from paresthesia on the skin (Harris, et al., 2006). It has been previously reported that higher dosages than 0.8 g has been associated with this side effect (Harris, et al., 2006). In order to reduce the side effects of β-alanine, the ingestion of the supplement was divided into two different dosages taken four hours (the first dosage) and 45 minutes (the second dosage) before the warm-up. Previously, it was reported that the peak increase of β-alanine in plasma was 30-45 minutes upon this supplement intake, and it is estimated that β-alanine levels keep elevated even 3-4 hours after the ingestion (Harris, et al., 2006). Therefore, this supplementation protocol was carried out with a mission to maximize acute β-alanine/carnosine concentrations to increase the effects on exercise performance while reducing possible side effects.

Only three previous studies evaluated the effects of acute β-alanine on exercise performance (Bellinger & Minahan, 2016; Glenn, et al., 2015; Huerta-Ojeda, et al., 2019). Two studies assessed endurance performance with mixed results (Bellinger & Minahan, 2016; Huerta-Ojeda, et al., 2019). Although results in these two studies may be important, they are not comparable to our study's results due to different metabolic outcomes being measured. On the other hand, the remaining study assessing acute effects was conducted by Glenn et al. (2015), who measured anaerobic performance. Participants in that study ingested an acute dosage of 1.6 g β-alanine and did not improve exercise performance in three consecutive Wingate tests. In comparison to the results found in the present study, those authors possibly did not find significant results due to an insufficient acute dosage. The differences between the findings of both works could be explained by the fact that an acute dosage of 3.2 g might be more effective than a 1.6 g dosage. Therefore, a higher acute dosage of β-alanine could exert better results regarding sports performance. In addition, in Glenn et al.'s study (2015) participants were a trained population, while in this intervention, the population was healthy young males. Therefore, the difference between the studies' results could be explained by the following: it is more difficult to achieve a significant improvement in a trained population than in a healthy untrained population (Spurway & MacLaren, 2006). To the best of the authors' knowledge, no study was carried out after fatigue protocol with β-alanine alone. However, one study measured the effects of the mixed supplementation of β-alanine plus carnosine (2 g of both) on jump performance after a fatigue protocol (45 seconds of CMJ) (Invernizzi, et al., 2016). These authors found similar results to ours attenuating jump performance loss after strenuous exercise, although the studies' fatigue protocols differed.

The fatigue protocol could elevate muscle acidosis and hence influence subsequent exercise performance. In this study, fatigue protocol consisted of 4x400 meter running trails, interspersed with 3-minute ecoveries between the trails. Participants completed all individual running trials in the range of ~0:59–1:34 min, accumulating between 4.5–5.4 min of total high-intensity activity (four running trials in total). This fatigue protocol was selected for the main purpose of eliciting a high amount of intra-muscle acidosis. The ATP yield from glycolysis is highest in exhaustive short-term exercise (i.e., 400 meters sprint), which increases muscle acidosis (measured by blood lactate) (Hirvonen, Nummela, Rusko, Rehunen, & Härkönen, 1992). In addition, this level of acidosis attains an individual maximum (Hirvonen, et al., 1992) and stays elevated for 3-to-5-min post-exercise (Divito, McLaughlin, & Jacobs, 2021).

Probably the physiological pathway to attenuate jump performance decrement after a fatigue protocol could be explained by the indisputable role of carnosine to act as a pH buffer under an acid environment (Swietach, et al., 2013). Carnosine is capable of binding muscle H+, reducing myocyte cytoplasm pH (Swietach, et al., 2013). Dutka and Lamb (2004) demonstrated that increased carnosine concentration inside cytoplasm could reduce cytoplasm H+, augmenting Ca2+ sensitivity in both slow-twitch and fast-twitch muscle fibers. Therefore, there could be an increase in skeletal muscle force production (Swietach, Leem, Spitzer, & Vaughan-Jones, 2014). Furthermore, the results of this work could also have been influenced by a possible β-alanine induced placebo effect. A previous meta-analysis suggested that nutritional ergogenic aids' produced placebo effect could exert a small to moderate effect on sports performance (Hurst, et al., 2020).

This study is not exempt from potential limitations. Therefore, the findings of the present experimental trial should be interpreted with caution. Firstly, the sample size (n=12) involved in the study could be considered small. Secondly, there was a lack of biochemical markers to control the β-alanine effect on exercise-induced acidity (e.g., blood lactate). Finally, the absence of muscle carnosine levels measurement could also be considered a limitation of this study. For that reason, future research might investigate the acute effects of β-alanine supplementation on CMJ performance after a fatigue protocol by increasing the sample size and measuring the blood acidity and muscle carnosine levels.

In conclusion, an acute dose (3.2 g) of β-alanine supplementation, divided in two equal dosages (four hours and 45 minutes prior to the exercise) could attenuate jump height loss after a 4x400 running bouts. Therefore, athletes, coaches, sport scientists and nutritionist should consider acute β-alanine supplementation to attenuate sports performance decrease after high intensity exercises in which muscle acidosis is highly increased. Nevertheless, future studies evaluating acute β-alanine supplementation on sport-specific performance after strenuous exercise are needed to support these results.

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CAN SELF-ESTEEM MEDIATE THE ASSOCIATION BETWEEN SOCIAL SUPPORT AND DIFFERENT LEVELS OF PHYSICAL ACTIVITY IN ADOLESCENTS?

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Abstract:

The aim was to analyze the mediation role of self-esteem in the interaction between social support from the best friend, friends, and parents, and physical activity (PA). Participants were N=444 adolescents of both genders (male= 205), aged between 12-18 years (M= 16.02; SD= 1.57). Structural equation modeling, serial mediation and multigroup analysis were used to test the proposed hypothesis. Self-reported instruments were used to collect both PA social support and self-esteem. Self-esteem mediates partially the interaction between different social supports and vigorous PA, independently of adolescent sex. Interestingly, self-esteem was fully mediating the interaction between parents' social support and vigorous PA in female adolescents. In contrast, self-esteem revealed no mediation in the interaction between social support and light and moderate PA. In conclusion, self-esteem mediates the relationship between social support and vigorous PA, the strength of mediation is higher in girls than in boys, in both genders the mediation is higher when the social support has come from parents.

Key words: *friends, parents, vigorous physical activity, best friends, self-worth, youth*

Introduction

Physical activity (PA) participation is of utmost importance since it represents a healthy way to reduce chronic diseases and mortality (WHO, 2018). The evidence on the health benefits of PA is considerable, overwhelming, and irrefutable. The benefits are not only evident in the prevention of physical diseases (Warburton & Bredin, 2017) but also in the area of mental health and well-being (Fox, 1999; Pascoe, et al., 2020), and even in social relationships (Di Bartolomeo & Papa, 2019). Despite this evidence, PA levels of the adolescent world population are low. For instance, in 2016, 81% of students aged 11–17 years, according to the current WHO recommendation (WHO, 2020; participating in 60 min of daily PA of moderatetovigorous intensity or being active for at least 60 min on five days per week), were insufficiently physically active (Guthold, Stevens, Riley, & Bull, 2020).

Adolescence is a life period of dramatic changes, from somatic to psychological ones. Social interactions play an important role among adolescents; parents, peers, friends as well best friends may cause behavioral and lifestyle changes, namely, they all may influence the young whether be or not to be physically active and involved in exercise and sports (Gill, et al., 2018). In addition, adolescence is known as a period when PA levels decline (Dumith, Gigante, Domingues, & Kohl, 2011; Farooq, et al., 2018). Several factors could contribute to PA levels in adolescents. For instance, Sallis, Prochaska, and Taylor (2000), in a review study about the correlates of PA in children and adolescents, identified a pool of psychosocial variables related to adolescents' (13 to 18 years) PA, namely social support from parents and from others: peers, friends as well as the best friend (Gill, et al., 2018; Mendonca, Cheng, Melo, & De Farias Junior, 2014).

Social support can have a beneficial effect on a person's health and emotional state acting as a motivating factor in positive health behaviors (Uchino, Cacioppo, & Kiecolt-Glaser, 1996) and can be carried out in several ways: emotional, instrumental, informational and appraisal support

(Birch, 1998). In a systematic review (Mendonca, et al., 2014), it was found that social support was positive and consistently associated with the PA level of adolescents in cross-sectional and longitudinal studies. Those who received more overall social support as well as support from both parents, friends and family showed higher levels of PA. Although parents are important actors in the social support for adolescents' PA, friends play a crucial role (Cheng, Mendonça, & Júnior, 2014; Lopes, Gabbard, & Rodrigues, 2013; Marks, de la Haye, Barnett, & Allender, 2015).

Several theories considering psychosocial determinants have been proposed to explain PA (Glanz, Rimer, & Viswanath, 2015) such as the social cognitive theory (Bandura, 1998), the health belief model (Janz & Becker, 1984), the theory of planned behavior (Ajzen, 1991), the transtheoretical model (Prochaska & DiClemente, 1982), as well as the self-determination theory (Ryan & Deci, 2018). These theories have mainly been applied to adults and are based on cognitive reflections, which allow for conscious behavioral control, therefore, they may not work well in adolescents. Adolescents' brains are still in the state of development having limited cognitive control (Andrews-Hanna, et al., 2011; Luna, 2009)

Harter (1987) proposed the self-worth model to explain motivation for behavior of children and adolescents (8 to 18 years). The model is based on a developmental perspective and simultaneously considers the social and emotional factors (Harter & Marold, 1991). In Harter's model, social support and perceived competence predict self-esteem (Harter, 1987, 1993). Weiss and Ebbeck (1996) adapted the Harter's model to PA domain proposing that self-esteem was associated with PA levels. Perceived competence and social support are determinants of self-esteem and enjoyment and PA are outcomes (Weiss, 2000).

Self-esteem has been recognized as a major determinant of behavior throughout the history of educational and social psychology. Some researchers have suggested that self-esteem is a unidimensional construct reflecting a general view of the self (e.g. Rosenberg, 1979). Nevertheless, self-concept researchers, who have relied primarily on the single self-concept, have not provided strong support for their interpretations (Harter & Marold, 1991). There is a general agreement among researchers that self-esteem is a multifaceted, hierarchical, and dynamic construct (Harter & Marold, 1991; Marsh & Redmayne, 1994; Marsh, Smith, & Barnes, 1983). Shavelson, Hubner, and Stanton (1976) proposed a model where general self-concept was at the apex of a hierarchy with academic self-concept, social self-concept, emotional self-concept, and physical self-concept being considered as the second-order factors. Fox and Corbin (1989) proposed a multidimensional and hierarchical model of physical self-concept, which is consistent with Shavelson et al.'s approach. The model posits global self-esteem at the apex of a hierarchy, followed by the physical self-worth at the domain level, and sport competence, attractive body, physical strength, and physical condition at the sub-domain levels. Additionally, they have devised the Physical Self-Perception Profile (PSPP), which assesses the four specific facets of physical self-concept as well as the global self-esteem and the physical self-worth (Fox & Corbin, 1989). The PSPP is an instrument widely used and validated (e.g., Bernardo & Matos, 2003; Karteroliotis, 2008; Nezhad, Nordentoft, Gildeh, & Stelter, 2011; Page, Fox, Biddle, & Ashford, 1993; Welk & Eklund, 2005).

Early and more recent self-esteem theorists have also suggested that self-esteem is a dynamic, changing construct depending on one's successes and expectations (Baldwin & Hoffmann, 2002). Quick physical, emotional, and social relationship changes during adolescence could be demanding and stressful, putting adolescents at risk of a decrease in self-esteem (Baldwin & Hoffmann, 2002; Robins & Trzesniewski, 2005). During adolescence, self-esteem is a dynamic rather than a static construct (Baldwin & Hoffmann, 2002).

Physical activity, exercise and sports practice may be seen as factors that have the potential to stabilize or enhance physical self-perception and self-esteem during adolescent years (Bowker, 2003; Fox, 2000). Engagement in physical exercise contributed to a positive body image and positive health perceptions among undergraduate students (Korn, Gonen, Shaked, & Golan, 2013). In a systematic review (Ekeland, Heian, & Hagen, 2005), it was found that exercise might have short term beneficial effects on self-esteem in adolescents. A meta-analysis (Liu, Wu, & Ming, 2015) found that PA interventions were associated with increased self-concept and self-esteem in adolescents. Other studies found that global self-esteem was associated with increased PA levels, acting as a mediator between pubertal development in girls at age 11 and PA at age 13 (Davison, Werder, Trost, Baker, & Birch, 2007), and being a predictor of PA levels during an 8-month period (Neumark-Sztainer, Story, Hannan, Tharp, & Rex, 2003). On the other hand, Inchley, Kirby, and Currie (2011) found that high self-esteem was associated with PA among girls but not among boys.

It was suggested (Harter, 1987; Weiss, 2000, 2008) that PA, social support and perceived competence for PA improve self-esteem. In addition, high self-esteem will cause a positive affect, that is, enjoyment in PA. Moreover, PA enjoyment and self-esteem are hypothesized to predict the amount of PA. This model was tested by Jekauc et al. (2019), and they concluded that the prominent role of self-esteem in the model could not be confirmed. Despite important insights provided by previous literature (Ekeland, et al., 2005), there are still some issues that should be addressed, especially in terms of the relationship between PA and global self-esteem as well as in terms of the mediation role of global self-esteem between social support and different levels of PA (Jekauc, et al., 2019).

Therefore, the aim of the present study was to analyze the mediation role of global self-esteem in the interaction between social support from the best friend, friends and parents, and different intensity levels of PA, including light, moderate and vigorous ones, in male and female adolescents. More specifically, in agreement with the above-mentioned literature, we hypothesized that: (a) global self-esteem mediates the association between social support from the best friend, friends and parents with different PA intensity levels, including light, moderate and vigorous PA; (b) social support from the best friend, friends and parents should be associated positively with global self-esteem; (c) social support from the best friend, friends and parents should be associated positively with moderate and vigorous PA; (d) social support from the best friend, friends and parents should be associated positively, but not significantly with light PA in both sexes, and (e) global self-esteem should be positively associated with light, moderate and vigorous PA.

Methods

Participants and procedures

Participants were recruited from six different secondary schools in the north of Portugal. All students aged 12-18 years in the contacted schools were invited to participate and refusal was minimal (0.01%). To be eligible for this study, potential participants needed to be aged between 12 and 18 years, the age period accepted to correspond to adolescence (Sacks, 2003). Participants were N=444 adolescents (male= 205), aged 12-18 years (M= 16.02; SD= 1.57). School directors provided their authorization for data gathering. Written informed consent was obtained from participants' parents or legal tutors. Adolescents gave their verbal consent prior to data collection. Before data collection, the study was approved by the ethics committee of the institution of the first author, process No. 290221. All procedures were in accordance with the Helsinki declaration (2013) and its later amendments (World Medical Association, 2013).

The surveys were filled out in a classroom during school hours. Before students started to answer the surveys, researchers, who collected all the data, explained the objective of each questionnaire, and removed any doubt.

Instruments

Physical activity

Physical activity behavior was assessed via the International Physical Activity Questionnaire (IPAQ) – short form (Craig, et al., 2003; Hagströmer, et al., 2008). This questionnaire was self-administered. It referenced to the last seven days of the recalled PA and asked about the three specific types of activity: leisure time, domestic activities, e.g., gardening/yard activities or work activities (for the purpose of the present study, this last domain was replaced with school related PA, including activity during physical education classes and breaks), and transport-related activity. Furthermore, three specific levels of PA intensity were assessed: walking, moderate (MPA) and vigorous (VPA). Frequency was measured in days per week and duration was measured by time per day, which was collected individually for each specific type of activity. The items were organized to offer a distinct score on walking, moderate and vigorous PA as well as a combined global score of PA level, which was given in metabolic equivalents per minutes per week (e.g., MET-min−1 · week−1), using the following formulas: Walking: MET-min · week−1 = 3.3 × walking minutes × walking days; Moderate: MET-min · week−1 = 4.0 × moderate-intensity activity minutes × moderate days; Vigorous: MET-min week−1 = 8.0 × vigorous-intensity activity minutes × vigorous-intensity days. More details about this questionnaire are available at https://sites.google.com/site/theipaq/. The short version of the IPAQ has been tested extensively with the reported reliability and validity of .80 and .30, respectively (Craig, et al., 2003). Using a sample of adolescents, the reported reliability was .49 to .83 and validity .24 to .55 (Guedes, Lopes, & Guedes, 2005).

Psychosocial variables

The Portuguese version of the Physical Self-Perception Profile for Children and Youth (PSPP-CY) (Bernardo & Matos, 2003) was used to measure global self-esteem. The PSPP-CY consists of 36 items and uses Harter's (1982) structured alternative format designed to minimize the tendency towards socially desirable responses. This instrument has six subscales: sport competence, physical condition, attractive body, physical strength, physical self-worth, and global self-esteem. Each subscale consists of six items in which participants are presented with two contrasting descriptions (e.g., those with unattractive bodies and those with attractive bodies) and are asked which description is most like themselves and whether the description they select is "sort of true" or "really true" for them. Item scores can range from 1 to 4. A value of 3 or 4 represents a positive perception and a value of 2 or 1 a negative perception. The result of each subscale is obtained with an average of six items belonging to the scale. The reported internal consistency (alpha) for the different subscales was between 0.73 and 0.85, while test-retest reliability was between 0.71 and 0.77 (Bernardo & Matos, 2003). Test-retest reliability for our study sample varied between 0.63 and 0.91.

For the purpose of the present study, we used only the global self-esteem subscale. The CFA of this subscale displayed the following fit: (χ^2= 70.01 (9); *SRMR*=.048; *B-Sp* <.001; *RMSEA*=.078 [90%*CI*=.062, .081]; *TLI*=.907; *CFI*=.917). Internal consistency showed a suitable value (.78).

Perception of social support from the best friend, friends and parents was assessed through a Portuguese adaptation of the Friend Support Scale (Jago, Page, & Cooper, 2012), which is an adaptation of Prochaska, Rodgers, and Sallis' Peers Support Scale (2002). The only difference was the item stem used before items-questions. In the case of the best friend, the following stem was used: "How often does your best friend...?"; regarding parents, the following stem was used: "How often do your parents...?"; in terms of friends, the following stem was used: "How often do your friends...?". The following items-questions were used: (1) … encourage you to exercise or do sports?; (2) … exercise or do sports with you?; (3) … tell you that you are doing well in exercise or sports?; and (4) … watch you take part in exercise or sports?. The CFA of this questionnaire was the following: (χ^2= 16.76; *SRMR*=.026; *B-Sp*= <.001; *RMSEA*=.077 [90%*CI*=.061, .080]; *TLI*=.946; *CFI*=.982); (χ^2= 53.42; *SRMR*=.069; *B-Sp*= <.001; *RMSEA*=.067 [90%CI=.059, .078]; *TLI*=.9006; *CFI*=.918); (χ^2= 6.12; *SRMR*=.018; B-Sp= .236; *RMSEA*=.057 [90%CI=.003, .117]; *TLI*=.981; *CFI*=.994), for the best friend, parents and friends' social support, respectively. Posteriorly, the items-questions were grouped into a single factor, which aimed at the social support from the best friend, friends, and parents. Internal consistency showed suitable values of each social support: the best friend social support (.86); friends social support (.82) and parents social support (.77).

Statistical analysis

Data were initially screened for missing values and normality. Descriptive statistics and bivariate correlations were calculated using IBM SPSS STATISTICS v.23. Data were imputed in participants with missing values >5% using the multiple imputation approach (Allison, 2000).

According to Fritz and Mackinnon (2007), the present sample size was in line with simulations for mediation purposes with this number of variables, thus, ensuring proper statistical power. Finally, multicollinearity diagnoses through tolerance and variance inflation factor (*VIF*) were performed as proposed by Hair, Babin, Anderson, and Black (2019), considering scores ≤ 10 as acceptable.

For hypothesis testing, paralel mediation procedures (model 4) of Hayes (2018) were developed using IBM SPSS macro-PROCESS v.3.5 and according to Hayes, suggestions. This procedure allows the estimation of the direct and indirect effects in the proposed models, while controling for *k* mediators influence between variables. Additionally, when the independent variables are significantly correlated, it is advised to beware of possible variables influence in the proposed test. Thus, the independent variables not considered in each model were included as covariates to account for their effects in the proposed models (Hayes, 2018).

In all variable interactions, bias-correct bootstrapped point estimates were calculated (considering standard errors and 95% CI). A 5000 samples bootstrap was used according to several authors' recommendations (Hayes, 2018; Williams & MacKinnon, 2008), and significant indirect effects were considered if the confidence interval did not include zero (α = .05). The ratio of total indirect effect over total effect (PM) was calculated to quantify mediation strength (Shrout & Bolger, 2002).

Results

Preliminary analysis

Regarding normal distribution, no univariate outliers were observed. The results showed that both in tolerance and VIF tests scores were above 0.1 and below 10, respectively, ensuring the appropriate conditions to test the regression model.

Descriptive results (Table 1) revealed that the participants perceived higher social support from friends and the best friend than from parents. In addition, all the bivariate correlations were positive and significant, except for the associations across different social support and self-esteem with light and moderate PA.

Table 2 shows the results of the mediation models between social support from the best friend (model 1), friends (model 2), and parents (model 3), and different levels of PA via self-esteem for the whole sample. Overall, partial mediation appeared in all the models with VPA, since the total indirect effect was significant, but not higher than the total direct effect. In addition, the mediator self-esteem explained .21, .41, and .06 for models 1, 2 and 3, respectively, of the interaction between different sources of social support and VPA. No mediation was observed with walking and MPA.

Table 3 shows the results of the mediation models in the female sample. Partial mediation occurred in models 1 and 2 and full mediation in model 3. In the case of models 1 and 2, partial medi-

Table 1. Descriptive statistics and zero order bivariate correlations

				Whole sample				
Variables	M	SD	1	2	3	4	5	6
1. SS-BF	3.10	.75	-	-	-	-	-	-
2. F-SS	3.14	.64	.70**	-	-	-	-	-
3. P-SS	2.72	.75	.36**	.36**	-	-	-	-
4. GSE	2.74	.54	.23**	.34**	.14**	-	-	-
5. WPA	842.46	1033.07	.01	-.03	.03	-.01	-	-
6. MPA	763.28	798.83	.05	.03	.03	.06	.22**	-
7. VPA	1842.49	1529.23	.14**	.11*	.08	.16**	.14**	.35**
				Female sample				
Variable	M	SD	1	2	3	4	5	6
1. SS-BF	3.07	.79	-	-	-	-	-	
2. F-SS	3.11	.69	.71**	-	-	-	-	
3. P-SS	2.73	.75	.43**	.48**	-	-	-	
4. GSE	2.72	.55	.22**	.39**	.17**	-	-	
5. WPA	891.43	1094.53	-.01	-.05	-.02	-.06	-	
6. MPA	789.25	907.71	.07	.05	.05	.06	.24**	-
7. VPA	1867.92	1541.32	.10*	.06*	.26**	.15**	.18**	.40**
				Male sample				
Variables	M	SD	1	2	3	4	5	6
1. SS-BF	3.12	.71	-	-	-	-	-	-
2. F-SS	3.19	.57	.70**	-	-	-	-	-
3. P-SS	2.72	.75	.27**	.20**	-	-	-	-
4. GSE	2.78	.53	.24**	.24**	.14*	-	-	-
5. WPA	779.97	947.88	.03	.01	.02	.08	-	-
6. MPA	730.15	634.04	.02	.01	.04	.09	.19**	-
7. VPA	1810.05	1516.85	.20**	.20**	.16**	.18**	.08	.29*

Note. M = mean; SD = standard deviation; BF-SS = best friend social support; F-SS = friend's social support; P-SS = parents' social support; GSE = global self-esteem; WPA = walking; MPA = moderate physical activity; VPA = vigorous physical activity; ** $p<.01$; *$p<.05$.

ation was observed with VPA, since the total indirect effect was significant but not higher than the total direct effect. In the case of model 3, full mediation was identified since the total indirect effect was significant and higher than the total direct effect. Furthermore, the mediator self-esteem explained .31, .16, and .67 for models 1, 2 and 3, respectively, of the interaction between different social supports and VPA. However, in model 1, both in terms of walking and moderate physical activity, the mediation was not observed since the indirect effect was not significant. In model 1 (walking) and model 2 (MPA), no mediation was observed.

Table 4 shows mediation models between social support from the best friend, friends, and parents, and different levels of PA via self-esteem in male sample. In general, partial mediation emerged in all models with VPA, since the total indirect effect was significant but not higher than the total direct effect. In addition, the mediator self-esteem explained .18, .20, and .56 for model 1, 2 and 3, respectively, of the interaction between different social supports and VPA. Regarding the models with walking and moderate PA as an outcome variable, no mediation was observed because the total indirect effect was not significant.

Table 2. Mediation analysis – the whole sample

Models	Paths	β	CI -95%	Total indirect effect
Model 1	BF-SS→GSE	.19	[.102, .204]	-.001ns
	BF-SS→WPA	.01	[-.115, .134]	
	GSE→WPA	-.01	[-.181, .162]	
	BF-SS→GSE	.19	[.102, .204]	.02ns
	BF-SS→MPA	.11	[.071, .275]	
	GSE→MPA	.05	[-.072, .177]	
	BF-SS→GSE	.19	[.102, .204]	.04 [.014; .071]
	BF-SS→VPA	.15	[.025, .271]	
	GSE→VPA	.25	[.078, .275]	
Model 2	F-SS→GSE	.28	[.210, .357]	.004 ns
	F-SS→WPA	-.06	[-.208, .096]	
	GSE→WPA	.02	[-.163, .195]	
	F-SS→GSE	.28	[.210, .357]	.03 ns
	F-SS→MPA	.01	[-.139, .165]	
	SE→MPA	.11	[-.065, .192]	
	F-SS→GSE	.28	[.210, .357]	.07 [.024; .126]
	F-SS→VPA	.10	[.048, .252]	
	GSE→VPA	.26	[.079, .433]	
Model 3	P-SS→GSE	.10	[.036, .168]	-.001 ns
	P-SS→WPA	-.02	[-.186, .153]	
	GSE→WPA	.05	[-.019, .019]	
	P-SS→GSE	.10	[.036, .168]	.01 ns
	P-SS→MPA	.09	[-.071, .269]	
	GSE→MPA	.03	[-.093, .150]	
	P-SS→GSE	.10	[.036, .168]	.03 [.009, .053]
	P-SS→VPA	.29	[.124, .459]	
	GSE→VPA	.10	[.023, .233]	

Note. Model 1 = best-friend social support (independent variable), GSE = global self-esteem (mediator). WPA (walking), MPA (moderate physical activity), and VPA (vigorous physical activity) are dependent variables. Model 2 = friends social support (independent variable), SE = self-esteem (mediator). WPA (walking), MPA (moderate physical activity), and VPA (vigorous physical activity) are dependent variables. Model 3 = parents social support (independent variable), SE = self-esteem (mediator). WPA (walking), MPA (moderate physical activity), and VPA (vigorous physical activity) are dependent variables. BF-SS = best-friend social support; F-SS = friends social support; P-SS = parents social support; β = effects; CI 95% = confidence interval.

Table 3. Mediation analysis – the female sample

Models	Paths	β	CI -95%	Total indirect effect
Model 1	BF-SS→GSE	.16	[.073, .241]	-.02ns
	BF-SS→WPA	.07	[-.162, .176]	
	GSE→WPA	.11	[-.349, .133]	
	BF-SS→GSE	.16	[.073, .241]	.01ns
	BF-SS→MPA	.08	[-.096, .265]	
	GSE→MPA	.09	[-.167, .349]	
	BF-SS→GSE	.16	[.073, .241]	.04 [.016; .112]
	BF-SS→VPA	.10	[.064, .253]	
	GSE→VPA	.25	[.078, .275]	
Model 2	F-SS→GSE	.31	[.223, .405]	-.02 ns
	F-SS→WPA	-.06	[-.263, .147]	
	GSE→WPA	.08	[.177, .332]	
	F-SS→GSE	.31	[.223, .405]	.03 ns
	F-SS→MPA	.04	[-.177, .263]	
	GSE→MPA	.10	[.076, .370]	
	F-SS→GSE	.31	[.223, .405]	.09 [.021; .164]
	F-SS→VPA	.08	[.091; .195]	
	GSE→VPA	.27	[.034, .515]	
Model 3	P-SS→GSE	.13	[.037, .217]	-.01 ns
	P-SS→WPA	-.02	[-.196, .157]	
	GSE→WPA	.11	[-.339, .137]	
	P-SS→GSE	.13	[.037, .217]	.01 ns
	P-SS→MPA	.07	[-.120, .258]	
	GSE→MPA	.10	[.153, .357]	
	P-SS→GSE	.13	[.037, .217]	.04 [.007, .067]
	P-SS→VPA	.13	[.067, .165]	
	GSE→VPA	.28	[.051, .501]	

Note. Model 1 = best-friend social support (independent variable), GSE = global self-esteem (mediator). WPA (walking), MPA (moderate physical activity), and VPA (vigorous physical activity) are dependent variables. Model 2 = friends social support (independent variable), SE = self-esteem (mediator). WPA (walking), MPA (moderate physical activity), and VPA (vigorous physical activity) are dependent variables. Model 3 = parents social support (independent variable), SE = self-esteem (mediator). WPA (walking), MPA (moderate physical activity), and VPA (vigorous physical activity) are dependent variables. BF-SS = best-friend social support; F-SS = friends social support; P-SS = parents social support; β = effects; CI 95% = confidence interval.

Table 4. Mediation analysis – the male sample

Models	Paths	β	CI -95%	Total indirect effect
Model 1	BF-SS→GSE	.18	[.077, .279]	.03ns
	BF-SS→WPA	.02	[-.169, .203]	
	GSE→WPA	.14	[.109, .388]	
	BF-SS→GSE	.18	[.077, .279]	.03ns
	BF-SS→MPA	.04	[-.156, .165]	
	GSE→MPA	.13	[.089, .341]	
	BF-SS→GSE	.18	[.077, .279]	.05 [.003; .105]
	BF-SS→VPA	.24	[.040, .433]	
	GSE→VPA	.26	[.007, .517]	
Model 2	F-SS→GSE	.22	[.098, .348]	.03 ns
	F-SS→WPA	-.02	[-.244, .173]	
	GSE→WPA	.15	[.101, .397]	
	F-SS→GSE	.22	[.098, .348]	.03 ns
	F-SS→MPA	-.03	[-.226, .173]	
	GSE→MPA	.13	[.080, .350]	
	F-SS→GSE	.22	[.098, .348]	.06 [.006, .135]
	F-SS→VPA	.29	[.042; .503]	
	GSE→VPA	.26	[.066, .519]	
Model 3	P-SS→GSE	.07	[.025, .168]	01 ns
	P-SS→WPA	.13	[.038, .199]	
	GSE→WPA	.13	[.116, .367]	
	P-SS→GSE	.07	[.025, .168]	.01 ns
	P-SS→MPA	.14	[.009, .282]	
	GSE→MPA	.11	[.100, .316]	
	P-SS→GSE	.07	[.025, .168]	.05 [.004, .063]
	P-SS→VPA	.16	[.116, .245]	
	GSE→VPA	.32	[.061, .580]	

Note. Model 1 = best-friend social support (independent variable), GSE = global self-esteem (mediator). WPA (walking), MPA (moderate physical activity), and VPA (vigorous physical activity) are dependent variables. Model 2 = friends social support (independent variable), SE = self-esteem (mediator). WPA (walking), MPA (moderate physical activity), and VPA (vigorous physical activity) are dependent variables. Model 3 = parents social support (independent variable), SE = self-esteem (mediator). WPA (walking), MPA (moderate physical activity), and VPA (vigorous physical activity) are dependent variables. BF-SS = best-friend social support; F-SS = friends social support; P-SS = parents social support; β = effects; CI 95% = confidence interval.

Discussion and conclusions

The aim of the present study was to analyze the mediation role of global self-esteem in the interaction between social support from the best friend, friends, and parents, and different levels of PA, including light (walking), moderate and vigorous ones, in male and female adolescents. Overall, hypotheses (a), (c), (d), and (e) were partially confirmed, while hypothesis (b) was fully confirmed. The zero-order correlation among different sources of social support presented higher values, while lower values were observed across different sources of social support and global self-esteem (moderate to low association) as well as with different levels of PA (low associations). However, most of these bivariate correlations are significant. Therefore, it seems that all the studied variables will interact with each other and are important to explain PA levels in adolescents, namely VPA.

As predicted, social support was found to positively predict MPA and VPA but not walking, although parents' social support was only significant in the case of VPA. Friends seem to be a more important source of social support in both male and female adolescents. For instance, in a study developed by Stearns et al. (2019) it was found that, in girls, the female best friends exhibited more similar levels of overall PA than the non-friends did, whereas in boys similar PA levels were only presented among best friends. Similar results were found by Lopes et al. (2013) and Lopes, Gabbard, and Rodrigues (2015). The findings of the present study confirm what has been observed in previous studies (Duncan, Duncan, & Strycker, 2005; Hohepa, Scragg, Schofield, Kolt, & Schaaf, 2007; King, Tergerson, & Wilson, 2008) and demonstrate that social support is an important component of PA promotion in adolescents.

The results showed that the mediation effect of self-esteem only exists between the association of the different sources of social support (the best friend, friends, and parents) with VPA, and not with walking or MPA. Furthermore, the mediation strength is different for girls and boys. For boys and girls altogether, self-esteem partially mediates social support and VPA, this mediation being stronger in the case of a friend's social support.

For girls, self-esteem also partially mediates the associations between the best friend and friends' social support with VPA, but it fully mediates the relationship between parents' social support and VPA. For boys, self-esteem only partially mediates the associations between social support and VPA and the effect of this mediation is higher in the relationship between parents' social support and VPA. These differences maybe lay in the difference between boys and girls in their perception of social support. Indeed, some studies showed differences between adolescent boys and girls in perceived social support (Gill, et al., 2018; Väänänen, Marttunen, Helminen, & Kaltiala-Heino, 2014). The present results mean that, for adolescents, social support from friends is more relevant than from best friends and parents. However, parents' social support leads to higher self-esteem, and then the higher his or her self-esteem will be leading them to attain greater VPA. These results are in line with literature in this research field. For instance, in a systematic review it was found that those adolescents who received more support from both parents and friends showed higher levels of physical activity (Mendonca, et al., 2014). Gill et al. (2018) found that support from family and friends were both consistently strong predictors of adolescents' PA. The practice of VPA is more demanding in terms of motivation and commitment, therefore it requires greater social support, and usually this level of intensity is reached in structured physical practices like sport. According to Howie, Daniels, and Guagliano's (2018) review, and in line with our results, friendships were key to both initiation and maintenance of sports participation, whereas parents facilitated participation.

According to Harter's model of self-esteem (Harter, 1987), adapted by Weiss and Ebbeck (1996) for PA domain, the main factors for participating in PA are enjoyment, perceived competence, and social support. Self-esteem acts as the mediator of perceived competence and social support in the relationship with PA. Our results show that, in fact, self-esteem could act as the mediator, but only with VPA. It makes sense, since VPA practice needs more motivation and effort than light and moderate PA (Fenton, Duda, Appleton, & Barrett, 2017; Teixeira, Carraça, Markland, Silva, & Ryan, 2012), given its more strenuous physical effort demands.

We test self-esteem as a mediator in the relationship between social support and PA. Although there is a debate going on to know if self-esteem is a cause or consequence of social support. For instance, a study developed by Marshall, Parker, Ciarrochi, and Heaven (2014), analyzed two models (self-esteem as an antecedent and self-esteem as an outcome) and concluded that self-esteem predicted social support, while other studies (e.g., Bum & Jeon, 2016; Haugen, Säfvenbom, & Ommundsen, 2011) included self-esteem as an outcome. Bum and Jeon (2016) showed that parents', professors', and peers' social support were significant antecedent variables that increased the students' self-esteem. Haugen et al. (2011) found that increased levels of PA were beneficial for global self-worth in male and female adolescents ough enhancing their perceptions of physical self-esteem. Thus, future studies, namely more longitudinal studies, systematic reviews, and meta-analysis are needed to explore these associations in more detail.

Although the present study contributes to the understanding of the relationship between social support, self-esteem, and PA, it has some limitations. The study is cross-sectional, so we can only address the associations among the variables without determining their causality. In this sense, longitudinal or experimental studies are necessary to further examine the effects of the studied variables on each other. In addition, PA was assessed by a questionnaire. Although IPAQ is extensively used, valid, and reliable population wise, the use of questionnaires for assessing PA can be limitative, since they rely on participants' memory and, in the case of IPAQ, their capability to remember PA in the last seven days. Future research should include objective measures (e.g., pedometer and/or accelerometer). The data from this study were from the north of Portugal, which consequently imposes regional limits on their generalizability. Hence, forthcoming studies should try, to make an effort and collect a large and stratified sample of other regions of Portugal and analyze these variables across regions. To the best of our knowledge, it seems that this was the first study to consider the self-esteem as a mediator in the interaction between social support from the best friend, friends, and parents, and different levels of PA. Therefore, future studies should also test our hypothesized model under similar contexts and in different cultures. Finally, other variables such as age and sports practice experience should be included in future studies, and their interaction as a mediator or moderator between social support and PA might be considered. All in all, our findings suggest that the proposed model operates in the same way, independently of the adolescent sex, particularly in terms of VPA, which strongly corroborates previous findings (Reddon, Meyre, & Cairney, 2017). In this regard, the findings of the present study could help future researchers to improve their intervention in terms of enhancing PA levels in adolescents by considering the importance of self-esteem. In addition, another important avenue is related to social support. While changes toward lower self-worth, self-efficacy, self-esteem, lower perception of social support may be attributed to pubertal changes, an emerging capacity to think abstractly about oneself, confusion and shifts in roles and responsibilities as well as identity development, the social support from friends, parents and the best friends may be seen as one factor that operates to improve levels of self-esteem in adolescents and, consequently, to improve or maintain their PA levels.

In conclusion, self-esteem mediates the relationship between social support and VPA; the strength of mediation is higher in girls than in boys; in both genders the mediation is higher when the social support has come from parents. Therefore, it could be said that the more social support an adolescent receives, particularly from the parents, the higher his or her self-esteem will be, leading him or her to attain greater ous physical activity.

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EFFECTS OF TABATA TRAINING ON HEALTH-RELATED FITNESS COMPONENTS AMONG SECONDARY SCHOOL STUDENTS

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Abstract:

Physical education curricula in Polish schools should include more tasks to increase physical activity. The Tabata Training Program can help regulate body weight and induce changes in body fat and physical fitness. This study aimed to determine the effects of a 10-week PE curriculum supplemented by a Tabata Training Program on health-related fitness in 16-year-old secondary school students. The study examined 187 students (66 boys and 121 girls) assigned to either a Tabata Training Program intervention or control group. The intervention lasted 14 minutes during one physical education lesson per week. *Pre*- and *post*-intervention, anthropometric measurements were taken, and each participant performed physical fitness tests to evaluate muscular strength, flexibility, speed/agility, and cardiovascular efficiency. Boys of the intervention group significantly reduced body fat (by 1.77%, p<.05) and increased cardiovascular efficiency (the physical efficiency index was higher by 3.61 points, p<.05). Girls increased cardiovascular efficiency only (the physical efficiency index increased by 5 points, p<.001). However, slight changes in motor parameters were observed in all the participants. The Tabata Training Program demonstrated partial effectiveness but should be individualized and sex differences should be considered.

Key words: *physical education, intervention study, exercise training, youth*

Introduction

Physical activity has comprehensive health benefits for people of all ages. Generally, young people (13–17 years old) need 60 minutes of moderate-to-high-intensity physical activity daily (Costigan, Eather, Plotnikoff, Taaffe, & Lubans, 2015), to which physical education (PE) classes can significantly contribute. High-intensity interval training (HIIT) can be used in these classes to help cope with and prevent obesity and overweight (Camacho-Cardenosa, et al., 2016; Costigan, et al., 2018; Delgado-Floody, Latorre-Roman, Jerez-Mayorga, Caamano-Navarrete, & Garcia-Pinillos, 2019).

Physical inactivity's growing prevalence is associated with child/adolescent overweight and obesity: about 80% of young people do not perform the minimum physical activity level recommended by the World Health Organization (WHO) (Hallal, et al., 2012). Even physically active people reduce their activity by about 10% annually during adolescence (Dumith, Gigante, Domingues, & Kohl, 2011). In Poland, the same patterns are present, where regular physical activity decline surpasses that in other European and world countries. Physical education classes should improve students' physical literacy and other skills in various sports and promote health-related physical activity through the implementation of intervention programs based on increased exercise intensity (Heath, et al., 2012). Positive correlations between the implemented high-intensity exercises and a more favorable waist-to-hip ratio (WHR), blood pressure, and body mass index (BMI) have been indicated (Carson, et al., 2014; Hay, et al., 2012).

The HIIT method, which uses a short intervention time (up to a few minutes) with vigorous-intensity exercise (at about 75% of maximum heart rate), may offer a solution (Costigan, et al., 2015). Such an intensity improves adolescents' maximum oxygen uptake and morphological features (i.e., WHR, BMI, and body fat percentage). The mentioned studies were conducted mainly in clinical conditions, instead of in natural conditions during school PE classes, and/or with rather small samples (Buchan, et al., 2011; Camacho-Cardenosa, et al., 2016; Delgado-Floody, et al., 2019). Further, studies largely used repeated sprints for the HIIT exercises, while others used a circuit-training method (Lambrick, Westrupp, Kaufmann, Stoner, Faulkner, 2016; Weston, et al., 2016) or Tabata procedure (Afyon, Mülazimoğlu, & Altun, 2018; Ekström, Ostenberg, Bjorklund, & Alricsson, 2017). In Tabata procedure, short rests between efforts are key for increasing both aerobic and anaerobic capacity in exercisers. In HIIT interval training experiments, the program is usually run one, two, or three times a week. However, results show that morphological (fat reduction) and physiological changes occur even after a single workout but also that increasing the number of weekly workouts does not significantly increase the observed changes (Chin, et al. 2020). These different strategies for achieving high intensity usually yield different results and, even when used together, do not provide a holistic solution or address both physical capacity and body weight/height components.

Therefore, our research aimed to determine the effects of a 10-week PE curriculum supplemented with the Tabata-based interval training on 16-year-olds regarding individual health-related fitness (HR-F) components, such as morphological features, cardiovascular features, muscle strength, and motor skills (divided by gender). In Poland, no studies have been conducted to date on the impact of PE lessons supplemented with HIIT on morphological and physiological parameters. Further, Poland has no recommendations for using HIIT with PE lessons, so our results may contribute to the development of PE classes that integrate HIIT. They can also be used to justify changes to Poland's PE system regarding supplementing it with various elements to improve physical performance and prevent overweight and obesity among Polish youth (Osiński & Kantanista, 2017), with no need to abandon other sports conducted during PE lessons.

We hypothesized that the introduction of a 14-minute HIIT based on the Tabata training program to one PE lesson/per week, run for 10 weeks, was sufficient to observe improvements in health indicators such as fat reduction, physical performance and motor skills performance.

Methods

Participants and procedure

The G*Power (version 3.1.) was used to calculate the *a priori* sample size. For the general linear multidimensional analysis of variance (MANOVA) with repeated measures and the interaction term, the effect size of 0.25 (medium effect size), a p-value of .05, power of 0.80, number of groups (4), and two measurements the suggested total sample size was 179 (Steyn & Ellis, 2009). This sample size was accurate (sufficient but not excessive) for proper interpretation of the results.

The sample of participants was comprised of 187 adolescents (66 boys: age 16.24±0.34 years; 121 girls: age 16.12±0.42 years) from a preselected urban, comprehensive secondary school in Wroclaw, whose school principal responded to the invitation and consented to the study. Students were of the same sociocultural level and lived in the same geographical area (i.e., a big city of about 650,000 inhabitants). Before starting the experiment, all participants' parents provided the written informed consent. A control group (CG) and experimental group (EG) had randomly been selected from all the first-year secondary school students (six classes in total) before the school year began. All students from the three first-year classes were assigned to the EG (n=92), and all students from the other three first-year classes were included in the CG (n=95).

Participants of the EG performed a 14-minute HIIT exercise regimen based on the Tabata training program (TAP), presented as a video during one of three weekly PE lessons carried out in the fitness room. The TAP was used in the EG group for 10 weeks (from the 5th week of the school year) from 9:00 a.m. to 12:30 p.m. The remaining PE lessons were conducted according to the school's regular curriculum for the first-year secondary students. Participants of the CG followed the regular PE curriculum. The stretching or gym exercises were used instead of HIIT exercises used in the EG. Participants were instructed to maintain normal levels of their physical activity and refrain from other organized physical activities except for PE (Cvetković, et al., 2018). During the other two weekly PE lessons, both the EG and CG participated in various team sports, dance, and gym exercises.

The results of 19 EG and 26 CG participants were excluded from further analyses due to various reasons. These included the participants involved in organized physical activity (i.e., attendees of a fitness gym) or additional recreational activities during the previous six months (17 students), those who had medical contraindications for motor activity and/or those with cardiovascular/respiratory diseases (10 students), those who discontinued PE class participation (due to school or class change: nine students), and those who did not complete all the tests (nine students). No participant withdrew from the program because of fatigue or lack of interest. Therefore, 73 EG participants (girls: n=42, body height 164.89±6.08 cm; boys: n=31, body height 176.47±6.21 cm) and 69 CG participants (girls: n=47, body height 163.92±6.96 cm; boys: n=22, body height 177.13±5.98 cm) were analyzed.

The particular school was chosen since it offered a sufficient number of students and one researcher had contact to the school before the start of the study.

The project was approved by the Ethics Committee of the University of the Physical Education in Wroclaw (ECUPE No. 33/2018). All students and their legal guardians were informed in detail about the design of the study, including the potential risks and benefits, before providing their written informed consent to participate. Then all legal guardians were asked to sign a consent document prior to testing.

Intervention

During one weekly PE lesson, the EG participants performed the TAP (Fig. 1). This training aimed to improve aerobic and anaerobic efficiency, strengthen the ligamentous and muscular system, and improve resting metabolism, which should lead to gradual body fat reduction (Tabata, et al., 1996). In the current study, the TAP program was introduced in only one PE lesson per week for two reasons. First, measuring students' TAP outcomes was feasible once per week at this stage of the project. Second, the TAP implementation once a week allowed maintaining students' interest in other sports disciplines while still facilitating changes in HR-F components (Chin, et al., 2020; Logan, et al., 2016). During PE lessons, students were improving their physical literacy and other skills in various sports (e.g., volleyball, basketball, football, gymnastics, athletics, dancing, table tennis, Nordic walking). Thus, this research serves as a starting point for any further research with a larger sample size.

A PE lesson (total duration time 45 minutes) started with a standardized 10-minute warm-up of 5-minute slow jogging and 5-minute stretching (dynamic and static). The lesson's main activity was 14 minutes of TAP, which comprised three sessions, each lasting four minutes. Each session's Tabata protocol consisted of eight cycles of two exercises. The following exercises were used in the first session: push-ups and high knees. In the second session: dynamic lunges, spider crawl, and in the third: plank to push-up and side squeeze (Afyon, Mülazimoğlu, & Altun, 2018; Logan, et al., 2016; Wilke, et al., 2018). The exercises utilized were chosen because they require no or minimal exercise equipment and target several large muscle groups. Each cycle started with a maximum-intensity exercise lasting 20 seconds of as many repetitions as possible and then a 10-second active rest (low-intensity exercise) followed. There was a 1-minute break between each session during which no exercise was performed. After the TAP, the final PE lesson activity (flexibility and relaxation exercises) was performed for several minutes as a part of the regular curriculum of the subject. At the beginning and at the end of the lesson, organizational tasks were carried out and discussions on the Tabata protocol, its effects and research on Tabata training were presented.

The authors prepared the exercises (for the experimental purposes), recorded, and played them during the PE lesson on a screen so the exercise and rest times were measured accurately. To verify exercise intensity during the TAP, adolescents' maximum heart rate was determined with the formula $HR_{max} = 208 - 0.7 \times age$ (16 years) (Tanaka, Monahan, & Seals, 2001) where HR_{max} was maximum heart rate. The calculated maximum heart rate (197 bpm) was used to compute the high-intensity exercise ranging 75%–80% of maximum

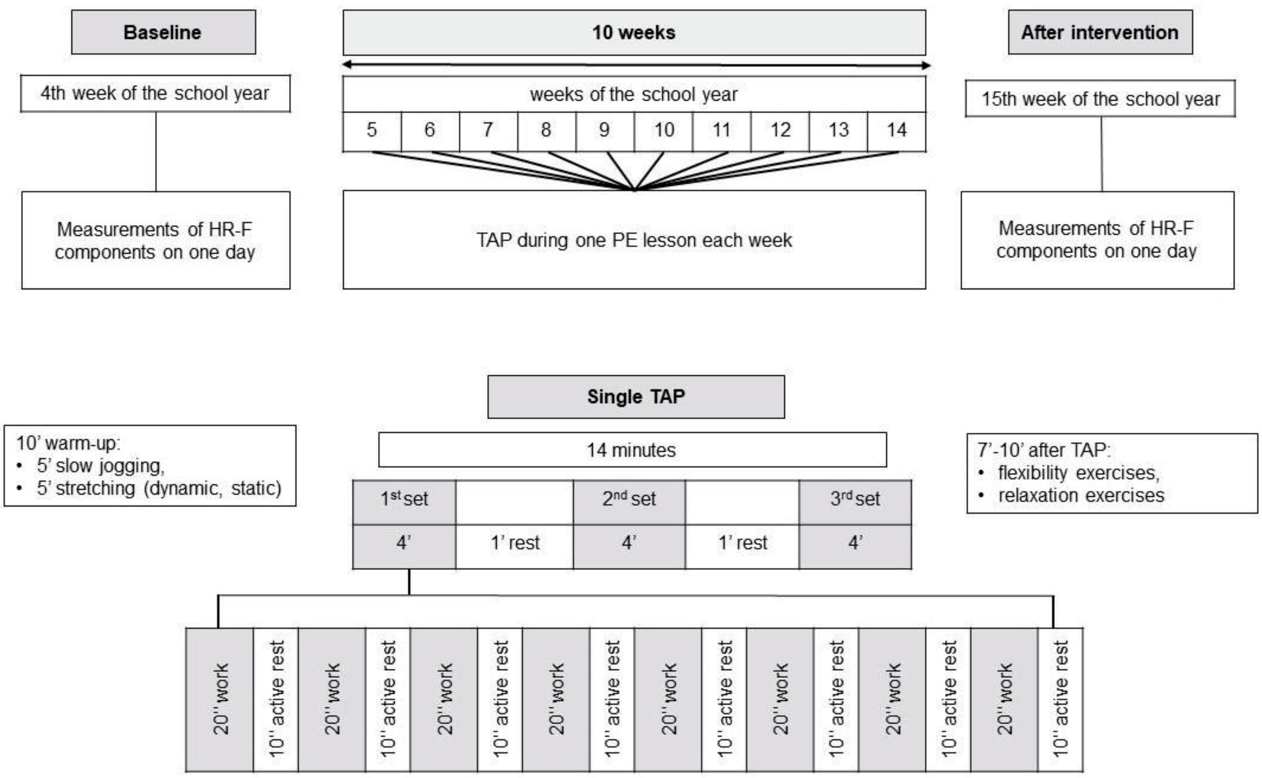

Figure 1. Scheme of the intervention. TAP – Tabata training program, PE – physical education.

heart rate (145–157 bpm). Students' heart rates were monitored during the first PE lesson with TAP using a Polar H1 heart rate monitor (Polar Electro, Kempele, Finland). The monitors were fitted to each student's chest, leveled with the xiphoid process and underneath clothing. Heart rate was displayed on the Polar H1 watch screens during TAP exercises to encourage users to maintain an adequate intensity level. The EG achieved an average of HR=155.8 bpm (±18.2; CI 121-184). In subsequent lessons of the Tabata protocol, the exercise intensity of HR measurement was similar to the intensity recorded during the first PE lesson.

Instruments

HR-F components were measured for the EG and CG *pre*- and *post*- TAP (in the 4th and 15th weeks of the school year). The tests were conducted on one day, from 8:00 a.m. to 1:00 a.m., in sports halls under the same conditions for each group. Each participant wore a T-shirt, shorts, and sports footwear. Only anthropometric measurements were conducted without sneakers.

Measurements of HR-F components

Measurements were taken *pre*- and *post*-intervention in the following order: anthropometric measurements, muscular strength and flexibility, speed and agility, and cardiovascular (physical) efficiency. Each measurement's protocol was based on HR-F measurement recommendations.

Anthropometric measurements

Two body height measurements were taken with an accuracy of 0.1 cm using anthropometers (GPM Anthropological Instruments). Body weight and body fat percentage were measured with a body composition analyzer using the InBody230 bioelectric impedance method (InBody Co. Ltd, Cerritos, CA, USA). The above data were used to calculate BMI.

Cardiovascular parameters

The physical efficiency index (PEI) that defines cardiovascular efficiency was determined using the Harvard Step Test. Participants stepped up and down on a 16.25 inch (41.3 cm) high stool at a pace of 30 cycles per minute with a metronome set at 120 bpm. The exercise continued for up to 300 seconds, unless participants' volitional exhaustion. Recovery pulse was recorded within 1.5 minutes into the recovery. Prior to each test, Polar H1 heart rate monitors were fitted to each student as per the afore-mentioned process. Resting heart rate, heart rate changes during exercise, and recovery pulse were measured. Heart rate monitors sampled participants' pulse at 5-second intervals and transmitted them to a smartwatch (Polar, Polar Electro; Kempele, Finland). PEI was calculated using the following formula (Bajaj, Appadoo, Bector, & Chandra, 2008):

$$PEI = (100 \text{ x } L)/(5{,}5 \times p)$$

where L = duration of the test in seconds, $L < 300$ seconds, and p = heart rate within 1.5 minutes after the subject stopped the test.

Musculoskeletal component parameters

To determine the musculoskeletal component parameters, hand muscular strength (HST) measurement, 30-second sit-up test (abdominal muscular strength) and sit-and-reach test (SRT; flexibility) were used. All the tests were performed according to the Eurofit guidelines (Adam, Klissouras, Ravazzolo, Renson, & Tuxworth, 1988). The Eurofit tests demonstrate very good test-retest reliability and validity (Tomkinson, et al., 2018).

HST was measured using the handgrip strength test via a hydraulic hand dynamometer (Baseline, FEI, Irvington, NY, USA). The dynamometer was sized to the individual with its spine parallel to the performer's thumb. The participant gripped the have demonstrated (with or without chalk, as desired) with a neutral wrist and squeezed it for 3–5 seconds. Any dynamometer *pumping* was considered a failed trial because it seemed to cause a falsely high reading, and the test was repeated. The better score of two trials was recorded for each hand.

The 30-second sit-up test measured the number of sit-ups with the hands placed at the side of the head, knees bent at 90º, and feet securely held by a partner. A full sit-up was defined as touching the knees with the elbows and returning shoulders to the ground. A total number of correctly performed sit-ups during 30 seconds was recorded. During the tests, the evaluators announced remaining time at the 10-, 20-, and 30-second marks. No other verbal encouragement other than counting the repetitions aloud was given during the test. Each participant performed the test once.

In the SRT, participants sat on the ground with straight legs against a standard reach box with 23 cm marked at the feet level. They were instructed to bend smoothly forward and sustain the extreme reach position for two seconds. The better score of two trials was recorded.

Motor component

The 4x10 m shuttle run test (agility) and the vertical jump test (VJT) were used to determine the motor component.

The 4x10 m shuttle run was performed according to Ortega, Ruiz, Castillo, and Sjöström, (2008). Two parallel lines were drawn on the floor 10 m apart. Participants ran as fast as possible from the starting line to the other line and returned to the starting line, crossing each line with both feet every time. The researcher stood at the starting line and stopped the stopwatch when participants crossed the line with one foot. The time taken to complete the test was recorded to the nearest tenth of a second. Participants wore sportswear and performed the test twice with a 5-minute rest, and the best time was selected.

Vertical jumping ability was assessed using the static vertical jump procedures in the VJT. In the VJT, a static position with a 90° knee flexion angle was maintained for two seconds before a jump attempt without any preparatory movement (Pereira, et al., 2018). All jumps were executed with the hands on the hips. Three attempts at each jump were performed, interspersed by 15-second intervals. Jumps were performed on a g-force tracker (Vert Jump; VERT, Fort Lauderdale, USA) with the obtained flight time (*t*) used to estimate the height of the rise of the body's centre of gravity (*h*) during the vertical jump (i.e., $h=gt^2/8$, where g=9.81 m/s^2). The best attempt was analyzed.

All measurements met HR-F guidelines. The scientific rationale for the selection of all the tests used, including their reliability for young people, have been previously verified (Bajaj, et al., 2008; Ortega et al., 2008, 2011).

Data analysis

The Shapiro-Wilk test was used to evaluate data distribution normality; all the data were normally distributed. Descriptive data were presented as mean ± standard deviation and skewness. General linear multidimensional analysis of variance (MANOVA) with repeated measures was used to evaluate the statistical significance of changes between the *pre*- and *post*-intervention measurement and the differences in all measurements between the EG and CG (boys and girls). Three factors were controlled for: *gender*, *intergroup differentiation* (EG vs CG), and *intervention* (repeated measures factor). We used Wilk's Λ and η_p^2 to interpret multidimensional statistical results. When statistically significant differences were observed, ANOVA with detailed comparisons of *post-hoc* tests (Tukey's HSD tests) was used. Statistical significance was set at α=.05. We used Statistica version 13.0 (StatSoft Polska, Cracow, Poland) for data analysis.

Results

Descriptive statistics of variables for the EG and CG *pre*- and *post*- intervention are presented in Table 1 and Table 2.

The pre-intervention MANOVA showed no statistically significant variation (group x gender interaction effect; Λ=.87, F=1.3, p=.20, η_p^2=.13) between the EG and CG (both boys and girls). Thus, the groups had a similar initial level in terms of body composition and aerobic and motor performance.

The MANOVA with repeated measures confirmed statistically significant changes in the variables following 10 weeks of the intervention (Λ=.43, F= 12.500, p=.000, η_p^2=.566). The *intervention* factor explained 57% of parameter variability. There was a statistically significant interaction of the first order of the *intervention* and *intergroup differentiation* factors (Λ=.77, F=2,800, p=.001, η_p^2=.228), meaning both factors were modified by their interaction and produced different results between the EG and CG. To identify the gender subgroups that showed differences in individual variable results, the second-order interaction of *intervention*, *intergroup differentiation*, and *gender* factors was analyzed. This interaction was statisti-

Table 1. Changes in body composition, aerobic performance, and motor performance before and after the 10-week intervention in boys; data are M±SD, skewness

Variables	Experimental group		Control group	
	Pre	Post	Pre	Post
BW [kg]	65.24±13.67, 1.41	63.81±11.81, 1,43	65.69±10.89, 0.85	66.87±11.34, 0.93
BMI [points]	20.90±3.92, 1.67	20.44±3.19, 1.33	20.89±2.96, 1,10	21.21±3.10, 1,17
WHR	0.83±0.06, 1.44	0.81±0.05, 1.53	0.82±0.05, 1.55	0.82±0.06, 1.44
FAT%	15.67± 7.03, 1.22	13.90±6.14*, 1.02	14.78±6.74, 1.89	14.11±7.38, 1.68
PEI [points]	42.96±4.23, 0.68	46.57±4.27*, 1.51	43.41±4.03, 0.03	43.84±2.20, -0.60
HST [kgF]	44.61±7.90, 0.57	44.71±7.40, 0.27	42.10±7.24, 0.48	44.05±7.57, 0.54
AbS (n)	26.19±3.58, -0.14	27.48±3.73, -0.19	26.38±3.58, -0.98	30.10±5.08†, 0.28
Flex (n)	21.58±7.53, -0.64	23.29±8.29, -0.45	23.95±8.59, -0.04	25.98±8.57, -0.14
Ag [s]	10.08±0.55, 0.79	10.25±0.78, 0.88	9.92±0.81, 1.63	10.05±1.11, 1.23
VJ [cm]	57.35±9.43, -0,55	54.35±8.37, 0.04	55.62±7.65, 0.25	55.21±9.39, -0.33

Note. *Pre* – the first examination before the intervention, *post* – the second examination after 10 weeks of the intervention, BH – body height, BW – body weight, BMI – body mass index, WHR – waist-hip ratio, FAT% – fat percentage, PEI – physical efficiency index, HST – handgrip strength test, AbS – abdominal strength, Flex – flexibility, Ag – agility, VJ – vertical jump, *post-hoc* Tukey's test results: * p≤.05, # p<.01, †p<.001.

Table 2. Changes in body composition, aerobic performance, and motor performance before and after the 10-week intervention in girls; data are M±SD, skewness

Variables	Experimental group		Control group	
	Pre	Post	Pre	Post
BW [kg]	56.08±7.48, 0.68	56.22±7.71, 0.69	57.27±12.23, 1.63	57.43±12.26, 1.61
BMI [points]	20.57±1.93, 0.07	20.62±2.01, -0.01	21.24±3.83, 1.68	21.30±3.87, 1.63
WHR	0.85±0.05, 0.65	0.85±0.05, 0.41	0.85±0.05, 1.01	0.86±0.07, 1.22
FAT%	26.72±4.92, 0.57	26.57±5.23, 0.34	28.77±6.14, 0.56	27.81±7.46, 1.14
PEI [points]	42.17±5.47, 0.61	47.17±5.10†, 0.58	44.34±5.58, 0.10	43.50±3.77, 0.52
HST [kgF]	31.31±4.28, 0.28	31.86±4.66, -0.09	32.09±6.23, 1.42	33.28±6.66, 0.94
AbS (n)	19.29±4.79, 0.22	23.26±4.27†, -0,68	20.57±3.55, 0.19	22.49±3.65#, -0.22
Flex (n)	27.20±6.06, 0.14	28.80±6.13*, -0.13	26.28±6.85, -0.32	28.39±8.09†, -0,76
Ag [s]	11.42±0.78, 0.42	11.56±0.70, 0.72	11.24±0.78, 0.77	11.43±0.74, 0.43
VJ [cm]	41.64±6.63, 0.17	41.83±6.77, 0.64	43.32±5.93, 0.69	43.14±6.46, 0.53

Note. *Pre* – the first examination before the intervention, *post* – the second examination after 10 weeks of the intervention, BH – body height, BW – body weight, BMI – body mass index, WHR – waist-hip ratio, FAT% – fat percentage, PEI – physical efficiency index, HST – handgrip strength test, AbS – abdominal strength, Flex – flexibility, Ag – agility, VJ – vertical jump, *post-hoc* Tukey's test results: * p≤.05, # p<.01, †p<.001.

cally significant (Λ=.81, F=2.30, p=.01, η_p^2=.19) and indicated differentiation in individual parameters between the four subgroups.

A series of ANOVAs identified variables that contributed to the changed *post*-intervention measurement (Table 1**,** Table 2). The comparison of results *pre*- and *post*- intervention revealed statistically significant effects of TAP on body fat percentage and physical fitness improvement in EG boys, who reduced body fat by 1.77% (p<.05). They significantly improved their PEI score by 3.61 points (p<.05, Table 1). Among EG girls, there was a statistically significant improvement (by 5 points) in physical capacity (p<.001, Table 2). Interestingly, motor ability test results also improved in some groups: abdominal muscle strength in EG girls (by 3.97, p<.001), CG girls (by 1.92, p<.01), and CG boys (3.72, p<.001). Changes also occurred in girls' flexibility; in EG girls, flexibility was improved by 1.6 cm (p=.04) and by 2.11 cm in CG girls (p<.001).

Discussion and conclusions

The study was mainly expected to achieve effects related to body weight and its components and the cardiovascular system. Detailed analysis of *post-hoc* tests confirmed a significant reduction of body fat and physical capacity improvements in EG boys and girls versus CG peers.

Similar results were obtained by Engel, Engel, Ackermann, Chtourou, and Sperlich (2018), who found improvements in certain aerobic and anaerobic performance variables in athletes aged 8–18 years following a HIIT training protocol. Favorable changes in aerobic and anaerobic capacity development in young female volleyball players were documented by Afyon et al. (2018) following six weeks of TAP participation. Furthermore, Cvetković et al. (2018) observed an insignificant reduction in body fat and a physical performance improvement in 11 to 13-year-old boys after their participation in a 12-week HIIT training program. In 14-year-olds in PE classes, Racil et al. (2016) found reduced body fat and improvement in maximal oxygen uptake and maximal aerobic speed following 12 weeks of HIIT or moderate-intensity interval training programs. Additionally, Camacho-Cardenosa et al. (2016) compared changes in 11-year-olds following a HIIT program and found increased fat mass percentage in the CG. However, there was no significant increase in body fat in the EG, which can be considered a positive result.

Therefore, the present study confirms the importance of HIIT protocols in physical activity aimed to reduce adolescents' body fat and improve their physical capacity. Regarding body composition (BMI or fat mass percentage), these changes may be minor, which may be because total energy expenditure is limited during interval training (Cvetković, et al., 2018). However, the HIIT training effect size may depend on training sessions frequency (Weston, et al., 2014). In the current study, Tabata exercises were used during one out of three weekly PE lessons, since the aim was to attract students' interest to this physical activity that can complement regular programs implemented in schools. Moreover, a short-term, intense exercise can cause positive changes in HF-R components in students. Furthermore, male adolescents respond more quickly and to a greater extent to external factors, like the high-intensity training used in our study (Silva, Rodrigues, Clemente, Bezerra, & Cancela Carral, 2019); in girls, however, body fat is more stable (Pulit, Karaderi, & Lindgren, 2017). No changes in girls' body fat might also have depended on their exercise involvement.

Boys tend to be more motivated during physical exercise. Girls after puberty are reluctant to start and fully engage in physical activity (Whitehead & Biddle, 2008). Despite PEI improvements observed in girls, this could have translated into insignificant body fat changes.

Because of the TAP, changes also occurred in EG girls in motor tests measuring abdominal strength and flexibility. However, similar changes occurred in CG girls. Therefore, it is not possible to state that Tabata exercises were critical to developing abdominal strength and flexibility, because changes could have come from different activities performed by all the first-year secondary schoole students in other PE classes.

Both groups of boys showed an improvement in strength after 10 weeks, despite the fact that significant changes occurred only in abdominal strength of CG. It may be a proof of the different pace of strength development in young boys. At the same time, it is difficult to identify the factors of power development, which may be largely determined by the sexual maturation of peasants (García-Baños, Rubio-Arias, Martínez-Aranda, & Ramos-Campo, 2020).

TAP has proved very safe for young people implementing the PE program. No one has reported any adverse effects or injuries resulting from participation in this form of exercise (Weston, et al., 2014).

A study limitation is that participants were local youths; students from other geographical locations may have different physical fitness characteristics/ preferences and be involved in other forms of physical activity. Therefore, similar studies are needed in different countries to evaluate TAP's usefulness during PE lessons in improving physical fitness and preventing overweight and obesity. Furthermore, participants' motor activity in their free time was not monitored (apart from *pre*- and *post*- intervention instructions).

Another important factor involves controlling for sexual maturation, which could have affected our results' consistency with previous studies. Sexual maturation can greatly affect metabolic outcomes, so considering puberty's effect on metabolism is important for results' validity (Camacho-Cardenosa, et al., 2016).

Moreover, research on the effectiveness of intervention interval protocols included in PE classes should also consider nutritional aspects.

The study was limited to a 10-week exercise intervention because *pre*- and *post*- measures needed to be completed during one school term. Future research could investigate effects of HIIT dose-response over a longer duration or with a higher weekly frequency (Zapata-Lamana, et al., 2019). Moreover, similar studies are needed to evaluate the sustainability of the intervention. It is also necessary to consider individual variability when determining exercise intensity and average HR (HR max) during HIIT exercises.

In conclusion, we found the program used in the study to be effective, but it should be individualized to consider sex differences. For example, exercise to increase muscle mass is a common motivator for boys to exercise, but they act as a motivation barrier to girls' activity (Casey, Mooney, Smyth, & Payne, 2016). In addition, excessive sweating during exercise can discourage girls from doing them (Cowley, et al., 2021). Moreover, individual monitoring of the heart rate in real time during exercise would allow for immediate response in case of intensity reduction. This would increase the effectiveness of the intervention program. The hypothesis was partially confirmed. The TAP improved physical fitness and reduced body fat, but only in boys; in girls, only physical capacity was improved. It is necessary to examine why changes did not occur in girls' body fat. Second, the sustainability of the induced changes is worth analyzing, making it advisable to repeat the tests after a certain time. However, PE classes are not enough to reduce obesity among school-age populations. Therefore, familiarizing young people with HIIT protocols and opportunities to perform this training during daily life may contribute to their decision of doing it in their free time, which may offer a viable solution to counter youth overweight and obesity.

This study's findings show that adding TAP to a PE program can produce positive changes in youth physical fitness and help reduce body fat. Exercise frequency may affect the magnitude of changes in HR-F components. In this context, schools may consider implementing a variety of physical activities and between-lesson breaks to promote physical fitness. A significant advantage is the exercises' availability as well as the fact that a large group can simultaneously perform such high-intensity exercises even in small rooms. Another advantage is that this training is inexpensive and easy to introduce.

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INFLUENCE OF CUPPING TREATMENT ON HIGH-INTENSITY ANAEROBIC PERFORMANCE

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Abstract:

The use of cupping therapy prior to sports events has increased in popularity, with limited evidence to support its efficacy. The purpose of this study was to evaluate the efficacy of dry and wet cupping therapy on subsequent Wingate anaerobic test (WAnT) performance. Twelve trained men participated in this repeated-measures randomized crossover study (age 24.9 ± 4.8 years; body mass index 27.6 ± 14.3 kg.m^{-2}). Participants were familiarized with the ergometer and the Wingate anaerobic test on three separate occasions. They then randomly performed three experimental Wingate tests separated by 48-72 h after either dry cupping (DRY), wet cupping (WET), or no treatment (CON). Repeated measures ANOVA and Pearson's correlation coefficient were used to analyze data and determine the relationships between WAnT and peak lactate and heart rate (HR). Peak power (PP), mean power (MP), and fatigue index (FI) were similar in all treatments (p=.47-.72). Heart rate (HR) and lactate increased similarly at all time points in all treatments (p<.001 for all comparisons). Post-WAnT peak HR was moderately negatively correlated with PP in all treatments and MP in CON only (p<.05 for all correlations). No other significant correlations were detected. The present findings demonstrate no beneficial effects of wet and dry cupping therapy, and hence do not support its use prior to high-intensity anaerobic sports events.

Key words: *Wingate test, anaerobic power, fatigue, sprint cycling, all-out exercise performance, bloodletting cupping*

Introduction

Cupping is a complementary and alternative therapy used worldwide in various clinical conditions for the management of pain and wellbeing (Al Bedah, et al., 2016). The main forms of this therapy include dry and wet cupping, and both involve negative pressure applied through a vacuum mechanism at selected skin sites. The negative pressure causes upward distraction of the skin and the underlying tissues. Additionally, wet cupping involves prior incisions to the superficial skin, which will be followed by cups suction for bloodletting (Al Bedah, et al., 2016; Stephens, Selkow, & Hoffman, 2020; Wang, et al., 2020). Recently, cupping treatment has become more popular in athletic populations as a sports medicine treatment for musculoskeletal disorders, and purportedly for enhancing recovery and maximal effort performance (Bridgett, Klose, Duffield, Mydock, & Lauche, 2018; Cao, Li, & Liu, 2012; Chiu, Manousakas, Kuo, Shiao, & Chen, 2020; Ekrami, Ahmadian, Nourshahi, & Shakouri, 2021). Despite the use of cupping by some athletes in the 2016 Rio Olympics and other sports events, there has been limited evidence to support its efficacy in improving the high intensity exercise performance (Bridgett, et al., 2018).

Cupping is traditionally considered a recovery modality, given that it has been shown to reduce post-exercise inflammatory response and systemic oxidative stress (Ekrami, et al., 2021; Tagil, et al., 2014). The use of cupping is growing as a pre-event strategy, where studies have examined the effects2153 of dry cupping on indices of aerobic fitness, isokinetic strength, balance, and flexibility parameters (Antush, Brilla, Suprak, Watson, & Olinger, 2020; Becerra, Wang, VanNess, & Jensen, 2021; Stoner, Petrizzo, Wygand, & Otto, 2017). Although providing limited benefits on the above performance parameters, cupping has been suggested to improve movement biomechanics through manipulating the fibrous adhesiveness of fascia layers, widely known as myofascial decompression (Okamoto, Masuhara, & Ikuta, 2014; Warren, LaCross, Volberding, & O'Brien, 2020).

Moreover, cupping has been shown to modulate metabolic acidosis, improve muscle oxygenation, blood flow and indices of vascular function (Arce-Esquivel, Cage, Tulloch, & Ballard, 2020; Stephens, et al., 2020; Wang, et al., 2020), and hence demonstrates potential to improve anaerobic exercise performance where metabolic acidosis and inadequate oxygen supply may be limiting factors. Anaerobic capacity is critical for athletic performance in power and team sports including soccer, football, sprinting, speed skating, basketball, lacrosse – and for endurance events particularly at the start- and end-spurts (Noordhof, Skiba, & De Koning, 2013; Scott, Roby, Lohman, & Bunt, 1991). Yet, the authors are unaware of research examining the influence of cupping treatment on anaerobic capacity. Given the emerging use and potential to benefit, it is important to assess the impact of cupping on this type of physical performance.

The aim of this study is to evaluate the effect of wet and dry cupping treatment on the anaerobic function of physically active participants using the Wingate anaerobic test (WAnT). According to the potential positive effects of cupping, we hypothesized that prior cupping treatment would improve subsequent performance and the associated physiological responses during the WAnT.

Methods

Participants

Twelve healthy participants completed all procedures of the study (age 24.9 ± 4.8 years; body height 174.8 ± 5.8 cm; body mass 72.9 ± 7.7 kg; body mass index 27.6 ± 14.3 kg.m^{-2}; % body fat estimated from seven skinfold sites 9.2 ± 2.6%; waist-to-hip ratio 0.8 ± 0.02). Due to the global lockdowns, this was the maximum sample size that could be recruited under the severe pandemic restrictions. A *post-hoc* power analysis for within-factor repeated measures ANOVA revealed a power of 0.83 for the current sample size with a calculated effect size f(V) 1, $\alpha = 0.05$, and nonsphericity correction 1 using G*Power (version 3.1 Kiel, Germany). Participants were involved in high-intensity (3 – 4 days per week, 75 ± 27.9 min per day) and moderate-intensity physical activities (3 – 5 days per week, 63.4 ± 31.1 min per day). Participants were competitive (n = 3) and recreational (n = 7) soccer players, a competitive distance runner (n = 1), and a concurrent training recreational athlete (n = 1). Participants were first screened for cardiovascular, metabolic, and respiratory diseases and/or the associated symptoms and were informed of the benefits and risks of the study before providing a written informed consent. The institutional review board of King Abdullah University Hospital approved the study procedures (GM7601).

Experimental design

The present study utilized a randomized cross-over design to investigate the effect of dry and wet cupping on anaerobic exercise performance test. Participants visited the laboratory on seven separate occasions at the same time of the day; three familiarization sessions, three experimental trials, and a session for wet cupping procedure which was performed 24 h prior to its respective experimental trial (Fig. 1). All participants were familiarized with the cycle ergometer, laboratory setting, and the WAnT during three separate familiarization trials. The 1st familiarization trial included pre-participation health and physical activity screening, as well as body composition examination. This was followed by a 30-min cycling at 70 – 75% HRmax and WAnT. The 2nd familiarization trial included a 30-min cycling at 70 – 75% HRmax followed by the WAnT. The purpose of the 30-min cycling sessions were to extensively familiarize the participants to cycling, due to their limited experience with this exercise modality. The third trial consisted of a single WAnT effort performed with full experimental procedures and measurements. In total, participants performed two 30-min cycling sessions at 70 – 75% HRmax on the 1st and 2nd familiarization trials, and three WAnTs on the 1st, 2nd, and 3rd familiarization trials. Following 72 h from the last familiarization trial, participants were randomly assigned to perform three experimental WAnT trials preceded either by: 1) no treatment, which served as the control trial (CON); 2) dry cupping (DRY); or 3) wet cupping (WET) (Fig. 1). All familiarization and experimental trials were carried out at 22 – 23 ºC between 10:00 and 13:00 a.m., with 48 – 72 h separating each trial. Participants were required to refrain from caffeine, alcohol, and supplements consumption, as well as strenuous exercise 24 h before the day of testing. Further, they were instructed to maintain same sleeping hours, and to replicate food and liquid intake the night before each day of testing. Participants were asked to consume 500 ml of water about 30 min and same type and quantity of fruits at least 2 h prior to reporting to the laboratory.

Wingate test

The WAnT is a reliable 30-second all-out test widely used to assess anaerobic power of athletes in a variety of sports (Ramírez-Vélez, et al., 2016; Zupan, et al., 2009). The WAnT was performed on a mechanically braked cycle ergometer (894 E, Monark, Sweden), with seat and handlebar heights recorded at the most comfortable position and replicated throughout the experimental trials for each participant. The test was preceded by a standard

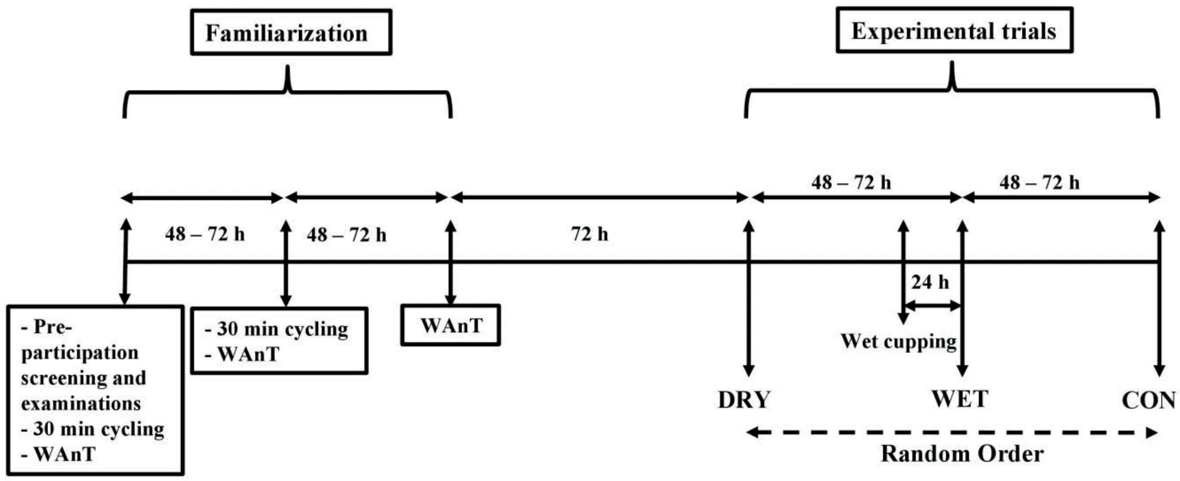

Fig. 1. A summary of the study design.

warm-up protocol of 8-min at 70 – 75% HRmax interspersed by three 5-second sprints at the 3rd, 5th, and 7th minute. Participants rested for 3-min after the warm-up, during which they were free to walk within the laboratory. The WAnT commenced with flying starts, while the participant accelerating for approximately five seconds (unloaded) to achieve maximum cadence before performing an all-out 30-second effort against a braking load corresponding to 7.5% of individual body mass. Strong verbal encouragement was given throughout the test. The resistance was immediately lifted following the 30-second effort, and participants continued pedaling for 1 – 2 min at low intensity. The test was video recorded and analyzed using Kinovea 0.8.15 (Kinovea.org, France) for pedal revolutions. Peak power output (PP), mean power output (MP), and fatigue index (FI) were calculated. PP was identified from the highest mechanical power produced during five consecutive seconds, which was attained during the first five seconds for all the participants. MP was identified as the average power produced during the entire 30-second performance. FI was identified as the percentage drop-off from the PP to the lowest power produced in the last five seconds.

HR and lactate measurements

HR measurement was obtained using a chest belt placed at the xiphoid process level linked to a GPS watch (Polar V800, Polar Electro Oy, Finland). HR was monitored throughout the familiarization trials and warm-up, and recorded at pre-, immediately post-, and 3-min-post WAnT. Capillary blood was collected through a finger prick and analyzed for lactate determination using a hand-held system (Lactate Scout+, SensLab GmbH, Germany) at pre-warm-up, pre-WAnT and at 3-min post-WAnT. All HR and blood lactate measurements were taken with participants seated on the cycle ergometer.

Cupping

Wet cupping (i.e., WET trial) was performed 24 h prior to the WAnT (Fig. 1). Wet cupping procedure followed the three-steps method: cupping, puncturing and cupping (CPC) as previously described in detail (El Sayed, Mahmoud, & Nabo, 2013). Participants first cycled for 10 min at low-moderate intensity before starting the cupping procedure. This short exercise was aimed at increasing blood flow and providing a gradient for the infiltration from blood capillaries at the sites of cupping (Goto, et al., 2007; Pober & Sessa, 2014). The cupping sites were thoroughly disinfected by 70% ethanol. During step 1 of the CPC, five disposable plastic cups were placed on the back of the participant: one cup below the C7 at between the two middle trapezius muscles (Cu1), two cups below the T12 each at the middle part of the latissimus dorsi muscle (Cu2 and Cu3), and two cups at the lower back each above the iliac crest at between the lower part of the latissimus dorsi and the thoracolumbar fascia (Cu4 and Cu5). Suction pressure was first applied at each site using a handpump gun for 5-min. The negative pressure was able to raise the skin surface 2 – 2.5 cm within each cup. During step 2 of the CPC, negative pressure was released and multiple superficial skin incisions, each 6 – 8 mm in length were applied within the diameter of each cup using a stainless steel sterile surgical blade (No. 15). Step 3 of the CPC included the application of suction pressure again as previously described in step 1 for another 10 min for bloodletting. The cupping sites were then cleaned and disinfected with 10% povidone-iodine and left to air dry. A total of 109.2 ± 37 ml of blood was collected during wet cupping and was distributed as follows: Cu1 32.6 ± 13.5; Cu2 32.6 ± 13.5; Cu3 19.6 ± 6.6; Cu4 20.1 ± 11.2; and Cu5 16.6 ± 8.8 ml. The collected blood was discarded once volume was determined.

The dry cupping procedure was similar to the wet cupping procedure, except that the dry cupping did not include skin incisions and bloodletting, i.e., it included only step 1 of the CPC. The suction pressure was applied for 15 min to parallel the total suction duration performed during the wet cupping. Cupping sites were cleaned, and participants immediately started the pre-WAnT warm-up. The participants were seated during both the wet and dry cupping on bar chair without back support. Participants received neutral recommendation towards both cupping procedures, i.e., might positively or negatively impact performance, to avoid any psychological effect of either procedure.

Statistical analysis

Data are presented as mean ± SD. Shapiro-Wilk test was performed to determine normality, to which all variables conformed to normal distributions. One-way repeated measures ANOVA followed by the Tukey's *post-hoc* test was used to detect differences in WAnT performance outcomes between the three trials (CON, DRY, and WET). A two-way (trial and time) repeated measures ANOVA was used for analyzing the HR and lactate results at the allotted measurement time points. When time × trial interaction and omnibus main effects were detected, Student paired *t*-tests were utilized to find the differences at the individual time points. Sphericity assumption was evaluated using Mauchly's *W*. Pearson's correlation coefficient was used to determine the relationship between WAnT performance (PP and MP) and peak lactate at 3-min post-WAnT and maximum HR immediately post-WAnT. The strength of the relationships were classified according to the Pearson's coefficient (r) value as very strong (r ≥ 0.8), moderately strong (r = 0.6 – 0.8), fair (r = 0.3 – 0.5), and poor (r < 0.3) (Chan, 2003). The Statistical Package for Social Sciences (SPSS, Inc., Chicago, IL, USA) was used for all analysis. Significance was set at p<.05. In addition, effect sizes (Cohen's d) were calculated where appropriate to indicate trivial, small, moderate, large, and very large effect when the obtained d was < 0.2, 0.2 – 0.6, 0.6 – 1.2, 1.2 – 2.0, and >2.0, respectively (Al-Horani, Wingo, Ng, Bishop, & Richardson, 2018; Cohen, 1992).

Results

The WAnT performance outcomes for the three conditions are presented in Table 1. There were no significant differences between the conditions for PP (p=.47), MP (p=.72), and FI (p=.53). The effect sizes of treatments were trivial for PP (Cohen's d = 0.05 – 0.13), and MP (Cohen's d = 0.006 – 0.08), and trivial to small for FI (0.06 – 0.2) between any two trials.

The HR responses at the pre-warm-up, pre-WAnT test, immediately post-WAnT, and 3-min post-WAnT were similar for all the trials (Fig. 2). There was no significant effect of treatment (p=.06) and treatment x time interaction (p=.3) on HR responses. Not surprisingly, there was a significant increase in HR across time in all the trials (p<.001) where HR was similar at the pre-warm-up for all the trials (p=.2) and increased similarly at all the time points during and following WAnT (p<.001 for all comparisons). The effect size of treatments was trivial to small at the pre-warm-up (d = 0.05 – 0.6), and small at the pre-WAnT (d = 0.3 – 0.6), post-WAnT (d = 0.2 – 0.6), and 3-min post-WAnT (d = 0.2 – 0.5) for all the between treatments comparisons.

Figure 3 shows the lactate responses to the three trials. There was no significant treatment (p=.46) or treatment x time interaction (p=.99) effect on lactate responses; however, there was a significant time effect (p<.001). Blood lactate was significantly elevated after the warm-up and peaked at the 3-min post-WAnT compared to baseline (p<.001 for all the trials at pre-WAnT and 3-min post-WAnT). The effect size of treatment was trivial to small at the pre-warm-up (d = 0 – 0.5), and trivial at the pre-WAnT and 3-min post-WAnT (d = 0.05 – 0.1) for all the comparisons.

A moderate negative correlation was detected between PP and post-WAnT HR during all the trials (Table 2). However, only CON demonstrated

Table 1. WAnT performance outcomes (mean ± SD), peak power (PP), mean power (MP), and fatigue index (FI), following control (CON), dry cupping (DRY), and wet cupping (WET)

	CON	DRY	WET
PP (W)	772 ± 86	767 ± 91	778 ± 76
MP (W)	565 ± 56	565 ± 65	570± 63
FI (%)	48 ± 5	45 ± 11	47 ± 7

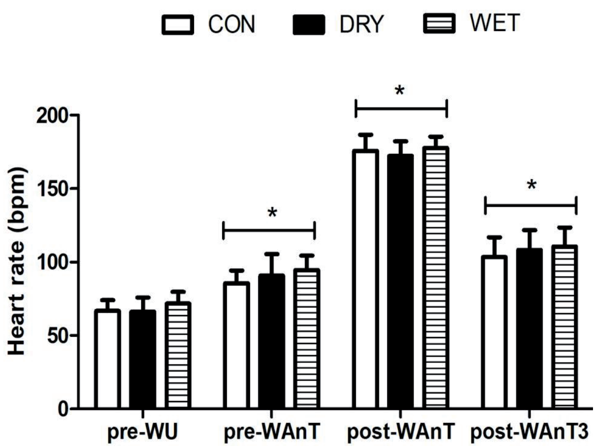

*Fig. 2. Heart rate changes from prior to warm-up (pre-WU) to immediately before commencing the WANT (pre-WAnT), immediately after the WAnT (post-WAnT), and to 3-min after finishing the WAnT (post-WAnT3) during control (CON), dry cupping (DRY), and wet cupping (WET) trials. * Significant difference from pre-WU in all conditions at p<.05.*

Table 2. The Pearson's correlation coefficients (r) for WAnT outcomes, peak power (PP) and mean power (MP), and the HR immediately post- and lactate 3-min post-WAnT for control (CON), dry cupping (DRY), and wet cupping (WET)

	CON		DRY		WET	
	PP (W)	MP (W)	PP (W)	MP (W)	PP (W)	MP (W)
Heart rate (bpm)	-0.77*	-0.66*	-0.62*	-0.21	-0.65*	-0.51
Lactate (mmol/L)	-0.15	-0.18	0.30	-0.51	0.40	0.43

* Significant correlation at p<.05

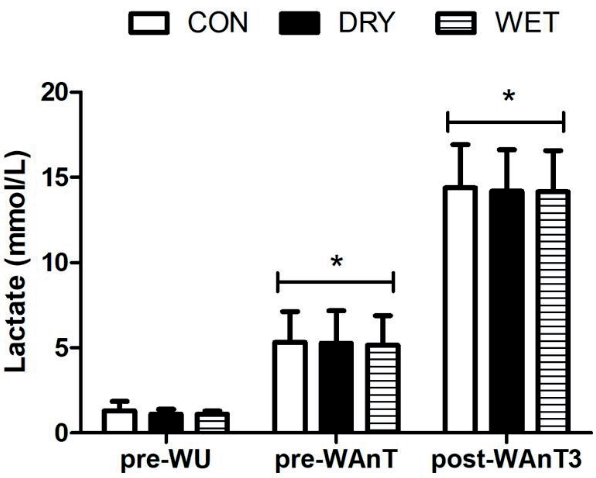

*Fig. 3. Blood lactate changes prior to warm-up (pre-WU) to immediately before commencing the WAnT (pre-WAnT), and to 3-min after finishing the WAnT (post-WAnT3) during control (CON), dry cupping (DRY), and wet cupping (WET) trials. * Significant difference from pre-WU in all conditions at p<.05.*

a significant moderate negative correlation between MP and post-WAnT HR. No significant correlations were observed for lactate with PP and MP.

Discussion and conclusions

The present study investigated the effect of pre-exercise dry and wet cupping on the anaerobic performance during a 30-second all-out Wingate anaerobic test. There was no influence of dry or wet cupping on PP, MP, FI, or lactate and HR responses during WAnT performance. We hence conclude that cupping therapy prior to short-term all-out high-intensity exercise confers no ergogenic effects.

Cupping has been purported to enhance exercise performance through facilitating myofascial decompression, increased vascular function and tissue oxygenation, and reduced inflammatory response and oxidative stress (Antush, et al., 2020; Becerra, et al., 2021; Ekrami, et al., 2021; Stephens, et al., 2020; Stoner, et al., 2017; Tagil, et al., 2014). Accordingly, despite the increasing use of cupping therapy prior to sports events (Bridgett, et al., 2018; Musumeci, 2016), there is limited research examining of the efficacy of this modality on anaerobic exercise performance. The present study demonstrates no performance or physiological benefit when dry or wet cupping therapy is performed prior to a WAnT effort. Our findings contribute to the literature demonstrating minimal beneficial effects of dry cupping on various physical performance indices such as muscle strength and power, running economy, maximal oxygen uptake and range of motion (Antush, et al., 2020; Becerra, et al., 2021; Stoner, et al., 2017; Wygand, Stoner, Petrizzo, & Otto, 2017). In addition, the effect of wet cupping on subsequent anaerobic performance was lacking within the literature, to which we have provided preliminary evidence.

Blood lactate and HR responses to WAnT were not altered following cupping treatment compared to the control. Our findings somewhat contrast the purported physiological mechanisms surrounding cupping therapy, including modulating metabolic acidosis, decreased oxidative stress, enhanced mitochondrial function, and increased oxygen availability and utilization (Arce-Esquivel, et al., 2020; Dun, et al., 2015; Ekrami, et al., 2021; Hofmann, et al., 2007; Powers & Jackson, 2008; Tagil, et al., 2014). Consequently, these were plausible mechanisms that could modify the physiological responses to the anaerobic exercise, to which the present study reports no beneficial effects based on HR and lactate responses. Possibly, these suggested mechanisms underpinning cupping therapy are either rapidly transient or site specific. More investigations are highly warranted to further explore the physiological impacts of cupping therapy.

The correlation coefficients analysis revealed an inverse relationship between MP and peak HR only within CON during WAnT. It is unclear yet why the peak HR – MP relationship remained significantly negative without treatment compared to the cupping therapy. It is likely that cupping might have contributed to changing this relationship through differentially redistributing blood flow during exercise compared with no treatment, since cupping has been shown to induce reactive hyperemia and increase skin blood flow by more than 16 folds (Wang, et al., 2020). Peak blood lactate and WAnT performance outcomes were not related in all the trials. Moreover, negative associations between PP and peak HR were observed for all the trials. In contrast to our findings, lactate and HR were previously found to positively relate to power output during a repeated force-velocity exercise (Temfemo, Carling, & Ahmaidi, 2011). However, the repeated force-velocity exercise involved repeated 6-second sprints with increasing load every repetition, and every two repetitions were interspersed with a long recovery period (5 min). Thus, comparison between these responses with the responses during a single 30-second all-out sprint performed under constant load during the WAnT is not appropriate. Therefore, establishing relationship patterns between the physiological responses and performance outcomes in a single all-out anaerobic sprint are warranted in different athletic populations.

The authors are highly confident of the reliability and validity of the current findings, given that WAnT has been shown to retain a very high test-retest reliability (intraclass correlation coefficient > 0.98, > 0.97, > 0.95, 0.93, and 0.94% for PP, MP, FI, peak heart rate, and lactate responses, respectively) using a range of braking forces (7.5 – 11% of body mass) on mechanically- or electromagnetically-braked cycle ergometers (Bringhurst, Wagner, & Schwartz, 2020; Jaafar, et al., 2014; Watt, Hopkins, & Snow, 2002; Weinstein, Bediz, Dotan, & Falk, 1998). Reliability has been shown to improve further when adding a practice session prior to baseline measurement, suggesting that a minimum of one full familiarization trial is required to increase the reliability of power output (Barfield, Sells, Rowe, & Hannigan-Downs, 2002; Bringhurst, et al., 2020). In our study, there were three 30-second all-out cycling practice sessions, during which full experimental procedures were undertaken with one of them. Additionally, stringent measures were adhered to prior to all the experimental trials to determine and isolate whether cupping therapy will be an effective strategy to enhance anaerobic performance. These included replicating sleeping hours, food and liquid intake, the time-of-day of testing, abstinence from potential ergogenics, alcohol and intensive exercise, many of which have been shown to influence WAnT performance (Grgic & Mikulic, 2021; Souissi, Sesboüé, Gauthier, Larue, & Davenne, 2003). In addition, to eliminate the psychological effect of the cupping therapy, neutral feedback was given to the participants regarding the treatments' efficacy. Therefore, we are confident that dry and wet cupping treatment provided no beneficial performance effect on the Wingate anaerobic performance and associated physiological responses when administered within 24 h or less.

Limitations

It might be argued that the cupping sites were not at the major muscle groups involved in cycling. While previous work have reported localized effects such as increased tissue oxygenation, hyperemia and myofascial decompression (Arce-Esquivel, et al., 2020; Stephens, et al., 2020; Warren, et al., 2020), it is not certain whether systemic effects are evident with cupping therapy. Nevertheless. previous reports have shown no additional effects of cupping therapy on a subsequent exercise performance compared to no treatment when cupping was applied at the major body sites involved during the exercise (Antush, et al., 2020; Becerra, et al., 2021; Stoner, et al., 2017). Further, this study did not measure the physiological biomarkers related to the potential mechanisms of cupping therapy, such as inflammatory cytokines, oxidative stress, and tissue oxygenation, which may assist in identifying future directions in cupping and exercise research. The current procedure, therefore, could not identify how long the effects of cupping lasted after the treatment on these biomarkers, if there were any. It might be speculated that the effects of cupping remained until the following trials, and the results could be confounding. The authors, however, are unaware of any study that determines the long-lasting effects of cupping on performance-related factors in healthy subjects. Nonetheless, the randomization of trials may have helped in ameliorating this suspicion and eliminating the bias that may result from treatments order. One more limitation that might be argued about was different time gaps between the cupping treatment and exercise testing in WET and DRY. Dry cupping has been shown to induce immediate effects on factors that might be related to performance such as increased blood flow and reduced muscle stiffness (Jan, et al., 2021; Wang, et al., 2020). It seemed appropriate that the performance task was undertaken soon after the cupping procedure. On the other hand, wet cupping has been reported to confer delayed effects that may last >12 hours post-treatment, such as increased arterial O_2 saturation (Hekmatpou, Moeini, & Haji-Nadali, 2013). Importantly, exercise immediately following the wet cupping was reportedly unwanted amongst our athletes during piloting due to the unpleasant marks, skin incisions and blood loss. Nevertheless, investigating the time gap effect between cupping treatment and exercise testing is warranted in future studies.

The present findings demonstrate no beneficial effect of pre-exercise dry and wet cupping therapies on anaerobic performance outcomes and the associated physiological responses. Anaerobic performance is critical for power and team sports including – soccer, football, sprinting, speed skating, basketball, lacrosse. Therefore, coaches and practitioners working with team or power athletes are not encouraged to use cupping therapy prior to sports events. However, athletes may still wish to use cupping treatment for recreational or therapeutic purposes before such events. Our findings demonstrated no detrimental effect resulting from cupping therapy, and hence athletes may opt to continue with this therapy if it is part of their standard routine procedure or if they perceive an ergogenic benefit.

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VARIABILITY IN PERFORMANCE INDICATORS OF THE NETHERLANDS WOMEN'S NATIONAL HANDBALL TEAM AT THE 2019 WORLD CHAMPIONSHIP

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Abstract:

The primary objective of this study was to discover the positional attack performance indicators of the winning Netherlands women's national handball team during the 2019 World Championship in Japan. An ideographic, follow-up and multidimensional observational design was used to record and analyse positional attacks disputed in equal numbers of players (6v6) excluding attacks with an empty goal. Polar coordinates allowed us to determine behaviour patterns as well as performance indicators related to attack continuity, situations used to destabilise the opponents' defence, and actions involved in completing the attack. Two levels of analysis were used: each match individually and all the team's matches as a whole. Results show that each match had its own specific game dynamics as different behaviour patterns were activated and different performance indicators were observed depending on the match. These findings highlight the variability and dynamic nature of the offensive behaviours and performance indicators of the world champion team, emphasising the need to study performance indicators with research projects that respect that they are specific and changing.

Key words: *match analysis, behaviour patterns, polar coordinates analysis*

Introduction

Performance indicators are diverse variables; examples of these are technical, tactical or strategic aspects which are associated with achieving sporting success. They not only report variables that facilitate winning a specific match or championship, but also shed light on successful behaviours in the different phases of the game (Higham, Hopkins, Pyne, & Anson, 2014). Performance indicators therefore set winning teams apart from the rest, creating performance profiles that athletes aspire to. In handball, access to performance indicators has provided valuable information on the game dynamics in a given championship or on the evolution of the game, after comparing data from different championships (Prieto, Gómez, & Sampaio, 2015).

Obtaining performance indicators is therefore of great interest to coaches and researchers. Two research approaches can be differentiated when reporting on performance indicators in handball: static and dynamic (Prieto, et al., 2015). The static approach is the most common and also the least complex; it only analyses some actions during the match, mainly when a team loses the ball, such as shots and turnovers. Static research is based on the analysis of data obtained at the end of one or more matches, being used in other team sports such as basketball or volleyball (Sampaio, Ibáñez, & Lorenzo, 2013). It mainly analyses behaviours of different teams competing in the same championship, whether the men's world championship (Gruic, Vuleta, & Milanović, 2006; Ohnjec, Vuleta, Milanović, & Gruić, 2008; Srhoj, Rogulj, Padovan, & Katić, 2001; Vuleta, Milanovic, & Sertic, 2003), Olympic Games (Montoya, Moras, & Anguera, 2013) or European leagues (Rogulj, Srhoj, & Srhoj, 2004). Also, some studies using this approach also compare performance indicators obtained from different championships (Meletakos & Bayios, 2011; Meletakos, Vagenas, & Bayios, 2011; Volossovitch, Dumangane, & Rosati, 2010). Nevertheless, scientific knowledge regarding women's elite team handball demands is limited, highlighting an important review of the physical and physiological characteristics related to women's team handball players' performance (Manchado, Tortosa-Martínez, Vila, Ferragut, & Platen, 2013).

Research projects carried out using the static approach have paid a lot of attention to completing of attacks; they focus on analysing what happened, paying little attention to how it happened. Consequently, some elements with a decisive influence on game development (score, playing time, opponent actions, tactical means used, etc.) are not taken into account (Sampaio, et al., 2013).

Differently, the dynamic approach pays more attention to game context (Prieto, et al., 2015), studying some elements that decisively condition actions such as systems of play (Lozano, Camerino, & Hileno, 2016), players on the court at a particular time (Flores & Anguera, 2018) or the result and playing time. Behaviours of players are also studied in chronological order to ascertain changes in game dynamics during a match (Lames, 2006; Lames & McGarry, 2007; Russomanno, et al., 2021). Research conducted according to the dynamic approach has used different tools: sequential analysis, polar coordinates analysis, probabilistic analysis and even neural networks.

Whether using a static or dynamic approach, most research projects offer a stable, fixed image of performance indicators, a general rule that winning teams always meet. Furthermore, performance indicators have mainly been obtained by mixing data from multiple matches played with different teams (Lames & McGarry, 2007). This can present certain problems. Firstly, this type of performance indicator does not respect the emerging, dynamic nature of actions in handball. The sport is developed in contexts of great uncertainty, where players rarely face the same situation twice due to complex interactions between the elements present (Balagué & Torrents, 2011). Behaviours of a team in attack are specifically conditioned by multiple elements, for example: characteristics of players, the use of certain game-play systems, the opponent defence system, style of actions at a given time, refereeing style, the score or playing time (Martins, Mesquita, Mendes, Santos, & Afonso, 2021). These factors can also change during a match and throughout a championship. Therefore, considering performance indicators as fixed and stable can be at odds with the dynamic reality of the game. On the other hand, obtaining performance indicators that are equally valid for all teams can be a difficult task: Do all teams have the same ability to take long-range shots, to play with a line player, or to score from the wing? Specific performance indicators must be found for each team, ones which also respect the specific nature of each match (Laporta, et al., 2021).

Likewise, the study of performance indicators must also be consistent with the variability inherent to the actions performed during handball games. That variability is expressed as the ability to adapt a given action to unforeseen changes that occur in a sporting context and as the ability to solve the same game situation in a different way (Correia, Carvalho, Araújo, Pereira, & Davids, 2018). In fact, variability in attacking behaviours is a characteristic of teams that perform well (Corrêa, Bastos, Silva, Clavijo, & Torriani-Pasin, 2020).

For this reason, the primary objective of this study was to discover the positional attack performance indicators of the winning Netherlands women's national handball team during the 2019 World Championship in Japan. Behaviour patterns carried out specifically in each match and also during the overall championship were therefore analysed.

Methods

This study was conducted according to the follow-up/ideographic/multidimensional (F/I/M) observational design (Anguera, Blanco-Villaseñor, Hernández-Mendo, & Losada, 2011): (a) ideographic because behaviour of different handball players was studied who, as members of the same team, worked as a unit; (b) follow-up because various matches were analysed, and also an intra-session follow-up during each match that contributed the frequency and sequence of the behaviours recorded; and (c) multidimensional because several response levels, collected using the observation instrument, were studied.

Participants

Six matches of the Netherlands national team, winners of the 2019 Japan Women's World Handball Championship, were analysed: preliminary round matches: Netherlands—Serbia and Netherlands—Norway; main round matches: Netherlands—Germany and Netherlands—Denmark; the semi-final match: Netherlands—Russia; and the final match: Netherlands—Spain. In total, six out of the ten matches played by the Netherlands national team during the championship were analysed.

The study was conducted in accordance with the ethical principles set out in the Declaration of Helsinki and in accordance with the Belmont Report (1978); neither informed consent nor a review by the relevant ethics committee were necessary since: (a) the study involved observing people in a public setting (sports facility); (b) the people and groups observed had no reasonable expectation of privacy (matches were broadcast around the world); and (c) the study did not involve any intervention by researchers or direct interaction with the individuals studied.

Instruments

Observation instrument

An *ad-hoc* observation instrument was created (Table 1) in order to record the most relevant behaviours in relation to the objectives proposed. A design was chosen that combined the field format with comprehensive and mutually exclusive category systems. This combination leveraged the strengths of both instruments; category systems offer theoretical consistency, while the field format lends flexibility when recording the specific behaviours to be studied (Anguera & Hernández-Mendo, 2013).

The observation units were the positional attacks of the Netherlands national team disputed in equal numbers of field players (6v6), excluding attacks with an empty goal. Positional attack and fast break are the two offensive phases of handball. A positional attack is organised and played against an organised defence. Therefore, each observation unit began at the beginning of the positional attack and ended when the Netherlands team lost the ball (due to a shot taken or a turnover) or following a referee's decision with no change in possession, such as a free throw or throw-in (Lozano, et al., 2016).

The observation instrument was developed in three phases. (1) Two national handball coaches with prior experience in observational studies created an initial version in order to collect the most important behaviours in the different sub-phases of the positional attack: beginning, development and completion (Gruic, et al., 2006; Montoya, et al., 2013). (2) The instrument was then subjected to a caution test (Anguera, 2003), which consisted of recording three matches not included in the sample. This test was used to either add, amend or eliminate criteria and categories from the initial version of the instrument. The caution test was considered passed when no new behaviours were detected in any criteria. (3) The instrument was judged by five experts, univer-

Table 1. Observation instrument

Criteria	Categories
Number (NUM)	Six against six (6v6) / seven against six (7v6) / six against six with empty goal (E6v6) / six against five (6v5) / six against five with empty goal (E6v5) / other (XvX).
Defensive System (SDF)	Defensive system used against the attack: 6:0 (SIX) / 5:1 (AVN) / 4:2, 3:3 or man marking (ABI) / mixed defence (MIX).
Offensive System (SAT)	3:3 offensive system (T33) / One wing moves from its position to the second line player (DEX) / left, right or centre back leaves its position to play as a line player (T24).
Sequence (SEC)	A new sequence begins when play is interrupted (for example, a free throw is called) and possession is not lost: first sequence (SQ1) / second sequence (SQ2) / third sequence (SQ3) / fourth sequence or more (S4M).
Type of main attack (TAF)	A situation involving two or three players trying to destabilise the opponent defence (Figure 1): 2v2 centre back-line player, with the line player between the left and right middle defenders (A34) / 2v2 centre back-line player, with the line player between the middle and half defenders (A45) / 2v2 left or right back-line player, with the line player between the half and middle defenders (A23) / 2v2 left or right back-line player, pairing the line player with the outside defender (A12) / 2v2 left or right back-line player, with the line player between the half and outside defenders (A22) / a situation played by the centre back, left or right back and line player positions, after the wing has moved to the line player position (CLP) / 1v1 by the left or right back with the line player between the middle defenders (LPA) / 3v3 by the left or right back and two line players (LPP) / attempting to destabilise the opponent defence with a situation other than the above (OTR).
Place of main attack (LAF)	Place where team tries to destabilise the defence: left attacking area (ZIZ) / right attacking area (ZDE) / centre (ZCN).
Main attack player (JAF)	A player involved in destabilising situation: number 18 (N18) / number eight (N08) / number nine (N09) / number 79 (N79) / number six (N06) / number 5 (N05) / other (NIN).
Number of passes after the main attack (PAF)	The number of passes after the destabilisation and before the completion: from zero to one pass (P01) / from two to three passes (P23) / four or more passes (P4M).
Crosses and/or swaps after the main attack (XAF)	The number of crosses during the attack, either to destabilise the defence or after it has been completed: zero (X00) / two (XP2) / three or more (X3M).
Place of completion (LFI)	Area where attack is completed: left attacking area (FIX) / right attacking area (FDE) / centre (FCN).
Completing player (JFI)	First line player who completes attack or gives an assist to the winger or line player: number 18 (F18) / number eight (F08) / number nine (F09) / number 79 (F79) / number 6 (F06) / number five (F05) / other (FOT).
Completion action (AFI)	Individual action that completes the attack: action by the line player (PIV) / action by the winger (EXT) / fake or penetration by the first line player (J6M) / a long-range shot or action around the nine-metre line (J9M).
Attack outcome (DFI)	Attack ending in: goal scored, penalty throw or two-minute suspension for a defender (G72) / missed shot (MIS) / turnover (PER) / free throw or other interruption of play with no change in possession (NOL).

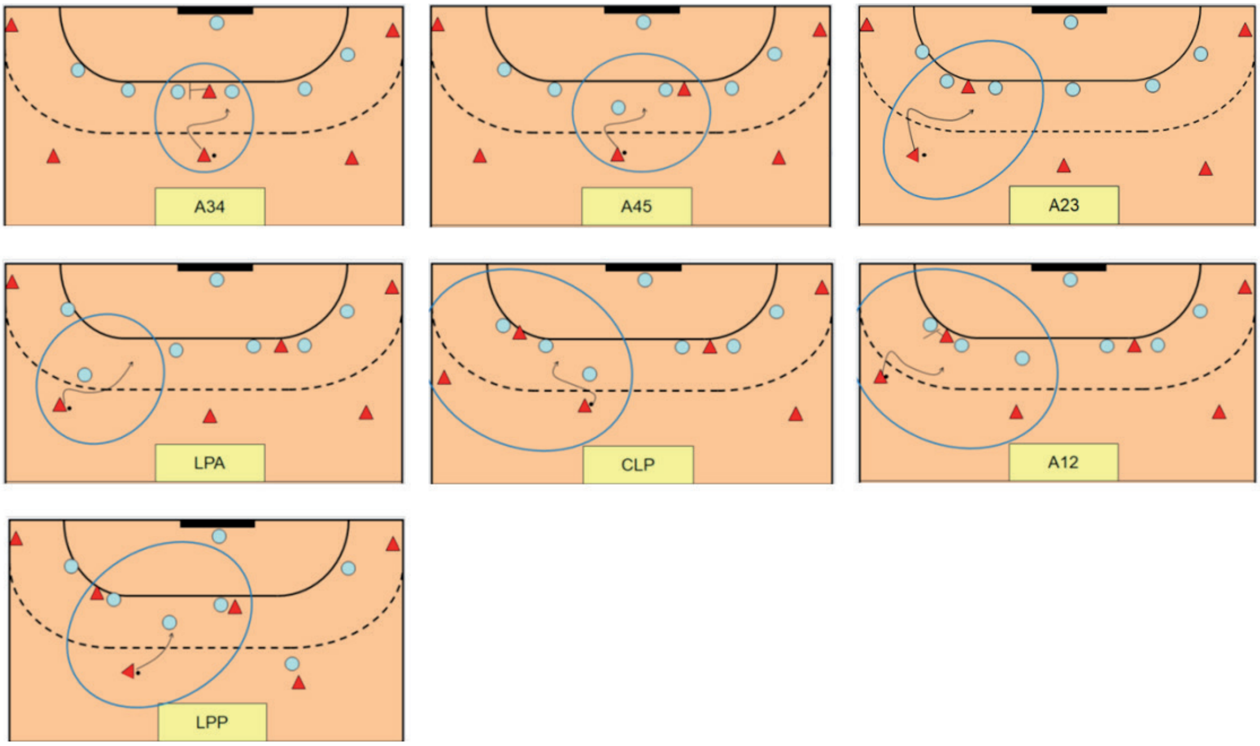

Figure 1. Graphic representation of categories in the 'Type of main attack (TAF)' criterion.

sity handball teachers and national coaches. They filled in a rating template indicating whether they agreed or disagreed with each criterion and category. Finally, all criteria and categories included in the observation instrument achieved a rating of 80% or more, i.e., at least four of the five experts approved them. The final observation instrument consisted of 13 criteria and 60 categories.

Recording instruments

The observation instrument was entered into the Dartfish 5.5. program in order to record and code actions; this software was therefore used as the recording instrument. The polar coordinates analysis was applied using HOISAN 1.2 software (Hernández-Mendo, López, Castellano, Morales, & Pastrana, 2012). Prior to calculating polar coordinates and as a prerequisite, a sequential lag analysis was performed using GSEQ 5.1 software (Bakeman & Quera, 2011); +1 to +5 were considered positive lags for the prospective perspective, and -1 to -5 for the retrospective perspective. Finally, after completing the polar coordinates analysis, significant associations were represented graphically using Snowflake 0.2.

Procedure

Actions were recorded and coded by two observers, handball coaches with experience in observational methodology. Both took part in creating the observation instrument, had experience in observational studies, and were familiar with the recording instrument. To optimise the reliability of their observations, the observers took part in a training process in which they recorded matches not included in the sample. The training process ended when concordance levels over 0.80 in Cohen's Kappa statistic were obtained for all criteria, both at the intra-observer level (a single session recorded by the same observer at two different times 18 days apart), and at the inter-observer level (a single session recorded by the two observers). After the training phase, behaviours in each of the six matches included in the study sample were recorded and coded. Intra- and inter-observer concordance levels were calculated; in both cases a Cohen's Kappa index of over 0.95 was obtained in all criteria. According to Landis and Koch (1977, p. 165), the level of agreement in both tests can be considered 'almost perfect'.

Data analysis

A polar coordinates analysis offers information on behaviour patterns that emerge during the match. This analysis is used in team sports research studies (Castañer, et al., 2016). This analysis means that activation and inhibition associations in the behaviours studied can be represented in graphic form. The behaviours analysed in the polar coordinates analysis take on two roles: focal behaviour, considered to be the generator of relationships, and conditioned behaviour, which are all other behaviours analysed.

A prospective and retrospective lag sequential analysis must be conducted prior to calculation. The same number of lags in both perspectives is considered, from 1 to 5 for prospective and -1 to -5 for retrospective. The prospective perspective reports on conditioned behaviours that are activated or inhibited after the focal behaviour has been performed. In turn, the retrospective perspective reports on conditioned behaviours that activated or inhibited the appearance of the focal behaviour (Anguera, et al., 2011).

After completing the prospective and retrospective sequential analyses, the polar coordinates analysis integrates them using Zsum statistic (Sackett, 1980), a powerful data reduction technique. Each prospective and retrospective Zsum can be either positive or negative. Thus, the combination of signs (+ or -) will determine in which of the four possible quadrants (I, II, III, IV) to place significant associations, those with a radius greater than 1.96 ($p<.05$), between the focal behaviour and conditioned behaviours. Quadrant I indicates a mutually activating relationship between focal and conditioned behaviours; quadrant IV indicates that the focal behaviour activates the conditioned behaviour, yet is inhibited by it; quadrant III shows a mutually inhibiting relationship between the behaviours; and finally, quadrant II points to the focal behaviour inhibiting the conditioned behaviour, while the conditioned behaviour activates the focal behaviour (Anguera, et al., 2011).

Results

Figures 2 and 3 and Tables 2 and 4 show the results obtained after the polar coordinates analysis. Each figure has seven polar coordinates maps that represent significant associations between the focal and conditioned behaviours, one for every single match analysed plus another one that shows the analysed records from the six matches as a whole. Figure 2 shows the behaviour patterns that emerged during attacks in equal numbers with six attackers against six defenders. Therefore, the 6v6 category acted as the focal behaviour while the conditioned behaviours were the rest of the categories of the observation instrument. Associations in quadrants I and IV are represented, i.e., behaviours activated by the focal behaviour. Figure 3 shows the performance indicators, therefore the union of 6v6 and G72 categories acts as the focal behaviour and the other behaviours in the observation instrument are conditioned. Associations in quadrants I and II are represented to ascertain which behaviours took place first and activated offensive success, in attacks developed in equal conditions with six attackers against six defenders.

Behaviour pattern analysis

In Figure 2, the seven maps show how positional attacks with six attackers against six defenders activated (quadrants I and IV) different behaviours related to main attacks and completions. In relation to main attacks, in match Netherlands—Serbia were activated: A23 (2v2 left or right back-line player), LPA (1v1 from the left or right back) and LPP (left or right back attacks with two players at the line player), as well as those right attacking area (ZDE); in match Netherlands—Norway were activated A23 and A45 (2v2 centre back-line player, with the line player between the central and half defenders); in match Netherlands—Germany A23; in Netherlands—Denmark A34 (2v2 centre back-line player, with the line player between the central defenders), A45 and LPP (3v3, with the left or right back and two players in the line player position); in the semi-final match Netherlands—Russia: A45; and in the final match Netherlands—Spain situations A34, CLP (centre back, left or right back and line player playing 3v3 after the wing has moved to the line player position) and LPP were activated. Finally, when the records from all the matches are analysed as a whole, the main attacks A45, LPA, CLP, and LPP were activated.

Regarding completions, in Netherlands—Serbia were activated: completions from the centre (FCN), by the line player (PIV) and by player number 18 (F18); in match Netherlands—Norway completions from the right attacking area (FDE); in match Netherlands—Denmark completions from the central attacking area (FCN); in the semi-final match Netherlands—Russia completions from the centre (FCN) and attacks with two or three passes after the main attack (P23). In the final match Netherlands—Spain were activated: completions from the central attacking area (FCN), from the nine-metre line (J9M) and from six metres (J6M). Finally, when the records from all matches are analysed as a whole, completions from the centre (FCN), by the line player (PIV) and completions involving player number 79 (F79) were activated.

Performance indicator analysis

The behaviours firstly performed that activated success (quadrants I and II) were different in each match. In match Netherlands—Serbia: attacks against a 5:1 defence (AVN) and main attacks LPA and A12 (2v2 pairing the line player with the outside defender). In match Netherlands—Norway: attacks against a 6:0 defence (SIX), main attack A23 and attacks with two or three passes after the main attack (P23). In match Netherlands—Germany there were no behaviours that significantly activated success. In match Netherlands—Denmark: main attack A34 and completions involving players number six (F06) and number five (F05). In the semi-final match: main attacks by player number eight (N08), attacks with no cross or swap (XP0) and attacks with a maximum of one pass after the main attack (P01). In the final match: attacks using the 3:3 system from start to end of the positional

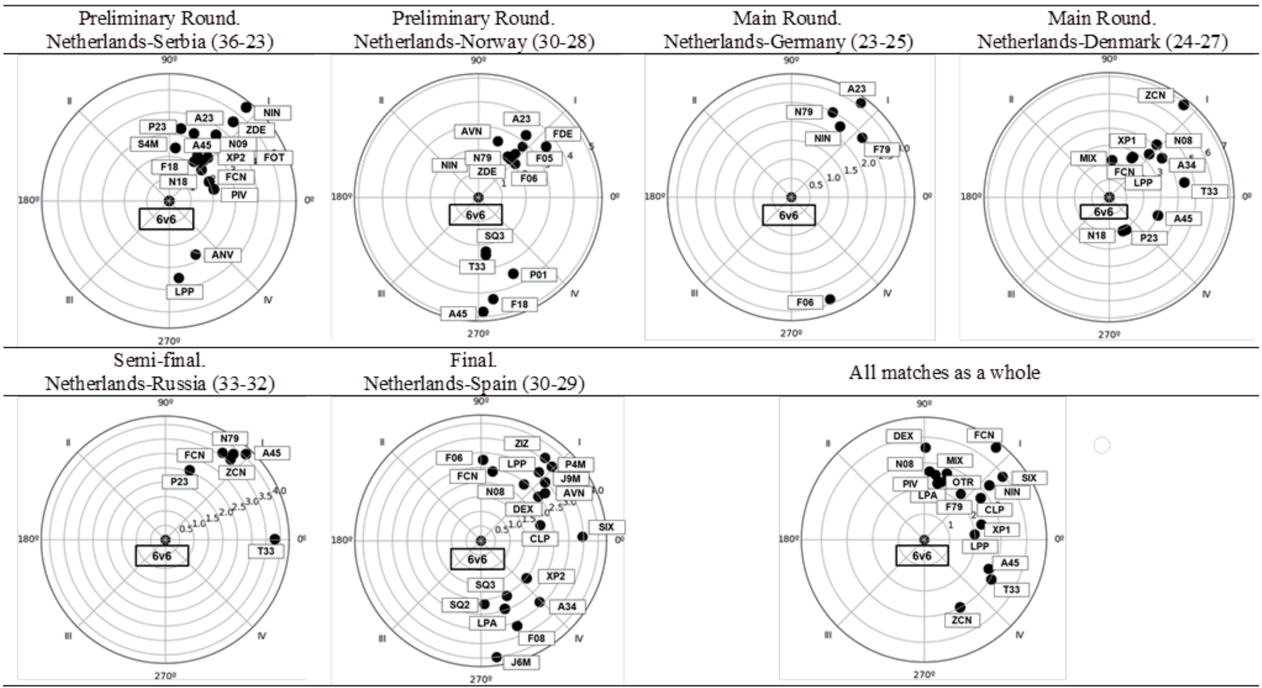

Figure 2. Behavior patterns analysis.

Table 2. Behaviour patterns analysis

Preliminary Round. Netherlands-Serbia (36-23)				Preliminary Round. Netherlands-Norway (30-28)				Main Round. Netherlands-Germany (23-25)				Main Round. Netherlands-Denmark (24-27)			
C.	Q.	R.	A.	C.	Q.	R.	A.	C.	Q.	R.	A.	C.	Q.	R.	A.
S4M	I	2.42	83.61	AVN	I	2.49	70.76	NIN	I	2.27	55.54	MIX	I	2.19	85.52
A23	I	3.24	70.01	A23	I	3.29	52.56	N79	I	2.50	64.27	T33	I	4.44	11.44
A45	I	2.35	50.08	N79	I	2.13	54.30	A23	I	3.10	53.73	A34	I	3.81	36.69
N18	I	2.02	44.18	NIN	I	2.09	49.89	F79	I	2.45	40.14	LPP	I	2.73	59.98
N09	I	3.65	54.73	ZDE	I	2.38	50.00	F06	IV	2.87	290.98	N08	I	4.11	47.94
NIN	I	5.46	50.55	FDE	I	3.56	37.12					ZCN	I	6.88	51.43
ZDE	I	4.61	51.21	F06	I	2.09	42.86					XP1	I	3.42	47.47
XP2	I	2.62	48.28	F05	I	2.84	49.19					FCN	I	2.63	61.09
P23	I	3.31	81.00	F18	IV	4.28	278.23					A45	IV	3.01	339.77
PIV	I	2.08	15.26	T33	IV	2.41	277.61					N18	IV	2.10	291.37
FCN	I	2.00	26.15	SQ3	IV	2.27	277.97					P23	IV	2.11	297.61
F18	I	2.09	57.98	A45	IV	4.79	272.34								
FOT	I	2.40	58.12	P01	IV	3.49	294.47								
AVN	IV	2.55	295.95												
LPP	IV	3.49	227.27												
Semi-final. Netherlands-Russia (33-32)				Final. Netherlands-Spain (30-29)				All matches as a whole							
C.	Q.	R.	A.	C.	Q.	R.	A.	C.	Q.	R.	A.	C.	Q.	R.	A.
T33	I	3.79	0.62	SIX	I	3.46	2.57	SIX	I	3.92	38.78	NIN	I	3.31	40.14
A45	I	4.09	46.94	AVN	I	2.72	36.65	MIX	I	2.74	71.11	XP1	I	2.29	15.00
N79	I	3.79	51.76	DEX	I	2.46	37.93	DEX	I	3.60	89.28	PIV	I	2.58	80.24
ZCN	I	3.59	51.26	CLP	I	2.08	14.80	LPA	I	2.26	79.60	FCN	I	4.55	52.17
P23	I	2.57	70.99	LPP	I	3.07	50.08	CPL	I	2.74	36.75	F79	I	2.29	51.44
FCN	I	3.62	56.74	N08	I	2.41	52.88	LPP	I	1.97	6.06	T33	IV	3.04	329.37
				ZIZ	I	3.58	52.54	OTR	I	2.36	73.39	A45	IV	2.75	335.91
								N08	I	2.69	85.82	ZCN	IV	2.98	297.69

Note. C: category; Q: quadrant; R: radius; A: angle

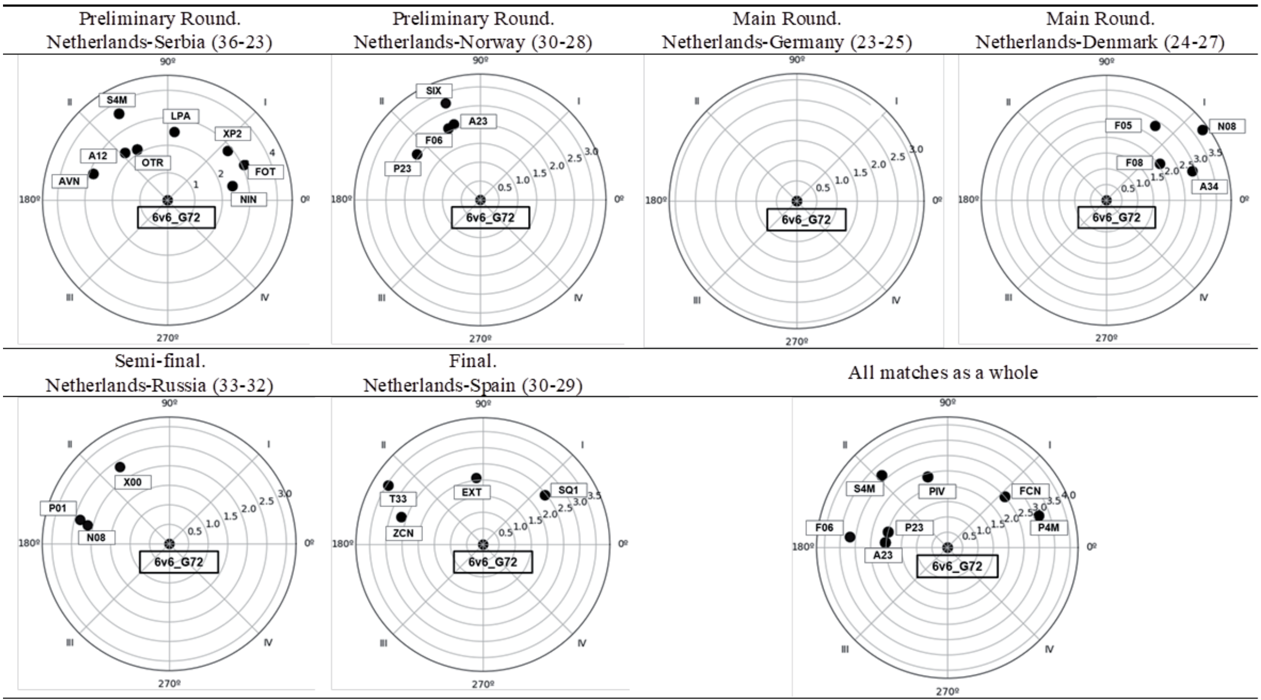

Figure 3. Performance indicators analysis.

Table 3. Performance indicators analysis

Preliminary Round. Netherlands-Serbia (36-23)				Preliminary Round. Netherlands-Norway (30-28)				Main Round. Netherlands-Germany (23-25)				Main Round. Netherlands-Denmark (24-27)			
C.	Q.	R.	A.	C.	Q.	R.	A.	C.	Q.	R.	A.	C.	Q.	R.	A.
LPA	I	2.50	84.19	A23	II	2.13	109.23					A34	I	2.88	18.74
NIN	I	2.43	12.63	P23	II	2.08	144.19					N08	I	3.78	36.35
XP2	I	2.85	39.47	F06	II	2.08	114.30					F08	I	2.06	34.85
FOT	I	3.06	25.03	SIX	II	2.73	109.84					F05	I	2.83	57.07
AVN	II	2.86	160.43												
S4M	II	3.62	119.14												
A12	II	2.16	120.44												
OTR	II	2.32	132.15												
Semi-final. Netherlands-Russia (33-32)				Final. Netherlands-Spain (30-29)				All matches as a whole							
C.	Q.	R.	A.	C.	Q.	R.	A.	C.	Q.	R.	A.	C.	Q.	R.	A.
N08	II	2.15	167.26	SQ1	I	2.45	38.59	P4M	I	3.16	19.30	P23	II	2.00	164.86
X00	II	2.34	122.61	T33	II	3.47	147.99	FCN	I	2.50	42.09	PIV	II	2.40	105.60
P01	II	2.36	164.67	ZCN	II	2.66	161.20	S4M	II	3.18	132.14	F06	II	3.19	173.68
				EXT	II	2.08	95.73	A23	II	2.04	175.34				

Note. C: category; Q: quadrant; R: radius; A: angle

attack (T33), main attacks from the centre (ZCN) and completions from the wing (EXT). Finally, once all the matches were analysed as a whole, the behaviour that activated success were: main attacks A23 and LPA (1v1 on the left or right back), attacks with two or three passes (P23) and attacks with four or more passes after the main attack (P4M), as well as completions from the line player (PIV), in the centre (FCN) and involving player number six (F06).

Discussion and conclusions

The primary objective of this study was to discover the positional attack performance indicators of the winning Netherlands women's national handball team during the 2019 World Championship in Japan. Behaviour patterns carried out specifically in each match and also overall during the championship were therefore analysed. The results of the polar coordinates analysis indicated that the Netherlands national handball team achieved success in different ways and with different styles of play, depending on the demands of each match.

Behaviour pattern analysis

The analysis of the records from all the matches as a whole offered information on overall behaviour trends in the Netherlands team during the championship. With regard to the area from which the main attack was carried out, an activation association was found from the centre. However, the picture was different when analysing each match individually: main attacks were activated from the right in the preliminary round matches, Netherlands—Serbia and Netherlands—Norway; from the centre in the main round match Netherlands—Denmark and the semi-final Netherlands—Russia; while main attacks were activated from the left in the final Netherlands—Spain. These results prove that each match had its own play dynamics, in line with the findings of Lames (2006) and Russomanno et al. (2021).

This divergence is repeated when studying the situations used for the main attack. The following situations were activated when analysing all the championship matches as a whole: A45, LPA and CLP. Different results were found when analysing each match independently: situation A23 was activated in the first three matches of the championship, A34 against Denmark, and LPA only in the final against Spain. These diverging results can be explained by the strategic approach to each match. It is logical that the Netherlands coaching team would select the elements of their game model that allow them to exploit the weaknesses of each opponent. The variety of situations used by the Netherlands team to attack 6:0 defensive systems reinforces the findings of Laporta et al. (2021) when they claimed that teams can be successful using different ways of playing.

Attack completion was less variable as completions were activated from the centre in four out of the six matches. These results coincide with Srhoj et al. (2001), in his research on the 1999 Men's World Handball Championship, who pointed out that the most frequent completions were from the centre of the attack. The use of main attack LPP (left or right back and two line players playing 3v3) could also be considered a team behaviour trend when the opponent uses a 5:1 defensive system as this type of main attack was activated in both matches where this defensive system was used. In view of the results, it seems that the Netherlands team shows greater variability in its offensive behaviours when facing the 6:0 defensive system than against the 5:1 system.

Regarding behaviours related to attack completion, all the matches analysed as a whole showed completions involving player number 79 and completions from the line player position. The results were different when analysing each match individually. Completions from 9 metres and from the 6-metre line were activated in the final, behaviours not activated in any other match. This criteria also shows that the development of each match is different. Therefore, in line with Lames and McGarry (2007), the usefulness of performance indicators obtained from analysing matches as a whole can present some problems.

Performance indicator analysis

As for performance indicators, different behaviours were found related to attack continuity (expressed as the number of passes after the main attack), main attacks and completions activating success. As with behaviour patterns, two types of analysis were conducted: each match individually and all the matches as a whole. The joint analysis found that attacks with two or more passes after the main attack activated success. This does not match the findings of other research (Rogulj, et al., 2004; Vuleta, Sporiš, Purgar, Herceg, & Milanović, 2012), which indicated that winning teams completed short positional attacks. In our research, this is only true in the championship semi-final where success was activated by attacks with a maximum of one completed pass.

In relation to main attacks, joint analysis of records from all the matches found that situation A23 activated success in attack. The same result was found in only one match (Netherlands—Norway) when analysing each match individually. In the Netherlands—Serbia match, situations A12 and LPA acted as performance indicators, while it was A34 in Netherlands—Denmark. These results highlight two issues: (1) the importance of playing with the line player to destabilise the opponent defensive system, in line with Meletakos et al. (2011); and (2) the variety of situations used by the Netherlands national team to destabilise the opponent defence associated with success.

Completions from the centre were associated with success when all the matches were analysed as a whole. The joint analysis also found that completions by the line player came before offensive success, in line with the findings of other studies that emphasise the effectiveness of shots from the six metres in the centre (Srhoj, et al., 2001). As with other performance indicators, these results were not observed when matches were analysed one by one. For example, completions from the wing activated success in the final, coinciding with other research studies (Montoya, et al., 2013; Vuleta, et al., 2003) that associated completions from the wing with winning teams. However, the Netherlands team did not show this result in any other championship match. In this criterion, the Netherlands national team also shows variability in their behaviour typical of elite athletes (Correia, et al., 2020).

Although most research papers on handball have offered fixed and stable performance indicators, this paper has verified that the world champion team does not play in the same way throughout the championship and that its performance indicators vary with each match. It seems logical that the Netherlands national team, and any other team, would change elements of its game model and strategy depending on the demands of each match: to exploit opponent team weaknesses, to surprise and deactivate the opponent's strategy, or due to injuries, penalties or changes in player fitness (Martins, et al., 2021). Therefore, in line with Lames and McGarry (2007), the usefulness of performance indicators obtained by jointly analysing various matches can be problematic as the dynamic and variable characteristics of the sport cannot be reflected. Furthermore, if a given behaviour or game situation is associated with success, this does not mean that it should be repeated continuously, as there is a risk of attacks becoming predictable and helping the defence. This highlights the non-linearity of sport (Balagué & Torrents, 2011) and, therefore, of performance indicators: a behaviour that led to success in one match may not have the same effect in another, not even in another match against the same opponent as the opponent team may change aspects of its defensive system to counteract them. Likewise, some behaviours that did not initially lead to success may later do it after some adjustments have been made.

Performance indicators obtained after analysing the behaviours of different teams as a whole, in one or more championships, have also served to understand general trends in play at a given time, to understand the effect of any change in regulations, or to observe how the pace of play gradually increases (Meletakos & Bayios, 2010; Volossovitch, et al., 2010). However, for performance indicators to help coaches in their day-to-day, whether to fine tune the design of training programmes or to strategically prepare for a competition, they must be specific to a team. The ecological perspective and from the theory of non-linear dynamic systems help us to understand that, depending on their characteristics and the other elements that condition the game, teams organise themselves in a certain direction, performing the behaviours that are successful for them (Balagué & Torrents, 2011). Consequently, a game-play model design, training process planning and preparation for a competition are specific and original processes for a given team. Behaviour pattern and performance indicator analysis can help to prepare these processes, with information on behaviours in certain situations during the competition (what behaviours are displayed against a 5:1 defensive system, what actions are carried out when the referees threaten to call passive play, what strategies are used at the end of a match with a tied score, etc.). Moreover, not only technical, tactical and strategic performance indicators must be specific but also performance indicators related to physical training as implementing a certain game model has its own demands, different from other game models.

In relation to the objective of this study and taking the results obtained into account, the following conclusions can be drawn:

- The Netherlands national team does not play the same way throughout the championship, varying its behaviours depending on the match.
- Performance indicators are dynamic and variable behaviours; they change according to the match analysed.
- The practical usefulness of performance indicators obtained from analysing various matches together is in doubt.
- Most situations used to destabilise the opponent defensive system include the line player.
- Situations used to destabilise the 6:0 defensive system are more variable than those used against the 5:1.
- Some behaviours offer great stability: completions from the centre.

Although this study provides valuable information on the variability of attacking behaviours and performance indicators of the world champion team, it does have some limitations. It cannot analyse the intrinsic dynamics of each match and, therefore, understand changes in strategy during the match. Nor does it analyse behaviours according to which players are on the court at a given time and occupy key positions, such as the centre back (Flores & Anguera, 2018). Furthermore, the study of behaviour patterns and performance indicators did not take into account the influence of prior actions. If we imagine that during a given match the last two attacks have ended with a pass to the line player, during the next attack, the defence is likely to try to fall back to protect against this action, assuming the risk of conceding a long-range shot. Taking these aspects into account could help future research studies aiming to delve deeper into the variability inherent to performance indicators in handball.

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ANALYSIS OF PHYSICAL ACTIVITY AS A MEDIATOR BETWEEN NON-ERGONOMIC POSITION OF UPPER BODY SEGMENTS AND MUSCULOSKELETAL HEALTH IN BUS DRIVERS

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Abstract:

The number of injuries and accidents at the workplace are constantly rising, and the most pronounced injuries are related to the musculoskeletal health. Numerous studies have revealed that city bus drivers have a high incidence of musculoskeletal pain. The aim of this study was to determine whether physical activity levels might be a mediator between the non-ergonomic position of the body's upper segments and musculoskeletal health in professional bus drivers. The study protocol included the assessment of participants' musculoskeletal health using the Örebro Musculoskeletal Pain Questionnaire, assessment of the non-ergonomic position of the upper body segments when seated by means of the Rapid Upper Limb Assessment, and measuring of the level of physical activity using the Yamax 200 pedometer. The sample consisted of 115 bus drivers, from 40 to 55 years of age, with a minimum work service of 15 years. The relationships among variables were tested using the Spearman correlation coefficient and the Wilcoxon rank sum test to include the selected variables in the multivariate linear regression model. The Box-Cox test indicated the need for logarithmic transformation of the ÖMPQ results used to measure musculoskeletal health, so a log-linear model was used in the regression analysis. The normality of the distribution of the residual regression models was tested by the Shapiro-Wilk test. The main findings of this study indicate that 95.6% of participants reported the presence of musculoskeletal pain and in 24.4% of them a very high risk of the musculoskeletal disorder was observed, which indicated the need for urgent changes. The average number of steps per day was 5,090.8. The physical activity proved (obtained by the regression analysis) as a mediator between the non-ergonomic position of the upper body segments and musculoskeletal health (p=.027). The obtained data may serve as an important argument for designing future public health and kinesiology interventions for the improvement of the health of professional bus drivers.

Key words: *ergonomics, driver's workplace, health, walking*

Introduction

Musculoskeletal health problems are considered to be one of the important groups of disorders that are fully or partially caused by unfavourable working conditions such as repetitive movements, repetitive application of force, static and non-ergonomic body posture and vibrations (NIOSH, 2014) and they often depend on the type of occupation. The available data show that 85% of nurses, 86% of tractor drivers and 83% of bus and truck drivers report disorders in their musculoskeletal system (NIOSH, 2014). Almost 40 years ago, Backman (1983) identified three key categories of health disorders in bus drivers, namely: cardiovascular diseases, gastrointestinal disorders, and musculoskeletal problems. Some of the studies researched only the presence of musculoskeletal pain in bus drivers, without possible impacts of risk factors, and the results showed that about 61% of respondents experienced back pain, about 52% had cervical pain, 48% experienced shoulder pain, 35% had pain in the knee/thigh, and somewhat less than 20% experienced pain in other parts of the body (Grace & Peggo, 2007).

However, some studies indicate the possible reasons for the occurrence of musculoskeletal pain, so they mention the occurrence of localized fatigue of the *erector spinae* muscle, which was observed in bus drivers during prolonged non-ergonomic sitting, as well as the lack of physical activity and ergonomic and psychosocial conditions (Casagrande & Ferreira, 2022; Krogh-Lund & Voss, 1989).

Studies evaluating the non-ergonomic position while sitting have shown that when, due to the workstation discomfort, the body is bent, tilted to one side, twisted in flexion and strained for more than four hours; all these can increase the probability ratio of developing musculoskeletal pain due to the creation of mechanical strain on the spine (Alperovitch-Najenson, Katz-Leurer, et al. 2010; Bovenzi & Zadini, 1992; Bridger, Groom, Jones, Pethybridge, & Pullinger, 2002; De Vitta, et al., 2013; Keyserling, Punnet, & Fine, 1988; Massacessi, et al., 2003; Pynt, Higgs, & Mackey, 2002).

Many authors, encouraged by these indicators, try to explain the risk and preventive factors that could be associated with musculoskeletal health.

Physical activity is one of the preventive factors whose influence has been investigated in numerous studies. Studies have shown that the respondents who had higher levels of daily physical activity also had lower levels of disorders in their musculoskeletal system (Lordan & Pakrashi, 2014; Yarandi, Koohpaei, Arsang-Jang, & Ebrahimi, 2018).

Studies conducted on the impact of physical activity and musculoskeletal health in bus drivers show that musculoskeletal pain is more common in drivers who are not physically active (Alperovitch-Najenson, Santo, et al. 2010, Katz-Leurer, Santo, Goalkeeper, & Kalichman, 2010).

Furthermore, it is important to emphasise the interrelationship between health and physical activity since many studies have established the benefits of physical activity. Thus, the US Department of Health and Human Services (1996) points out that an active and individualized lifestyle has many health benefits and that sedentary habits are associated with an increased risk of numerous chronic diseases and reduced longevity.

Based on the previous research, a study has been designed that examines physical activity as a possible mediator between musculoskeletal health and the non-ergonomic position of the upper body segments at the driver's workplace, which is also an important prerequisite for developing the guidelines for the design of future public health and kinesiology interventions aiming at preserving musculoskeletal health. To our knowledge, this is the first study of this kind dealing with this topic and therefore the results obtained are even more significant, for both science and practice. It is necessary to take the required steps to preserve the health of every human being, especially those in high-risk jobs, such as the occupation of bus drivers.

Methods

Participants

This cross-sectional study was conducted with a sample of professional bus drivers, employees of the Zagreb Electrical Tram (ZET), a public city transportation service of the Croatian capital. The study included male drivers with a minimum service experience of bus driving for ZET of 15 years and it did not include the participants who were under 40 or over 55 years of age. All the drivers were in permanent employment and capable of performing the job of bus drivers. The participants of the study were selected by a systematic random selection. Each bus driver was equally likely to be selected if they met the criteria that were predefined in this research (age, gender, and length of service). The analysis was performed on data collected from 115 bus drivers. All the respondents signed informed consent, participated in the research voluntarily and anonymously, and they could withdraw from the survey at any time.

Procedures

The study used the Örebro Musculoskeletal Pain Questionnaire (ÖMPQ), which was implemented in several scientific studies in various countries (Linton & Boersma, 2003). It was developed to determine possible risks of developing persistent back pain problems. This paper used the usual categorization proposed by Linton and Halldén (1998): ÖMPQ $\leq$ 90: a low risk of long-term incapacity for work, 90 < ÖMPQ $\leq$ 105: a moderate risk of long-term incapacity for work, and ÖMPQ >105: a high risk of long-term incapacity for work. The descriptive analysis of the ÖMPQ questionnaire results included the original ÖMPQ values as well as categorized values in accordance with the described procedures. In the analysis of the interrelationship of ÖMPQ results and other characteristics observed in this study, the original ÖMPQ values were used, i.e., ÖMPQ was used as a continuous variable so as not to lose some of the information that this variable contained, which is inevitable during the categorization process.

To assess the impact of non-ergonomic working conditions on the musculoskeletal system, the method for assessing the condition of the upper limbs was used (Rapid Upper Limb Assessment—RULA). RULA was developed as a measuring instrument to assess the exposure of the workers to non-ergonomic risk factors associated mainly with disorders of the upper segments of the musculoskeletal system that are important in bus drivers. The level of musculoskeletal risk is divided into four score groups, based on points (Mirmohammadi, Mehrparvar, Olia, & Mirmohammadi, 2012): 1 – 2 points: a negligible risk, nothing needs to be done, 3 – 4 points: a low risk, a change may be necessary, 5 – 6 points: a medium risk, further research, immediate intervention needed, and 6 + points: a very high risk, urgent change needed. Also, short interviews with the drivers led to a better understanding of their tasks while driving and the complexity of the job itself.

In this study, physical activity levels of bus drivers were measured using a pedometer that measured the number of steps made in a given time, so exclusively step-based physical activity was monitored. A Yamax 200 pedometer was used, which proved to be stable and suitable for scientific research (Schneider, Crouter, & Bassett, 2004). The respondents wore a pedometer for four days, three working days and one non-working day (due to the specifics of working hours, instead of a weekend day a day off was used) that recorded their number of steps made during the entire measurement period. For the purposes of statistical analysis, the average number of steps per day for each respondent was calculated.

Statistical analysis

The relationships among variables were tested using the Spearman correlation coefficient and the Wilcoxon rank sum test. Based on the results of these tests, variables for inclusion in the multivariate linear regression model were identified. The Box-Cox test indicated the need for logarithmic transformation of the ÖMPQ results used to measure musculoskeletal health, so that a log-linear model was used in the regression analysis. The normality of the distribution of the residual regression models was tested by the Shapiro-Wilk test and graphical review of their distribution. P-values less than or equal to 0.05 were considered statistically significant. Statistical analysis was carried out using the SAS System software package (SAS Institute Inc., North Carolina, USA).

Results

The Örebro Musculoskeletal Pain Questionnaire (ÖMPQ) indicated a moderate or high risk of long-term incapacity for work observed in almost every fifth driver (22 of them, i.e., 19.1%). A low risk of long-term incapacity for work was present in the majority of drivers (93 drivers, i.e., 80.9%) (Table 1).

The majority of respondents, 110 of them (95.6%), reported the presence of musculoskeletal pain. Observing the participants who reported pain, the lower back was the most common area of pain (81 drivers, i.e., 70.4%), followed by the neck (36 drivers, i.e., 31.3%), leg (28 drivers, i.e., 24.3%), shoulders and upper back (24 drivers, i.e., 20.9%) and arms (15 drivers, i.e., 13.0%) (Table 2). Other types of pain usually included problems with hips (seven drivers) and knees (three drivers).

The assessment of exposure of the musculoskeletal system to non-ergonomic upper body postures (RULA) indicated that in the majority of drivers, 66 of them, i.e., 57.4%, a medium risk of the occurrence of musculoskeletal disorders was observed, i.e., the need for immediate intervention was observed; further, in 21 drivers (18.3%) a low risk was observed and in 28 drivers (24.4%) a very high risk of musculoskeletal disorder, which indicated the need for urgent changes at their workplace and of their lifestyle (Table 3).

The level of physical activity was measured by pedometers over four days (three working days and one non-working day). For each participant, an average number of steps per day was calculated. The distribution of the average number of daily steps was analysed in Table 4. The average number of steps per day amounted to 5,090.8 (2,883.3), and the median was 4,809.8 (3,424.0 – 5,937.0).

The results of the regression analysis of the physical activity as a mediator between the non-ergonomic position of the upper body segments and musculoskeletal health are presented in Table 5. The Shapiro-Wilk test indicated an approximately normal distribution of the regression model residual (p-value=.144). White's heteroscedasticity test indicated the homogeneity of the residual variance (p=.131).

Table 1. Distribution of categorized ÖMPQ values

Risk of long-term incapacity for work	ÖMPQ value	N	%
Low	ÖMPQ ≤ 90	93	80.9
Moderate	90 < ÖMPQ ≤ 105	13	11.3
High	ÖMPQ >105	9	7.8

Table 2. Pain in musculoskeletal system according to the affected areas of the body

Pain-affected area of the body	N	%
Lower back	81	70.4
Neck	36	31.3
Leg	28	24.3
Shoulders	24	20.9
Upper back	24	20.9
Arm	15	13.0
Other	14	12.2

Table 3. Distribution of RULA values

Risk level of musculoskeletal disease	RULA	N	%
Negligible risk	RULA < 2	.	.
Low risk	3 ≤ RULA ≤ 4	21	18.3
Medium risk	5 ≤ RULA ≤ 6	66	57.4
Very high risk	RULA > 6	28	24.4

Table 4. The indicators of the distribution of average number of steps per day

Variable	$\bar{x}$	SD	Med	Q1	Q3	Min	Max
Number of steps	5,090.8	2,883.3	4,809.8	3,424.0	5,937.0	965.0	18,331.3

Note. $\bar{x}$ = arithmetic mean; SD = standard deviation; Med = median; Q1 = first quartile; Q3 = third quartile; Min = minimum; Max = maximum.

Table 5. Regression analysis of physical activity as a mediator between non-ergonomic body position and musculoskeletal health (dependent variable is the logarithmic value of the ÖMPQ result)

Variable	Coefficient	Exp (coefficient)	Standard error	p-value	Tolerance	Inflation of variance
Constant	3.080		0.425	<.001		
Number of daily steps (in 000)	0.114	1.121	0.073	.119	0.031	32.236
Posture (RULA)	0.219	1.245	0.071	.003	0.245	4.078
Number of daily steps (in 000) * Posture (RULA)	-0.028	0.973	0.012	.027	0.031	31.807

R^2 = 0.192; Corrected R^2 = 0.170.

Physical activity was shown to be a mediator between the non-ergonomic position of the upper body segments and musculoskeletal health. This was indicated by the interaction between the average number of daily steps and RULA points, which was significant (p=.027). This means that the effect of the upper body segments on musculoskeletal health depends on the physical activity of the drivers – in the case of those who were more physically active, the effect on musculoskeletal health was smaller (based on the ÖMPQ result) as compared to the drivers who were less physically active.

Discussion and conclusions

Our study has found a high incidence of pain in the bus drivers' musculoskeletal system, in as many as 96%, out of which 70.4% of the pain was reported in the lower back and 31% in the neck, followed by 24% of leg pain, 21% of shoulder and upper back pain, and 13% of reported pain sites were arms. The categorization of ÖMPQ values indicated a low risk of long-term incapacity for work in the majority of drivers (81%), while a moderate and high risk of long-term incapacity for work was observed in almost every fifth driver (19%). The average ÖMPQ value was 66.9. The results have shown that physical activity may be a mediator between musculoskeletal health and the non-ergonomic position of the body's upper segments.

Many other studies have also reported a high level of pain incidence in bus drivers. Thus, Netterstrom and Juel (1989) indicate in their study that the incidence of lower back pain was present in 57% of cases among bus drivers. Furthermore, a five-year study by Krause, Ragland, Fisher and Syme (1998), examining over 1,000 Californian drivers of various vehicles, identified 501 injuries to the lower back. The results of more recent studies keep reporting a high rate of incidence of the disorder of the musculoskeletal system in bus drivers, i.e., about 55% (Pradeepkumar, Sakthivel, and Shankar, 2020).

One of the possible explanations for such a high rate of pain in the musculoskeletal system of bus drivers may be associated with uncomfortable and irregular upper segment body postures during long hours of driving. In their studies, the authors report that in bus drivers, uncomfortable/incorrect body postures and asymmetrical body positions when sitting can cause mechanical strain in the spine, and therefore, lower back and neck pain (Grace & Peggo, 2007).

In this study, the RULA method was used for the ergonomic assessment of mechanical and postural load at work the participating bus drivers were exposed to. RULA assesses the exposure of the workers to non-ergonomic risk factors related mainly to the disorders of the upper segments of the musculoskeletal system that are quite important in bus drivers. The majority of drivers (57%) had a moderate risk of developing a musculoskeletal disease, i.e., the need for immediate intervention; in 18% of drivers a low risk and in 24% of them a very high risk of developing a musculoskeletal disorder was recorded. The latter indicated the need for urgent changes. The non-ergonomic position of the upper body segments may contribute to ever greater muscle strain, higher compression on the joints and spine and higher load force on the joints involved in driving. This is precisely why it is possible that the factors such as deviations from the natural position of the body and the prolonged duration of these actions may result in a higher rate of disorders in the musculoskeletal system (Grace & Peggo, 2007; Westgaard, 2000).

Some of the authors agree that just sitting itself does not represent a risk of pain, but rather that the unnatural twisting of the body through flexion or extension, for longer than four hours, can increase the probability ratio of developing musculoskeletal pain (Casagrande & Ferreira, 2022; Lis & Black, 2007; Massaccesi, et al., 2003).

Previous studies on the level of physical activity usually used questionnaires, and by examining the available literature no research could be found in which the level of physical activity of bus drivers was determined using objective and more accurate pedometer measurements. The average number of steps per day amounted in our participants to 5,091, whereas the maximum number of steps was 18,331.3, and the minimum was 965. Considering the values of the level of physical activity, it can be concluded that the obtained values were still below the recommended level of daily physical activity that, for the population between 20 and 65 years of age, is 7,000 – 8,500 steps (Tudor-Locke, et al., 2011). Physical activity is undoubtedly an important factor in maintaining the optimal level of health as confirmed by many authors around the world (Eyler, Browson, Bacak, & Housemann, 2003; Lee & Paffenbarger, 2000; Pate, et al., 1995). It can be therefore assumed that the explanation of the high incidence of pain in 96% of the bus drivers resulted from their insufficient and inadequate physical activity (Hildebrandt, Bongers, Dul, & Kemper, 2000; Toroptsova, Benevolenskaya, Karyakin, Sergeev, & Erdesz 1995).

Krause, Rugulies, Ragland, and Syme (2004) monitored the professional bus drivers with the reported pain in their musculoskeletal system for 7.5 years. Their study provided strong evidence of physical risk factors at the workplace for the occurrence of pain. The results of that study showed that the professional bus drivers who had rated the ergonomic issues as high had a significantly higher risk of musculoskeletal disorders. They also pointed out that by correcting the ergonomic conditions, lower back pain may be reduced by 19% in all bus drivers. Addressing this issue could prevent disorders in the musculoskeletal system and reduce the occupational disabilities in this high-risk occupation and reduce significant economic expenses related to lower back pain.

Observing physical activity as a mediator between the non-ergonomic position of the upper body segments and musculoskeletal health, the results indicated statistical significance (p=.027) of physical activity as a mediator between ergonomics and health. This means that in the drivers who were more physically active, one may expect that the effect of a poorer posture of the upper body segments had less impact on their musculoskeletal health (Table 5). In the research by Hildebrandt et al. (2000) the authors also concluded that stimulating physical activity can represent one of the methods of reducing musculoskeletal problems in the working population, especially in workers who spend a lot of time sitting at their workplace.

Results of our research suggest that physical activity mediates the effect of the non-ergonomic position of the upper body segments on the musculoskeletal health level; a higher level of physical activity could promote the health of the musculoskeletal system in non-ergonomic working conditions among bus drivers. Although according to the available literature, there is no research on physical activity as a mediator between the ergonomic working conditions and the health of musculoskeletal systems in professional bus drivers, the physical activity variable has been the subject of consideration in many studies.

In the present study, physical activity levels were determined using a pedometer. Using this method, enabled us to avoid possible mistakes made by the participants' subjective self-evaluation of the level of their physical activity, which is one of the advantages of this research.

This research has a limitation that should be considered when generalizing the results. The research was conducted on a convenience sample, and it is not possible to generalize the results to the population of Croatian bus drivers aged between 40 and 55 years. Only male bus drivers were surveyed in this study; however, since women have recently become involved in these occupations as well, professional female bus drivers should be included in the next research. Female drivers could have an even higher disorder incidence and pain in the musculoskeletal system due to anthropometric factors because they are smaller, and the driver's seats are designed for male drivers.

Taking into account the obtained results of this research, it is first of all necessary to make a good strategy of promoting physical activity among bus drivers as one of the possible factors for improving the health of the musculoskeletal system. Furthermore, it is necessary to program the guidelines for designing the kinesiology and public health programs that will focus on educating bus drivers about the proper upper body segment posture while driving and increasing the level of their physical activity in the form of walking and other kinesiology programs to reduce the incidence of pain in the musculoskeletal system. It is also important to emphasise that the introduction of such strategies can greatly contribute to preserving the health of the younger generations of drivers who are yet to come.

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IDENTIFICATION OF THE OPTIMAL HIIT PROTOCOL FOR FATIGUE RESISTANCE IN ADOLESCENT ATHLETES: A RANDOMIZED CONTROLLED TRIAL

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Abstract:

The combat sports athletes developed great gains in both muscular function and fatigue resistance by utilizing high-intensity interval training (HIIT). However, it has not been investigated fully whether different work-to-rest ratios of HIIT show the effectiveness on muscle function in adolescent athletes. The purpose of the study was to compare different work-to-rest ratios by applying different rest times in response to the identical work time during HIIT on muscle function in adolescent taekwondo athletes. Forty-seven adolescent male taekwondo athletes (mean age: 16.7±0.8 years) were randomly assigned to the control group (n=11) vs. three HIIT groups by work-to-rest ratios; (1) 1:2 [30s:60s] (n=12), (2) 1:4 [30s:120s] (n=12), and (3) 1:8 [30s:240s] (n=12). All groups completed 10 experimental sessions over four weeks, while the control group maintained their regular taekwondo training. Muscular functions were measured by assessing isokinetic muscle strength and endurance of the knee extensor and flexor. The participants performed three sets of twenty maximal extension and flexion contractions at 120°s^{-1} with a 1-min interval between the sets for fatigue resistance. Blood samples were collected to measure free-testosterone, cortisol, creatine kinase, and urea as stress-to-recovery indicators. A positive effect on improving muscle fatigue resistance was observed at the first set of assessments in the HIIT with 1:4 (Δ10.2%, p<.05) and 1:8 groups (Δ8.6%, p<.05). Additionally, the 1:4 group exhibited fatigue resistance improvement in the second set (Δ7.7%, p<.01) without any changes of stress-to-recovery indicators, while the other groups did not show any improvement. The 30s all-out work with 120s rest time, lasting over a brief 4-week period, improved participants' fatigue resistance. A certain amount of rest time between high-intense movements is required to optimize muscle development in adolescent athletes compared with insufficient rest time.

Key words: *HIIT, muscle function, stress-to-recovery indicator, optimal protocol, adolescent athlete*

Introduction

High-intensity interval training (HIIT) has become increasingly popular in the field of strength and conditioning training because of its time-efficient improvements on athletic performance, specifically muscle function (Engel, Ackermann, Chtourou, & Sperlich, 2018). Previous literature has shown that HIIT increases the rate of large motor unit recruitment through the alteration of motor unit properties (i.e., discharge rate, discharge rate variability, and recruitment threshold) (Kinnunen, Piitulainen, & Piirainen, 2019). The increase in rate of force development is associated with the development of type II muscle fibers, and it is evidenced that HIIT increases the number of type II muscle fibers in well-trained athletes (Kohn, Essén-Gustavsson, & Myburgh, 2011). It is also postulated that enhancement in athletic performance with HIIT stems from an increase in ATP content and glycogen storage, and/or from a decrease in the accumulation of hydrogen ions (H^+) and lactate in skeletal muscle (Bishop, Edge, Thomas, & Mercier, 2008). Despite its merit, it is unknown if there is an optimal combination of working and resting time (i.e., work-to-rest ratio) for the muscle function and fatigue resistance described above (Seo, Lee, Jung, Jung, & Song, 2019).

Previous studies have compared various work-to-rest ratios of HIIT in an attempt to find protocols yielding the greatest improvements in muscle function. Lloyd Jones, Morris, and Jakeman (2017) investigated the effect of three different work-to-rest ratios of sprint training on exercise performance in physically active adults. The study found that 10 × 6 seconds "all-out" sprints on a cycle ergometer with a 1:8, 1:10, or 1:12 work-to-rest ratio demonstrated similar improvements on peak power, with no differences among the protocols. Moreover, Ouergui et al. (2020) reported that 10 × 35 m sprint running for four weeks could not improve the neuromuscular performance in adolescent taekwondo athlete and Ojeda-Aravena et al. (2021) did not show any change in physical performance utilizing a 4-week HIIT in taekwondo athletes. However, Seo et al. (2019) demonstrated that the protocol involving a 30s all-out sprint running with a 120s recovery time led to better aerobic and anaerobic capacity developments during the HIIT in adolescent athletes compared with 60s and 240s. The studies highlight that a certain amount of rest time can be a primary deriver of generating optimal improvement in physical performance.

Neural and muscular mechanisms are responsible for muscle fatigue, impairing exercise performance as evidenced by reductions in speed and power output (Girard, Mendez-Villanueva, & Bishop, 2011). HIIT-induced neuromuscular adaptations may increase fatigue tolerance (or resistance), thereby increasing the ability to endure the extreme physiological and/or psychological stress associated with this training (Carroll, Taylor, & Gandevia, 2017; Reilly, Drust, & Clarke, 2008). Consequently, HIIT increases central fatigue tolerance and develops exercise performance through improvements in the neuromuscular system. As a result, the capacity to endure the extreme physiological and/or psychological stress is improved through being affected during the continued high-intensity movements (O'Leary, Collett, Howells, & Morris, 2017). However, the relationship between fatigue resistance and various HIIT protocols has not been studied previously. Taekwondo competition is an official Olympic sport that consists of intermittent attacks and defenses executed by high-intensity movements such as kicks and punches. Particularly, muscle fatigue resistance is an important variable affecting the competition success in taekwondo athletes. Examining the muscle fatigue resistance adaptations in response to various HIIT protocols can reveal an optimal HIIT strategy for adolescent taekwondo athletes.

Optimal balance between training load and recovery is crucial for enhancing maximal athletic performance (Siegl, et al., 2017). Stress-to-recovery indicators are valuable surrogate serum markers for evaluating the physiological response associated with training-induced fatigue because of their high accuracy and precision (Hecksteden, et al., 2016). These surrogate markers can also help to minimize the risk of overtraining syndrome or injury.

HIIT has been shown to positively impact athletic performance in various sports athletes; however, there is a lack of research that has examined the effects of different HIIT protocols during in-season training on muscle function in adolescent taekwondo athletes. We hypothesized that although muscle function and fatigue resistance would improve in all HIIT groups, the 30s of sprint running with 120s of active recovery time, compared with 60s and 240s of recovery time, would provide greater improvements in muscle function after the intervention (Seo, et al., 2019). The aim of the present study was to compare the effects of different work-to-rest ratios on muscle function and fatigue resistance in adolescent taekwondo athletes by applying different recovery times in response to the identical exercise time during HIIT.

Methods

Participants

In the present study, 55 adolescent male taekwondo athletes, aged 15-18 years (mean age 16.7 ± 0.8 years), were recruited from South Korea. They had been regularly performing both strength and conditioning programs and skill and technique training at least five times a week (15 to 21 hours/week) for a minimum of three years. The inclusion criteria for the present study were the following: (1) no history of medical conditions, medications use, and disease states, and (2) no injuries experienced in the last six months. All participants were affiliated with the Korea Taekwondo Association. A power analysis using G*Power program 3.1.9.2 (Düsseldorf, Germany) was used to determine the sample size required to detect within- and between-factor differences for a repeated-measures ANOVA. With an estimated power of 0.80 and alpha of 0.05, a total sample of 40 was required to detect a medium effect size (effect size of f = .33). Written informed consent was obtained from the participants, their legal guardians, and coaches after the study procedure, withdrawal process, potential risks, and benefits had carefully been explained to them. The present study was carried out following The Code of Ethics of the World Medical Association (Declaration of Helsinki) and approved by the Institutional Review Board at Kyung Hee University (KHSIRB-17-39).

Randomized controlled trial (RCT)

Fifty-five adolescent athletes initially participated in the present study and were randomly assigned to the following four groups (Figure 1): (1) 1:2 (30s:60s) group (n=14), (2) 1:4 (30s:120s) group (n=14), (3) 1:8 (30s:240s) group (n=14), and (4) the control group (CON, n=13). However, eight participants dropped out during the intervention period due to personal reasons and injuries that were not due to the applied HIIT program. Note that four participants were excluded due to the quadriceps or ankle strains during the simulated taekwondo sparring session. Eventually, forty-seven participants completed the present study.

Training intervention

A certified strength and conditioning specialist (CSCS) from the National Strength and Conditioning Association conducted the HIIT program. Table 1 details the HIIT program. The HIIT program was implemented in ten sessions over four weeks: two times in the 1st and the 3rd week, and three times in the 2nd and the 4th week. All participants in the 1:2, 1:4 and 1:8 work:rest ratio groups performed either six for week 1 and 2 or eight repetitions for week 3 and 4 of 30s all-out sprint exercise, and rested between repetitions for 60s, 120s, and 240s, respectively. Participants had their heart rates recorded during training sessions (Polar RS400, Polar Electro Oy, Kempele, Finland) while performing a sprint running on the track. Heart rate monitors were set to record heart rate at five-second intervals. The HIIT intensity was aiming at achieving 90% or higher than individual HR_{max}, interspersed with rest periods of walking (active recovery). The CSCS verbally encouraged each participant to sprint at an "all-out" effort. In addition, each participant completed a taekwondo technique and skill training program along with their regular in-season training program. The taekwondo technique and skill training, led by a coaching staff, included 20 sessions over four weeks and was executed at the light to moderate intensity for 2.0 to 2.5 hours.

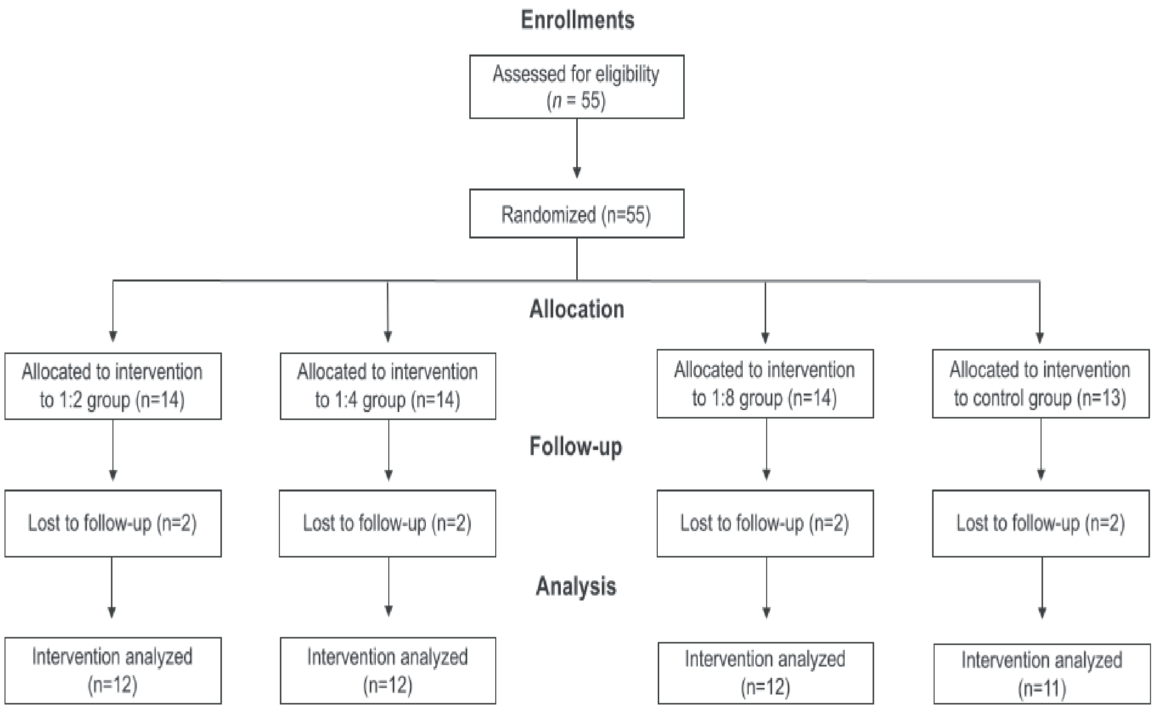

Figure 1. Flow chart of the study.

Table 1. HIIT protocol

Exercise type	Weeks	Intensity	Reps	Total work time	Total volume		
					1:2 group (30s:60s)	1:4 group (30s:120s)	1:8 group (30s:240s)
30-s running sprint	1-2	All-out	6	3min	9min	15min	27min
	3-4		8	4min	12min	20min	36min

Anthropometric measurements and body composition

Participants' standing body height and weight were measured to the nearest 0.1 cm using a stadiometer (T.K.K. Takei Scientific Ins Co., Tokyo, Japan) and balance beam scale (Seca 841, Gmbh & Co. KG, Hamburg., Germany) to the nearest 0.1 kg, respectively. Body mass index (BMI) was calculated as body weight (kg) divided by the square of height (m^2). Body composition variables (i.e., % body fat, fat tissue, and lean tissue) were measured by dual X-ray absorptiometry (DXA: QDR-4500W, Hologic, Marlborough, MA, USA). All participants were measured while wearing light clothing, barefoot, and after removing all metal from their person in a whole-body scan. The coefficient of variance of scanning was 1.5 % or less, which was in accordance with that indicated by the manufacturer. The reliability of the repeated measurements and intraclass correlation coefficient (ICC) was 0.99.

Muscle function

Muscle function was assessed by isokinetic muscle strength and endurance of the quadriceps (knee extensor) and hamstrings (knee flexor) with an isokinetic dynamometer (Cybex Humac Norm Model 770, Computer Sports Medicine Inc., New York, NY, USA). Prior to the measurement, the chair rotation scale, dynamometer rotation scale, and morale scale-secure chair were adjusted according to participants' preferences. Participants performed a full range of motion for peak torque with five maximal effort contractions at $60°·s^{-1}$. Total work done was measured with twenty maximal effort contractions at $180°·s^{-1}$. The data were normalized with each participant's body mass and calculated as peak torque and total work done ([Nm] ÷ [kg]).

Fatigue resistance

The fatigue resistance was assessed using an isokinetic dynamometer (Dipla, et al., 2009). The participant performed three sets of twenty maximal extensions and flexion contraction at $120°·s^{-1}$ with 1-minute intervals, and the researcher provided verbal feedback of encouragement. Only the dominant leg of preference was assessed. Total work done was calculated as the sum of work done during the three sets, and each set was recorded. Rating of perceived exertion (Borg scale; baseline RPE: 17.0±1.16, post-test RPE: 16.7±6.77) and heart rate were recorded at baseline and post-tests of each set (baseline peak heart rate: 155.1±14.05 bpm, post-test peak heart rate: 155.1±13.06 bpm). Blood samples for lactate concentration (mmol/L) were collected from fingertip with strips (Accutrend® lactate, Roche Diagnostics, Mannheim, Germany) by Accutrend® Plus (Roche Diagnostics, Mannheim Germany), before, immediately after, and 5 min and 10 min after the rest (baseline peak lactate: 8.9 mmol/L, post-test peak lactate: 8.6 mmol/L). The reliability of the repeated measurements assessed by the ICCs ranged from 0.92 to 0.97.

Stress-to-recovery biomarkers

Fasting venous blood samples were obtained at the beginning of baseline, after two weeks (i.e., mid-term test), and three days after the intervention period. We performed an additional analysis for a blood sample at mid-term period in order to identify the changes between exercise load changes (number of repetitions, weeks 1 to 2: six times; weeks 3 to 4: eight times) in HIIT programs. Participants arrived at the laboratory at a standardized time (between 08:00 and 08:30) after a 12 hour overnight fast and avoided moderate to vigorous physical activity or training 48 hours after training. Fasting venous blood samples (5 ml) were taken by a medical laboratory technician from the left arm's antecubital vein area and separated into individual serum separator tubes. Participants rested in the seated position for 10 to 15 min before blood collection. The clotted blood was separated using centrifugation at 3000 rpm for 15 min and was stored at -80C° in a mechanical freezer for later analysis. The bloodborne markers assays were performed at the national committee for experiments in the clinic laboratory (Green Cross Lab Cell, certified by the Korea laboratory accreditation scheme, South Korea). Stress-to-recovery biomarkers, including FT, C, CK, and urea U, were analyzed. FT was analyzed by an automatic radioimmunoassay (RIA) analyzer system (R counter, Packard, Meriden, USA) with free Testosterone RIA CT kit (Asbach Medical Products, Obrigheim, Germany). C was assessed using an automatic ECLIA (Electro-chemiluminescence Immunoassay) analyzer (Cobas 8000, Roche Diagnostics, Mannheim, Germany) with Cortisol II kit (Roche Diagnostics, Mannheim, Germany). CK, a marker of muscle damage, was analyzed with a creatine kinase kit (Roche Diagnostics, Mannheim, Germany) and estimated on an auto-analyzer (Roche Diagnostics, Roche Cobas 8000 Modular, Mannheim, Germany), which is a UV (ultraviolet) assay. U was analyzed with a UREAL kit (Roche Diagnostics, Mannheim Germany), a kinetic UV assay. The inter- and intra-class coefficient of variance was between 0.2 and 4.8%.

Statistical analyses

The data were analyzed using SPSS, version 26 for Windows (SPSS Inc, Chicago, IL, USA). All data were presented as means (M), standard deviations (SD), and 95% confidence interval (CI). Repeated measures ANOVAs were used to assess the interaction effect for the group by the time. In addition, one-way repeated-measures ANOVAs with Bonferroni correction and dependent *t*-test were used to compare within-group values. If there were any significant differences in baseline variables, repeated measures ANCOVAs were conducted adjusted for baseline covariate. Effect sizes were calculated as dependent Cohen's *d* and partial eta-squared values. The statistical significance level was set at 0.05.

Results

Anthropometric measurements and body composition

Table 2 summarizes the baseline characteristics of the participants. There were no significant differences in height, weight, and BMI at baseline among the four groups. Table 3 displays changes for body composition of the participants during four weeks of HIIT training. There were no significant interaction effects for the group by time in body weight, percent body fat, fat tissue, and lean tissue during the training period.

Muscle function and fatigue resistance

There were no significant group by time interaction effects for all groups in the lower limb muscle strength and endurance (Tables 4 and 5). However, repeated-measure ANOVA confirmed significant interaction effects in the fatigue resistance (Figure 2). There was a significant interaction effect for group by time on the first ($p<.05$, $\eta^2_p=.45$) and second set in fatigue resistance ($p<.05$, $\eta^2_p=.50$). The first set of fatigue resistance increased significantly in the 1:4 and 1:8 groups. However, the second set of fatigue resistance improved significantly in the 1:4 group only, while the 1:2, 1:8, and CON groups did not show any significant changes (Figure 3). No significant interaction effect for the group by time on the third set in fatigue resistance was found.

Table 2. Baseline characteristics of the participants

Variables	1:2 group (n=12)	1:4 group (n=12)	1:8 group (n=12)	Control group (n=11)	*p*-value
Age (years)	16.7±0.78	16.9±0.67	16.5±0.90	16.5±1.04	.64
Body height (cm)	174.7±7.10	176.1±6.98	175.4±5.36	174.7±4.64	.94
Body weight (kg)	66.3±11.80	66.4±12.51	65.4±6.04	66.7±11.71	.99
BMI (kg·m^{-2})	21.7±2.99	21.3±2.89	21.3±1.27	21.8±2.88	.95

Note. Values are expressed as mean ± SD. BMI – body mass index.

Table 3. Change in body weight and body composition between baseline and post-test in adolescent athletes

Variables	Group	Baseline (95% CI)	Post (95% CI)	*Cohen's d*	Group (ES)	Time (ES)	Group × Time (ES)
Body weight (kg)	1:2	66.3±11.80 (58.8-73.8)	66.1±11.22 (59.0-73.3)	0.15	0.06 (0.06)	0.85 (0.14)	2.59 (0.43)
	1:4	66.4±12.51 (58.5-74.4)	66.3±12.11 (58.6-74.0)	0.16			
	1:8	65.4±6.04 (61.6-69.3)	65.4±6.13 (61.5-69.3)	0.06			
	CON	66.7±11.71 (58.8-74.6)	67.7±11.63 (59.9-75.5)	0.56			
Percent body fat (%)	1:2	12.6±4.74 (9.5-15.6)	12.3±5.10 (9.1-15.5)	0.29	1.06 (0.27)	5.71^{+} (0.36)	1.45 (0.32)
	1:4	11.6±2.46 (10.1-13.2)	11.1±2.36 (9.6-12.6)	0.94			
	1:8	13.7±3.03 (11.8-15.6)	13.8±2.39 (12.3-15.3)	0.10			
	CON	13.6±3.71 (58.8-74.6)	13.1±3.59 (10.8-15.8)	0.72			
Fat tissue (kg)	1:2	8.7±5.61 (5.2-12.3)	8.6±5.58 (5.1-12.2)	0.23	0.30 (0.15)	2.39 (0.24)	0.27 (0.14)
	1:4	7.9±2.86 (6.1-9.7)	7.6±2.71 (5.9-9.3)	0.59			
	1:8	9.0±2.32 (7.5-10.5)	8.9±2.17 (7.6-10.3)	0.04			
	CON	9.2±4.29 (6.4-12.1)	9.1±4.17 (6.3-11.9)	0.27			
Lean tissue (kg)	1:2	54.8±6.57 (50.6-59.0)	55.5±6.30 (51.5-59.5)	0.48	0.17 (0.11)	14.50^{+++} (0.58)	0.01 (0.03)
	1:4	56.0±9.77 (49.8-62.2)	56.8±9.21 (50.9-62.7)	0.51			
	1:8	53.8±5.07 (50.6-57.0)	54.5±5.75 (50.9-58.2)	0.61			
	CON	55.3±7.97 (49.9-60.6)	56.0±8.12 (50.5-61.5)	0.63			

Note. Values are expressed as mean ± SD. ES – partial eta squared. $^{+}$Significant main effect, $^{+}p<.05$, $^{+++}p<.001$.

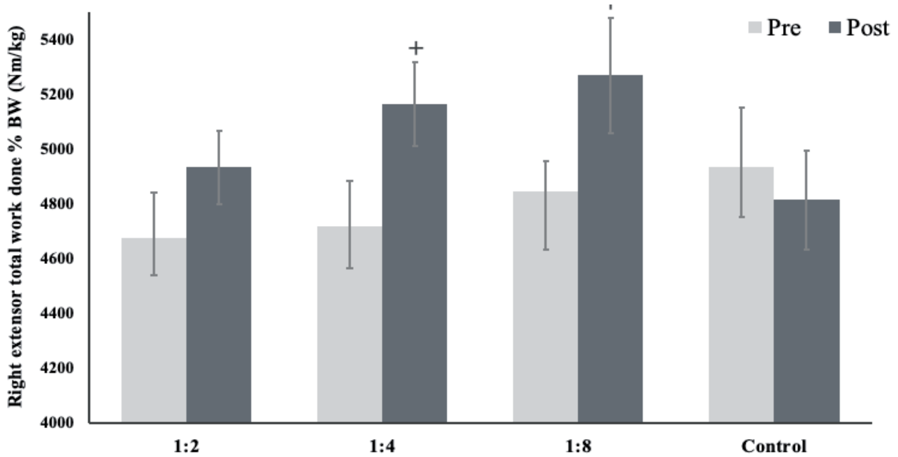

Figure 2. Comparisons of the first set of fatigue resistance following various protocols with HIIT. Values are expressed as mean and standard error of mean. Significant difference between pre- and post-test, ⁺p<.05

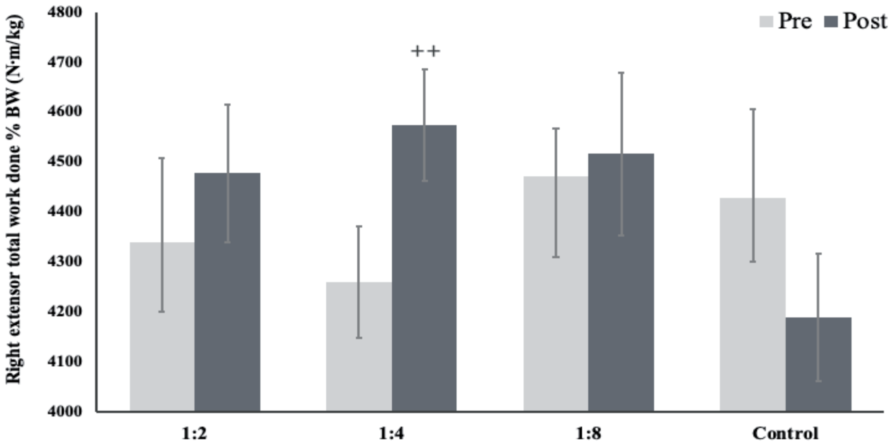

Figure 3. Comparisons of the second set of fatigue resistance following various protocols with HIIT. Values are expressed as mean and standard error of mean. Significant difference between pre- and post-test, ⁺⁺p<.01

Table 4. Change in bilateral isokinetic muscular strength between baseline and post-test in adolescent athletes

Variables	Group	Baseline (95% CI)	Post (95% CI)	*Cohen's d*	Group (ES)	Time (ES)	Group × Time (ES)
Right extensor peak torque %BW (N·m/kg)	1:2	333.3±43.3 (302.0-364.7)	336.1±47.5 (305.9-366.3)	0.16	2.32 (0.40)	0.03 (0.03)	0.93 (0.25)
	1:4	345.1±51.0 (312.7-377.5)	354.0±48.12 (232.4-384.6)	0.27			
	1:8	302.1±52.76 (268.6-335.6)	296.0±36.84 (272.6-319.4)	0.18			
	CON	326.0±56.00 (288.4-363.6)	317.46±61.88 (275.9-359.0)	0.28			
Right flexor peak torque % BW (N·m/kg)	1:2	184.3±20.89 (171.0-197.5)	196.6±28.49 (178.5-214.7)	0.58	2.82 (0.44)	12.91⁺⁺⁺ (0.59)	1.15 (0.28)
	1:4	197.0±22.63 (182.6-211.4)	219.7±19.22 (207.5-231.9)	1.12			
	1:8	183.0±20.72 (169.8-196.2)	192.1±29.81 (173.1-211.0)	0.33			
	CON	176.8±32.87 (154.7-198.9)	182.3±39.90 (155-5-209.1)	0.21			
Left extensor peak torque % BW (N·m/kg)	1:2	340.1±45.25 (311.3-368.8)	339.3±52.46 (305.9-372.6)	0.03	1.79 (0.35	2.84 (2.56)	2.56 (0.42)
	1:4	349.6±25.98 (333.1-366.1)	349.4±35.20 (327.1-371.8)	0.01			
	1:8	312.2±39.99 (286.8-337.6)	312.4±37.77 (288.4-336.4)	0.01			
	CON	343.1±44.82 (313.0-373.2)	311.5±66.81 (266.6-356.3)	0.64			
Left flexor peak torque% BW (N·m/kg)	1:2	178.5±19.81 (165.9-191.1)	186.4±21.79 (172.6-200.3)	0.40	2.37 (0.41)	4.16⁺ (0.31)	0.01 (0.03)
	1:4	195.9±33.85 (174.4-217.4)	209.8±24.88 (1940-225.6)	0.40			
	1:8	181.5±22.91 (166.9-196.1)	186.5±17.38 (175.5-197.5)	0.20			
	CON	183.4±25.01 (166.6-200.2)	186.5±30.37 (166.1-206.9)	0.17			

Note. Values are expressed as mean ± SD. ES – partial eta squared. *Significant main effect, ⁺p<.05, ⁺⁺⁺p<.001.

Table 5. Change in bilateral isokinetic muscular endurance at 180°/s between baseline and post-test in adolescent athletes

Variables	Group	Baseline (95% CI)	Post (95% CI)	*Cohen's d*	Group (ES)	Time (ES)	Group × Time (ES)
Right extensor Total work %BW (N·m/kg)	1:2	3809.7±702.22 (3363.5-4255.8)	4230.8±487.12 (3921.3-4540.2)	0.81	0.44 (0.18)	23.22^{+++} (0.74)	1.28 (0.30)
	1:4	3978.7±448.33 (3693.8-4263.5)	4433.2±388.87 (4159.1-4980.2)	1.07			
	1:8	3954.3±445.84 (3671.0-4237.5)	4182.6±363.35 (3951.7-4413.4)	0.80			
	CON	3945.9±574.5 (3560.0-4331.8)	4094.5±566.54 (3713.9-4475.2)	0.28			
Right flexor Total work % BW (N·m/kg)	1:2	2551.8±534.47 (2212.2-2891.4)	2758.1±419.33 (2491.7-3024-5)	0.57	0.44 (0.18)	6.43^{+} (0.39)	1.32 (0.30)
	1:4	2461.0±437.41 (2183.1-2738.9)	2724.4±438.73 (2445.7-3003.2)	1.09			
	1:8	2527.4±348.66 (2305.9-2748.9)	2588.3±537.01 (2227-1-2909-5)	0.08			
	CON	2450.0±410.45 (2174.3-2725.7)	2470.6±476.20 (2150.7-2790.6)	0.07			
Left extensor Total work % BW (N·m/kg)	1:2	3921.9±568.33 (3560.8-4283.0)	4209.8±492.47 (3895.9-4255.7)	1.10	0.11 (0.08)	14.63^{+++} (0.58)	1.59 (0.33)
	1:4	3836.3±422.74 (3567.7-4104.9)	4164.6±394.62 (3913.9-4415.3)	0.80			
	1:8	4030.8±485.38 (3722.4-4339.2)	4155.1±340.14 (3939.0-4371.2)	0.38			
	CON	4014.5±419.12 (3733.0-4296.1)	4066.5±481.62 (3743.0-4390.1)	0.12			
Left flexor Total work % BW (N·m/kg)	1:2	2636.3±633.45 (2233.8-3038.7)	2660.8±356.57 (2434.3-2887.4)	0.06	1.37 (0.31)	0.41 (0.10)	0.45 (0.18)
	1:4	2573.3±413.74 (2310.5-2836.2)	2697.3±323.16 (2492.0-2902.7)	0.28			
	1:8	2571.6±251.10 (2412.0-2731.1)	2510.6±339.21 (2295.1-2726.1)	0.19			
	CON	2343.5±418.05 (2062.6-2624.3)	2404.3±472.30 (2087.0-2721.6)	0.13			

Note. Values are expressed as mean ± SD. ES – partial eta squared. $^{+}$Significant main effect, $^{+}p<.05$, $^{+++}p<.001$.

Table 6. Change in stress-to-recovery indicate biomarkers between baseline, mid-, and post-tests in adolescent athletes

Variables	Group	Baseline (95% CI)	Mid (95% CI)	Post (95% CI)	Within groups *post-hoc* (ES)	Group (ES)	Time (ES)	Group × Time (ES)
Free testosterone (pmol/L)	1:2	40.8±7.23 (36.3-45.5)	43.3±7.67 (38.5-48.1)	41.1±9.69 (34.9-47.0)	N/A (0.02)	1.46 (0.32)	0.95 (0.15)	3.34^{++} (0.48)
	1:4	47.4±13.7 (38.5-56.2)	48.1±11.3 (41.1-55.4)	47.7±10.80 (41.1-54.7)	N/A (0.00)			
	1:8	41.5±6.94 (37.1-45.9)	49.2±10.9 (42.2-56.2)	40.4±9.65 (34.1-46.3)	Mid > Baseline, Post (0.16)			
	CON	44.1±15.16 (33.8-54.3)	36.3±9.1 (30.1-42.2)	40.4±13.36 (31.6-49.2)	N/A (0.12)			
	Between groups *post-hoc* (ES)	N/A (0.09)	1:4, 1:8 > CON (0.27)	N/A (0.13)				

Cortisol (μg/dL)	1:2	9.2±2.30 (7.7-10.6)	11.3±3.57 (9.0-13.6)	10.6±2.34 (9.2-12.1)	Mid, Post > Baseline (0.09)	1.11 (0.39)	6.60^{++} (0.62)	3.46^{++} (0.49)
	1:4	8.6±1.99 (7.4-9.9)	12.2±2.92 (10.3-14.0)	11.2±2.56 (9.5-12.8)	N/A (0.27)			
	1:8	9.8±2.22 (8.4-11.2)	8.9±3.13 (6.9-10.8)	11.3±3.47 (9.1-13.5)	N/A (0.11)			
	CON	9.0±2.14 (8.4-11.2)	8.1±3.94 (5.5-10.8)	10.0±3.10 (7.9-12.1)	N/A (0.16)			
	Between groups *post-hoc* (ES)	N/A (0.06)	1:2, 1:4 > CON, 1:4 > 1:8 (0.28)	N/A (0.04)				
Creatine kinase (U/L)	1:2	453.4±178.60 (325.6-581.2)	524.0±179.49 (410.0 -638.0)	320.7±124.9 (241.3-400.0)	N/A (0.04)	6.41^{++} (0.73)	3.55^{+} (0.50)	2.98^{+} (0.32)
	1:4	506.4±176.1 (388.1-624.7)	554.1±359.0 (326.0-782.2)	535.6±507.85 (145.2-928.9)	N/A (0.00)			
	1:8	222.4±89.76 (165.4-279.4)	283.9±96.07 (222.9-345.0)	248.9±91.09 (191.0-306.8)	N/A (0.08)			
	CON	213.3±65.26 (169.4-257.1)	315.9±97.27 (250.6-381.3)	336.8±180.08 (208.0-465.6)	N/A (0.05)			
	Between groups *post-hoc* (ES)	1:2, 1:4 > 1:8, CON (0.49)	1:2, 1:4 > 1:8, CON (0.27)	N/A (0.09)				
Urea (mg/dL)	1:2	32.1±7.59 (25.3-35.6)	29.9±7.92 (22.8-34.3)	27.9±5.31 (23.4-31.3)	N/A (0.06)	0.51 (0.19)	2.98 (0.26)	0.92 (0.25)
	1:4	32.9±7.17 (28.6-40.5)	29.6±6.41 (27.1-36.1)	29.0±7.14 (23.9-33.5)	N/A (0.05)			
	1:8	28.3±5.94 (24.5-32.1)	26.9±3.89 (24.4-29.4)	29.0±6.80 (24.6-33.3)	N/A (0.02)			
	CON	29.9±8.15 (23.9-36.2)	28.1±5.28 (25.5-32.4)	29.8±6.12 (25.0-34.1)	N/A (0.01)			
	Between groups *post-hoc* (ES)	N/A (0.09)	N/A (0.08)	N/A (0.01)				

Note. Values are expressed as mean ± SD. ES – partial eta squared, N/A – not aplicable. $^{+}$Significant main and interaction effect, $^{+}p<.05$, $^{++}p<.01$.

Stress-to-recovery biomarkers

A significant interaction effect for group by time on FT ($p<.01$, $\eta^2_p=.48$), C ($p<.01$, $\eta^2_p=.0.49$), and CK ($p<.05$, $\eta^2_p=.32$) (Table 6) was observed. FT increased significantly in the 1:8 group at the mid-term test (mid > baseline and post), while the 1:2, 1:4, and CON groups did not show any significant changes. The *post-hoc* results revealed the 1:4 and 1:8 groups had a significantly higher value of FT than the CON group in the mid-term test ($\eta^2_p=.27$). The C levels of the 1:2 group increased significantly at mid-term and post-test when compared to baseline (mid, post > baseline, $\eta^2_p=.16$), while the 1:4, 1:8, and CON groups did not show any significant improvements. There was a significant difference in C at the mid-test among the groups (1:2, 1:4 > CON, 1:4 > 1:8, $\eta^2_p=.28$). CK increased significantly in the 1:2 group (baseline, mid > post, $\eta^2_p=.20$) during the intervention. Moreover, there were no significant changes from baseline, mid-term and post-test in CK in the 1:4, 1:8, and CON groups, and the 1:2 and 1:4 groups had a significantly higher level of CK than the 1:8 and CON groups at baseline ($\eta^2_p=.49$) and mid-test ($\eta^2_p=.27$). However, repeated ANCOVA with baseline as a covariate showed no significant interaction effects for the group by time on creatine kinase.

Discussion and conclusions

The optimal HIIT protocol that maximally increases muscle function and fatigue resistance still remains unknown. The present study compared the effects of various work-to-rest ratios of HIIT on muscle function and fatigue resistance in adolescent athletes. The major findings of the study are as follows: (1) the HIIT 1:4 group improved fatigue resistance at the first and second sets over a 4-week period, and (2) the 1:4 group better maintained a stress-to-recovery balance compared to the other groups.

This study found that various work-to-rest ratios of HIIT displayed no changes in lower limb muscle strength and endurance measured by an isokinetic dynamometer in adolescent athletes. This finding was in line with previous literature where six sessions of HIIT over 2-3 weeks were insufficient to improve the isokinetic muscle strength and endurance of healthy young adults (Astorino, Allen, Roberson, & Jurancich, 2012). Based on these results, it is assumed that an insufficient training period was provided for well-trained athletes to elicit positive effects (DeWeese, Hornsby, Stone, & Stone, 2015; Handsfield, et al., 2017). Previous studies have also found that resistance training is a potent stimulator of neuromuscular adaptations that increase muscle strength. Thus, further study is needed to establish optimal long-term (> 24 weeks) or mid-term (> 12 weeks) effects of HIIT interventions in combination with resistance training on muscle strength and endurance (Ross, et al., 2009; Sabag, et al., 2018; Seo, Jung, Song, & Kim, 2015).

Muscle fatigue is defined as a decline in muscle performance that occurs in response to repetitive muscle contractions and associated muscle activities such as accumulation of H^+ ions, decrease in Ca^{2+} sensitivity, and reduction in shortening velocity (Allen, Lamb, & Westerblad, 2008). High-intensity repeated movements result in rapid fatigue, which directly causes a decrease in athletic performance (Goodall, Charlton, Howatson, & Thomas, 2015; Perrey, Racinais, Saimouaa, & Girard, 2010). In the present study, the 1:4 and 1:8 groups improved in the first sets compared with the 1:2 and CON groups. The 1:4 group increased significantly in the second set, while the 1:2, 1:8, and CON groups did not manifest any change from pre- to post-tests. These results indicated that improvements in fatigue resistance in the 1:4 group, indicated by increases in total work done, were only observed in both the first and second sets. It is possible that sufficient rest time during HIIT has allowed the enhancement of fatigue resistance and neuromuscular adaptations (MacInnis & Gibala, 2017; Mendez-Villanueva, Hamer, & Bishop, 2008; Racinais, et al., 2007; Torma, et al., 2019). A previous study suggested that muscle contraction is related to the peripheral nervous system (PNS) and that, although voluntary exercise activates the central nervous system (CNS) to a greater extent than PNS, it may have different effects depending on the stimulation type in the muscle (Billaut & Basset, 2007; Fernandez-del-Olmo, et al., 2013). The extent of voluntary muscle contractions brought about by the modified fatigue induction protocol could be assessed by the CNS and fatigue resistance (Taylor, Amann, Duchateau, Meeusen, & Rice, 2016). As a result, optimal HIIT protocols induced greater activation in the CNS compared with the PNS and might improve tolerance to afferents inhibitory (i.e., group III/IV afferents) (O'Leary, et al., 2017). In contrast to the hypothesis that fatigue resistance would be improved in the 1:2 group because of similar work-to-rest ratios, it did not show any change. These results might be caused by recovery type (i.e., dynamic vs. static), and differences arise in HIIT effectiveness on muscle endurance according to the angular velocity. A great increase could be obtained if we set the protocol for the high angular velocity protocol by an isokinetic dynamometer.

The best athletic performance can be achieved by meeting or exceeding the results of a predefined training plan in a multifaceted manner (Kellmann, 2010). Excessive training, however, causes overtraining syndrome (OTS) due to increased fatigue and nonfunctional overreaching (NFO), which in turn adversely affects athletic performance (Berryman, et al., 2018; Grivas, 2018). The results of stress-to-recovery indicators in this study showed that the 1:8 group observed a significantly increased FT following the 2-week intervention period; however, after four weeks, it decreased to the baseline values at pre-test ($p<.01$). C increased significantly in the 1:2 group only, between pre-, mid-, and post-tests. In addition, a significant increase was found in CK in the 1:2 group only, among baseline, mid- and post-tests. Julian et al. (2017) reported that after a 4-week low-intensity, high-volume training (LIHV) even a 5-week HIIT did not produce any change in the levels of FT, C, CK, and U. In the case of C levels (Julian, et al., 2017), it was considered that the 1:2 group showed an increase in C levels after only two and four weeks as compared with the results of baseline and that this group had a higher stress response than the other groups. However, there may be a wide range of stress-to-recovery indicators as per individual training levels and adaptability. Hence, the generalization of muscle fatigue across different populations could be limited because it varies with individuals. Consequently, the results of the stress-to-recovery indicators are likely to cause statistical errors due to the large difference range in the group-based statistical approach; thus, future studies need to be conducted to create algorithms or individualized reference range for variables that can provide a clear classification. Nevertheless, 30 seconds all-out running coupled with a 120s rest seems to maintain balance in stress-to-recovery indicators during the 4-week HIIT intervention.

Body composition is an important parameter responsible for attaining success in various sports (Reale, Burke, Cox, & Slater, 2020). However, no significant changes in body composition were founded in all groups. Monks, Seo, Kim, Jung, and Song (2017) observed that a 4-week HIIT intervention showed no significant interaction effects on body composition in collegiate athletes compared with high-intensity continuous training. Naimo et al. (2015) reported an increase in muscle thickness; however, it did not alter lean tissue, fat tissue, or percentage body fat in ice hockey players. A short-term HIIT (2-6 weeks) is focused on neuromuscular and skeletal adaptations. Thus, it is speculated that body composition during a short-term training period may be more influenced by nutrition intake, age, and gender than the training effects. The status of lean tissue and fat tissue influences athletic performance and is an essential factor that warrant evaluation during the training. HIIT increases the release of cortisol, catecholamines, and growth hormone, which in turn stimulates fat metabolism (Boutcher, 2011). HIIT has a positive effect on the remodeling of the skeletal muscle. PGC-1α can activate mitochondrial biogenesis and oxidative metabolism during HIIT and consequently can influence muscle protein synthesis (Gallo-Villegas, et al., 2018). However, a short-term HIIT may be less effective for improving body composition, such as muscle structure (Whyte, Gill, & Cathcart, 2010). If a systematic nutrition strategy program is followed along with a short-term HIIT, it may effectively improve the body composition of well-trained adolescent athletes; future studies should be conducted to investigate related issues.

The strength of this study was that it was well-designed with randomized control, and all training sessions were supervised by a CSCS from our research group. Nevertheless, limitations of the present study include a comparatively particular sport, one gender only, and a small sample size, which may limit the generalizability of our findings. Although the present study assessed some stress-to-recovery indicators (FT, C, CK, and U), other variables should be measured to determine balance between training load and recovery of athletes such as growth hormone, insulin-like growth factor-1 (IGF-1), IGF-1 binding protein 3, c-reactive protein, tumor necrosis factor, and interleukin 6, etc. In addition, running-based HIIT is not a taekwondo-specific movement technique. Future research should be conducted to apply the HIIT program with specific taekwondo kicks and movements for adolescent athletes.

Our findings suggest that a 30-second all-out sprint running with a 120-second rest time may be more effective in improving muscle function in adolescent athletes. The present study confirmed that the HIIT of 1:4 work-to-rest ratio, lasting over a brief 4-week period, induced a significant improvement in fatigue resistance compared with the other work-to-rest ratios studied. The present data may provide useful, practical implications to develop a training program for HIIT in adolescent athletes.

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LOW ENERGY AVAILABILITY AND CARBOHYDRATE INTAKE IN COMPETITIVE ADOLESCENT CLIMBERS

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Abstract:

Competitive adolescent sport climbers are reported to keep very low energy intake in order to achieve the highest possible strength-to-mass ratio required for their sport. Long term low energy availability (< 30 kcal/kg fat free mass/day) is known to have a detrimental effect on health and performance. Due to the potential severity of consequences and the lack of the data on specific population, our aim was to assess energy availability and dietary intake of 27 members of the Slovenian Youth Climbing Team (13-18 years of age). Three-day food and activity records, questionnaires and anthropometric measurements were used to determine participants' energy availability, nutritional intake, avoidance of food groups and selected health history. Average energy availability in climbers was 27.5 ± 9.8 kcal/kg fat free mass/day and 63% of participants failed to meet the recommended 30 kcal/kg fat free mass/day. Their average carbohydrate (4.3 ± 1.3 g/kg body mass/day), calcium (780 ± 300 mg/day) and vitamin D (2.6 ± 2.3 µg/day) intake were also too low. Average protein intake was in recommended range, but 56% of participants did not meet the minimum recommended limit. Iron intake was too low in females (10 ± 5 mg/day; target 15 mg/day). Only 15% of participants reported not avoiding any food groups. The menstrual dysfunction was detected in five female climbers (36%); all had energy availability < 30 kcal/kg fat free mass/day. We recommend nutritional education of climbers, their coaches, and parents as well as regular individual nutritional assessment of competitive adolescent sport climbers.

Key words: *energy intake, food avoidance, dietary intake, body composition, relative energy deficiency in sport*

Introduction

Sport climbing is a rapidly growing and popular sport that has been part of the Olympic games since Tokyo 2020 (IOC, 2016). It is composed of three disciplines: bouldering, speed climbing, and lead climbing which differ in terms of their physiological requirements. Anaerobic and aerobic systems participate in the production of adenosine triphosphate. Data suggest that climbing requires the use of a significant portion of whole body aerobic capacity, with anaerobic power being more important in more difficult routes with steeper angles (Bertuzzi, Franchini, Kokubun, & Kiss, 2007; Sheel, 2004). Climbing is considered a gravitational sport and thus for achieving success in it requires a high strength-to-mass ratio (Watts, Martin, & Durtschi, 1993). Adolescent climbers, as well as adults, tend to have a smaller stature, lower body mass (BM), lower body fat (BF) and a greater handgrip-to-BM ratio compared to their peers (Watts, Joubert, Lish, Mast, & Wilkins, 2003). Their body mass index (BMI) is similar to the control group of non-climbers, while lower sums of skinfolds indicate a greater share of fat free mass (FFM) (Watts, et al., 2003). Research has shown that the variance in climbing performance could be explained by the trainable variables such as knee and shoulder strength, grip strength, upper and lower body power, hang time and %BF rather than by the anthropometric characteristics like BM, body height, leg length, arm span, and ape index (Mermier, Janot, Parker, & Swan, 2000). Despite that, anecdotal evidence suggests that low BM is desirable among climbers which is why they resort to different restrictive diets, most often characterized by very low carbohydrate (CHO) intake irrespective of training volume or intensity (Gibson-Smith, Storey, & Ranchordas, 2017). Importance of adequate CHO intake for athletes is well recognized for its role in performance and adaptation to training (Thomas, Erdman, & Burke, 2016).

There is limited information available about the nutritional needs and nutritional intake of young climbers. Energy requirements in adolescent climbers were assessed only in a single study (Watts & Ostrowski, 2014), and recently a pilot study that monitored macronutrient intake and eating attitudes in recreational and competitive adolescent rock climbers was published (Michael, Witard, & Joubert, 2019). Both studies and others, performed with adult climbers (Gibson-Smith, Storey, & Ranchordas, 2020; Kemmler, et al., 2006; Merrells, Friel, Knaus, & Suh, 2008; Sas-Nowosielski & Wycislik, 2019; Zapf, Fichtl, Wielgoss, & Schmidt, 2001), report suboptimal energy intake (EI). The aforementioned studies, except for the study by Gibson-Smith et al. (2020), used energy balance (EB) as the traditional metric for determining the adequacy of EI. However, the body adapts to chronic low EI by resourcing energy needed for training from other physiological functions, which results in a lower resting metabolic rate (RMR) and makes the athletes only appear in EB, while their physiological systems are not working properly in an effort to adapt to a chronic lack of energy (Loucks, Kiens, & Wright, 2011). Therefore, energy availability (EA), which represents the amount of energy that is available for bodily functions, growth and development, taking into consideration energy expenditure during the planned physical activity (Loucks, et al., 2011), is encouraged to be used in research. Low EA (LEA), defined as EA <30 kcal/kg FFM/day, has severe negative impact on athlete's health, training consistency and competitive performance (Mountjoy, et al., 2014, 2018). Optimal and therefore recommended EA has been identified to be at least 45 kcal/kg FFM /day in female adults (Loucks, 2013) and 40 kcal/kg FFM/day in adult exercising men (Koehler, et al., 2016), but may be even higher in adolescents who are still growing and developing (Weiss Kelly, Hecht, & Council on Sports Medicine and Fitness, 2016). This is why we used a cut-off value of 45 kcal/kg FFM/day in this study to identify optimal EA in adolescent climbers for both sexes. EA of 30-45 kcal/kg FFM/day was considered a reduced EA. Athletes should only stay within this range for a short period of time, e.g. when aiming to reduce BM (Melin, Heikura, Tenforde, & Mountjoy, 2019).

LEA is perceived to be the main reason for relative energy deficiency in sport (RED-S) which refers to disturbed physiological functions caused by the relative energy deficiency, which, among other things, includes the metabolic rate and also reproduction, bone health, immunity, protein synthesis, and cardiovascular health (Mountjoy, et al., 2014). Long-lasting LEA in adolescent athletes may result in numerous health issues, such as the late onset of puberty, menstrual cycle abnormalities, poor bone health, stunted growth, the development of disordered eating, and higher risk of injury (Desbrow, et al., 2014).

Due to the increase in popularity of sport climbing and the lack of data on EA and dietary intake for elite and advanced climbers in the period of adolescence, our aim was to determine them exactly since LEA can be subclinical. The long-term effects of LEA can be debilitating and potentially irreversible; however, they can be prevented if diagnosed in time.

Methods

Participants

All the members of the Slovenia Youth Climbing team (38) were invited to participate in the measurements performed during the national team selection camp in February 2020. Final cohort consisted of 27 subjects. The study was approved by the Republic of Slovenia National Medical Ethics Committee (No.: 0120-690/2017/8). All the participants and their parents provided written informed consent.

Anthropometric measurements

Body height (BH) was measured to the nearest 0.5 cm and BM to the nearest 0.01 kg on a scale with integrated stadiometer (M304641-01, AED, Germany). The whole body bioelectrical impedance analysis in supine position was performed using an alternating sinusoidal electric current of 400 μA at an operating frequency of 50 kHz (BIA 101 Anniversary AKERN, Florence, Italy, medically approved: EN ISO 13485 − ISO 9001 and approved for pediatric use) according to recommendations (Kyle, et al., 2004) with emptied urine bladder and with no physical activity, alcohol or food intake in the last eight hours. FFM, percentage of fat mass (%FM), and predicted basal metabolic rate (BMR) were calculated by an integrated software (BODYGRAM® PLUS, AKERN, Florence, Italy). Due to the age interval (13-18 years of age), BH, BM and BMI were expressed in percentiles for individual age and sex using growth charts from Centers for Disease Control and Prevention (CDC, 2019) for better comparison with standards.

Dietary assessment, energy consumption evaluation and EA calculation

Climbers were asked to continue their normal diet and physical activity but to keep weighted food and activity records for three consecutive days, including one training free day. They were fully briefed (written and oral instructions by a dietitian) on how to complete the diary. They were asked to include food labels, photos, and recipes for mixed dishes in their record and to be accurate and sincere. All records were reviewed and if any abnormalities were observed, climbers were contacted to clarify the issue. Dietary intake was assessed with a dietary assessment and planning tool Open Platform for Clinical Nutrition (OPEN; http://www.opkp.si/en_GB/cms/vstopna-stran, accessed in July 2021). Physical activity was recorded by type, duration, and intensity. Energy expenditure for planned exercise (EEE) was calculated based on the activity logs using metabolic equivalent of task (MET), in accordance with the literature (Ainsworth et al., 2000).

EA was calculated with the following equation (Loucks, et al., 2011):

$$EA = \frac{EI - EEE}{FFM}$$

Evaluation of the dietary intake of macro- and micronutrients was based on valid sports nutrition guidelines for young athletes (Desbrow, et al., 2014). Where reference values were not defined for adolescent athletes specifically, we used Slovene Reference values for energy and nutrient intake (NIJZ, 2020). Given the type, intensity and duration of the exercise, we set the minimum threshold for CHO intake at 5 g/kg, the minimum required intake for protein 1.3 g/kg (Desbrow, et al., 2014), whereas the dietary fat intake minimum was set at 30% of EI, calcium intake at 1200 mg, vitamin D at 20 µg and iron intake at 12 mg per day for male and 15 mg per day for females based on general recommendations for this age group (NIJZ, 2020).

Questionnaires

Information on climbing ability, dietary habits, frequency of infections and menstrual history was obtained by a questionnaire. Climbing ability was determined with the International Rock Climbing Research Association (IRCRA) scale (Draper et al., 2015). Primary amenorrhea was determined as the failure of menses to occur by the age of 16 years, secondary amenorrhea as the loss of menses for three or more months and/or oligomenorrhea as 35 or more days between menses (Nattiv, et al., 2007).

Statistical analysis

SPSS 20.0 for Windows (IBM Corp., New York) and Microsoft Excel were used to analyse the data. Data are presented as mean ± standard deviation. Normality of distributions was determined with Shapiro-Wilk's test of normality. Differences between the means of two groups were tested with independent-samples *t*-tests for normally distributed data. Nonparametric Mann-Whitney test was used when distribution normality was violated. To test differences between actual and target dietary intake, paired sample *t*-tests were used. Wilcoxon Signed Rank tests were used when normality was violated. To test differences between two categorical variables, Pearson chi square test was used. Significance was considered when $p<.05$.

Results

Participants

Twenty-seven adolescent climbers (15.7 ± 1.5 years of age; 14 females) participated in the study. Their average climbing experience was 9.50 ± 1.25 years. Based on the IRCRA scale (Draper, et al., 2015), the group was comprised of eight elite, 15 advanced and one intermediate climber; three climbers did not report their climbing standard. Other characteristics of the climbers are presented in Table 1

Table 1. Characteristics of adolescent climbers divided by sex

	All (N= 27)	Male (n= 13)	Female (n=14)	p
Age (years)	15.7 ± 1.5	15.5 ± 1.6	15.9 ± 1.5	.477
Body height (cm)	166.0 ± 8.0	170.5 ± 8.0	161.5 ± 5.0	.002
Body mass (kg)	54.0 ± 8.5	56.4 ± 11.0	51.7 ± 4.3	.177[a]
BMI (kg/m²)	19.5 ± 1.8	19.2 ± 2.2	19.8 ± 1.5	.383
BM percentile (CDC)	48 ± 19	49 ± 23	46 ± 14	.665
BH percentile (CDC)	58 ± 25	64 ± 23	52 ± 25	.191
BMI percentile (CDC)	40 ± 21	36 ± 24	44 ± 18	.355
EI (kcal/day)	1790 ± 470	1880 ± 470	1710 ± 460	.366
BMR (kcal/	1560 ± 160	1630 ± 210	1500 ± 70	.051
FFM (kg)	47.5 ± 8.2	51.4 ± 10.2	44.0 ± 3.1	.026[a]
Fat mass (%)	12.0 ± 4.4	8.9 ± 3.3	14.9 ± 3.2	<.001[a]
Phase angle (°)	7.0 ± 0.60	7.0 ± 0.73	7.0 ± 0.48	0.961
Training load (h/week)[c]	15.6 ± 3.5	15.3 ± 3.9	15.9 ± 3.1	.659
Climbing ability (IRCRA)	20.4 ± 2.3[d]	21.1 ± 2.2[e]	19.9 ± 2.3[f]	.198

Note. BH – body height; BM – body mass; BMI – body mass index; CDC – Centers for Disease Control and Prevention; BMR – basal metabolic rate; EI – energy intake; FFM – fat free mass; IRCRA – International Rock Climbing Research Association; PA – phase angle; [a]equal variances not assumed; [b]predicted; [c]self reported; [d]N = 24; [e]N = 10; [f]N = 14.

Dietary intake vs recommended values

Average EA (27.5 ± 9.8 kcal/kg FFM/day) was below the recommended level (p<.001), with no participant meeting the target of 45 kcal/kg FFM/day and 63% being in the range of LEA (Figure 1A). Average daily CHO intake (4.3 ± 1.3 g/kg BM) was below the target of 5.0 g/kg BM (p=.007), 75% of participants were below the target (Figure 1B), whereas 44% of participants were above the target for protein intake (Figure 1C). Average protein intake was 1.3 ± 0.4 g/kg BM/day. Average daily fat intake was 31.8 ± 4.7% EI, but 37% of participants did not meet the target of 30% EI (Figure 1D). Only 15% of participants met the target of 1200 mg of calcium per day (Figure 1E). Average calcium intake was 780 ± 300 mg/day which was significantly lower than the target (p<.001). As regarded iron intake, 70% of males met the target, 12 mg/day (Figure 1F) with an average intake of 14 ± 5 mg/day, while the average iron intake of females was 10 ± 5 mg/day, which was significantly lower than the target, 15 mg (p=.007). Only 21% of females met the target (Figure 1F). None of the participants met the target vitamin D intake of 20 µg. The average intake was significantly lower, 2.6 ± 2.3 µg/day (p<.001).

Summary of characteristics by the energy availability classification status

Taking into consideration the LEA cut-off point, we divided participants in two groups: the group EA<30 (EA < 30 kcal/kg FFM/day; 17 climbers; 47% males and 53% females) and the group EA30-45 (EA between 30 and 45 kcal/kg FFM/day; 10 climbers; 50% males and 50% females) and compared their characteristics (Table 2). No significant difference between the two groups was found

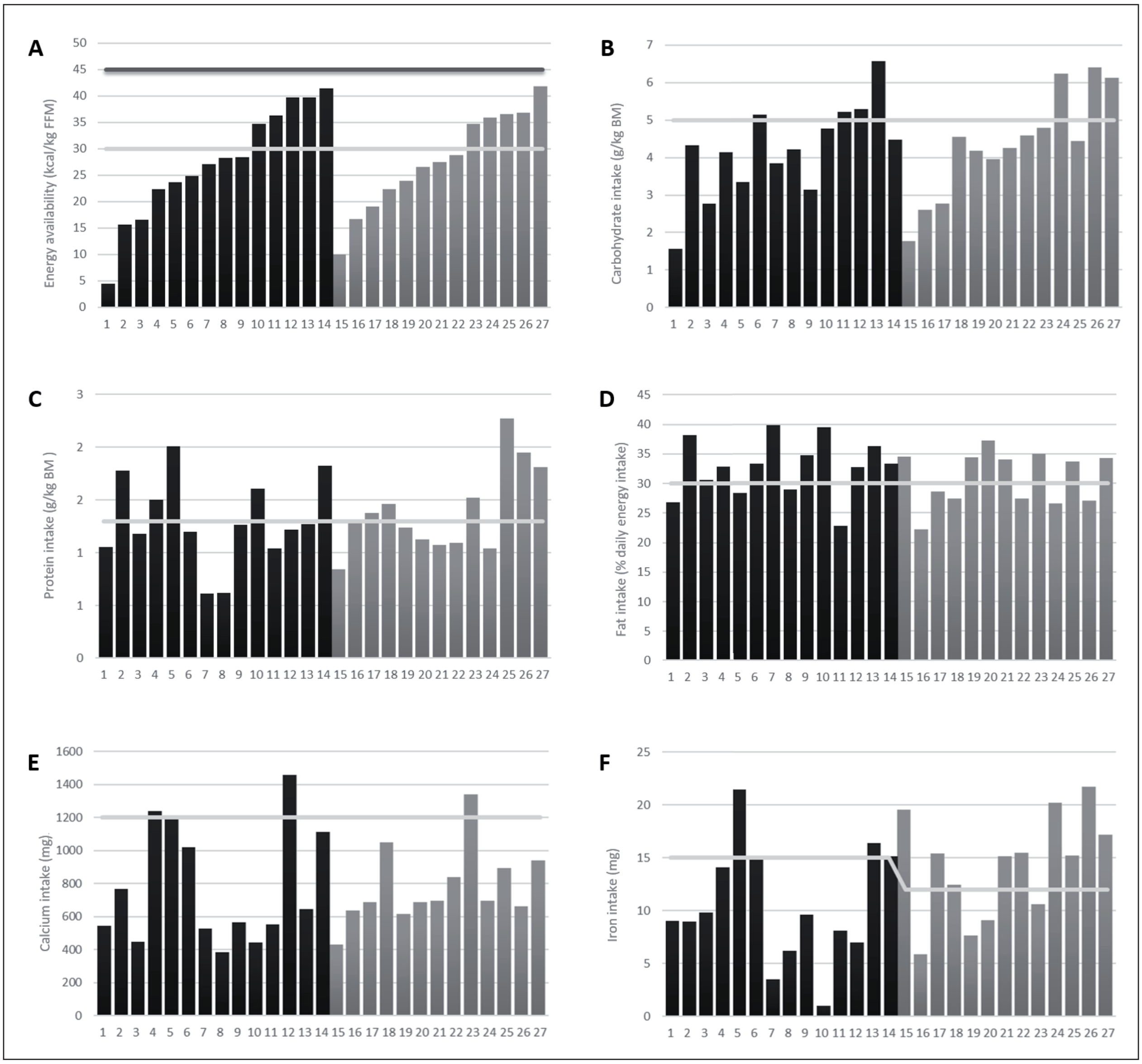

Figure 1. Dietary intake of competitive adolescent sport climbers. A – Energy availability, B – Carbohydrate intake, C – Protein intake, D – Fat intake, E – Calcium intake, F – Iron intake. Black bars – female climbers; grey bars – male climbers; full line – recommendation: where applicable: light line – lower limit; dark line – upper limit.

Table 2. Characteristics of participants divided by energy availability

	EA<30 (N=17)	EA30-45 (N= 10)	p
Energy availability (kcal/kg FFM)	21.5 ± 6.9	37.7 ± 2.7	<.001[a]
Body height (cm)	167.30 ± 8.77	163.60 ± 6.00	.251
Body mass (kg)	56.0 ± 10.0	51.0 ± 5.0	.168
BMI (kg/m²)	19.8 ± 1.8	19.1 ± 1.9	.347
BM percentile CDC	53 ± 18	38 ± 18	.048
BH percentile CDC	65 ± 25	46 ± 19	.052
BMI percentile CDC	44 ± 18	33 ± 24	.194
Fat free mass (kg)	49.0 ± 9.6	45.0 ± 4.5	.443[a]
Fat mass (%)	12.1 ± 4,5	11.8 ± 4.4	.835
Energy intake (kcal/day)	1590 ± 430	2140 ± 300	.001
Basal metabolic rate (kcal/day)	1590 ± 190	1500 ± 100	.152
EEE (kcal/dan)	530 ± 220	450 ± 140	.223[a]
Training load (h/week)	15.3 ± 3.5	16.2 ± 3.5	.551
Carbohydrate intake (g/kg BM)	3.6 ± 1.0	5.4 ± 0.8	<.001
Protein intake (g/kg BM)	1.2 ± 0.3	1.6 ± 0.4	.005
Fat intake (g/kg BM)	1.0 ± 0.3	1.5 ± 0.2	<.001
Fat intake (%EI)	31.3 ± 5.1	32.6 ± 4.2	.505

Note. BMI – body mass index; CDC – Centers for Disease Control and Prevention; EEE – energy expenditure for planned exercise; FFM – fat free mass; BM – body mass; BH – body height; EI – energy intake; [a]equal variances not assumed.

for climbing ability, although in group EA<30, three climbers did not report their climbing ability.

Eating habits and health condition

The majority of participants were omnivores, except for two males and two females who reported being vegetarian or vegan. One female reported intermittent fasting, without specific description of her eating pattern.

As regards energy intake restriction, 41% (two females and nine males) of the participants never consciously restricted EI; 37% of them (nine females and one male) reported that they rarely did it, while 22% of participants (three females and three males) reported that they sometimes did it.

Further, 15% (one female, three males) of participants reported that they did not avoid any food. Most of the others avoided high-fat meat (67%, 11 females, seven males) and sugar and sweet foods (44%, seven females, five males), while 26% (five females, two males) avoided medium-fat meat and 19% (two females, three males) avoided fats and fatty foods. No significant differences in food avoidance were found between the two EA groups (p>.05).

Also, 63% (nine females, eight males) of participantss reported that they had never visited a doctor due to a respiratory infection, while others had visited a doctor once or twice in the last 12 months.

Regarding menstrual cycle regularity, 43% of female climbers reported having regular menstrual cycles, while 29% had not yet got their first period. Among the latter group, we identified primary amenorrhea in one climber (7%). We also identified one climber with secondary amenorrhea (7%) and in three climbers (21%) we identified oligomenorrhea. All the girls with menstrual dysfunction had EA under 30 kcal/kg FFM/day, while three of them also had too low calcium and vitamin D intake. Assumptions for testing significant differences in menstrual cycles between the two EA groups were not met (more than 25% cells had expected count less than five).

Discussion and conclusions

EA and dietary intake were assessed in competitive adolescent sport climbers. We observed low EA and low carbohydrate and other key nutrients intake in our participants, advanced and elite adolescent climbers, aged 13 to 18 years. This is the first study on adolescent climbers, which, in addition to the dietary intake of macronutrients, also determined micronutrients key for sports performance and EA.

Average EA was significantly lower than 45 kcal/kg FFM/day without any major differences between the sexes. This is of concern, as 45 kcal/kg FFM/day is reported to support all physiological functions needed to maintain optimal health (Loucks, et al., 2011). Further, adolescents are still growing, which requires additional energy for growing tissues (Torun, 2005). Yet, 37% of the investigated climbers achieved the value of EA between 30 and 45 kcal/kg FFM/day, which is conditionally acceptable for a shorter time period (Mountjoy, et al., 2018), while others had EA under the minimum recommended limit of 30 kcal/kg FFM/day, which is concerning. It is known that longer-lasting energy shortage and LEA lead to RED-S which may lead to a dysfunction of numerous physiological systems and may endanger health and performance (Desbrow, et al., 2014; Smith, Holmes, & McAllister, 2015), and in adolescents, also growth and maturation status (Desbrow, et al., 2014). All the studies with climbers known to us concluded that EI, when compared to predicted energy expenditure (calculated as a product of basal metabolic rate and physical activity factor), was too low in both adolescent (Michael, Joubert, & Witard, 2019) and adult climbers (Kemmler, et al., 2006; Merrells, et al., 2008; Sas-Nowosielski & Wycislik, 2019; Zapf, et al., 2001). The only study that determined EA was conducted with adult climbers and the average EA of the participants was 41.4 ± 9 kcal/kg FFM/day, with significantly higher EA in females than in males (45.6 ± 7 kcal/kg FFM/day vs. 37.2 ± 9 kcal/kg FFM/day, respectively) (Gibson-Smith, et al., 2020). Further, 78% of elite adult climbers failed to meet the predicted energy requirement to support a moderate level of physical activity with an average of 12 hours of training/week, while 18% failed to meet the predicted RMR values (Gibson-Smith, et al., 2020). In our study, EI of as many as 26% of adolescent climbers (four males, three females) failed to meet the predicted BMR, despite the high training load. The only research that determined EI in adolescent climbers found that as many as 82% of the participants did not reach the recommended EI of 2,471 ± 493 kcal/day (Michael, Joubert, et al., 2019). They reported an average EI of 1,963 ± 581 kcal/day, while we observed even lower EI in our study. Despite the observed low EA, our adolescent climbers were distributed within the normal CDC percentile range for their age for all the three observed anthropometric parameters (BM, BH, and BMI). Similar BMI values in adolescent climbers as in control group were reported before (Watts, et al., 2003). The International Federation of Sports Climbing has been monitoring BMI during competitions for the past 10 years, so normal BMI was expected for our participants. If BMI falls below the parameters, the athlete and the National Federation are informed. Medical, psychological and nutritional help should be provided to support the affected athletes (IFSC, 2021). However, LEA and RED-S may be present even if no loss of BM has occurred (Mountjoy, et al., 2018). Interestingly, the group EA<30, which comprised nearly 2/3 of the participants, had statistically higher value of BM expressed in CDC percentiles and lower EI than the group EA30-45. There were no differences between the groups in other EA components (EEE, FFM), other anthropometric characteristics, the climbing ability, nor in training load. We believe that higher BM, according to CDC tables, might be the reason for the observed lower EI in the group EA<30, as higher BM is perceived as not desirable in sport climbing. With our crossectional study, however, we cannot determine whether the recorded low EA was the acute one during the preparation for the national team selection camp or a longer-term effort of the climbers to counteract genetic anthropometric predispositions. The climbers with lower EA were also higher in stature; the difference was close to statistical significance.

Of the macronutrients, low CHO intake contributed the most to the observed low EA in our climbers. Three quarters of the participants did not reach the target of at least 5-g of CHO/kg BM/day and average intake of CHO, 4.3 ± 1.3g CHO/kg BM/day, was below the target. Michael et al. (2019) came to a similar conclusion, namely, 86 % of their adolescent climbers did not reach the same target, 5-g CHO/kg BM/day, their average daily CHO intake was 4.3 ± 1.6 g CHO/kg BM. Studies with adult climbers show even lower intakes of CHO, below 4.0 g CHO/kg BM/day (Gibson-Smith, et al., 2020; Sas-Nowosielski & Wycislik, 2019). Considering the lack of studies, the minimum daily recommended intake is unclear, so Michael et al. (2019) recommend 3-7 g CHO/kg BM, while setting 5-g CHO/kg BM is the value which would prevent the depletion of glycogen in activities with similar physiological requirements as sport climbing. The group with lower EA had lower CHO intake than the group with higher EA.

It has been known that young athletes who have an adequate EA reach or exceed protein intake recommendations (Gibson, Stuart-Hill, Martin, & Gaul, 2011; Heaney, O'Connor, Gifford, & Naughton, 2010; Petrie, Stover, & Horswill, 2004). Considering the fact that none of our climbers reached the optimal EA of 45 kcal/kg FFM/day, we wanted to determine whether the climbers managed to satisfy their protein requirements. We estimated increased protein requirements in adolescent climbers to be 1.3-1.8 g/kg BM/day. The determined average value for male and female climbers was not significantly different from the minimum recommended value, 1.3 g/kg BM/day; however, 56% of the participants did not achieve that minimum recommended limit, which was a much higher number than it was determined in a similar study (Michael, Joubert, et al., 2019) where the minimum required daily intake was assessed to be 1.6 g/kg BM and only 23% of the participants did not reach it. Group EA<30 had lower protein intake, with most participants from the group not reaching the minimum recommended limit. Sufficient protein intake is very important in the case of low EA, especially in combination with low CHO intakes, because part of the protein is used in gluconeogenesis to form glucose as an energy substrate, potentially lowering the amino acid availability for basic physiological functions (Desbrow, et al., 2014). It is proven that only five days of EA below 30 kcal/kg FFM/day reduce muscle protein synthesis by 27% (Areta, et al., 2014) and is therefore highly undesirable.

According to sports nutrition guidelines, young athletes should consume a moderate amount of fats, which in accordance with national recommendations represent 30% of EI (NIJZ, 2020). On average, our subjects were within the recommended range, 63% reached the recommended values. Considering this was a relative share of total EI, which on average was too low, the results are not relevant and the guidelines for young athletes should express fat intake recommendations in grams relative to BM, as they do for CHO and proteins. The majority of our climbers reported avoiding foods containing fat. Group EA<30 had significantly lower fat intake than group EA30-35.

Low EI and food avoidance is reflected in micronutrient intake of our group of adolescent climbers. In young athletes, special attention is suggested to be paid to iron, calcium and vitamin D intake due to the elevated risk of deficiency of these nutrients (Desbrow, et al., 2014). The average daily calcium intake was significantly lower than the recommended intake of 1200 mg per day and close to the fact stated in the literature that young athletes achieve only half of the recommended calcium intake (Gibson, et al., 2011; Juzwiak, Amancio, Vitalle, Pinheiro, & Szejnfeld, 2008). There were no differences between the sexes or EA groups, although there was a trend of lower calcium intake in group EA<30. Inadequate calcium intake and increased calcium loss may increase risk of osteopenia and osteoporosis, which is especially emphasized in athletes with low EA (Sale, & Elliott-Sale, 2019), as were our subjects. National recommendations for daily contribution to vitamin D pool are 20 µg of vitamin D, which is to be achieved by way of internal synthesis in the skin or with food (NIJZ, 2020). Since the study was conducted in wintertime, when the incident angle of the sun at our latitude (above 35th parallel north) is too small for the biosynthesis of vitamin D in the skin (Owens, Fraser, & Close, 2015), all daily contribution to vitamin D pool was by dietary intake. The daily vitamin D intake was poor. For an adequate assessment of the vitamin D status, we should determine 25-(OH) D serum values (Halliday, et al., 2011). We do not have data for adolescents, but among Slovenian adults, there is high prevalence of insufficient serum 25(OH)D and vitamin D deficiency during extended wintertime (November-April) (Hribar, et al., 2020). In case of insufficiency, vitamin D intake should be appropriately replaced with vitamin D supplements (Desbrow, et al., 2014). We observed too low daily iron intake in females for which recommended intake is higher than for males (15 mg vs. 12 mg). This was in contrast with other reports, where dietary intake of iron in young male athletes exceeded recommendations, while the females were within the recommended limits (Gibson, et al., 2011; Heaney, et al., 2010; Juzwiak, et al., 2008). A recent study of adult climbers showed that approximately 17% of male climbers and 45% of female climbers had suboptimal iron status, with a significant medium-strength correlation between iron intake and daily EI (Gibson-Smith, et al., 2020). A too low iron intake may lead to iron deficiency, with or without anemia, which negatively affects endurance performance capacity and aerobic adaptation (Rodenberg & Gustafson, 2007). LEA may contribute to iron deficiency and, at the same time, iron deficiency, through its effect on the thyroid function, causes a decrease in appetite and average energy consumption which leads to further deterioration of EA (Petkus, Murray-Kolb, & De Souza, 2017). Indeed, the group with lower EA had lower iron intakes.

The literature reports a higher susceptibility for infection in association with a low EI (Mackinnon, 2000); however, our subjects did not report any frequent infections. Menstrual dysfunction was detected in five female climbers (36%), all appertaining to group EA<30. A lack of research on adolescent female climbers prevents us from comparing our results. Menstrual dysfunction prevalence may vary and has been reported to be between 26% and 43% in young athletes (Austin, Reinking, & Hayes, 2009; Barrack, Rauh, & Nichols, 2008; Tenforde, Fredericson, Sayres, Cutti, & Sainani, 2015), with the highest rate among the athletes of sports that emphasize leanness and low BM (Ackerman & Misra, 2018; Torstveit & Sundgot-Borgen, 2005). Primary amenorrhea prevalence was reported to be 7% among the general population and 22% among cheerleaders, divers, and gymnasts (Beals & Manore, 2002). Menstrual dysfunction is often not given enough attention and remains overlooked despite the fact that it increases the risk of the early onset of osteoporosis (Mountjoy, et al., 2014). Too low calcium levels and vitamin D intake represent an additional risk factor and were discovered in three female climbers in addition to their menstrual dysfunction and low EA.

The absence of protocol for determining EA outside of a laboratory and methodological issues in measuring each individual EA component (Burke, Lundy, Fahrenholtz, & Melin, 2018) might contribute to the observed low EA. To minimize these issues, we tried to limit the majority of possible errors with detailed instructions by a dietitian for filling out the 3-day food records, including training-free days, revision and explanation of ambiguities in the record, strictly following the protocol when carrying out bioimpedance measurements and selecting a device clinically approved for pediatric use. Measurement of EEE was the biggest obstacle and we assessed it from activity logs using the MET (Ainsworth, et al., 2000), which was described as less precise (Burke, et al., 2018). To determine whether the observed low EA was acute or chronic, the athletes should be subjected to regular screening for risk factors and symptoms included in RED-S over a longer period and in different periods of annual training periodisation.

This study suggests that two thirds of the investigated advanced and elite adolescent sport climbers were at risk of LEA, which can, if persistent for a longer time, lead to a decline in performance and compromise their health.

Low energy and dietary intake, regardless of whether intentional or unintentional, combined with high training load in competitive adolescent sport climbers, led to macronutrient (most markedly CHO) and/or micronutrient (most markedly Ca^{2+} and vitamin D) intake insufficiency as well, which can have further negative consequences.

Based on the acquired information and considering the findings by other authors, we conclude that adolescent climbers, both female and male, should be subjected to regular screening for risk factors and symptoms included in RED-S, implying that their regular professional nutrition management should also be considered.

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ACUTE EFFECTS OF A TYPICAL RHYTHMIC GYMNASTICS TRAINING DAY ON PHYSIOLOGICAL PARAMETERS IN OLYMPIC ATHLETES

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Abstract:

The aim of this study was to evaluate the effects of a day with two separate training sessions (morning and afternoon) of rhythmic gymnastics on erythrocytes, leukocytes, muscle damage, oxidative stress, and hydration of Brazilian team [age 17.7 (±1.1) years; body height 165 (±0.5) cm; body mass 49.7 (±4.2) kg]. Heart rate and session-ratings of perceived exertion were used to monitor training intensity. Blood samples were collected immediately before (M1) and after (M2) the training day for analyzing erythrocytes, leukocytes, plasma creatine kinase activity, lactate dehydrogenase, alanine aminotransferase, aspartate aminotransferase, ferric reducing ability plasma, thyroid-stimulating hormone, and free T4. Saliva was collected for cortisol analysis. After 24 hours rest (M3), blood collection was performed to analyze creatine kinase and lactate dehydrogenase. The moderate-intensity training day induced significant elevations of total leukocytes (5,163.3 to 9,617.8), lymphocytes (1,752.7 to 2,729.7), neutrophils (2,873.9 to 6,163.6), monocytes (255.7 to 519.1), platelets (280,000.0 to 300,666.7), aspartate aminotransferase (13.1 to 25.6), lactate dehydrogenase (102.5 to 249.1), thyroid-stimulating hormone (1.0 to 3.2), and ferric reducing ability plasma (136.8 to 165.4), as well as significant reductions in red cells (4,691,111.1 to 4,497,777.8), hematocrit (42.1 to 39.3), and hemoglobin (12.9 to 12.5) at M2. There were also significant increases in creatine kinase (144.2 to 519.3) and lactate dehydrogenase (102.5 to 538.2) at M3. The average dehydration rate was 1.3%. A moderate-intensity day of training in rhythmic gymnastics of 8h21min duration caused hemolysis, leukocytosis, muscle damage, redox status perturbations, and insufficient hydration status. These findings show that athletes are exposed to physiological vulnerabilities that can possibly harm their performance and health.

Key words: *erythrocytes, sports, creatine kinase, metabolic response, leukocytes*

Introduction

Competition-driven sports training programs require high volume and intensity training loads with aiming to continuously improve sports performance that must be balanced with strategies for appropriate recovery in order to optimize morphological and metabolic adaptive processes, eventually leading to the improvement of sports performance (Issurin, 2010; Meeusen, et al., 2013) However, there is an inherent complexity regarding the determination of the most appropriate proportion between training load and recovery aiming to achieve more robust improvements in performance (Kellmann, et al., 2018).

Boundaries between physiological adaptations that lead to further performance improvements and pathological adaptations are harsh and not always feasible to be delimited precisely (Cadegiani & Kater, 2019b). Elite athletes with imbalanced routine and social and nutritional vulnerabilities (Cadegiani & Kater, 2019b; Tian, et al., 2015) are more likely to develop pathological adaptations that impair multiple systems, such as immune response (Walsh & Oliver, 2016), dehydration (Arnaoutis, et al., 2015), increased and unrepaired oxidative stress, overreactive muscle damage and impaired and prolonged muscle recovery (Owens, Twist, Cobley, Howatson, & Close, 2019), anemia and pathological hemolysis response to exercise (Kokubo, Yokoyama, Kotemori, & Kawano, 2020), menstrual or fertility disturbances (Cadegiani & Kater, 2019b), pathological impairment of hormonal responses to exercises, in addition to the more than 100 dysfunctions described to be directly resulted from unhealthy sports training regimens.

Rhythmic gymnastics (RG) has been considered a sport with high risk of exposure athletes to unhealthy training regimens, since it has high concurrent requirements, including flexibility, power, strength, coordination, balance, movement technical precision, body and facial expression, and rapid decision-making abilities for optimal performance (Flessas, et al., 2015). To meet all these demands, the gymnast's routine is characterized by unusually high training loads, leading to higher risk of dysfunctional adaptations than other sports (Antualpa, Aoki, & Moreira, 2018; Codonhato, et al., 2018; Debien, Miloski, Timoteo, Ferezin, & Bara Filho, 2019; Debien, et al., 2020)

Additionally, given the sports specialization and intense training begin very early in RG, and the time window of peak performance often coincides with adolescence, these athletes have to cope with both the demands of a high-performance environment and the changes associated with physical and sexual growth and maturation (Tan, Calitri, Bloodworth, & McNamee, 2016). Thus, exposing young gymnasts to unhealthy training regimens can be even more worrisome.

While the understanding of the expected specific physiological responses to an RG training session in elite athletes is critical to distinct physiological from pathological states, there are no investigations on the specific metabolic, hormonal, and biochemical physiological adaptations to RG training. Since conditioning processes and part of biochemical adaptations to exercise are sport-specific (Cadegiani & Kater, 2019a), the extrapolation of findings from other sport modalities when analyzing RG athletes may lead to imprecise conclusions.

Owing to the lack of understanding of what to be physiologically expected from RG elite athletes, the objective of the present study was to evaluate the acute effects of an RG training day with two sessions on multiple biochemical and metabolic parameters in professional athletes of the RG Brazilian national team of RG during the pre-Olympics intensified training period.

Methods

Participants

Participants were nine group athletes of the RG Brazilian national team, starters and non-starters, among which five participated in the Japan Olympic Games in 2020. For the present study, inclusion criteria were: 1. being part of the Olympic RG Brazilian national team, based in training camp in Aracaju, Sergipe, Brazil; 2. absence of major musculoskeletal injuries; 3. absence of infections, inflammations or other disturbances during the study; and 4. not consuming supplements that include antioxidants or probiotics.

Of 11 RG athletes of the RG Brazilian national team, nine were included and two were excluded due to musculoskeletal injuries. Baseline characteristics of participants are presented in Table 1.

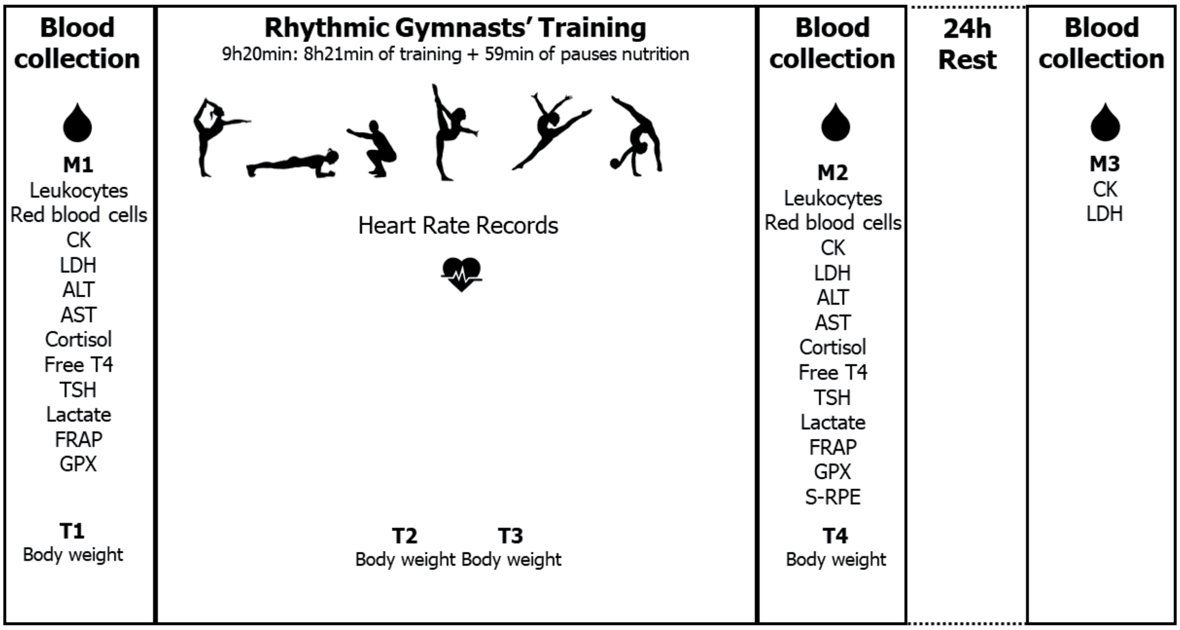
Table 1. Baseline characteristics of the participants (n=9)

Variables (M ± SD)	
Age (years)	17.7 ± 1.10
RG experience time (years)	9.44 ± 2.8
Body height (m)	1.65 ± 0.05
Body mass (kg)	49.70 ± 4.20
Body mass index (kg/m^2)	18.20 ± 1.20
Fat mass (kg)*	5.10 ± 0.80
Body fat (%)	10.30 ± 1.20

Note. M = mean; SD = standard deviation; m = meters; kg = kilograms.

Ethical approval was obtained from the local review board (Research Ethics Committee of Federal University of Sergipe, process No. 16452219.5.0000.5546, report No. 3.677.291). Participation was voluntary, and all participants signed an informed consent form before participating in the study. This study was conducted in accordance with the original Declaration of Helsinki and further amendment.

Study design (Figure 1)



Note. M1 = moment 1; M2: moment 2; M3: moment 3. T1 = time 1 for body weight; T2 = time 2 for body weight; T3 = time 3 for body weight; T4 = time 4 for body weight; CK: creatine kinase concentrations; LDH: lactate dehydrogenase concentrations; ALT: alanine aminotransferase; AST: aspartate aminotransferase; FRAP: ferric reducing antioxidant power; GPx: glutathione peroxidase.

Figure 1. Time points of blood and salivary collection after exercise

Training characteristics

The overall intervention was a day with two separate training sessions (morning and afternoon), of 9h20min duration, including 8h21min of training and 59 minutes of intervals for meals, resting and diuresis. The RG training was coached by the technical staff, had not being interfered by any of the researchers, was recently intensified as part of a pre-season training routine, and consisted of non-standardized individual warm-up and low intensity jogging (5-min); ballet training included regular routine of classical ballet exercises on the bar, center, and floor (59 minutes); flexibility training included basic exercises for the trunk and lower limbs (15 minutes); physical training was based on resistance training exercises, such as squats, sit-ups, and trunk elevations (46 minutes); technical-driven training exercises were based on body difficulties and repetitions of isolated elements, such as dance steps, risks, exchanges, and collaborations (38 minutes), and practicing of parts of the routine training, with and without music (5h38min). This had been the same training loads as the two weeks previous to the study.

Training intensity

Objective and subjective measurement methods of training intensity were applied. Thirty minutes after the end of training sessions, gymnasts reported the self-perceived training intensity according to the session-Ratings of Perceived Exertion (s-RPE) (Foster, et al., 2001), on a scale from 0 to 10, in which zero corresponded to rest and 10 to maximal effort. Also, four of the athletes had their heart rate (HR) (beats per minutes – bpm) (Polar Team Pro, Kempele, Finland) monitored throughout the session, and training intensity was classified according to the American College of Sports Medicine (ACSM) six-intensity level category scale (Garber, et al., 2011): very light, < 57% of maximum HR; light, 57 – 63%; moderate, 64 – 76%; vigorous, 77 – 95%; near-maximal to maximal, >96%.

Blood and saliva measures

Biochemical data from blood and saliva samples were collected at three different time points: Moment 1 (M1) – immediately before the beginning of the training session used for the experiment, approximately 48 hours after the last training load was experienced; Moment 2 (M2) – immediately after the training sessions, at the end of the day, and Moment 3 (M3) – 24 hours after the training day (Figure 1).

Blood samples were collected by a qualified professional, and the materials used were adapters, 25x7 needles, and vacuum tubes; each blood sample contained 5ml of blood in tubes with EDTA (ethylenediaminetetraacetic acid) and separating gel for serum analysis. Saliva was stored in tubes specifically designed and prepared to receive saliva (Salivete®); disposable gloves; blood stop gauze dressing; and cotton and 70% alcohol for asepsis.

Samples were immediately stored in an ice cooler box at 4° C and transported for 15 minutes to the respective laboratories, where the necessary analyses were immediately performed. Athletes were required to avoid teeth brushing at least two hours before saliva collect in order to avoid microscopic blood contamination in saliva.

Biochemical parameters included red cells characterization, including erythrocytes (*10^6/mm^3), hemoglobin (g/dL), hematocrit (%), mean corpuscular volume (MCV) (fl) and red cell distribution width (RDW) (%), leucocytes, including neutrophils, lymphocytes, eosinophils and monocytes, platelets (*10^3/mm^3) (Electrical Impedance Flow Cytometry), hormones, including salivary cortisol, thyroid-stimulating hormone (TSH) (chemiluminescence immunoassay – CLIA), free tetraiodothyronine (fT4) (CLIA), muscle- and liver-derived parameters, including serum lactate, creatine kinase (CK), lactate dehydrogenase (LDH), aspartate aminotransferase (AST), alanine aminotransferase (ALT), and oxidative stress indicators, including ferric reducing ability of plasma (FRAP) and glutathione peroxidase (GSH-Px). Except for FRAP and GSH-Px, commercially available assays were used (LabTest®, COBAS MIRA, Roche, Germany). FRAP was determined according to the protocol by Benzie and Strain (1996) and GSH-Px according to Sies, Koch, Martino and Boveris (1979). Hormonal analyzes were carried out in a laboratory with ISO 9000-2015 certification, which guaranteed the reliability of the results. Neutrophil-to-lymphocyte ratio was also calculated for all time points.

Variations in fluid balance and biochemical parameters were assessed to determine the impact of a single RG training day on hematological, immune thyroid axis, muscle homeostasis and oxi-reductive state responses. T4 from the clinical characterization corresponds to M2 of biochemical measurements.

Hydration status

To estimate hydration status, body weight was measured at four time points of the training day: time 1 (T1), termed as initial weight 1, considered as the resting, basal body weight, immediately before the first training session started; time 2 (T2), termed as final weight 1, immediately after the morning training session (of 4h duration), before lunch interval; time 3 (T3), termed as initial weight 2, immediately before the afternoon training session, and time 4 (T4), immediately after the end of the afternoon training session (of 8h21min duration), while fluid balance was calculated by measuring oral fluid intake and estimated water content in foods as inputs, and urinary, fecal and estimated sweat volumes as outputs, and calculated for T2 and T4 of body weight.

Total sweating was estimated through an equation (Horswill, 1998), as follows:

sweating = (initial weight + quantity of liquids ingested) - (final weight - volumes of urine and fecal produced).

Hourly sweating rate was calculated through total sweating divided by the duration of the assessed period in hours. The estimated percentage of water loss was obtained by the following equation:

% dehydration = (change in body weight - urinary and fecal volume during training) / initial body weight x 100 (Burke & Hawley, 1997).

Diet

Ad libitum water intake was allowed throughout the intervention period. One day before the evaluation, athletes underwent anthropometric measurements (body mass, body height, and skinfold thicknesses) (Jackson, et al., 1980), and maintained their regular diet recommended for resting days, which consisted on average of 2031 kcal, 201g of carbohydrates (4g/kg), 86g of protein (1.7g/kg) and fat corresponding to 22% of the calories. On the day of the experiment, one hour before the beginning of training sessions, gymnasts had a controlled meal with 1.0g/kg, 0.3g/kg and 0.1g/kg of carbohydrate, protein and fat, respectively. Meals during intervals consisted of carbohydrate-electrolytes-based supplements containing ~0.3g CHO/kg of body weight/hour (~2.4g/kg for the 8h of training), while a full meal at lunchtime was provided with 1.0g/kg of carbohydrate, 0.33g protein/kg and 8g of fat. These meals reflected the usual caloric and macronutrient intake of a typical training day.

Statistical analyses

To obtain the results, descriptive statistics was first applied, with the presentation of the results in means and standard deviations. Normality and homoscedasticity were tested using Shapiro-Wilk and Levene tests, respectively. Subsequently, the t-test and ANOVA were employed to obtain statistical differences in normally distributed parameters, and results were shown as mean and standard deviation (SD), while Friedman test was employed for non-parametric parameters, and results were disclosed using medians and 95% confidence intervals (95% CI). Effect size (ES) was calculated using the following Hopkins criterion: 0-0.19 trivial; small 0.2-0.59; 0.6-1.19 moderate; 1.2-1.99 large; > 2 very large. Data were analyzed using SPSS version 21.0. The significance was $p<.05$.

Results

During all training stages performed in one day, with two separate training sessions, the average HR remained 129 (±11.3) bpm (64.0% maximum HR), corresponding to a moderate intensity as per the ACSM intensity level category scale. Athletes' average s-RPE corresponded to moderate-intensity training (3.2 [±0.4]).

Table 2 presents the blood count data, muscle damage indicators, and markers of training stress and redox status for all the participants at the moments immediately before and after the training (M1 and M2, respectively). There were significant increases ($p<.05$) in total leukocytes, lymphocytes, neutrophils, monocytes, platelets, MCHC, AST, TSH, and FRAP, as well as significant reductions in erythrocytes, hemoglobin, hematocrit, MCV, and cortisol at M2. There were no significant changes at M2 for neutrophil-lymphocytes ratio, MCH, RDW, ALT, T4 free, lactate or GSH-Px; however, a very large effect was observed for GSH-px at M2.

Figure 2 shows markers of muscle damage (CK and LDH), and their variation from the analysis at three time points. There was a significant increase ($p<.05$) in CK only at M3 ($p=.001$), and in LDH at M2 ($p=0$) and M3 ($p=0$ in relation to M1 and $p=.001$ in relation to M2). There was no difference in CK at M2.

Table 2. Biochemical parameters observed immediately before (M1) and immediately after (M2) a training day of the Brazilian rhythmic gymnastics national team (M ± SD)

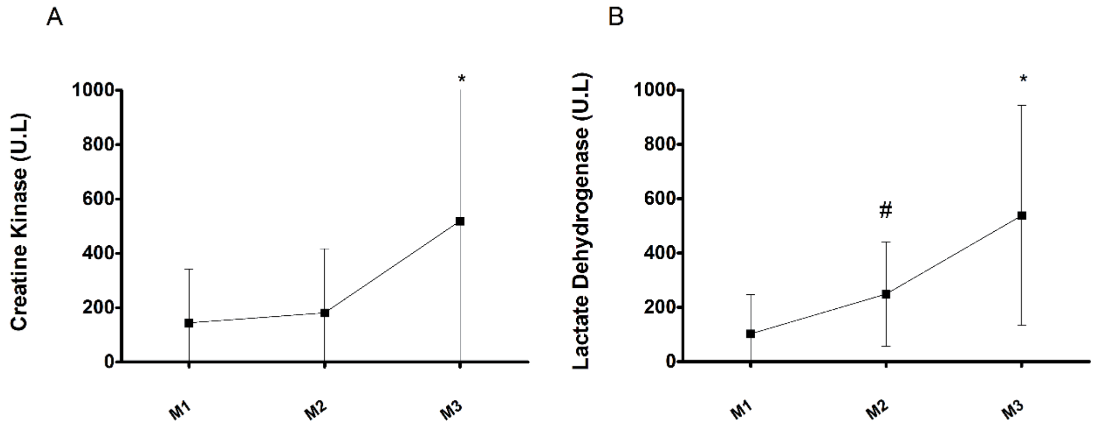
Parameters	M1	M2	p-value	ES
Total leukocytes (/mm³)	5163.3 ± 998.9	9617.8[a] ± 1883.8	0.001	4.5
Lymphocytes (/mm³)	1752.7± 498.0	2729.7[a]± 807.0	0.003	2.0
Neutrophils (/mm³)	2873.9 ± 826.9	6163.6[a] ± 1519.9	0.001	4.0
Neutrophils:Lymphocytes ratio	1,79±0,76	2,48±1,15	0.196	1.3
Monocytes (/mm³)	255.7 ± 172.6	519.1[a] ± 212.9	0.006	1.5
Platelets (/mm³)	280,000.0 ±76,767.5	300,666.7[a] ± 89,335.0	0.009	0.3
Erythrocytes (/mm³)	4,691,111.1 ±194,643.5	4,497,777.8[a] ±243,658.5	0.001	1.0
Hemoglobin (g/dl)	12.9 ± 1.0	12.5[a] ± 1.0	0.001	0.5
Hematocrit (%)	42.1 ± 2.1	39.3[a] ± 2.5	0.001	1.3
MCV (fL)	90.1 ± 6.8	87.7[a] ± 6.7	0.001	0.4
MCH (pg)	27.7 ± 2.6	27.7 ± 2.6	1.000	0.0
RDW (%)	11.1 ± 0.6	11.2 ± 0.4	0.695	0.1
MCHC (%)	30.8 ± 1.0	31.6[a] ± 1.1	0.008	0.8
AST (U/L)	13.1 ± 6.5	25.6[a] ± 5.9	0.007	1.2
ALT (U/L)	13.1 ± 4.7	10.9 ± 2.4	0.104	0.0
TSH (μIU/ml)	1.0 ± 0.2	3.2[a] ± 2.8	0.008	9.5
Free T4 (ng/dL)	0.9 ± 0.1	0.9 ± 0.1	0.117	0.4
Lactate (mmol/L)	1.7 ± 0.2	1.8 ± 0.8	0.648	0.8
Salivary cortisol (μg/dL)	0.5 ± 0.2	0.2[a] ± 0.1	0.001	2.8
FRAP (μM)	136.8 ± 29.3	165.4[a] ± 32.1	0.001	1.0
GSH-Px (μM)	4.8 ± 4.7	15.0 ± 9.4	0.051	2.1

Note. M = mean; SD = standard deviation; M1 = moment 1; M2: moment 2; ES: effect size; AST = aspartate aminotransferase; ALT = alanine aminotransferase; TSH = thyroid-stimulating hormone; FREE T4 = free tetraiodothyronine; FRAP = ferric reducing ability of plasma; GSH-Px = glutathione; MCV = mean corpuscular volume; MCH = mean corpuscular hemoglobin; RDW = red cell distribution width; MCHC = mean corpuscular hemoglobin concentration.

[a] Statistically significant difference in relation to M1 ($p\leq.05$).

Table 3. Body hydration indicators observed between the beginning of the training and the lunch break (PRE-LUNCH), and between the end of the lunch break and the end of the training day (POST-LUNCH) of the Brazilian rhythmic gymnastics national team (M ± SD)

Parameters	Morning training session	Afternoon training session	p-value
Average liquid intake (mL)	1150.0 ± 291.0	1123.3 ± 358.7	0.781
Total sweating (mL)	1720.0 ± 520.1	1760.0 ± 540.0	0.641
Sweating rate per hour (mL/hour)	390.1 ± 120.2	340.0 ± 110.0	0.104
Percentage of dehydration (%)	1.16 ± 0.85	1.44 ± 0.65	0.496



Note. *Statistically significant difference in relation to M1 (p≤.05); #Statistically significant difference in relation to M3 (p≤.05).

Figure 2. Muscle damage marker changes at three time points.

Table 3 presents parameters related to the athletes' body hydration status in the two training periods, pre-lunch and post-lunch. There was no statistical difference between the two evaluated moments in any of the parameters.

Discussion and conclusions

The main findings of the present study demonstrate that a day of RG training of moderate intensity lasting 8 hours and 21 minutes caused: 1. Increase of overall leukocytes, neutrophils, lymphocytes and monocytes; 2. Reduction in hematocrit, erythrocytes, hemoglobin and MCV; 3. Increase of platelets; 4. Elevation in muscle-derived markers, including AST immediately after it, in LDH immediately after it and 24h after it, and in CK only 24h after it; 5. Increase of TSH; and 6. Increase in oxidative-stress markers, including FRAP increase, and large effect size for GSH-Px after training; 7. Average dehydration rate of 1.3%, despite the average intake of 2.3 L of liquids during the training day.

Considering a wide variety of types of training adopted during the periodization of an elite team, it is essential to identify the intensity of a training day before evaluating its impact on physiological parameters of athletes (Zimmermann, et al., 2022). In our study, during all training stages, the intensity was moderate; nonetheless, moderate but to an extreme prolonged RG exercises probably lead to distinct responses from moderate but shorter physical efforts.

In our study, there was no significant change in lactate levels, possibly because it is better correlated with training intensity rather than training duration. Also, it is likely that intermittency, a common feature of RG training sessions (Flessas, et al., 2015), justifies the stability of lactate in our study, especially because increased speed of lactate clearance is a physiological adaptation found in athletes (Ferguson, et al., 2018). So, it would be more efficient for this analysis to be carried out at specific moments of the training.

Salivary cortisol is a stress marker inherent in training; however, the present study revealed lower cortisol levels at the end of the training day. The reduction of cortisol at M2 may be explained by a long duration of training (>8h), since cortisol is highly influenced by the circadian cycle. To overcome this limitation, sequential cortisol measurements throughout the day are necessary (Silva, Silva, & Enumo, 2017).

In the present study, as expected, significant changes were observed in the total and differential leukocyte count at the end of the training day. The total number of leucocytes circulating in peripheral blood is strongly influenced by physical exercise (Gleeson, 2006). This acute increase can be perceived as a response of the innate system (neutrophils and monocytes) to tissue damage and its need for repair and remodeling, and this hypothesis is reinforced by the significant elevation of platelets (Keaney, Kilding, Merien, & Dulson, 2018), which was observed in the present study as well. Additionally, the stress arising from exercise stimulates the neuro-endocrine axis, promoting greater synthesis and secretion of catecholamines by the adrenal glands. Such hormones are responsible for the migration of these cells into the circulation, causing an acute effect of increased absolute counts of circulating leukocytes, lymphocytes, neutrophils, and monocytes (Dias, et al., 2017), just as occurred in the present study. While catecholamines induce acute rise in leucocytes, cortisol has a late effect of inhibiting mitogenesis and lymphocyte functionality, promoting immunosuppression and increasing the incidence of URIs, and consequently, lowering the volume and quality of training among athletes (Keaney, et al., 2018; Pedersen & Hoffman-Goetz, 2000). However, in the present study, besides the fact that no increase in cortisol was observed at M2, it is also noteworthy that leukocyte analyses were only performed immediately after training, which prevented the investigation of the delayed effects of this training on leukocytes and their likely implications for the athletes' immunity. This temporal limitation in the analysis of leukocyte counts may also justify the absence of statistical difference between the values of the neutrophils-lymphocytes ratio before and immediately after the training. Both values were within the normal range.

The acute leukocytosis detected in the present study corroborates the findings of Bessa et al. (2016) and Gomes et al. (2020), who also found leukocytosis at the moment immediately after the exercise in addition to a greater contribution of neutrophils in this increase. Nevertheless, in these studies, a drop to baseline levels of most markers was also noticed after 24 hours and 30 minutes, respectively, confirming the need for these markers to be analyzed later.

In the present study, despite significant changes resulting from training, hemoglobin values were within the normal range considering reference standards for healthy individuals according to the age and sex of women athletes, thus ruling out the diagnosis of anemia. Nonetheless, it is relevant to highlight that nearly all counts related to erythrocytes and their integrity (erythrocytes, hematocrit, and MCV) presented significant decreases at the end of the training day. Elevation of these compounds is expected, especially when there is insufficient fluid replacement (Logan-Sprenger, Heigenhauser, Killian, & Spriet 2012), as observed in our study. So, in our study, the unexpected increase in erythrocytes, hematocrit, and MCV demonstrates the presence of hemolysis.

MCV should be attentively regarded, as this marker tends to increase in physiological adaptation to exercise. But we found unexpected reduction of MCV, that indicated hemolysis, reinforced by the elevation in MCHC, which revealed a reduction in viable erythrocytes compensated by a hyperchromia in the organic attempt to continue delivering oxygen efficiently to the tissues (Sureira, Amancio, & Braga, 2012).

While training was considered as being of moderate intensity, there were significant immediate elevations in LDH and AST and late elevations in LDH and CK levels, demonstrating muscle damage, in a similar manner of what was typically found in high-intensity training sessions in other sports (Gomes, et al., 2020; Harty, Cottet, Malloy, & Kerksick, 2019; Naderi, Rezvani, & Degens, 2020). CK and LDH has been correlated to bone injurie (Miyamoto, et al., 2018), and the risk of bone fractures is particularly high in aesthetic modalities such as RG (Hassmannová, Pavlů, & Nováková, 2019); therefore, assessment of bone health status and markers deserves more attention.

In our study, a very large effect size for GSH-Px and significant increase in FRAP observed immediately after the exercise reflect the effort and ability to keep balance between oxidants and antioxidants, and to prevent excessive exposure to oxidative stress, or even the ability to repair damage caused when the production of oxidants is found in greater proportions (Bellafiore, et al., 2019; Finaud, Lac, & Filaire, 2006; Fisher-Wellman & Bloomer, 2009; Petry, Alvarenga, Cruzat, & Tirapegui, 2010; Pisoschi & Pop, 2015; Savasky, Mascotti, Patel, & Rodriguez-Collazo, 2018).

In the present study, there was a significant increase in TSH immediately after the training, yet it remained within normal values, according to the reference population (Sgarbi, et al., 2013), and similar to those found in response to other sports, in an attempt to optimize the obtainment of energy for the practice of sports (Arkader, Rosa, & Moretti, 2016; Bogdanis, Philippou, Stavrinou, Tenta, & Maridaki, 2022).

To the best of our knowledge, this is the first study to analyse the acute effects of one RG training day on immune parameters, red cells, hormonal concentrations, muscle damage, oxidative stress, and hydration. The results found can be useful faced with the increasing number of very young RG practitioners, which makes it essential for the interdisciplinary health team to establish strategies ducts.

In conclusion, a day of RG training of moderate intensity and duration of 8h and 21min caused hemolysis, leukocytosis, muscle damage, perturbations in redox status, and insufficient fluid replacement during training.

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PERFECTIONISM AND AFFECT AS DETERMINANTS OF SELF-PERCEIVED MOTOR COMPETENCE IN PRIMARY SCHOOL CHILDREN

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Abstract:

The aim of this study was to analyze the primary school students' perception of their motor competence in the area of Physical Education, with respect to the affective domain and improvement. The sample consisted of 428 primary school students aged between 8 and 12 years (M=10.43; SD=0.837) (Castilla La Mancha, Spain). Perceived motor competence (PMC) was measured by the Perception of Competence Questionnaire (POC); perfectionism was measured by the three subscales of the Child Perfectionism Questionnaire, and, finally, affectivity was assessed by the PANAS (Positive and Negative Affect Schedule) questionnaire. Positive correlations were obtained between all the dimensions of the PMC and self-improvement (p<.05). Significant gender differences were found in the PMC dimension Peers and Self-Experience, with higher scores in males (p<.05). Differences were also found in the PMC dimension Peers as a function of weight status, being lower in the overweight group (p<.05). Age was related to self-experience being higher the older one was (p<.05). A model was generated that explained 23.7% of PMC with the total dimension of self-improvement and weight status. Three distinct profiles, called high, medium and low self-improvement, were detected. These groups in turn showed an analogy in perceived motor competence, high, medium and low, the result also obtained in the regression analysis (p<.05). These results extend the relationship between perceived motor competence and self-improvement in primary school children and are potentially of interest to the fields of education and psychology.

Key words: *perceived motor competence, perfectionism, affective domain, primary school, health*

Introduction

According to global health experts, all kids of school age should practice at least 60 minutes of moderate to vigorous physical activity daily (≥ 5 days/week). However, a low perceived motor competence (PMC) can affect the adequate achievement of this objective (Gil-Madrona, Carrillo-López, Rosa-Guillamón, & García-Cantó, 2020a). Perceived motor competence refers to the belief that a person is able to successfully perform a given motor task, which is conditioned by personal experience, peers and teacher (Gil-Madrona, Cejudo, Martínez-González, & López-Sánchez, 2019). This perception of physical mastery based on motor competence and health behaviors can be understood in terms of a mechanism by which motor coordination can have an indirect impact on emotional outcomes through various domains of self-perception (Rigoli, Piek, & Kane, 2012).

During the last decades and due to a critique made of rationalist psychology, the emotional dimension of human beings has been revendicated in the scientific field. Thus, through various academic perspectives, the concept of emotion has been extended to the psychological, motor and sociocultural spheres (Johnson, 2019). This manuscript reflects that this situation has also been reflected in the context of pedagogical disciplines and in Physical Education as well, where an increase in the interest in investigating this subject in its different didactical contents can be acknowledged.

The investigation of emotions in the area of Physical Education is attributed to the need to understand the different meanings various psychological states can represent (Johnson & Sánchez, 2021). Emotional regulation has been described as the person's capacity to manage his or her emotions in a proper way, modifying their intensity and duration (Alcaraz-Muñoz, Alonso-Roque, & Yuste-Lucas, 2022). For this reason, emotional regulation is linked to psychological well-being. Likewise, motor practice is considered beneficial for health, although the results of previous research on its association with psychological and emotional well-being have not been conclusive (Fuentes-Sánchez, Jaén, González-Romero, Moliner-Urdiales, & Pastor 2017). According to the type of motor task or gender, differences and similarities have been identified, highlighting the role of competition and the relationship with a sporting requirement in each educational center. In this sense, it has been concluded that to promote the subjective well-being of students in Physical Education sports practices, it could be appropriate to apply alternative strategies for teaching sports, adaptive strategies and a task-oriented achievement climate.

Research into children's perfectionism is fundamental to understanding different variables that might affect students' development. A literature review reveals that an integrative definition understands perfectionism as a personality disposition characterized by efforts of impeccability and the establishment of high-performance standards, accompanied by a tendency to excessive critical self-evaluations (Aguilar-Durán & Castellanos-Lopez, 2016). It implies a set of very strict self-imposed demands about what the person believes he or she should become or do. This review indicates the relationship between psychological distress during childhood and adolescence and excessive perfectionism. Hence, the authors express the warning that perfectionism in elementary school children might seem innocuous and even desirable, but that it brings innumerable negative consequences for children's physical and emotional health if it is excessive (Cazalla-Luna & Molero, 2018).

In this sense, there are different implications for parents and teachers, who, together with counsellors and psychologists, should be cautious about pressuring schoolchildren; they should assess exactly what kind of perfectionism is present in children and help them to manage both dimensions of perfectionism (Méndez-Giménez, Cecchini-Estrada, & Fernández-Río, 2015a). When schoolchildren adopt self-demanding perfectionist behaviors, the advice should be to stick to them without being too self-critical in case they do not reach the desired personal standards. Likewise, students of the pure external pressure type should be helped to internalize their desire for perfection and evaluate themselves more realistically to assume standards more in line with their perceived motor competence.

Currently, it is of interest to analyze the relationship between self-perceived motor competence, perfectionism, and affective mastery in elementary school children. In the study by Pineda-Espejel, Morquecho-Sánchez, Fernández, and González-Hernández (2019), the aim was to test a predictive model that analyzed the sequence: perfectionist concerns, fear of failure, and consequences of positive and negative affect in sports training sessions in children and adolescents as well as to analyze the mediating role of fear of failure. The results showed that the perception of pressure exerted by two primary sources of evaluation of athletes—parents and coach, predicted a negative affect only if the fear of failure had developed in the athlete during sports training sessions. A simultaneous study of the role of close associates is important since it may guide future interventions focused on maximizing the beneficial influence of parents and coaches. In conclusion, fear of failure is a subjective experience, which has environmental antecedents—interpersonal perfectionism, and affective consequences.

In this line, the competitive sports practice group mentioned above showed higher emotional competencies and greater psychological well-being compared to the group that did not practice sports, who showed lower scores on the anxiety and depression scales as well as on the negative affect scale, while they showed higher scores on the clarity of feelings and emotional repair scales (Fuentes-Sánchez, et al., 2017).

It has been observed that the relationship between perceived motor competence, perfectionism and affective dominance in elementary school children may be mediated by moderating variables such as gender, age, or weight status (Gil-Madrona, et al., 2020a). For example, in one study whose purpose was to analyze various types of emotions—positive or pleasant and negative or unpleasant—and their intensity in the extent to which they are felt by fifth and sixth grade Primary Education students in the area of Physical Education (Gil-Madrona, et al., 2019) and the comparison of emotional states according to gender, age and their body mass index (BMI), it was found that in the dimension of positive emotions, all the highest mean scores were achieved by the students without obesity/overweight issues. Regarding the negative emotions dimension, all the highest mean scores were found in students with obesity/overweight issues. The results showed significant differences according to BMI between the students with obesity/overweight problems and students without obesity/overweight problems in positive emotions (Gil-Madrona, Pascual-Francés, Jordá-Espi, Mujica-Johnson, & Fernández-Revelles, 2020b).

Based on these precedents, the general objective of this study was to evaluate the primary school children's perception of their motor competence in the area of Physical Education, with respect to the affective domain and improvement. This general objective was achieved through the following specific objectives:

I) To know the relationship between perceived motor competence, self-improvement, and affective competence.
II) To analyze self-improvement, affective competence, and perceived motor competence according to sex, age and weight status of 4th, 5th and 6th grade students.
III) To create a model that allows predicting the perception of perceived motor competence according to self-improvement, affective competence, age, gender, and weight status.
IV) To create typologies of primary school students in Physical Education characterized by perceived motor competence, self-improvement, and affective mastery.

Methods and materials

Participants

The final sample consisted of 428 students from nine public schools located in the region of Castilla-La Mancha, Spain. This region is in the southeast area of the country. The province chosen for developing this study was Albacete. The 428 participants were between 8 and 12 years of age (M= 10.43; SD = 0.837); 52.1% being boys (n= 223) and 47.6% girls (n= 205). The sample was non-probabilistic and intentional by accessibility.

Instruments

Perceived Motor Competence (PMC). The measurement instrument for the assessment of perceived competence (PMC) (Scrabis-Fletcher & Silverman, 2010), was used in the second version (M3F). Personal experience (eight items) reports on the student's perceived feelings of failure, likes and dislikes, and personal ability. Peers (three items) reports on social relationships with peers. Teacher (four items) reports on the students' view of their teacher's actions. Each item was evaluated according to a 5-point Likert scale, with 1 = strongly disagree to 5 = strongly agree.

Perfectionism. The three subscales of the Child Perfectionism Questionnaire (CPQ), adapted to PE, were used. Self-demand (eight items) reports the perfectionist attitude with which the child faces while executing his or her tasks (e.g., I try to be the best in everything I do.). External pressure (eight items) refers to the child's perception of his or her immediate environment as demanding perfect behaviors (e.g., My parents do not accept the mistakes I may make.). Self-evaluation (nine items) reports the valuation attitude that the child has toward him- or herself (e.g., If I am not the best at the things I do, I feel bad.). A 5-point Likert scale was used, with 1 = strongly disagree to 5 = strongly agree (Lozano, Cueto, Vázquez, & González, 2012).

Affectivity. We used the version of the PANAS (Positive and Negative Affect Schedule) validated in Spanish (Ortuño-Sierra, Bañuelos, Pérez de Albéniz, Molina, & Fonseca-Pedrero, 2019; Ortuño-Sierra, Santarén-Rosell, de Albéniz, & Fonseca-Pedrero, 2015) for use with children and adolescents (PANASN) in the context of PE. It is a 20-item self-report questionnaire measuring two dimensions: positive affect (e.g., I am interested in people or things.) and negative affect (e.g., I feel fear.), with 10 items for each subscale. A 5-point Likert scale was used, with 1 = strongly disagree to 5 = strongly agree.

Procedure

A descriptive methodology with a cross-sectional research design was used. Informed consent was requested from the educational centers and parents as well as the consent of the Physical Education teacher at the premises where the research was conducted. Anonymity and the exclusive use of the data for research purposes were guaranteed. An action protocol was elaborated saying which time should be respected while answering each instrument and the information to be given at each moment was marked. The instruments were completed during Physical Education classes, in January 2019, in the presence of the researcher who also informed the students of the objective of the research. The completion of the instruments took approximately 30 minutes.

Data analysis

Descriptive analysis (means, standard deviations, skewness and kurtosis) and bivariate correlation analysis were performed. The internal consistency of the variables from the three questionnaires was calculated using Cronbach's alpha coefficient. For the identification of different self-improvement and affective domain profiles, a hierarchical cluster analysis was performed with Ward's method using the three variables of the self-improvement questionnaire (self-evaluation, self-experience, and external pressure), and also the affective domain variables of the positive and negative PANAS questionnaire. By means of the subsequent k-means analysis with three clusters, the characterization of the three groups was obtained, contrasted by means of ANOVA in all the variables introduced in the cluster analyses.

Subsequently, a multivariate differential analysis (MANOVA) was performed with the three groups with the variables of perceived motor competence (personal experience, peers, and teacher). Univariate F tests were performed to analyze the significant differences in these variables, applying the Bonferroni *post-hoc* test in the cases of significant differences. The magnitude of the differences between the groups studied was obtained using the effect size. Cohen (1988) defines the effect size as small (d= 0.2), medium (d= 0.5) or large (d= 0.8). All analyses were performed using the SPSS 24.0 statistical package.

Results

Descriptive analysis and bivariate correlation analysis

In order to answer the first study objective, i.e., to find out the relationship between PMC and self-perfection and affective competence, descriptive and correlational analyses were carried out.

Table 1 shows the results of the descriptive analysis and the correlations of the variables studied. Mean values, standard deviations, skewness, kurtosis and Pearson's 'R' are shown. Reliability is shown through Cronbach's alpha. The variables of perceived motor competence obtained significant correlations: personal experience with self-evaluation (r= 0.43), self-experience (r = 0.27), external pressure (r = 0.39), and positives r = (-0.14); peers with self-evaluation (r = 0.25), self-experience (r = 0.26), external pressure (r = 0.27), and negatives (r = -0.17); teacher with self-evaluation (r = 0.15), self-experience (r = 0.20), and external pressure (r = 0.18). Significant and positive correlations are therefore contemplated in the three factors of perceived motor competence with the three factors of self-perfection; however, no correlations were found with the positive and negative aspects of affectivity.

To answer the second objective of this study, we analyzed the relationships between the variables and the sex, age and weight status of 4^{th}, 5^{th} and 6^{th} grade primary school students.

Relationship between the variables and gender analysis

The relationship between gender and variables was analyzed. After this analysis, statistically significant differences were found in the variable *partner* (t=3.55;p<.001; d=0.34) with a higher mean in boys (M=9.25 ± 2.66) than in girls (M=8.38 ± 2.36) and also in the variable *personal experience* (t=4.14;p<.001; d=0.20) with a higher mean in boys (M=27.39 ± 5.66) than in girls (M=25.08 ± 5.87). No significant differences were found in the other variables.

Analysis of the relationship between the variables and groups (according to BMI average).

The relationship that the variables could have with respect to the group (overweight yes/no) was analyzed. Thanks to this analysis, statistically significant differences were only found in the

Table 1. Descriptive statistics, Cronbach's alpha coefficient and correlations between the variables

		M	SD	α	1	2	3	4	5	6	7	8
1	Self-evaluation	21.12	7.34	0.83		0.42**	0.51**	0.43**	0.25**	0.15**	-0.15**	0.20**
2	Self-experience	26.28	5.87	0.83			0.32**	0.27**	0.26**	0.20**	0.04	-0.06
3	External pressure	14.10	5.37	0.83				0.39**	0.27**	0.18**	-0.08	0.04
4	Personal experience	19.71	5.22	0.68					0.31**	0.40**	-0.14**	0.05
5	Peers	8.83	2.55	0.68						0.18**	-0.04	-0.17**
6	Teacher	11.97	3.37	0.68							0.00	0.04
7	Positives	24.14	2.93	0.6								-0.23**
8	Negatives	17.38	3.84	0.78								

Note. **p<.01; *p<.05; M = mean; SD = standard deviation; A = skewness; K = kurtosis; α = Cronbach's alpha value.

Table 2. Student's t-test for the variables according to gender

	Male (n=223)		Female (n=205)				
	M	SD	M	SD	*t*	*p*	*d*
Personal experience	19.65	5.24	19.79	5.21	-0.28	0.78	0.03
Peers	9.25	2.66	8.38	2.36	3.55	0.00	0.34
Teachers	12.06	3.45	11.87	3.28	0.60	0.55	0.06
Self-evaluation	20.95	7.51	21.30	7.16	-0.49	0.62	0.02
Self-experience	27.39	5.66	25.08	5.87	4.14	0.00	0.20
External pressure	14.14	5.20	14.06	5.56	0.15	0.88	0.01
Positives	24.26	2.90	24.01	2.96	0.88	0.38	0.09
Negative	17.11	3.64	17.68	4.03	-1.54	0.12	0.07

Note. M = mean; SD = standard deviation; t = Student's t-test; p = p-value; d= effect size Cohen.

companions' dimension (t= -2.3; p=.02; d= 0.25), "I feel greater in the normal weight group" (mean= 9.00 ± 2.53) than in the overweight group (mean= 8.36 ± 2.57). No statistically significant differences were found in the other dimensions.

Analysis of the relationship between the variables and participants' age

The correlations between age and the study variables were analyzed and only statistically significant relationships were found with the variable *self-experience* r= 0.231.

To address the third objective of our study, the multiple regression analysis was used to create a model to predict the perception of perceived motor competence as a function of improvement, affective competence, age, gender, and weight status.

Multiple regression analysis

Once the bivariate relationships were analyzed, a multiple linear regression model was created with the intention of estimating the Perceived Motor Competence (PMC) as a function of the variables of self-perfection, affective competence, and with the variables sex, age, and weight status. The self-perfectionist dimensions (self-evaluation, self-experience and external pressure) were grouped into a single variable. The variables sex and group were converted into dummy variables.

Non-significant variables (p>.05) were excluded from the final model. In all cases, the models meet the assumptions of acceptance, linearity between predictor and criterion variables, as well as homoscedasticity and normal distribution of the residuals. The Durbin-Watson values obtained were adequate, being between 1.5 and 2.5 (Pardo & San Martín, 2010), thus fulfilling the assumption of independence of the residuals. The variance inflation and tolerance index values were adequate.

Table 5 shows the linear regression models generated. In the first model shown, all the variables are presented regardless of their significance. In the second model, only the significant variables are shown, which were self-improvement and the weight group as a dummy variable. In the third model, the weight group variable was excluded to see if it could be a modifying variable of self-perfectionism. It was found that it was not, that the beta coefficient of self-perfectionism was hardly affected by body weight. The resulting simple model with the variable self-perfectionism explained PMC by 22.8%, rising to 23.7% when weight status was included. Weight status does not play a moderating role between perfectionism and PMC since the beta coefficient is not affected by weight.

Finally, to address the fourth objective of this study, which aims at the creation of typologies of schoolchildren in Primary Physical Education characterized by perceived motor competence, self-improvement and affective mastery, the multivariate technique of cluster analysis and differential analysis was used.

Cluster analysis

The values of all the variables were standardized using Z-typing. No scores above three were found to indicate outliers in the sample. After sample purification and descriptive analyses, we proceeded to perform a cluster analysis with the

Table 3. Student's t-test for the variables according to participants' weight

	Overweight (n=112)		Normal weight (n= 316)				
	M	SD	M	SD	*t*	*p*	*d*
Self-experience	19.12	4.94	19.92	5.31	-1.41	0.16	0.15
Peers	8.36	2.57	9.00	2.53	-2.30	0.02	0.25
Teacher	11.78	3.52	12.04	3.31	-0.70	0.48	0.08
Self-evaluation	21.58	8.31	20.96	6.98	0.71	0.48	0.08
Personal experience	26.41	6.12	26.23	5.79	0.27	0.78	0.03
External pressure	13.86	5.38	14.19	5.38	-0.56	0.57	0.06
Positives	23.96	3.02	24.21	2.90	-0.80	0.43	0.09
Negatives	17.21	3.57	17.44	3.93	-0.53	0.59	0.06

Note. M = mean; SD = standard deviation; t = Student's t-test; p = p-value; d = effect size Cohen.

Table 4. Pearson's correlations between age and the study variables

		Self-evaluation	Self-experience	External pressure	Personal experience	Peers	Teacher	Positives	Negatives
AGE	*r*	0.004	0.231**	-0.082	0.032	-0.070	-0.077	0.011	0.018
	p	0.931	0.000	0.091	0.515	0.147	0.113	0.823	0.708

three dimensions of the self-perfection questionnaire (self-evaluation, personal experience, and external pressure) and the two dimensions of the PANAS questionnaire (Positives, Negatives). The dendrogram suggested three different groups.

One profile with high self-perfectionism (n=153), the second profile with low self-perfectionism (n= 162), and the third group with a medium self-perfectionism profile (n= 108). The profile with "high self-enhancement" presented high values in self-evaluation, personal experience and external pressure, moderate values in positives and low values in negatives. The profile with low self-perfectionism presented the lowest values in self-evaluation, personal experience, and external pressure, high in positives and low in negatives. And finally, the medium self-enhancement profile presented medium values in self-evaluation, personal experience and external pressure, and low values in positives and high values in negatives. Differences of 0.5 in Z-scores were used as a criterion to describe whether a group scored relatively high or low compared to the others (Wang & Biddle, 2001).

Differential analysis

To study different features of each profile obtained in terms of perceived motor competence

Table 5. Linear regression analysis

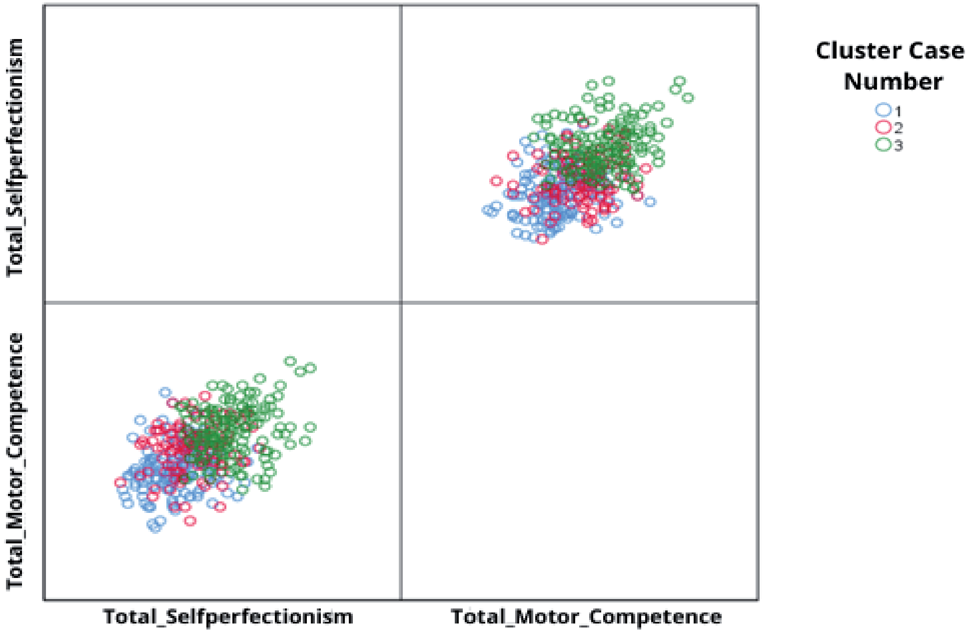
Variable criteria	r-cua	D-W	Predictor variables	Beta	t	p	T	FIV
PMC	0.249	1.982	(Constant)	37.109	6.301	0.000		
			Positives	-0.209	-1.675	0.095	0.940	1.064
			Negatives	-0.140	-1.468	0.143	0.937	1.068
			Self-perfectionism	0.275	11.213	0.000	0.977	1.023
			Sex	0.748	1.028	0.305	0.948	1.054
			Overweight	-1.968	-2.392	0.017	0.959	1.043
			Age	-0.565	-1.318	0.188	0.976	1.024
PMC	0.237	1.96	(Constant)	24.091	15.550	0.000		
			Self-perfectionism	0.275	11.300	0.000	1.000	1.000
			Overweight	-1.841	-2.277	0.023	1.000	1.000
PMC	0.228	1.936	(Constant)	23.657	15.312	0.000		
			Self-perfectionism	0.274	11.214	0.000	1.000	1.000

Table 6. Means, standard deviations, Z-scores for each cluster

	Cluster 1: Low perfectionism, n = 162 (37.8%)			Cluster 2: Medium perfectionsim, n = 108 (25.2%)			Cluster 3: High perfectionism, n = 153 (36,92%)				
	M	SD	Z	M	SD	Z	M	SD	Z	F	pot.
Self-evaluation	17.28	5.88	-0.52	21.27	6.69	0.02	24.96	7.11	0.52	54.79	0.21
Self-experience	23.60	5.46	-0.46	24.10	4.97	0.41	30.51	4.21	0.72	93.61	0.31
External pressure	11.15	3.44	-0.55	12.61	4.20	-0.28	18.15	5.24	0.75	111.02	0.34
Positives	26.09	2.00	0.66	21.12	2.37	-1.03	24.22	2.29	0.03	164.28	0.44
Negatives	16.69	3.18	-0.18	20.06	3.19	0.70	16.27	4.00	-0.29	42.50	0.17

Table 7. Multivariate analysis of PMC dimensions personal experience, peers and teacher according to clusters

	Cluster 1: Low perfectionism, n = 162 (37.8)		Cluster 2: Medium perfectionism, n = 108 (25.2%)		Cluster 3: High perfectionism, n = 153 (36.92%)			
Variables	M	SD	M	SD	M	DT	F	Power
Self-experience	16.20	3.58	19.96	4.44	23.15	4.78	105.89	0.33
Peers	8.02	2.35	8.57	2.37	9.84	2.54	23.36	0.10
Teacher	11.07	3.43	12.08	3.09	12.82	3.28	11.39	0.05



Note: "As can be seen in the point diagram, the three groups offered by the cluster analysis are clearly differentiated, the students with low self-perfectionism have a low PMC, those with average self-perfectionism also have a medium PMC and the same occurs with those with high self-perfectionism who have a high PMC".

Figure 1. Point diagram of perfectionism and perceived motor competence in the three clusters.

in its three dimensions (Table 7, peers and teachers), a multivariate analysis of variance (MANOVA) was performed. The clusters obtained were used as independent variables or factors, and the three dimensions of perceived motor competence were used as dependent variables (see Table 7).

The results obtained showed significant differences in the three dimensions of perceived motor competence, personal experience (F= 105.89, p<.001, p =.33), peers (F= 23.36, p<.001, p=.10) and teacher (F= 11.39, p<.01, p=.05), with the highest scores of the three dimensions found in the high self-improvement cluster, the lowest scores in the low self-improvement cluster, and the means in the medium self-improvement cluster.

Discussion and conclusions

The aim of this research was to establish if different dimensions of self-perfectionism and emotional competence are related to the perceived motor competence in Primary Education students. By relating all the variables, a model that explained the perceived motor competence was created. It was considered interesting to analyze different groups or types of students of Primary Education that can be established to address the relationships with perceived motor competence. In this sense, positive correlations were obtained between all the dimensions of perceived motor competence and self-improvement. It is worth noting the absence of a significant relationship between the dimensions of perceived motor competence and affective domain in Primary Education students.

These results may be due to the satisfaction or frustration generated by a motor task since they can determine the locus of causality or the type of motivation that a student has in his or her different contexts where he or she participates (e.g., an activity, a lesson, a curricular content, physical education lessons, lifestyle, etc.) where internal, external, and impersonal forms may appear. Within this motivation, a learner is intrinsically motivated when he or she voluntarily participates in an activity for the mere interest, pleasure and personal satisfaction obtained by practicing it (Méndez-Giménez, et al., 2015a). However, in this research, it is pointed out that the student can be extrinsically motivated whenever participation in an activity is determined by external rewards or agents. In this sense, a student can perform an activity because it is part of his or her lifestyle (integrated regulation), knows the benefits and the importance it has in the overall development of the person (identified regulation), wants to feel good and avoid feelings of guilt or anxiety (introjected regulation) or wants to get an external reward or avoid punishment by the school institution (external regulation).

Motivation is a dynamic process that accounts for the interaction and filtering of the information by the student and the effect it has on the student's behavior. The perception of competence, an embedded motivational theory, postulates that the influence of precious experience and the received information from external sources affects the student's behavior. Attitude is also a multifaceted construct that can be defined from different dimensional viewpoints (Scrabis-Fletcher & Silverman, 2017). In this regard, some specific factors have been identified in this manuscript as determinants of student attitude, including teacher, curriculum, and context.

In turn, depending on the subjective well-being of the student in each motor task, a classification of positive and negative affect can be generated, where positive emotions are understood as favorable and negative emotions as unfavorable for such well-being (Redorta, et al., 2006); an aspect that would explain the absence of a relationship between the dimensions of perceived motor competence and the affective domain in elementary school students. For example, motor interaction and the sociocultural context where it takes place are aspects that determine the type of motor play, providing specific characteristics that differentiate it in the Physical Education class (Gil-Madrona, et al., 2020a). These characteristics of motor play can be a differentiating element in the affective domain. Specifically, this study, like ours in terms of methodology, concluded that the type of sociomotor games with sociocultural content allows students to develop social skills in a positive learning environment. Therefore, they suggest that the affective dimension has to be incorporated in the analysis of pedagogical practices in order to favor an integral education that considers the human being as a being who is sensitive to his or her environment and who is moved during the activities developed in the sessions.

Although both constructs are socio-cognitive in nature, they are not correlated as previously believed (Scrabis-Fletcher & Silverman, 2017). Low correlations between the models suggest that the two constructs should be measured independently of each other and that one should not be used to predict the other. Attitude and perceived motor competence are two distinct socio-cognitive constructs that share similar characteristics and factors, as reported here, function independently of each other.

Another of the findings obtained in this research was a model that explained the perceived motor competence in 23.7% with the total dimension of self-perfectionism and weight status. Three different profiles were detected and differentiated, called high self-perfectionism, medium self-perfectionism and low self-perfectionism; these groups in turn showed an analogy in perceived motor competence, high, medium and low, a result also obtained in the regression analysis.

One study points out that self-demand positively predicts achievement goals, while external pressure predicts, negatively, approach-mastery goals and, positively and directly, controlled motivation and demotivation (Méndez-Giménez, et al., 2015b). The latter was also mediated by approach-mastery goals. Likewise, approach goals positively predicted autonomous motivation and performance goals positively predicted controlled motivation. The expected patterns of achievement goals were confirmed, and the different implications of perfectionism were discussed too. However, another study, after analyzing the influence of the dimensions of anger expression and perfectionism on self-evaluation, the pillars on which personality is built, revealed how the different dimensions of maladaptive perfectionism were related to a lower self-evaluation; contrary to what was found with different dimensions of adaptative perfectionism (Villena, et al., 2016). The trait anger dimension correlates inversely with self-evaluation. In addition, the indicators of adaptive perfectionism—Organization and Personal Standards—are significantly associated with a higher perception of self-evaluation of the players; in contrast to what happens with those who present maladaptive perfectionist tendencies. In this regard, they point out that the evaluation of this type of variable in the educational environment allows the design of health prevention programs and/or stimulation of adaptive behaviors for team sports.

Luna et al. (2019) carried out research whose objective was to evaluate the impact of a pilot physical-sports education program on the subjective well-being of teenagers (health-related quality of life, positive and negative affect), emotional intelligence traits and social anxiety. This program was based on a pedagogical model of sports education within a framework of quality physical education, and it was approached from the perspective of social and emotional learning. The results of the research revealed that the physical-sports pilot program promoted significant improvements in a specific indicator of subjective well-being and emotional intelligence trait in the experimental group. These findings support the pedagogical efficiency of the program with respect to the program's objective. The findings also highlighted the feasibility and appropriateness of the program in terms of an innovative didactical proposal.

The results obtained in the other study (Johnson, 2019) show how students perceived negative and positive emotions regarding their subjective well-being before and after practicing sports activities. These emotions were mainly attributed to factors such as the level of preference for the task, the perceived motor competence, previous sports experiences, and classroom organization. The study also identified similarities and divergences according to the type of motor task, gender, and school. The teachers were also able to perceive positive and negative emotions for the subjective well-being of the students. In a broad sense, it is concluded that emotions around a sports didactical unit have been associated with psychological, didactical, motor, environmental, moral, ethical and cultural aspects and have been identified according to the type of motor task, gender and educational center.

With respect to the findings obtained according to gender, differences were only found in the dimension of perceived motor competence of peers and also in personal experience, with higher scores in the males than in the females. These results show similarities to another study (Méndez-Giménez, et al., 2015a), which showed that girls had a lower perception of competence than boys. However, it is important to highlight that these differences depend on the motor task. That is, girls perceived a higher self-determined motivation, fun and cognitive attitude in acrosport and boys showed higher values in the motivational variables in the football contents compared to the acrosport contents. On the contrary, girls scored higher in the motivational variables in acrosport compared to the other two cooperative-oppositional collective sports contents. Therefore, this study proposes guidelines to reorient the teaching-learning process in these didactical units through the development and implementation of specific strategies that allow influencing the motivational processes according to gender.

In this sense, motor interaction is a key aspect which determines the type of socio-motor game, providing specific features that differentiate this kind of game from any other type of didactical resource used during physical education lessons (Espi, et al., 2019). The main results of this research indicate that during cooperation games a lower positive affect is perceived than in cooperation-opposition games. It is concluded that positive affection predominates in both socio-motor games, so it is an ideal content to build a great learning atmosphere. According to sex, it is concluded that women perceive more positive affect than men in the cooperation-opposition games and less in the non-opposition cooperation games. As for negative affection, in both games, men perceive it more than women. Another study (Méndez-Giménez, et al., 2018) found that males scored higher on approach-task, approach-other, and avoidance-other goals. Approach-task and approach-friendship goals were the main positive predictors of positive affect.

Regarding weight, the results obtained considering weight showed differences in the motor competence dimension perceived by the peers in relation to weight, being lower in the overweight group. On the other hand, age was only related to personal experience, being higher the older the age.

Another study (Sanmartín, et al., 2018), that analyzed the relationship between affect and its different theoretical categories: positive and negative affect and the different dimensions of social functioning (school performance, family relationships, relationships with peers and household tasks), found that high levels on all dimensions of social functioning also reported significantly higher levels of positive affect than their peers who reported low levels; conversely, students who reported high levels of social functioning reported significantly lower levels of negative affect than their peers who reported low levels. Similarly, logistic regression analyses showed that an increase in positive affect increased the likelihood of high levels of social functioning and that an increase in negative affect decreased the likelihood of presenting high-level dimensions of social functioning, except for school performance.

In this sense, following the model of González-Arratia, et al., (2017), a direct and significant effect of the negative affect on the positive aspect and resilience is suggested but also a significant indirect effect of self-evaluation on resilience, which supports the main hypothesis. Further specification of the model in a diversified sample is required for the analysis of possible differences in gender and age.

It is important to highlight that the findings of this research must be interpreted carefully because of the methodological limitations derived from its transversal nature (it is not possible to establish causality relationships), the sample size as well as the application of self-reporting questionnaires, generating biases of evaluation.

However, despite these results are the result of external validity and are not generalizable, they can be used as indications to be taken into account in intervention and longitudinal programs to corroborate whether an intervention program aimed at improving perceived motor competence can improve perfectionism and affective mastery in primary school children; these being located in a transcendental period in the life cycle of the person, where the formation of the personality and the acquisition of healthy life habits begin.

Due to the obtained results, these are the main conclusions obtained from this research: there is a positive correlation between all dimensions of perceived motor competence and self-improvement; regarding their genre; male subjects obtained higher values of motor competence and self-improvement perceived by their mates and in personal experience. Considering the weight status, a lower perceived motor competence was found in the overweight group; the older the age, the higher the personal experience; and 23.7% of the perceived motor competence was explained by the total dimension of self-improvement and weight status. These results acquire importance since they extend the relationship between perceived motor competence and self-improvement in elementary school children, which is potentially of interest in the fields of education and psychology.

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IS THE RELATIVE AGE EFFECT PREVALENT IN ELITE BRAZILIAN MALE FUTSAL? AN INVESTIGATION BASED ON AGE CATEGORIES AND PLAYING POSITIONS

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Abstract:

This study aimed to investigate the existence of relative age effect (RAE) in male Brazilian futsal athletes according to age categories and playing position. Data from male futsal athletes from the top five teams in Brazil were collected during May and June 2021. The distribution of birth dates of 387 male futsal athletes was analyzed, based on their age categories (U15, n = 97; U17, n = 88; U20, n = 116; senior, n = 86) and playing positions (defender, n = 76; winger, n = 162; pivot, n = 69; goalkeeper, n = 80). Chi-squared tests were used to analyze the birth dates distribution based on quarters and semesters of the year according to age categories and playing positions. The overall analysis of birth quarter indicated a higher occurrence of births in the first quarter of the year ($p<.001$; $V = 0.188$). The age categories analysis indicated a uniform distribution in U15 ($p=.09$; $V = 0.15$) and unequal distributions in U17 ($p<.001$; $V = 0.29$), U20 ($p<.007$; $V = 0.19$) and senior ($p<.01$; $V = 0.21$) categories. The playing position analysis indicated a uniform distribution for the pivots ($p=.11$; $V = 0.17$) and unequal distribution for goalkeepers ($p<.04$; $V = 0.19$), wingers ($p<.002$; $V = 0.19$) and defenders ($p<.002$; $V = 0.27$). We concluded that RAE was present in Brazilian elite men's futsal, especially in the U17, U20, and senior categories, and goalkeepers, wingers, and defenders. Our results reinforce the need to consider the effects of relative age in the development of Brazilian elite futsal players.

Key words: *RAE, birth-date, birth effect, talent selection, elite athletes*

Introduction

Age categories in team sports for young players are often determined according to the athletes' birth years. Based on this separation emerges the relative age effect (RAE), which is understood, from a developmental point of view, as the set of differences related to the birth date of athletes within the same age category (Andronikos, Elumaro, Westbury, & Martindale, 2016). These differences may provide a possible advantage to athletes born closer to the beginning of the selection year when compared to those born later (Ostapezuk & Musch, 2013). This effect can influence not only the athletes' recruitment but also how they develop their motor skills or athletic capacity (Lidor, Maayan, & Arnon, 2021). For this reason, RAE has been extensively researched as a factor that can influence the selection and talent identification in different team sports (Rada, Padulo, Jelaska, Ardigò, & Fumarco, 2018; Rubajczyk & Rokita, 2020; Schorer, Cobley, Büsch, Bräutigam, & Baker, 2009; Schorer, Wattie, & Baker, 2013).

Specifically in Brazil, recent studies have found evidence of RAE in team sports like volleyball (Castro, Aguiar, et al., 2022), handball (Costa, et al., 2021; Figueiredo, Gantois, Lima-Junior, Fortes,

& Fonseca, 2020), beach handball (Figueiredo, Ribeiro, et al., 2020), track and field (Figueiredo, Silva, et al., 2021), soccer (Figueiredo, Gomes, et al., 2022), and futsal (Castro, Aguiar, Clemente, et al., 2022; Castro, Figueiredo, et al., 2022; Ferreira, et al., 2020; Morales Júnior, Alves, Galatti, & Marques, 2017).

One of the explanations for the differences found between individuals within a category is based on the fact that older athletes are more likely to present advanced maturation compared to the athletes born farther from the starting selection cut-off date. Accordingly, these athletes may benefit in terms of sports performance, depending on the specific demands of the sport modality and their developmental characteristics. Wattie, Schorer, and Baker (2015) propose a constraints-based model (individual, environment, and tasks constraints) to explain RAE (Kelly, Cotê, Hancock, & Turnnidge, 2021). In this constraints-based model (Wattie, et al., 2015), the individual constraints refer to athlete's individual qualities, such as body composition, sex-specific qualities, height, and maturational status; the environmental constraints relate to the sport's popularity, policies, and physical environment; and the task constraints regard the sport's specificity, the physical capabilities that are more important for success, and its competitive level (Wattie, et al., 2015). In general, relatively older athletes are more likely to exhibit advanced physical characteristics and enter puberty earlier than their younger peers (Cobley, Baker, Wattie, & McKenna, 2009; Lovell, et al., 2015; Musch & Grondin, 2001). This gives to relatively older athletes performance advantages in most team sports, including futsal (Figueiredo, Seabra, Brito, Galvão, & Brito, 2021). These advantages occur due to more favourable and developed attributes such as height, muscle mass, aerobic power, muscle strength, endurance, and speed (Malina, Bouchard, & Bar-Or, 2004), factors that may influence performance in a particular sport modality (Castro, Aguiar, Figueiredo, et al., 2022; Figueiredo, Seabra, et al. 2021).

In this sense, some studies indicate that the RAE will be gradually reduced throughout the athletes' sports career, until it ceases to exist (Bjørndal, Luteberget, Till, & Holm, 2018; Brazo-Sayavera, Martínez-Valencia, Müller, Andronikos, & Matindale, 2018; Buekers, Borry, & Rowe, 2015; de la Rubia, Lorenzo-Calvo, & Lorenzo, 2020; Joyner, et al., 2020). Even though the reduction in RAE can be explained by a maturational bias (considering that the division by age groups usually ends around 19-21 years of athletes' age, when physical maturity differences are expected to be irrelevant), this explanation depends on whether relatively younger athletes remain actively engaged in the sport modality during the years of selection or not (Cobley, et al., 2009). Another explanation for this phenomenon is given by Mann and van Ginneken (2017), who affirm that although RAE may cause a biased talent identification in young categories, relatively younger players may be more likely to succeed in the long run, considering that they must consistently overcome the challenges of training and competing against older children, which can lead to advantages. However, some studies have reported that RAE remains up to senior elite sports in some contexts where this effect is very pervasive in younger categories (Costa, et al., 2021; Figueiredo, Ribeiro, et al., 2020; Joyner, et al., 2020; Lidor, et al., 2021).

Another aspect that should be considered when investigating RAE in team sports is the athletes' playing positions since they present specific demands. Evidence from studies with Brazilian soccer (Figueiredo, et al., 2022) and handball (Figueiredo, Gantois, Gomes, et al., 2020) athletes, indicate that RAE is more prevalent in playing positions in which physical capabilities are more determinant for success. Furthermore, some RAE investigations have tried to determine whether this effect is associated with competitive success. To illustrate, Arrieta, Torres-Unda, Gil, and Irazusta (2015) found that relatively older players scored more points and showed increased performance index ratings compared to relatively younger athletes in European basketball championships. However, the investigation of the association between RAE and the performance obtained during games in team sports is still limited, especially when it comes to futsal.

Futsal is a multiple-sprint sport with intermittent high-intensity activities. Its popularity has grown in recent years with more than 12 million players involved in the sport (Beato, Coratella, & Schena, 2016). However, studies that have investigated RAE in futsal athletes are still scarce. In the senior or professional futsal categories, studies have indicated controversial results. In the study of Brazilian athletes, Morales Júnior et al. (2017) found evidence of RAE in male athletes, which was later confirmed by Castro, Aguiar, Clemente, et al. (2022), with the addition that the effect seemed position-dependent in the latter sample of elite athletes. On the other hand, Carraco, Galatti, Massa, Loturco, and Abad (2020) indicated that being born in the first months of the year did not seem to determine success in the modality. Lago-Fuentes, Rey, Padrón-Cabo, Prieto-Troncoso, and Garcia-Núñez (2020) even found a reverse RAE, corroborating that RAE findings in futsal are still controversial.

Although most RAE research approaches and methodologies have been used to document the "why" and "how" of the relationship between characteristics of the athlete's birth date and development, it is argued that more studies on specific contexts are still necessary (Kelly, et al, 2021). In addition to the controversial RAE results found in futsal, no previous research has analyzed the RAE in Brazilian male futsal players from different age categories while considering playing positions. Thus, this study aimed to investigate the existence of RAE in the most competitive teams of male Brazilian futsal athletes according to age categories (from U15 to senior) and playing positions. Our hypothesis is that RAE will be found in athletes from different age categories and playing positions, considering the theoretical model from team sports proposed by Wattie et al. (2015).

Methods

Participants

This is a retrospective and descriptive study with a cross-sectional design. The sample of this study was composed of 387 male futsal athletes from the top five teams in Brazil, divided by age categories: U15 (n = 97; mean age = 13.8 ± 0.8 years), U17 (n = 88; mean age = 15.8 ± 0.7 years), U20 (n = 116; mean age = 18.2 ± 0.9 years) and senior (n = 86; mean age = 26.3 ± 6.1 years); and playing positions: defender (n = 76), winger (n = 162), pivot (n = 69), and goalkeeper (n = 80). All athletes competed in national and international competitions for their respective team in the 2021 season. The division from U15 to senior categories was chosen because these are the competitive age categories and playing positions defined in Brazil. To select the sample, the Brazilian teams that most participated and won titles in national and international championships in the last five years were considered, since no official teams rankings are maintained by futsal federations either in Brazil or worldwide. To illustrate the relevance of these teams in Brazil and worldwide, in the last five years they won five national titles and four international titles. The exclusion criterion was the absence or inconsistency in any of the information necessary for the research, such as the athletes' date of birth, age category and/or playing position.

Data collection and procedures

This study applied similar methods as were used in previous studies in futsal (Lago-Fuentes, et al., 2020). Data were obtained from the official teams' websites or made available by the teams upon request made by the researchers. Once data were collected, a member of the technical staff of the teams that made up the sample checked it for reliability purposes. All data collection procedures occurred during May and June 2021. The information included players' date of birth, playing positions (goalkeeper, winger, defender, or pivot), age categories (U15, U17, U20, and senior), and teams. All information was kept confidential and was used specifically for this study, after athletes' anonymity and the teams' agreement.

For the purpose of this study, we defined the birth year as beginning on January 1st, as used by the other studies in sports (Cobley, et al., 2009). The data were organized in a spreadsheet, and the variables analyzed included the athletes' birthdate quarters, as used in the previous studies in futsal (Carraco, et al., 2020; Morales Júnior, et al., 2017): quarter one: Q1 (January-March), quarter two: Q2 (April-June), quarter three: Q3 (July-September), and quarter four: Q4 (October-December), age categories (U15, U17, U20, and senior), and playing positions (defender, winger, pivot, and goalkeeper).

Statistical analysis

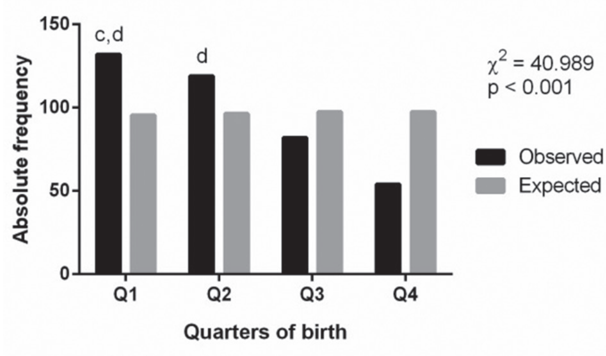
The frequencies of Brazilian futsal athletes born in each of the quarters were presented in absolute values. Chi-square tests (χ^2) were performed to compare the birthdates' distribution by age categories and playing positions. The observed distributions of athletes' birthdates in each quarter were compared with the expected frequencies (Edgar & O'Donoghue, 2005). The effect size (Cramer's V) of the chi-square tests was calculated for all analyses, considering 0.1 a small effect, 0.3 a medium effect and 0.5 a large effect, based on Cohen (1988). Additionally, odds ratio (ORs) and 95% confidence intervals for Q1 versus Q4 and the first versus the second semester (1st:2nd) were calculated, similarly to Figueiredo, Ribeiro, et al. (2020). Analyses were performed using the Statistical Package for the Social Sciences (SPSS), version 20.0 (Chicago, USA). The significance level was set to 0.05. Multiple comparisons between the quarters were performed as *post-hoc* analyses, when necessary. In these cases, Bonferroni's corrections were performed, and the significance level was adjusted to 0.0083.

Results

The analysis of the overall sample of futsal athletes indicated an uneven distribution according to the quarters of birth (χ^2 = 40.989; p<.001; V = 0.188), with a small effect size, as seen in Figure 1. The *post-hoc* analyses indicated more athletes in Q1 compared to Q3 and Q4 (p<.0083). Moreover, more athletes were found in Q2 compared to Q4 (p<.0083).

The analysis of futsal athletes' birthdates distribution according to age categories indicated an even distribution in the U15 (p=.09; V = 0.15) category (Table 1). On the other hand, uneven distributions were found in the U17 (p<.001; V = 0.29), U20 (p<.007; V = 0.19) and senior (p<.01; V = 0.21) categories. In these cases, small effect sizes were reported, and *post-hoc* analysis revealed an overrepresentation of athletes born in Q1 compared to Q4 (p<.0083) in the U17 and U20 categories. As for the senior category, the *post-hoc* analysis revealed an overrepresentation of athletes born in Q2 compared to Q4 (p<.0083).

The analysis of futsal athletes' birthdates distribution according to playing positions indicated an even distribution for pivots (p=.11; V = 0.17) (Table 2). On the other hand, uneven distributions were found for goalkeepers (p<.04; V = 0.19), wingers (p<.002; V = 0.19) and defenders (p<.002; V = 0.27). In these cases, small effect sizes were reported. The *post-hoc* analysis failed to identify the differences in the case of goalkeepers. However, the *post-hoc* analysis revealed an overrepresenta-



c = different from Q3; d = different from Q4.

Figure 1. Quarters of birth distribution of the overall Brazilian futsal athletes.

Table 1. Quarters of birth distribution of Brazilian futsal athletes according to age categories

Age category	Q1 (Exp) [%O-E]	Q2 (Exp) [%O-E]	Q3 (Exp) [%O-E]	Q4 (Exp) [%O-E]	χ^2	p	V	OR – Q1:Q4 95% IC	OR – 1st:2nd 95% IC
U15	29 (24) [5.2]	29 (24.2) [5]	25 (24.4) [0.6]	14 (24.4) [-10.8]	6.493	0.09	0.15	2.53 1.24 to 5.13	2.21 1.25 to 3.25
U17	39 [d] (21.7) [19.6]	21 (21.9) [-1]	19 (22.2) [-3.6]	9 (22.2) [-15]	22.005	<0.001	0.29	6.99 3.14 to 15.47	4.59 2.44 to 8.65
U20	40 [d] (28.7) [9.8]	36 (28.9) [6.1]	22 (29.2) [-6.2]	18 (29,2) [-9.7]	12.323	<0.007	0.19	2.87 1.52 to 5.37	3.61 2.1 to 6.2
Senior	24 (21.3) [3.2]	33 [d] (21.4) [13.5]	16 (21.7) [-6.6]	13 (21.7) [-10.1]	11.558	<0.01	0.21	2.17 1.02 to 4.59	3.86 2.05 to 7.26

Note. Q1-Q4 = birth quarters; (Exp) = expected distribution; [%O-E] = relative difference between the observed and expected distribution; χ^2 = chi-square; p = level of significance; V = effect size; OR – Q1:Q4 = odds ratio from Q1 to Q4; OR – 1st:2nd = odds ratio from 1st semester to 2nd semester; d = different from Q4.

Table 2. Quarters of birth distribution of Brazilian futsal athletes according to playing positions

Playing position	Q1 (Exp) [%O-E]	Q2 (Exp) [%O-E]	Q3 (Exp) [%O-E]	Q4 (Exp) [%O-E]	χ^2	p	V	OR - Q1:Q4 95% IC	OR - 1st:2nd 95% IC
Goalkeeper	29 (19.8) [11.5]	23 (19.9) [3.8]	16 (20.2) [-5.2]	12 (20.2) [-10.2]	8.938	<0.04	0.19	3.22 1.51 to 6.86	3.45 1.8 to 6.6
Winger	50 (40) [6.2]	56 [c,d] (40.4) [9.7]	29 (40.8) [-7.3]	27 (40.8) [-8.5]	16.638	<0.002	0.19	2.23 1.32 to 3.79	3.58 2.26 to 5.66
Defender	29 [d] (18.8) [13.4]	22 [d] (18.9) [4]	20 [d] (19.1) [1.1]	5 (19.1) [-18.6]	16.548	<0.002	0.27	8.76 3.24 to 23.5	4.16 2.11 to 8.18
Pivot	24 (17) [10.1]	18 (17.2) [1.2]	17 (17.4) [-0.6]	10 (17.4) [-10.7]	6.014	0.11	0.17	3.14 1.37 to 7.16	2.42 1.22 to 4.79

Note. Q1-Q4 = birth quarters; (Exp) = expected distribution; [%O-E] = relative difference between the observed and expected distribution; χ^2 = chi-square; p = level of significance; V = effect size; OR – Q1:Q4 = odds ratio from Q1 to Q4; OR – 1st:2nd = odds ratio from 1st semester to 2nd semester; c = different from Q3; d = different from Q4.

tion of athletes born in Q2 compared to Q3 and Q4 (p<.0083) for wingers. Additionally, the *post-hoc* analysis indicated an overrepresentation of athletes born in Q1, Q2 and Q3 compared to athletes born in Q4 (p<.0083) for defenders.

Discussion and conclusions

The present study aimed to investigate the existence of RAE in male futsal athletes that play on the most competitive Brazilian teams according to age categories (U15 to senior) and playing position (defender, winger, pivot, and goalkeeper). In the general analysis of birth quarter, the results indicated a higher occurrence of births in the first quarter of the year. In the analysis by age categories, there was a uniform distribution in U15 and an unequal distribution in U17, U20, and senior age categories. In the analysis by playing position, a uniform distribution was found for the pivots and an unequal distribution for goalkeepers, wingers, and defenders. According to our results, we confirmed our hypothesis, evidencing RAE across age categories (specifically in U17 to senior) and playing positions (specifically in goalkeepers, wingers, and defenders).

The overall analysis of our sample indicated more athletes in Q1 compared to Q3 and Q4. Moreover, more athletes were found in Q2 compared to Q4. Similar results were found by Morales Júnior et al. (2017), who also found the RAE in a sample of 376 male athletes that participated in the 2013 Brazilian National Futsal League (LNF). However, the differences were related to the semesters, indicating that in that season there were more futsal players born in the first semester of the year than in the second.

On the other hand, different results were presented by Carraco et al. (2020), who analyzed the birth dates of 950 players competing in FIFA Futsal World Cups (years of 2008, 2012, and 2016), and found no significant differences between quarter or semesters, which means that the authors did not find the RAE in their study. A similar result was presented in the study by Lago-Fuentes et al. (2020), which did not identify differences between the birth quartera of professional futsal players in the First Division of the Spanish National Futsal League between 2006-2007 and 2014-2015 seasons. It is noteworthy that the aforementioned studies were carried out only with senior elite futsal athletes, unlike our sample, which was composed of elite athletes from the U15 to senior categories.

Regarding the age categories, the analysis indicated an even distribution in the U15 category. This led us to speculate that the talent selection processes in younger generations of futsal players might not be based on the factors that could have increased the likelihood of the RAE in this sports system (Andronikos, et al., 2016). Similar results were reported in an investigation with elite female Brazilian handball players conducted by Figueiredo, Gantois, et al. (2020), in which the RAE was only found in U20 and senior categories, but not in the U18 category. This may indicate a paradigm shift in the talent selection models applied in younger categories, with coaches being more aware of the existence of RAE. However, to confirm these speculations we recommend longitudinal investigations with future generations of elite Brazilian futsal players and the assessment of the knowledge of coaches from different categories about the RAE.

Regarding the U17, U20, and senior categories, uneven distributions of birthdates were reported, with an overrepresentation of athletes born in Q1 compared to Q4 in the U-17 and U20 categories, and in Q2 compared to Q4 in the senior category. These results are in line with findings from other sports. For instance, Lidor et al. (2021) investigated 1397 young Israeli athletes (14 to 18 years of age) of both genders and observed the presence of the RAE in male swimming, basketball, soccer, and handball athletes, with a higher representation of those born in the first two quarters of the year compared to those born in the last two quarters. Additionally, Costa et al. (2021) evaluated the RAE in the Brazilian handball men's teams that competed in the World Championships of the U19, U21, and senior categories, and observed the prevalence of RAE in all categories.

However, Bjørndal et al. (2018) conducted a study with youth, junior and senior male and female international team selections of Norwegian handball players, and identified uneven birth dates distributions for youth and junior male and female athletes (favoring the relatively older players), but not an uneven distribution in the senior category. In other study, conducted by Figueiredo, Seabra et al. (2021), involving Portuguese soccer and futsal players of both genders from U7 to U19 categories, the authors observed the RAE in futsal only in U7 and U9 categories, with an overrepresentation of athletes born in Q1 and Q2 compared to Q4. These results are different from those found in our study, as we did find the RAE in the upper categories of futsal. In addition, the categories that showed the effect in the study by Figueiredo, Seabra et al. (2021) were not analyzed in the present study.

According to the constraints-based model (Wattie, et al., 2015), the presence of the RAE among age categories can be observed at different stages of the athletes' sports career, depending on the influence of physical maturation on performance in specific tasks. Other factors presented by this theoretical model (Wattie, et al., 2015) are the influences of sporting popularity in the country, indicating higher levels of competitiveness in youth categories, and the rules for the participation of young people in the sport context in an amateur or professional manner. Thus, due to the culture and a large number of futsal players in Brazil, there is greater concern with competitive aspects, thus increasing the RAE chances (Morales Júnior, et al., 2017).

Although some studies indicate that the RAE decreases or even disappears in senior elite sports (Bjørndal, et al., 2018; Brazo-Sayavera, et al., 2018; Buekers, et al., 2015; de la Rubia, et al., 2020; Joyner, et al., 2020) due to a smaller influence of the physical maturity bias (Cobley, et al., 2009), our study showed that the RAE was maintained even in the senior category. Some explanations can be proposed: 1) the popularity of futsal in Brazil—environmental constraints (Wattie, et al., 2015), as previously explored; and 2) as the effect was found in most of the younger categories, there were increased opportunities for athletes born in the first quarter of the year to reach the senior level.

Regarding the playing position, the analysis indicated an even distribution for pivots and uneven distributions for goalkeepers (no differences identified), wingers (overrepresentation of athletes born in Q2 compared to Q3 and Q4), and defenders (overrepresentation of athletes born in Q1, Q2 and Q3 compared to athletes in Q4). Figueiredo, Gantois, et al. (2020), in their study with U19 to senior Brazilian handball teams, only found RAE prevalence for male athletes in the wingers and defenders' positions. Despite being different modalities, they have very similar characteristics (invasion team sports), which may justify the similarity between the results. In another sport with the same particularities, the soccer, Towlson et al. (2017) investigated the RAE on young elite soccer players and found a likely small effect in the U13-14 category regarding the playing positions, with lateral-defenders and central-midfielders being older than central-defenders. No differences were found in the U15-16 and U17-18 categories.

In a study with futsal athletes Carraco et al. (2020) found no differences between playing positions. Our results also differ from those found by Lago-Fuentes et al. (2020), who presented a reversed RAE for pivots and goalkeepers in an investigation of 1873 professional futsal players who played in the First Division of the Spanish National Futsal League. Different physical demands may be the cause of the prevalence of RAE in different categories (Wattie, et al., 2015). Additionally, the needs for different physical and maturational capacities in the various playing positions of futsal must be considered. We did not perform the analysis of playing positions separated by age categories, which did not allow us a more specific discussion.

A limitation of the present study was that it did not compare athletes from different competitive levels and from teams with different classifications. In this study, all athletes competed at national and international levels and played on teams classified as the best in the country. In addition, our study only investigated male athletes; therefore, investigations with female athletes are warranted. It is also noteworthy that, due to the specificity of the sample, our results must be interpreted with caution. Considering the scarcity of studies that investigated RAE in futsal and the influence of multiple factors within each sports context, we suggest that future studies investigate the occurrence of RAE in futsal athletes from different categories according to competitive level, gender, and selection for national teams in different countries.

Our results have important practical applications, suggesting that organizations (mainly national and international federations), clubs, and coaches must consider the effects of the relative age in the processes of talent detection and selection in futsal, as well as in the division of age categories. Our findings indicated that athletes who were born in the last quarter of the year (Q3 and Q4) might not have the opportunity to play in the senior categories, and even to become professional players. Therefore, it is possible that youngsters who could become great futsal athletes are not provided with equal opportunities to develop in the sport.

Ultimately, we observed that the RAE was present in Brazilian elite men's futsal, especially in the U17, U20, and senior categories, and in goalkeepers, wingers and defenders. Our results reinforce the importance of trying to reduce the advantage of athletes who are born in the first quarters (Q1 and Q2) of the year. In addition, we demonstrated that this advantage extends to the most competitive teams of the senior category in Brazil, that is, throughout the entire sporting career of a male futsal athlete. We also highlight the need for national and international federations to review the criteria for the separation of categories, considering other factors than birth date.

In this sense, aiming to reduce the RAE and maturity-related biases, Helsen et al. (2021) propose the grouping of young team sports considering the midway point of athletes' chronological and estimated developmental age. Considering the fact that the RAE was present in most categories in our study, we suggest the division of young futsal categories also considering the athletes' maturation level, with the objective of giving equal opportunities to athletes from all birth quarters to reach senior and/or professional levels.

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SHOULDER ABDUCTION STRENGTH IS CORRELATED WITH ACROMIOHUMERAL DISTANCE IN PATIENTS WITH ACUTE SUBACROMIAL IMPINGEMENT SYNDROME SYMPTOMS BUT NOT WITH SUPRASPINATUS TENDON THICKNESS REGARDLESS OF DISEASE STAGE

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Abstract:

We aimed to investigate the relationships of isometric and eccentric shoulder abduction strength with acromiohumeral distance and supraspinatus tendon thickness based on the disease stage in patients with subacromial impingement syndrome. Eighty-two patients with subacromial impingement syndrome were assessed. Acromiohumeral distance and supraspinatus tendon thickness were measured using ultrasonography. Isometric and eccentric shoulder abduction strength were measured with a hand-held dynamometer. Spearman's correlation coefficients were calculated. Isometric (rho = 0.428, p=.021) and eccentric (rho = 0.487, p=.007) shoulder abduction strength showed moderate correlations with acromiohumeral distance in patients with acute symptoms (n = 29). There was no relationship between acromiohumeral distance and abduction strength in patients with chronic symptoms (n = 53) (p>.050). Supraspinatus tendon thickness showed no significant correlation with abduction strength (p>.050). These findings suggest that the relationship between acromiohumeral distance and abduction strength differs according to disease stage. However, supraspinatus tendon thickness was not correlated with abduction strength regardless of disease stage. In patients with acute subacromial impingement syndrome symptoms increasing shoulder abduction strength may be a potential strategy to improve acromiohumeral distance.

Key words: *muscle strength, rotator cuff, rehabilitation, ultrasonography*

Introduction

Subacromial impingement syndrome (SIS) is a common cause of shoulder pain and dysfunction (Ostör, Richards, Prevost, Speed, & Hazleman, 2005). The rotator cuff (RC) muscles play an essential role in shoulder stabilization and prevention of anterosuperior migration of the humeral head during shoulder abduction (Sangwan, Green, & Taylor, 2015). The supraspinatus, the most commonly involved muscle in SIS, is active during arm abduction (Ellis & Mahadevan, 2013; Reed, Cathers, Halaki, & Ginn, 2013) and is of the greatest practical importance among the RC muscles (Ellis & Mahadevan, 2013). Accordingly, decreased supraspinatus muscle activity (Reddy, Mohr, Pink, & Jobe, 2000) and shoulder abduction strength (Celik, Sirmen, & Demirhan, 2011; Miller, et al., 2016) and pathological changes in the supraspinatus tendon (Cholewinski, Kusz, Wojciechowski, Cielinski, & Zoladz, 2008; Leong, Tsui, Ying, Leung, & Fu, 2012; Michener, et al., 2015; Seitz, McClure, Finucane, Boardman, & Michener, 2011) are common in patients with SIS.

Although the general opinion is that the subacromial space (SAS) decreases (Graichen, et al., 1999; Hébert, Moffet, Dufour, & Moisan, 2003; Mackenzie, Herrington, Horlsey, & Cools, 2015) and supraspinatus tendon thickness (SsTT) increases (Leong, et al., 2012; Michener, et al., 2015) in patients with SIS, some studies reported no change (Leong, et al., 2012; Michener, et al.,

2015) or a decrease (Cholewinski, et al., 2008) in those parameters, compared to healthy controls. These conflicting results have been attributed to the stage of the disease (Mackenzie, et al., 2015; Seitz, et al., 2011).

There is some evidence of a possible relationship between shoulder muscle strength with SAS (Leong, et al., 2012; Leong, Tsui, Ng, & Fu, 2016; Schmidt, Engelhardt, Cools, Magnusson, & Couppé, 2021) and supraspinatus tendon morphology (Joensen, Couppe, & Bjordal, 2009). These relationships are often demonstrated by isometric muscle strength (Joensen, et al., 2009; Leong, et al., 2016; Schmidt, et al., 2021). Although assessment of the maximal isometric shoulder strength is an important component of the physiotherapy examination in clinical and research settings (Celik, et al., 2011; Cools, et al., 2014), none of these studies has investigated the relationship between SAS and SsTT with the maximal isometric or eccentric strength of RC muscles in patients with SIS. Besides, since pain often occurs also during the eccentric phase of the shoulder abduction (Camargo, Avila, Asso, & Salvini, 2010), and not only isometric strength deficits (Celik, et al., 2011; Miller, et al., 2016) but also eccentric strength deficits were demonstrated in shoulders with SIS (MacDermid, Ramos, Drosdowech, Faber, & Patterson, 2004), examining the eccentric strength may also be important. Determining these relationships and revealing whether they differ depending on the stage of the disease appears worth investigating (Mackenzie, et al., 2015). This can assist healthcare professionals in clinical decision-making while creating individual treatment programs tailored to the needs of patients at different disease stages.

We aimed to investigate the relationships of isometric and eccentric shoulder abduction strength with SAS measured by acromiohumeral distance (AHD) and SsTT based on the disease stage in patients with SIS. We hypothesized that the correlations between shoulder abduction strength and AHD and SsTT would be different for acute and chronic SIS.

Methods

Setting and participants

Eighty-two patients with SIS (45 females and 37 males) from Dokuz Eylul University Hospital volunteered to participate in this observational study. All participants provided written and oral informed consent, and the study was approved by the Ethics Committee of Dokuz Eylul University (Number: 4268-GOA). We performed sample selection and data collection at Dokuz Eylul University, School of Physical Therapy and Rehabilitation between August 2017 and September 2019. No previous study presented correlation data between isometric and eccentric shoulder abduction strength and SsTT and the SAS. Considering the findings of the previous studies, which investigated the relationships between the AHD and the strength of scapular muscles (Leong, et al., 2016) and shoulder external rotator muscles (Leong, et al., 2012), we anticipated medium correlations between variables and we used 0.50 value for correlation to calculate the number of patients (n=29 per group) required to determine a significant correlation with 80% power and 5% Type-I error level (GPower, version 3.1.7, Heinrich-Heine-Universität, Düsseldorf, Germany). Inclusion criteria were: (1) SIS diagnosis, (2) ≥18 years of age, (3) ≥three positives in five shoulder impingement tests: Neer's sign, Hawkins and Kennedy test, Empty Can test, painful arc of abduction, and external rotation (ER) resistance test (Michener, Walsworth, Doukas, & Murphy, 2009), (4) ability to complete the entire study procedure. The exclusion criteria were: (1) diagnosis of the adhesive capsulitis, (2) shoulder pain > 7/10 according to the Visual Analogue Scale (Timmons, Ericksen, Yesilyaprak, & Michener, 2016), (3) history of fracture in the upper extremity, (4) systemic musculoskeletal disease, (5) history of shoulder or cervical surgery, (6) glenohumeral instability (positive apprehension, relocation, or positive sulcus test), (7) positive findings for a full-thickness RC tear (positive lag sign, positive drop arm test or marked weakness with shoulder external rotation), (8) shoulder pain with cervical spine movement (Michener, et al., 2015) (9) diagnosis of chest deformity or scoliosis. Patients who had shoulder pain ≥ three months were classified as patients with chronic SIS symptoms and others as patients with acute SIS symptoms.

Procedures

Strength tests were performed by two physiotherapists who were experienced in the field of shoulder examination (five and four years for testers 1 and 2, respectively). Ultrasound imaging was performed by the first author who was experienced in the field of musculoskeletal ultrasound examination (nine years).

To measure SAS, a diagnostic ultrasound unit, LOGIQe (GE Healthcare, Wauwatosa, WI, USA) with a 7–12-MHz linear transducer set at 8 MHz was used to capture two-dimensional images in greyscale B-mode. Images were obtained while the patient was seated feet flat on the floor, with neutral trunk posture, head straight, and arms resting at the side (Michener, et al., 2015). We measured SAS twice at two locations and averaged the results for data analysis: 1. on the most anterior part of the acromial margin with the long axis of the transducer placed in the plane of the scapula and parallel to the flat surface of the acromion and 2. 1-cm behind the first measure. SAS was operationally defined as the AHD, the two-dimensional shortest linear distance between the anterior–inferior tip of the acromion and the humeral head (Desmeules, Minville, Riederer, Côté, & Frémont, 2004; Luque-Suarez, Navarro-Ledesma, Petocz, Hancock, & Hush, 2013; Mackenzie, et al., 2015). The AHD was measured (in mm) using the ultrasound unit's on-screen calipers by visually locating the superior aspect of the humeral head and the inferior aspect of acromion, and then measuring the linear distance (Figure 1A) (Michener, et al., 2015). As a result of test-retest measurements in ten patients, our intra-rater reliability for this method was excellent (ICC=0.99).

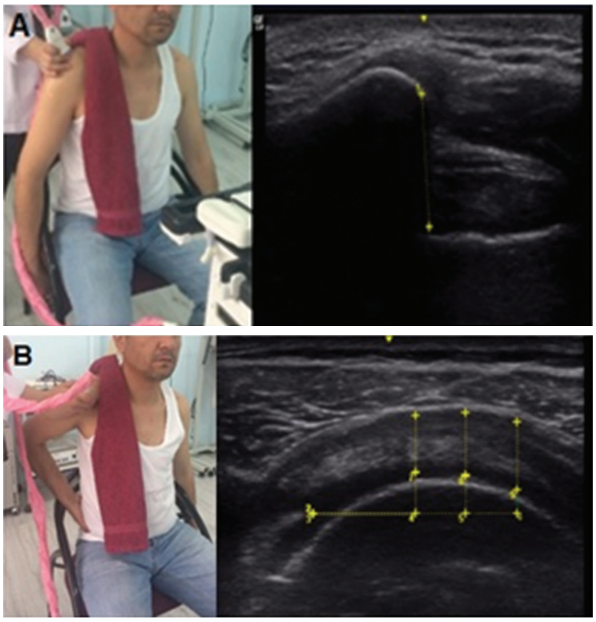

Figure 1. Ultrasonography measurement. A. Acromiohumeral distance assessment with ultrasonography, and ultrasound measurement of the acromiohumeral distance from the acromial tip to the humeral head. B. Supraspinatus tendon thickness assessment with ultrasonography and ultrasound measurement of the tendon thickness taken at 10, 15, and 20 mm lateral to the biceps tendon (transverse view).

SsTT measurement was performed using the same ultrasound unit with the same settings while the patient seated feet flat on the floor, with a neutral trunk posture and head straight. We asked the patients to place their hand of the involved side on the ipsilateral posterior hip with the humerus in extension. The transducer was placed on the anterior aspect of the shoulder, perpendicular to the supraspinatus tendon, and just anterior to the anterior-lateral margin of the acromion, and both the supraspinatus tendon and long head of the bicep's tendon were captured laterally in the transverse axis. Then, the transducer was tilted in the mediolateral direction, visualizing the long biceps brachii tendon, and the maximum tendon thickness was obtained. The lateral margin of the hyperechogenicity of the bicep's tendon was taken as the reference point. Three positions along the tendon were measured for thickness (in mm) at 10, 15, and 20 mm lateral to this reference point (Figure 1B).

First, we averaged the results of the three measurements for each of the two ultrasound images and then the average values for each image were averaged for data analysis. We measured the SsTT using the ultrasound unit's on-screen callipers via tendon borders, from the first hyperechoic region above the anechoic articular cartilage of the humeral head to the hyperechoic superior border of the tendon before the anechoic subdeltoid bursa (Cholewinski, et al., 2008; Joensen, et al., 2009; Michener, et al., 2015). Our intra-rater reliability for this method was excellent (ICC=0.93). In AHD and SsTT assessments, after the completion of capturing images of all the participants, AHD and SsTT measurements by the ultrasound on-screen callipers were performed without the strength results being known. An author who was not involved with the data collection performed the analysis.

We performed the strength tests with a handheld dynamometer (HHD) (MicroFET®3, Hoggan Health Industries, West Jordan, UT, USA). The patients sat with their feet flat on the floor. We placed the patient's arm into the scapular plane using a plastic goniometer (Universal Baseline® 12" Plastic Goniometer 360°, NY, USA). The participants were instructed to maintain this plane during the test, and the researcher monitored the arm position. Each test was conducted three times, and the results were averaged. We provided 30 seconds of rest between the tests (Schrama, Stenneberg, Lucas, & van Trijffel, 2014). To avoid bias, the author that performed the strength assessments was not allowed to read the results of the HHD throughout the testing period. A trained assistant read and recorded the results.

To measure the isometric strength of shoulder abduction, we positioned the shoulder at 90° abduction in the scapular plane and external rotation (thumb pointing up) and the elbow at full extension (Figure 2). The bubble inclinometer was attached to the arm to ensure 90° shoulder abduction. After the explanation of the test, the participant performed one sub-maximal test for familiarization. Then,

Figure 2. Measurement of the isometric strength of shoulder abduction

the participant performed maximal isometric shoulder abduction effort while the tester gave downward resistance over the wrist with the HHD for 5-seconds (Dollings, Sandford, O'Conaire, & Lewis, 2012). Our intra-rater (ICC=0.970 for both testers) and inter-rater reliability for this method were excellent (ICC=0.980).

To measure the eccentric strength of shoulder abduction, the starting position was 120° of abduction of the shoulder in the scapular plane, with the thumb pointing up and full extension of the elbow. The bubble inclinometer was attached to the arm to monitor humeral abduction angles throughout the test (Figure 3). Participants performed one sub-maximal testing for familiarization. Then, the participant performed the maximal eccentric effort, while the researcher pushed the arm just above the wrist from 120° to 30° of shoulder abduction at 30°/s (controlled with a metronome) using the HHD. Standardized verbal encouragement was provided during testing (Karabay, Yesilyaprak, & Sahiner Picak, 2020). Our intra-rater (ICC=0.976 and 0.978 for testers 1 and 2, respectively) and inter-rater (ICC = 0.940) reliability were excellent for this procedure. During the strength tests, some pain was allowed, however, this did not lead to not completing the test. Additionally, no patient reported increased pain on the test day and days following the test.

Figure 3. Measurement of the eccentric strength of shoulder abduction. A. Starting position. B. Ending position.

Statistical analysis

The normality of the distributions of the continuous data was analyzed with the Shapiro-Wilk test. Data are expressed as mean followed by standard deviation and median followed by interquartile range or percentages as appropriate. The distribution of sex, dominant side, and affected side between patients with acute SIS and chronic SIS were compared with the chi-square test. Age, height, mass, and body mass index of the acute and chronic SIS patients were compared with the independent samples *t*-test. Duration of symptoms and pain intensity were compared with the Mann-Whitney U test. The association of isometric and eccentric muscle strength values with ultrasonographic data was analyzed by Spearman's rank correlation analysis. Correlation was classified as strong (rho ≥ 0.70), moderate (rho= 0.40-0.69), or weak (rho ≤ 0.39) (Guilford, 1956; Rowntree, 1981). The significance level was set at p<.050.

Results

Eighty-two patients with SIS were tested. Twenty-nine of those were classified as patients with acute SIS symptoms and fifty-three were patients with chronic SIS symptoms. Demographic, anthropometric, and clinical characteristics were similar (except for pain duration) between patients with acute and chronic symptoms (Table 1).

The results of ultrasonography and strength measurements are shown in Table 2. The AHD showed moderate correlation with both isometric (rho = 0.428, p=.021) and eccentric (rho = 0.487, p=.007) shoulder abduction strength in patients with acute SIS symptoms. However, abduction strength was not correlated with the AHD in patients with chronic SIS (p>.050). Moreover, there was no correlation between the SsTT and abduction strength in patients with both acute and chronic SIS (Table 3).

Discussion and conclusions

To our knowledge, this is the first study investigating the relationships between shoulder abduction strength and AHD and SsTT based on the stage of the SIS and examining the relationship of eccentric shoulder abduction strength with these ultrasonographic measurements. We found that, in patients with acute SIS symptoms, AHD was positively correlated with both isometric and eccentric shoulder abduction strength. AHD was not correlated with abduction strength in patients with chronic symptoms. SsTT was not correlated with abduction strength.

The literature emphasizes the importance of RC muscles in maintaining the SAS via depressing the humeral head to counteract the deltoid action to prevent superior migration of the humeral head (Leong, et al., 2012; Page, 2011). The supraspinatus is the most commonly involved muscle in SIS, and it is considered to be of the greatest practical importance among the RC muscles (Ellis & Mahadevan, 2013). Isometric shoulder abduction muscle strength, which is often referred to as supraspinatus muscle strength (Celik, et al., 2011; Habechian, Van Malderen, Camargo, & Cools, 2018; Kibler, Sciascia, & Dome, 2006), is frequently evaluated in patients with SIS for clinical and research aims (Celik, et al., 2011; Cools, et al., 2014; Makhni, et al., 2015). Celik et al. (2011) found that isometric shoulder abduction muscle strength (tested in the same position that we performed in this study) of the shoulder with SIS was significantly lower than the healthy opposite side and supraspinatus weakness

Table 1. Demographic, anthropometric, and clinical data of participants

Variables	Patients with acute SIS (n = 29)	Patients with chronic SIS (n = 53)	
Sex, n (%)			
Female	16 (55.2)	29 (54.7)	p = 0.968
Male	13 (44.8)	24 (45.3)	X^2 = 0.002
Dominant side, n (%)			
Right	26 (89.7)	49 (92.5)	p = 0.668
Left	3 (10.3)	4 (7.5)	X^2 =0.188
Affected side, n (%)			
Right	17 (58.6)	25 (47.2)	p = 0.312
Left	12 (41.4)	28 (52.8)	X^2 =0.984
	Mean (SD)	Mean (SD)	
Age, year	51.55 (12.47)	47.74 (13.64)	p = 0.868 t = 1.281
Height, m	1.66 (0.10)	1.68 (0.10)	p = 0.821 t = -0.836
Mass, kg	72.10 (14.00)	77.28 (14.43)	p = 0.865 t = -1.584
Body mass index, kg/m²	26.25 (4.47)	27.50 (4.63)	p = 0.998 t = -1.197
	Median (interquartile range)	Median (interquartile range)	
Duration of pain, months	2.00 (1.00 – 2.00)	6.00 (3.75 – 11.00)	p < 0.001 * Z = -7.511
Pain intensity at rest, cm	1.00 (0.00 – 2.25)	2.00 (0.00 – 3.00)	p = 0.286 Z = -1.066
Pain intensity during overhead reaching, cm	4.80 (3.05 – 5.80)	6.00 (4.00 – 6.00)	p = 0.141 Z = -1.473

Note. * – significant difference between the groups; t – paired samples t-test; X^2 – chi-squared test; Z – Mann-Whitney U test.

Table 2. Ultrasonographic and strength data of the participants

Variables	Patients with acute SIS (n = 29)	Patients with chronic SIS (n = 53)
	Mean (SD)	Mean (SD)
AHD, mm	10.61 (1.34)	11.00 (1.24)
SsTT, mm	5.53 (1.22)	5.65 (0.92)
Shoulder abduction strength, kg	Median (interquartile range)	Median (interquartile range)
Isometric	5.90 (4.87 – 7.94)	6.87 (5.60 – 8.72)
Eccentric	7.00 (5.55 – 10.13)	8.03 (6.22 – 10.20)

Note. AHD – acromiohumeral distance; SsTT – supraspinatus tendon thickness.

Table 3. Correlations between ultrasonographic and strength measurements

	Patients with acute SIS (n = 29)				Patients with chronic SIS (n = 53)			
	Isometric strength		Eccentric strength		Isometric strength		Eccentric strength	
	rho	p	rho	p	Rho	p	rho	p
AHD, mm	0.428	.021	0.487	.007	-0.053	.709	0.076	.590
SsTT, mm	0.167	.387	0.083	.668	0.148	.291	0.212	.128

Note. AHD – acromiohumeral distance; rho – Spearman's correlation coefficients; SsTT – supraspinatus tendon thickness.

was related to the symptoms of SIS. Although they did not report the duration of symptoms for their population, the authors highlighted the importance of assessing supraspinatus strength and, if necessary, strengthening it during the treatment of SIS. Similarly, our findings highlight the importance of isometric shoulder abduction muscle strength in maintaining the SAS in patients with acute SIS symptoms.

SIS complaints often occur also during the eccentric phase of the shoulder abduction (Camargo, et al., 2010). Furthermore, lower electromyographic activity of the glenohumeral muscles has been demonstrated during the eccentric phase of the shoulder abduction (Hawkes, Khaiyat, Howard, Kemp, & Frostick, 2019). Reduced eccentric muscle control, as well as reduced isometric muscle control, may potentially increase superior humeral head translations, possibly leading to narrowing the SAS (Ludewig & Braman, 2011). However, to date, no study investigated the humeral head migration during the lowering phase of the shoulder abduction or the relationship between eccentric muscle strength and SAS. Despite the lower shoulder muscle activation, eccentric contractions create greater excitability in the motor cortex than concentric and isometric ones (Lepley, Lepley, Onate, & Grooms, 2017). High cortical activation levels in brain centers that are responsible for neuromuscular control have been reported during eccentric contractions (Kwon & Park, 2011; Lepley, et al., 2017). Perhaps this is why eccentric strength also plays a critical role in controlling the SAS. Overall, our findings support and further the Celik et al.'s (2011) suggestion. Increasing both isometric and eccentric shoulder abduction strength may be beneficial to improve SAS in patients with acute symptoms. In practice, while muscle strength measurement is generally performed as isometric strength testing (Celik, et al., 2011; Dollings, et al., 2012; Miller, et al., 2016), our results suggest that eccentric abduction strength should also be measured in patients with SIS and should be considered in strengthening programs in the presence of a deficit. Future longitudinal studies should be conducted on patients with acute SIS symptoms to investigate the ultrasonographic and clinical effects of shoulder abductors' strength training that targets both isometric and eccentric strength improvement.

The correlation found between shoulder abduction strength and AHD in patients with acute SIS symptoms was not demonstrated in patients with chronic SIS symptoms. Similarly, Leong et al. (2016) reported no correlation between scapular muscle strength and the AHD in athletes with RC tendinopathy with 29 months mean symptom duration. However, they did not discuss possible mechanisms underlying their finding. Increased scapular upward rotation in patients with chronic SIS symptoms is thought to be a compensatory mechanism used to maintain the width of the SAS and to reduce the shoulder pain experienced during movement in patients with SIS (Navarro-Ledesma, et al., 2019; Timmons, et al., 2016). In the present study, the patients with chronic SIS might have developed such compensatory biomechanical changes to avoid compression of the tendon in the SAS. However, our proposition should be interpreted with caution since we did not investigate scapular motions. In patients with chronic SIS symptoms, other factors that may affect the width of the SAS and the mechanisms that may explain the changes in SAS should be investigated. Nevertheless, the results of two studies that investigated the relationship between AHD and shoulder pain and function in patients with SIS may be consistent with our proposition (Desmeules, et al., 2004; Navarro-Ledesma, et al., 2017). Desmeules et al. (2004) found a significant correlation between increases in the AHD and shoulder function after a physiotherapy program in patients with SIS who were at the acute-subacute stage. In contrast, Navarro-Ledesma et al. (2017) found no correlation between AHD and shoulder pain and function in patients with chronic RC related shoulder pain. According to the combination of our findings and the abovementioned findings, the role of muscle strength and therefore AHD in the explanation of shoulder pain and disability may be different in patients at different SIS stages. The clinical implications of our findings are not yet fully understood, and further research is needed to examine the relationship between muscle strength and AHD in acute and chronic SIS, taking shoulder pain and disability into account.

Joensen et al. (2009) reported that side differences in SsTT and pain-free isometric abduction strength were weakly related (r = 0.24) in patients with unilateral SIS. We did not find a relationship between SsTT and abduction strength. The conflicting results may be explained by methodologic differences between the studies. Joensen et al. (2009) analyzed side differences for pain-free isometric strength and SsTT and they did not analyze their data based on the disease stage (their participants were a mixed population composed of patients in acute and chronic stages), but we assessed maximal strength of the symptomatic shoulder of the participants and analyzed the data of patients with acute and chronic symptoms separately. It should also be noticed that the strength of the correlation determined by Joensen et al. (2009) was weak. In line with our result, increased shoulder strength but no change in SsTT was reported in male recruits after 14 weeks of elite infantry training (Milgrom, Moran, Safran, & Finsestone, 2012). Moreover, Dischler, Baumer, Finkelstein, Siegal, and Bey (2018) reported that years of competition were positively correlated with SsTT and not correlated with isometric shoulder strength in swimmers. Accordingly, changes in SsTT might be related to long-term loadings, such as sports participation, work, or repetitive activities of daily living rather than abduction muscle strength in patients with SIS (Schmidt, et al., 2021; Seynnes, et al., 2009).

The limitation of our study is that as a mutual limitation of ultrasonography studies, although two-dimensional ultrasonography measures are frequently used in the literature, the SAS and tendon are three-dimensional structures, and for this reason, we did not fully capture these structures. The fact that this study is the first to examine (a) the relationship of eccentric shoulder abduction strength with the AHD and SsTT, and (b) the relationships between abduction strength and AHD and SsTT based on the disease stage is one of the strengths of our study. Other strengths of this study are that we used valid and reliable measurement methods, and anthropometric and demographic characteristics of patients in acute and chronic stages of the disease were similar.

In conclusion, in patients with acute SIS symptoms, AHD was positively correlated with both isometric and eccentric shoulder abduction strength. AHD was not correlated with abduction strength in patients with chronic symptoms. These findings suggest that the relationship between AHD and abduction strength differs according to disease stage. SsTT was not correlated with abduction strength regardless of disease stage. In patients with acute SIS symptoms, increasing both isometric and eccentric shoulder abduction strength may be a potential strategy to improve the width of the SAS.

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RELATIONSHIPS BETWEEN BIRTH WEIGHT, BREASTFEEDING AND DIGIT RATIO WITH PHYSICAL ACTIVITY AND PHYSICAL FITNESS IN SCHOOL ADOLESCENTS

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Abstract:

This study aimed to analyze the isolated and combined effects of non-modifiable factors on adolescents' physical fitness. This cross-sectional, descriptive study involved 1475 adolescents, aged 12 to 19 years, of whom 721 were girls, from four public schools in southern Spain. Physical activity, birth weight and breastfeeding time, and physical fitness were assessed. To calculate the 2D:4D ratio, three separate measurements of the length of the index finger (2D) and ring finger (4D) of both hands were taken. Results show no differences in the intake of breast milk nor its prediction power for physical fitness. Birth weight was related to horizontal jump and manual dynamometry results, while the 2D:4D ratio was not significant in the linear regression models. The non-modifiable factors studied in relation to physical activity practically ceased to be significant when variables such as sex, body mass index and physical activity practice were introduced into the models.

Key words: *physical fitness, adolescents, birth weight, breastfeeding*

Introduction

In recent years, the lifestyles of western populations have evolved significantly, motivated mainly by industrialization and the rise of new technologies (Hanafizadeh, Ghandchi, & Asgarimehr). This has led to a drastic decrease in predominantly physical activities and an increase in activities that require prolonged sitting, thus leading to a more sedentary lifestyle (Owen, Sparling, Healy, Dunstan, & Matthews, 2010). Since a low level of physical fitness, mainly in terms of aerobic capacity and strength level, is considered a key risk factor for several pathologies (Maestroni, et al., 2020; Morris, et al., 2013), and physical fitness level achieved in adulthood is closely related to physical fitness in childhood and adolescence (Huotari, Nupponen, Mikkelsson, Laakso, & Kujala, 2011), it would seem pertinent to analyze the factors that limit or enhance physical fitness levels among adolescents. In this regard, there is broad evidence that the level of physical activity has a positive impact on physical fitness (Eckerson, et al., 2013; Fang, et al., 2017; Twisk, Twisk, Kemper, & van Mechelen, 2002). However, the influence of non-modifiable factors (e.g., birth weight, breastfeeding and the 2D:4D digit ratio) requires further investigation.

Due to the beneficial effects of breastfeeding, some authors have argued that this nutrition strategy could have an impact on physical fitness in adolescents (Artero, et al., 2010). Regarding this, Corredor-Corredor, Castejon-Riber, Martínez-Amat, and Benítez-Sillero (2019) observed a trend indicating that Spanish boys (age: 14.74 ± 0.84 years) who were breastfed performed better in all the fitness tests, although only significant differences were reported in the abdominal strength test ($p<.019$). Additionally, these authors found that Spanish girls (age: 14.77 ± 0.84) who were breastfed obtained lower values in all the tests except the multi-stage fitness test, with significant differences only found in the flexibility test. Similarly, Vafa et al. (2016) and Zaqout et al. (2018) found a positive association between exclusive breastfeeding and physical fitness. On the other hand, inconclusive results about the effect of breastfeeding duration have been observed (Corredor-Corredor, et al., 2019; Labayen Goñi, et al., 2012; Vafa, et al., 2016), so future studies on this topic are needed.

The influence of birth weight on physical fitness levels among adolescents has not been studied in depth. Specifically, Corredor-Corredor et al. (2019) observed that those adolescents, both male and female, with higher birth weights presented a better performance in the handgrip test ($p<.01$). Additionally, these authors reported significant relationships between birth weight and performance in shuttle run ($p=.045$), long jump ($p=.008$) and abdominal strength ($p=.031$) tests in girls, while no significant relationships were observed in boys for these tests. Ortega et al. (2009) partially support these results since they also observed a positive relationship between birth weight and handgrip performance, mainly in girls ($p<.001$). However, these authors could not establish a relationship between birth weight and cardiovascular fitness ($p=.700$-$.810$). Despite the promising results obtained there are few studies on this topic, none of which is recent.

Since athletic performance is positively affected by circulating testosterone levels, prenatal testosterone may have a positive effect on physical fitness levels among adolescents (Hönekopp, 2012). In this sense, no significant relationship was observed between the 2D:4D digit ratio and several physical fitness tests in young scholars (Eghbali, 2016; Peeters, van Aken, & Claessens, 2013). Conversely, some authors found negative correlations between 2D:4D digit ratio and different fitness battery tests (Hönekopp, Manning, & Müller, 2006; Ranson, Stratton, & Taylor, 2015), showing the need to perform future studies to establish definitive conclusions on this topic.

Since the aforementioned non-modifiable factors seem to influence the physical fitness levels of adolescents, a multivariable analysis could shed light on this relationship and contribute to predictions and decisions that promote improved physical fitness levels among young people. In turn, this could help in the prevention of derived pathologies. Thus, the main aim of this study was to analyze the isolated and combined effects of non-modifiable factors (i.e., breastfeeding, birth weight, and 2D:4D digit ratio) on the physical fitness of adolescents. We hypothesized that physical fitness was influenced by non-modifiable factors, although this effect might seem to be sex-specific.

Methods

Participants

A convenience sample of 1,475 schoolchildren aged 12 to 19 years (mean = 14.87, standard deviation = 1.57), of whom 721 were girls (48.88%), voluntarily participated in this study. Participants belonged to four state schools in southern Spain (three in the province of Cordoba and one in Huelva). The participants were students of any of the first four years of secondary education (from 12 to 16 years of age) or the first year of baccalaureate (age 17), if they had not repeated a year. Subjects above that age were ruled out. The adolescents were informed of the main aim of the study and the anonymity, confidentiality, and voluntary nature of their participation. Written informed parental consent was obtained from each participant. This study protocol was in accordance with the latest version of the Declaration of Helsinki (2013), while the project was also approved by the Ethics Committee of the University of Cordoba.

Procedures

A descriptive and cross-sectional study design with non-probability-based sampling was used to determine the relationships between non-modifiable factors (i.e., breastfeeding, birth weight, and 2D:4D digit ratio) and the adolescents' physical fitness level. In four different sessions (during the school year), participants completed the EUROFIT battery and filled out the accompanying questionnaires.

Instruments

Physical activity

Two questions were asked to determine the level of physical activity, based on the modified version of the PAQ-A questionnaire (Martínez-Gómez, et al., 2009):

1. Physical activity in your free time: Have you done any activity in the last 7 days (last week)? If so, on how many days? The students answered by 0 to 7.
2. Do you regularly attend any kind of organized classes focused on physical activity, sports, etc.? Please specify the number of days per week. The days per week (0 – 7) were counted.

Based on these two questions, each student's level of total physical activity during free time and participation in organized physical activity was determined. Total physical activity included practical activities, both organized and independent, while organized activity referred to those regular activities repeated over time, dependent on a club or entity and directed by a person. In both cases, the compulsory hours corresponding to physical education at school were not counted.

Anthropometric characteristics

All measures were made with barefoot subjects wearing light clothing. On the first day, the focus was solely on anthropometric data collection. The body weight in kilograms (kg) was measured with a Tanita BF 350 scale (Tanita Corporation, Japan; precision 0.1 kg). A SECA stadiometer (Seca 213, Hamburg, Germany; precision 0.1 cm) was used for measuring body height. Based on these data, the body mass index [BMI = weight (kg)/height (m2)] was calculated.

Fitness tests

Before starting the assessment, a training session was held in order to guarantee the standardization, validation and reliability of the measurements. Five integrated tests were carried out within the EUROFIT battery (Committee of Experts on Sports Research EUROFIT, 1993). The scientific basis underlying the use of these tests in adolescents has appeared in previous publications (Evelein, et al., 2011) and has been used in the AVENA and HELENA international studies (Ortega, et al., 2009). All students had experience with these tests since they had been regularly used as a part of assessment tools throughout their education. The battery included the tests described below:

a) *30 seconds sit-up tests.* This is a trunk power test in which the subject tries to carry out as many sit-ups as possible during a period of 30 seconds. The subject lies on his/her back on a mat, and places his/her hands behind the back of their neck, with legs flexed at 90° and his/her feet on the ground. The subject should raise their trunk until he/she touches the knees with the elbows. The number of times the movement is performed correctly will be noted. A mat was given to each subject and a CasioHS-80TW chronometer was used.
b) *Sit-and-reach flexibility test.* This test measures the range of hip motion. Sitting on a mat with their legs stretched out and soles placed on a standardized box, the subjects must bend their trunk forward, trying to reach as far as possible with their hands outstretched, moving a ruler (in centimeters) placed on the surface of the box with their fingertips. According to protocol, the ruler is aligned with the edge of the box where the feet are placed, at the 15-centimeter mark.
c) *Horizontal jump.* It was used to assess lower body explosive muscular strength. The subject starts from a static position, located immediately before a line, with feet shoulder-width apart and parallel, having to make a jump as far as possible without losing balance on the landing. Two attempts were made on a hard, non-slip surface and the best of them was recorded. The result was recorded in centimeters, using a tape measure.
d) *Handgrip strength.* Manual grip strength in kilograms was assessed in both hands, using a TAKEY TKK 5110 dynamometer (interval 5-100 kg, precision 0.1 kg), with an adjustable handle. The subject holds the dynamometer keeping it slightly away from the body. He/she then presses gradually and continuously for two seconds. The optimal grip was calculated by the equation designed by Ruiz et al. (2006). Two attempts were made with each hand and the best result was recorded. For this study, the most common measure of the best performance with one hand was used (Committee of Experts on Sports Research EUROFIT, 1993).
e) *20 meters shuttle run test.* This is a maximal incremental field test that assesses the maximum aerobic capacity. The subject runs back and forth over 20 meters. The test begins at a slow pace. The subject should make the change of direction at the moment of the sound signal that occurs ever faster. The test ends when the subject is not able to follow the imposed rhythm. The time in minutes and seconds was determined to increase the precision of the measurements. The author's original software was used in an mp3 version (Léger, Mercier, Gadoury, & Lambert, 1988).

To avoid mutual impact between the tests, these were performed on different days in the following order: day two (sit-and-reach flexibility and sit-up tests), day three (20-m shuttle run), day four (handgrip and horizontal jump) (Corredor-Corredor, et al., 2019). The questionnaire was administered on the first day.

Birth weight and breastfeeding time

A shorter version of the questionnaire reported in the HELENA study (Jimenez Pavon, et al., 2010) was used, which was answered by the parents, who also filled out the consent form for their sons' and daughters' participation. The questionnaire provided us with data on birth weight and breastfeeding period. Birth weight was registered in kilograms, while breast milk intake time was coded as 0 (when the subject had not been breastfed), 1 (if breastfeeding lasted less than three months), 2 (if breastfeeding lasted from three to five months) and 3 (when breast milk intake lasted six months or more).

2D:4D ratio

To calculate the 2D:4D ratio, three separate measurements of the length of the index finger (2D) and ring finger (4D) of both hands were taken. The measurements were taken on the ventral side of the hand. Finger length was taken from the proximal crease at the base of the finger to the fingertip, as this measurement procedure has a high replication (Schneider, Pickel, & Stalla, 2006). A digital calliper with an accuracy of 0.1 mm, Tacklife DC01, was used. The 2D:4D ratio value for each hand was obtained by calculating the arithmetic mean of three measurements (Schneider, et al., 2006).

Statistical analysis

Descriptive data are presented as mean ± standard deviation (SD). The sample of data was first tested for distribution normality with the Shapiro-Wilk test. The subjects were compared by sex with the Student's *t*-test. Bivariate correlations were carried out with the Spearman test as some variables were non-parametric. Likewise, the breastfeeding variable was compared through ANOVA, and for a more complete analysis of breastfeeding, this variable was dichotomised between those who were and those who were not breastfed, using the Student *t*-test. To complete the analyses, a multiple regression analysis was carried out where the physical fitness variables were the dependent variables and age, sex, BMI, birth weight, breastfeeding, physical activity and 2D:4D ratio were the independent variables. The effect size was calculated according to Cohen (1988). Values above 0.8, between 0.8 and 0.5, between 0.5 and 0.2, and lower than 0.2 were considered as large, moderate, small, and trivial, respectively. The analyses were carried out using the IBM SPSS Statistics 25 statistical package.

Results

Table 1 presents descriptive data and differences between sex. Significant differences were found for all variables except BMI and the period of breast milk intake.

The relationships between study variables are shown in Table 2. Birth weight only correlated with the manual dynamometry test, while the 2D:4D ratio of the right hand correlated with all the physical fitness tests. The 2D:4D ratio of the left hand only correlated with the horizontal jump and shuttle-run tests. In the ANOVA analyses according to the period of breast milk intake, there were no significant relationships in any of the variables, nor in the *post-hoc* analysis, and therefore they are not shown in the tables. When comparisons were made between the two groups using the *t*-test, according to whether or not they were breastfed, the BMI variable was also not significant (M with breastfeeding: 22.30 [4.64]; M without breastfeeding: 21.52 [4.26]; p=.26).

Table 3 shows the linear regression models. For all the physical fitness tests, the predictors age, sex, and BMI were significant, as well as the practice of organized physical activity for the abdominal strength, horizontal jump and cardiovascular endurance tests. Birth weight was only significant in the model for jumping strength and manual dynamometry tests. Neither the breastfeeding period nor the 2D:4D ratio of the right hand was significant. The models with the left hand in 2D:4D ratio and the independent physical activity practiced in free time were also studied, but their values were lower than those shown in the tables and are therefore not shown.

Discussion and conclusions

The aim of this study was to demonstrate the influence of non-modifiable factors on physical aptitudes and to verify if this effect was mediated by gender. Knowledge and control could be

Table 1. Descriptive analysis of the variables according to the sex of the participants

	n	Total M (SD) **n=876**	n	**Boys M (SD) n=754**	**Girls M (SD) n=721**	t	ES
Age	1475	14.87 (1.57)	B:754 G:721	14.91 (1.55)	14.83 (1.58)	0.88	0.05
Weight	1475	59.26 (13.98)	B:754 G:721	61.79 (15.14)	56.61 (12.11)	7.26***	0.43
Height	1475	164.62 (9.60)	B:754 G:721	168.51 (10.27)	160.53 (6.76)	17.74***	1.18
BMI	1475	21.77 (4.32)	B:754 G:721	21.63 (4.39)	21.92 (4.24)	-1.31	-0.07
Sit-up	1335	23.05 (6.15)	B:685 G:650	25.15 (6.29)	20.84 (5.14)	13.71***	0.84
Sit and reach	1492	17.20 (8.81)	B:771 G:721	14.51 (8.11)	20.08 (8.62)	-12.82***	-1.08
Hor. jump	1436	161.79 (36.33)	B:734 G:702	181.17 (34.19)	141.52 (25.99)	24.81***	1.53
Shuttle run	1454	4.93 (2.51)	B:749 G:705	6.07 (2.62)	3.72 (1.69)	20.47***	1.39
Handgrip	1475	26.35 (7.99)	B:754 G:721	29.95 (8.65)	22.59 (4.97)	20.13***	1.48
Birth weight	862	3.27 (0.56)	B:425 G:437	3.31 (0.60)	3.23 (0.52)	2.13*	0.15
Breastfeeding	872	1.65 (1.16)	B:430 G:442	1.66 (1.17)	1.63 (1.15)	0.37	0.02
D2/D4 (right)	934	1.01 (0.49)	B:487 G:447	1.00 (0.06)	1.02 (0.04)	-6.06***	-0.5
D2/D4 (left)	935	0.99 (0.04)	B:488 G:447	0.98 (0.04)	0.99 (0.04)	-4.43***	-0.25
PA total	1425	2.46 (1.98)	B:719 G:706	2.74 (1.98)	2.17 (1.93)	5.23***	0.29
PA organized	1429	1.63 (1.76)	B:720 G:709	1.97 (1.85)	1.30 (1.60)	6.98***	0.42

Note. M= mean; SD = standard deviation; ES = effect size; BMI= body mass index; Hor. = horizontal; PA = physical activity.
* Established level of significance; p<.05.
*** Established level of significance; p<.001.

Table 2. Bivariate correlations between the quantitative variables of the study

Variable	Age	Weight	Height	BMI	Sit-up	Sit and reach	Hor. jump	Shuttle run	Hand-grip	Birth weight	D2/D4 (right)	D2/D4 (left)	PA total
Age	-	-	-	-	-	-	-	-	-	-	-	-	-
Weight	0.370**	-	-	-	-	-	-	-	-	-	-	-	-
Height	0.457**	0.558**	-	-	-	-	-	-	-	-	-	-	-
BMI	0.167**	0.835**	0.059*	-	-	-	-	-	-	-	-	-	-
Sit-up	0.261**	0.070*	0.285**	-0.092**	-	-	-	-	-	-	-	-	-
Sit and reach	0.159**	0.041	-0.077**	0.099**	-0.018	-	-	-	-	-	-	-	-
Hor. jump	0.234**	0.030	0.450**	-0.253**	0.498**	-0.078**	-	-	-	-	-	-	-
Shuttle run	0.248**	-0.011	0.385**	-0.266**	0.554**	-0.022	0.665**	-	-	-	-	-	-
Handgrip	0.432**	0.540**	0.699**	0.219**	0.374**	0.021	0.543**	0.433**	-	-	-	-	-
Birth weight	0.019	0.172**	0.150**	0.111**	-0.020	0.005	0.062	0.023	0.129**	-	-	-	-
D2/D4 (right)	-0.124**	-0.020	-0.107**	0.059	-0.111**	0.078*	-0.199**	-0.218**	-0.134**	-0.038	-	-	-
D2/D4 (left)	0.004	0.101**	0.012	0.127**	-0.011	0.051	-0.109**	-0.129**	-0.035	-0.013	0.405**	-	-
PA total	-0.030	0.045	0.129**	-0.051	0.221**	0.062*	0.194**	0.280**	0.126**	-0.016	-0.062	-0.012	-
PA organized	-0.043	0.029	0.111**	-0.062*	0.301**	0.025	0.280**	0.377**	0.121**	0.013	-0.040	-0.027	0.557**

Note. BMI= body mass index; Hor. = horizontal; PA = physical activity.
* Established level of significance; p<.05
** Established level of significance; p<.01

Table 3. Linear regression with age, sex (female), BMI, birth weight, breastfeeding, organized physical activity and D2/D4 index of the right hand as the predictors of the different physical fitness tests

	Sit-up		Sit and reach		Horizontal jump		Shuttle run		Handgrip	
	β	*t*	*β*	*t*	*β*	*t*	*β*	*t*	*β*	*t*
Age	0.257***	7.348	0.137***	3.611	0.316***	11.266	0.290***	9.809	0.382***	12.304
Sex (female)	-0.351***	-9.880	0.308***	8.053	-0.518***	-18.205	-0.418***	-13.941	-0.424***	-13.457
BMI	-0.143***	-4.062	0.118**	3.101	-0.342***	-12.077	-0.302***	-10.140	0.130***	4.149
Birth weight	-0.018	-0.517	0.041	1.083	0.054*	1.940	-0.009	-0.313	0.075*	2.434
Breastfeeding	0.005	0.139	0.026	0.696	0.044	1.611	-0.001	-0.028	0.007	0.216
Org. PA	0.200***	5.724	0.068	1.801	0.147***	5.233	0.283***	9.574	0.060	1.928
D2/D4 (Right)	0.049	1.395	0.009	0.249	-0.005	-0.189	-.050	-1.688	-0.025	-0.791
	$F_{(7)}$ = 32.89 p<.001 R^2 = .27		$F_{(7)}$ = 13.41 p<.001 R^2 = .13		$F_{(7)}$ = 99.24 p<.001 R^2 = .53		$F_{(7)}$ = 81.98 p<.001 R^2 = .48		$F_{(7)}$ = 62.63 p<.001 R^2 = .41	

Note. * p<.05; ** p<.01; *** p<.001. Organized physical activity (Org. PA) was considered in all models except in the flexibility model where total physical activity was considered. The D2:D4 ratio of the right hand was considered as it showed the best results in the model compared to when the index finger was considered in the left hand.

an excellent way to estimate the main factors that can affect—both negatively and positively—performance in certain physical skills, and its possible consequences (Ruedl, et al., 2019).

Exclusive breastfeeding is defined as a feeding pattern based only on breast milk without any complementary foods (Zaqout, et al., 2018) and is considered to be a key factor in improving the survival, health, and development of children (Victora, et al., 2016). The results of our study show that there are no differences between genders in terms of the breastfeeding period. However, there is no scientific consensus on this fact since there are studies that have determined the period of breastfeeding is greater in boys (Hafeez & Quintana-Domeque, 2018), and others that have found the opposite result, stating that the lactation period for males begins later and lasts less time (Sen, Mallick, & Bari, 2020; Shafer & Hawkins, 2017). It seems that external factors such as culture or geographic location may play a relevant role since the results differ depending on the population analyzed. There seems to be an agreement that breastfeeding has a positive effect on both physical abilities and cardiorespiratory ability, and that it improves when breastfeeding lasts longer (Berlanga-Macías, et al., 2020).

However, Corredor-Corredor et al. (2019) found that while birthweight did have a positive correlation with different physical tests, the same did not occur with breastfeeding. In this sense, breastfeeding time can play a fundamental role, since there are considerable differences among those adolescents who are breastfed for a longer time in some tests such as dynamometry (Greven, Richards, & Buitelaar, 2018; Heshmati, et al., 2018).

Another factor which has attracted much attention in the literature over recent years is the 2D:4D digit ratio, defined as the length of the second finger divided by the length of the fourth finger (Eghbali, 2016). This ratio appears to be a marker of prenatal testosterone levels, in which a lower 2D:4D digit ratio indicates higher prenatal testosterone (Eghbali, 2016). It has been shown that the differences between the right 2D:4D ratio and the left 2D:4D ratio is greater in girls, although the differences may vary depending on ethnicity (Manning, Stewart, Bundred, & Trivers, 2004; Manning & Fink, 2020). However, with respect to the right 2D:4D ratio and age, our results contradict those of certain studies (Trivers, Manning, & Jacobson, 2006). Nevertheless, they do coincide with physical condition tests, in which the relation is negative in all tests (Hönekopp, et al., 2006), with the exception of flexibility; while in our study the relationship with flexibility was positive, most studies do not find such a connection (Peeters, et al., 2013). Birth weight is considered to be a relevant index of the intrauterine condition which has a known programming effect on later body size and body composition (Labayen, et al., 2006). Regarding birth weight, there is a positive relationship with manual dynamometry (Corredor-Corredor, et al., 2019; Moura-Dos-Santos, et al., 2013), especially in women (Ortega, et al., 2009), but also with lower body strength, since in both our study and that by Moura-Dos-Santos et al. (2013), jumping strength was positively correlated with running speed.

The vast majority of studies conclude that men perform more physical activity than women and have a higher adherence rate (Barja-Fernández, Juste, Pino, & Leis, 2020; Pino-Juste, 2019). In addition, we can state that the adolescents who carry out non-regulated physical activity perform equally well in regulated physical activity (Rodríguez-Cabrero, et al., 2015). Free physical activity is related to an improvement in a high number of physical parameters (Eather, Morgan, & Lubans, 2013). Likewise, those adolescents who do not meet the minimum guidelines for physical activity are less likely to achieve healthy levels of physical fitness, aerobic capacity and they have a worse BMI (Morrow, et al., 2013). The association with BMI is especially strong since it has a high negative correlation with moderate and vigorous physical activity (Joensuu, et al., 2018). It is therefore clear that both organized and unorganized physical exercise improves physical fitness (Chen, Hammond-Bennett, Hypnar, & Mason, 2018; Mora-Gonzalez, et al., 2020). Moreover, it is worth highlighting the importance of unregulated physical activity in girls, since there are considerable differences, especially between those who participate in unregulated physical activity and those who do not, compared to boys (Chen, et al., 2018). These results may be due to the fact that, in general, boys perform more physical activity than girls. Finally, it should be noted that age, sex and BMI are significant predictors with respect to physical fitness tests. Regarding age, it has been proven it has an effect on physical aptitudes linked to developmental stages (Smith, Weir, Till, Romann, & Cobley, 2018). When it comes to gender, men will have greater physical abilities than women (Dawes, et al., 2017). In terms of body mass index, those with obesity have poorer abilities and skills, both in terms of physical skills (Korsten-Reck, et al., 2007) as well as emotional and social skills (Utesch, Dreiskämper, Naul, & Geukes, 2018) than those with normal BMI or who are overweight (Kukic, Cvorovic, Dawes, Orr, & Dopsaj, 2018). In fact, BMI can be used as a useful, non-invasive and fast predictor of physical performance (Kukic, et al., 2018).

This study is not without limitations, the main one being the need to point out the impossibility of establishing causal relationships between the variables under study, given the type of cross-sectional descriptive study used here. Furthermore, we cannot state that these data hold up over time given their cross-sectional nature. In spite of the aforementioned limitations, though, the study offers insight into the influence of non-modifiable factors on adolescents' physical condition and points us towards measures that favor the improvement of their physical condition in order to prevent derived pathologies. Consequently, it would be worthwhile for future research to study causal relationships through a correlational study to ascertain the influence of different variables on each other. Another limitation is that participants were considered peers according to their biological age, without considering their degree of sexual development, which could be interesting to do in future studies.

Differences regarding sex in the non-modifiable factors that influence physical fitness were observed, with boys performing better in all the tests compared to the girls, except for the sit-and-reach test. However, there are no differences based on the period of breast milk intake, nor is it a predictor of physical fitness between the sexes. On the other hand, physical activity seems to be positively related to abdominal strength, flexibility, jumping, cardio-respiratory fitness and manual dynamometry, while age, sex, and body mass index were significant predictors with respect to the physical fitness tests. In addition, the practice of organized physical activity was a significant predictor in the abdominal strength, jumping and cardiovascular endurance tests. Birth weight is a significant predictor with respect to horizontal jumping and manual dynamometry. Finally, we can conclude that the non-modifiable factors studied in relation to physical activity practically ceased to be significant when variables such as sex, BMI and physical activity practice were introduced into the models.

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PROFILE OF GRASSROOTS FOOTBALL COACHES OF SPANISH PROFESSIONAL CLUBS

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Abstract:

The aim of the study was to identify the profile and education of grassroots football coaches (working with 8-12-year olds) of Spanish professional clubs (first and second male division, and first female division), as well as the qualities and characteristics they should have. For this purpose, an *ad hoc* questionnaire of 57 questions was used, grouped into seven dimensions, and administered to 153 coaches. This research focuses on the socio-demographic variables as well as on the dimensions of the coach's qualities and coach's education. The results showed that the profile of the coach corresponded to the following: male between 20 and 30 years of age, with experience in football initiation of 4-7 years, but with a 2-year experience in coaching boys and girls aged 8-12 years, with the specific football qualification level II or Union of European Football Associations A. The coaches considered it very important to have pedagogical skills and to use coaching methods that focus on learning rather than on results in order to be a coach in these age categories. Moreover, the participants considered that the training received in the official coaching courses did not adequately qualify them to carry out the sporting and human education of boys and girls in the *benjamin* (under 10) and *alevin* (under 12) age categories. The coaches also felt that the contents of the coaching course should be adjusted to the requirements of these age groups. These considerations can help sports federations and training centres to establish strategies to improve the official training programmes for football coaches.

Key words: *coach education, football academy, U-12 football*

Introduction

The athletic training process has been discussed in the scientific literature (Pazo, Sáenz-López, Fradua, Barata, & Coelho, 2011; Robles, Abad, Robles, & Giménez, 2019), in which multiple variables influencing this process has been pointed out and analysed. Out of it, the figure of the coach emerges as one of the most important factors in the process of sports education (Abad, Giménez, Robles, & Rodríguez, 2011a; Paixão, et al., 2021; Vickers & Schoenstedt, 2011). The need to improve the profile of the coach in sports education has led numerous researchers to analyse different variables (Lemyre, Trudel, & Durand-Bush, 2007; Urbano-Arévalo, Mancha-Triguero, Gómez-Carmona, & Gamonales, 2020). The elements usually characterising the coaches of educational sports are their youth (Abad, et al., 2011a; Lledó & Huertas, 2012; Lledó, Martínez, & Huertas, 2014; Maestre, Garcés, Ortín, & Hidalgo, 2019) and their male gender (Paixão, et al., 2021). Other aspects which have been researched regarding the profile of coaches in grassroots football are the experience they accumulate as coaches in educational categories (Côté, Erickson, & Duffy, 2013) or their experience as a player (Abad, et al., 2011a). Furthermore, the profile of the coach working in educational categories is usually characterised by being very heterogeneous and not very specialised (Feu, García, Parejo, Cañadas, & Sáez, 2009; López-Muñiz, Vázquez-Cano, Jaenes-Sánchez, & López-Meneses, 2018), i.e., he/she has not acquired all the necessary skills to train a group of players at an early age.

According to Paixão et al. (2021), the figure of the coach can clearly and effectively influence the sporting and personal environment of children and young athletes. Consequently, the sports coach becomes a key figure in ensuring that school-age children have an adequate sports education (Ballester, Fernández, & Parra-Camacho, 2021). In fact, a very important aspect to keep in mind regarding the figure of the coach is the term used to refer to him or her in educational sport, since, when it comes to contextualising this figure in sport literacy, specialists recommend using the term educator or sports trainer (Abad, et al., 2011a; Wein, 2005). Additionally, among their areas of influence are the knowledge of the sport they teach, the psychological level to awaken and maintain the motivation of the athlete to practice sport (Pulido, Sánchez-Oliva, Sánchez-Miguel, Leo, & García-Calvo, 2016) or the contents and design of the training (González-Víllora, García-López, Gutiérrez-Díaz, & Pastor-Vicedo, 2013; Light & Harvey, 2017; Martín-Barrero, 2019), being essential for them to have undergone a good professional education.

In this sense, some studies highlight the need for more specific or specialised education for grassroots coaches (Abad, et al., 2011a; Rodríguez-Palacio, 2016). Accordingly, specific coaching qualifications are classified into four levels, with level 0 or Union of European Football Associations (UEFA) C, to coaching initiation. Level I or UEFA B is the qualification which enables coaches to train at the grassroots level up to youth level (U19), level II or UEFA A for amateur categories and level III or UEFA PRO for professional football. Nevertheless, many authors recommend a greater teaching load in pedagogical, psychological and methodological content (Abad, et al., 2011a; Lledó, et al., 2014; Paixão, et al., 2021), especially at the levels qualifying coaches to train at the beginners' level. Furthermore, the global and integrative conception of grassroots sport requires coaches to be educated from a multidisciplinary perspective (Bennie & O'Connor, 2010; Ortega, Jiménez, Palao, & Sainz, 2008), while the study of the pedagogical variables influencing the education process can facilitate its evaluation, modification and improvement (Cañadas, Gómez, García-Rubio, & Ibáñez, 2018).

On the basis of scientific literature, it is understood that the coach is one of the most influential figures in the training process of the football player. Do the coaches of the grassroots of professional clubs have the appropriate training and profile for the development of the players' talent? For this reason, the aim of this study was to identify the profile and education of grassroots football coaches (working with 8-12-year olds) of Spanish professional clubs (first and second male division, and first female division), as well as the qualities and characteristics they should have.

Materials and method

Participants

This research included the coaches of the *benjamín* (U10) and *alevin* (U12) categories of the Spanish professional clubs of LaLiga Santander, LaLiga SmartBank (males) and LaLiga Iberdrola (females). A total of 153 coaches participated, male (n=140) and female (n=13), distributed in both educational categories (Table 1).

In order to ensure that the sample was representative of the target population, the sample size needed was calculated (Otzen & Manterola, 2017). In this process, a confidence level of 99% was used, with a margin of error of 0.04 (4%) for a sample size of 153 subjects (Table 2).

Instrument

The instrument used was the questionnaire made *ad hoc* and validated by Martín-Barrero, Abad and Giménez (2020), which consisted of 57 questions, grouped into seven dimensions (socio-demographic variables, talent development, training methodology, competitive context, coach's qualities, coach's education and social context). For reasons of space, the study presented in this paper focused on three dimensions (25 questions): i) socio-demographic variables, which sought to obtain information on gender, age, level of training/education and experience both as a coach and as a player; ii) the coach's qualities, which analysed the characteristics considered most important by the coaches for training these age categories players; and iii) the coach's education, in which the aim was to find out what was the perception of the education the coaches who trained at the initiation stage received. The respondents answered on a Likert-type scale with values from 1 to 10, with the value 10 corresponding to totally agree and the value 1 not at all agree (Figure 1).

Table 1. Participants in the research

	***Alevines* – U12 (10-12 years old)**	***Benjamines* – U10 (8-10 years old)**	**Total**
Male coaches	81	59	140
Female coaches	4	9	13
Total coaches per category	85	68	153

Table 2. Sample data of participants

Study population	Sample error	Percentage of the sample	Confidence level	Sample size
186	4%	82.25%	99%	153

Figure 1. QR code measuring instrument

Procedure

Firstly, a list was drawn up with the total number of clubs belonging to the research context. Subsequently, in order to find out more accurately the number of teams which had in their grassroots football the categories of *alevin* (U12) and *benjamin* (U10), the club coordinators were contacted, and the register was consulted on the websites of the territorial and official federations of the clubs. Once this had been accomplished, a definitive list was drawn up in order to identify the teams to be studied. Finally, a summary was made of the total number of coaches to be surveyed and of the clubs according to competitive category and type of football.

In the second phase, the coaches of each of the teams were contacted (in person, by telephone and/or online) to subsequently pass the questionnaire on to them. Once the data were obtained through the questionnaire, they were entered into an *ad hoc* recording tool in an Excel sheet in Microsoft Office® version 14.7.7 for Mac. The data were then transferred to SPSS 25.0 (Statistical Program of Social Sciences) for analysis.

Before starting data collection, participants were informed about the purpose of the study and it was guaranteed that the information collected would remain confidential, complying with ethical standards and the Declaration of Helsinki. Informed consent was obtained from all the coaches. The study was approved by the Research Ethics Committee in Andalusia, Spain (Code 2138-N-20).

Statistical analysis

For the statistical analysis, Cronbach's alpha was calculated for each dimension studied: i) socio-demographic variables (0.624); ii) coach's qualities (0.871); and iii) coach's education (0.714). Secondly, a descriptive analysis of the data was conducted, where the frequencies, means and standard deviations of the items of the different dimensions analysed were attained. Thirdly, an inferential analysis was performed comparing the variables of the socio-demographic dimension with the variables of the other dimensions studied, in which the level of relationship and association among different variables was reflected. For the analysis with variables from more than two groups, the Kruskal Wallis test was applied with a significance level of 95% (p=.05) with Bonferroni adjustment (0.05/n-1). Subsequently, the U-Mann Whitney test was applied for pairwise comparisons.

Results

We will first present the results corresponding to the coach profile through the socio-demographic variables, followed by those related to the coach's qualities and, finally, those referring to the coach's perception of received education.

Socio-demographic variables

The intention of this dimension was to identify the profile of the football coaches who trained the age categories of *alevin* (U12) and *benjamin* (U10) of the Spanish professional clubs, considering his/her gender, age, total experience in grassroots football, work experience in the age groups of *alevin* (U12) and *benjamin* (U10), the specific coach's training, academic education and experience as a player (see Table 1). In this regard, the percentage of males corresponded to 91.56% (n=140) of the total, while the percentage of females was 8.44% (n=13). The mean age was 30.99 ± 7.26 years. It was observed that most of the coaches were in the age range between 20 and 30 years (53.59%), although the presence of coaches between 31 and 40 years of age was also important, with 35.71%, so it can be stated that most of the respondents were between 20 and 40 years of age (n=136).

In terms of work experience coaching in grassroots football, it was found that most of the coaches were in the range of four to seven years (n=61). A similar proportion of coaches had between seven and 10 years of experience (n=44) and more than 10 years of experience (n=14). The majority of the coaches surveyed had between zero and four years of experience in the *alevin* (U12) category (77.1%), with a predominance of two years of experience (n=37). Concerning the *benjamin* (U10) category, the data were very similar to those shown in the *alevin* (U12) category, with two years of experience being the most selected value (n=42).

As regards the specific coaching qualification, the results showed that level II or UEFA A qualifications were the most frequent (n=71). Coaches with level 3 qualifications also were highly represented (n=60). In terms of the educational profile of the coach, it was observed that the highest percentage had completed university studies related to sports (41.83%). Those who had completed secondary education, vocational training or upper secondary (23.53%) were in a lower range. On the other hand, the vast majority of coaches had been former players of non-professional grassroots football clubs or amateur categories (n=116), with only 7.2% being former professional football players (see Table 3).

Dimension of the coach's qualities

With this dimension, the aim was to determine, according to the respondents' perceptions, the qualities coaches working at the initiation stage should have, and their opinions on some specific issues regarding coaching these educational categories (Table 4). Firstly, the respondents (61.4%; M= 6.23 ± 2.16) considered the adaptations of the coaches to the psycho-evolutionary characteristics of the children at this stage to be insufficient. Moreover, coaches showed a high degree of agreement regarding the fact that the coach should have pedagogical skills (90.2%; M= 7.91 ± 1.89) and should use teaching methods favouring learning of the game over the result in competition (94.1%; M= 8.97±1.54). On the other hand, respondents thought that coaches tended to use methods which encouraged player autonomy (68.6%; M=7.03±2.60) (see Table 4). Nonetheless, they considered that coaches prioritised the promotion of themselves over the progression and development of the player (74.5%; M=7.05±2.38). Significant differences (p=.026) were found in this regard between the group of coaches with less experience in the *benjamin* (U10) category (M=6.66±5.05) and those with more experience in this same category (M=8.26±2.31), with large effect size (*d*=0.59) (see Table 6).

As for the good use of social networks (73.9%; M=7.37±2.93), significant differences (p= 0.035) were found between those who had never played football (M=5.33±2.33) and former semi-professional players (M=8.47±5.26), with a large effect size (*d*=0.69) (see Table 6). Finally, coaches considered it important to have specialist coaches at the initiation stage of football (94.8%; M= 8.94±1.57), with significant differences (p= 0.043) between the coaches under 20 years of age (M=4.00±0.00) and those between 41 and 50 years (M=9.61±0.75), with a large effect size (*d*=0.79) (see Table 6). In this last aspect, significant differences were also detected (p=.013) between those with more experience (more than 10 years) in grassroots football (M=9.37±1.16) and those with less experience (0-3 years) (M=6.57±3.92), with a large effect size (*d*=0.87) (see Table 6). In this way, it can be concluded that those with more experience and those who are older considered that in these categories it was necessary to have coaches who were specialists in the said categories.

Table 3. Main results of the dimension of the socio-demographic variables

Variable	Outstanding answer	%	*n*
Gender	Male	91.56	140
Age	20-30 years old	53.59	81
Grassroots football experience	4-7 years of experience	40.3	61
Experience with *alevines* (U12)	2 years	24.2	37
Experience with *benjamines* (U10)	2 years	27.5	42
Coaching qualification	Level II	46.6	71
Academic education	Sport-related university studies	41.8	64
Experience as a player	Former player of a non-professional club at grassroots or amateur level	75.8	116

Table 4. Main results of the dimension of the coach's qualities

Variable	Outstanding value	%	*n*
I consider the adaptations made by the coaches to be insufficient in relation to the capacities	5	20.9	32
I think the pedagogical skills of the coach are the most important in this age group	8	26.8	41
In these categories, coaches should use methodologies which enable the learning of the game above the result of the competition	10	52.3	80
I think that at this age, coaches tend to use strategies which allow the player to be autonomous and to have initiative in decision making during the game	10	24.8	38
I believe coaches at this stage have the ability to manage competition as a means within the training process and not as the sole end	10	28.8	44
I think coaches in these categories prioritise their promotion as coaches over the player development	8	22.9	35
I consider necessary for the coach to know how to make good use of social networks at this stage	10	36.6	56
I think it is important for clubs and schools to have specialist coaches for this stage	10	52.9	81

Dimension of the coach's perception of education

In the dimension of the coach's education, the aim was to obtain information on the opinions coaches had in relation to their education for coaching this age group (Table 5). In this sense, on the question of whether the coaches at this stage were usually well trained, they showed a medium degree of agreement (M= 4.99±2.38). They disagreed with the education received through football coaching qualifications, as they considered that it was not sufficient to be able to carry out a correct sporting and human education of the players in these categories (67.3%; M= 4.39±2.39), finding significant differences (p= 0.020) between the coaches with university studies related to sport (M=4.09±2.52) and the coaches with secondary education, vocational training or upper secondary studies (M=5.70±3.70), with a very large effect size (*d*=0.99) (see Table 6). Furthermore, respondents agreed with the need to change the contents offered by coaching courses so that they would be more in line with the requirements of this stage of sports training (87.6%; M=7.84±1.83). They also considered that the period of practical training carried out in coaching qualifications, which should enable them to coach in the categories *alevin* (U12) and *benjamin* (U10) (56.9%; M=6.13±2.43), should be extended. Finally, the respondents indicated that they agreed with modifying the academic criteria to access coaching courses so that they would have higher qualifications and higher education for the initiation stage of football (71.9%; M=7.18±2.35).

Regarding continuing education, coaches expressed strong agreement with the statement that those training these age categories should receive

Table 5. Main results of the dimension of the coach's education and training

Variable	Outstanding value	%	*n*
I think coaches of this stage are usually well trained	3	15.0	23
I think that the education coaches receive through football coaching qualifications is sufficient to be able to carry out the correct sporting and human education in a group of players in these categories	3	24.8	38
I would modify the contents offered by the coaching courses to be more in line with the requirements of this stage	8	27.5	42
I would modify the academic criteria to access coaching courses in order to get more qualified and educated coaches for this stage	10	20.3	31
I consider insufficient the training period established in the coaching qualifications required to qualify to coach in the *Alevín* (U12) and *Benjamín* (U10) categories	5	19.0	29
I believe coaches of these categories should receive training throughout the year on extra-sporting aspects (use of social networks, education in values, communication skills, etc.)	10	34.0	52
I consider it fundamental that there be official conferences and forums where the different coaches of schools and clubs of these categories can share experiences and knowledge	10	35.9	55
I think it is important that, during the official courses to acquire the coaching qualification, the coaches of these categories can exchange training experiences with clubs and football schools from other cultures, territories and countries	10	41.2	63

Table 6. Inferential statistics results

Question	Variable	M	DT	p	*Effect size*
They considered that coaches prioritised the promotion of themselves over the progression and development of the player	Benjamin (U10) coaches between 0-3 years' experience	6.66	5.05	0.026	0.59
	Benjamin (U10) coaches between most 10 years' experience	8.26	2.31		
Good use of social networks	Players who had never played football	5.55	2.33	0.035	0.69
	Former semi-professional players	8.47	5.26		
Coaches considered it was important to have specialist coaches at the initiation stage of football	Coaches under 20 years old	4.00	0.00	0.043	0.79
	Coaches between 41 and 50 years old	9.61	0.75		
Coaches considered it important to have specialist coaches at the initiation stage of football	With less experience (0-3 years) in grassroots football	6.57	3.92	0.013	0.87
	More than 10 years in grassroots football	9.37	1.16		
Education received by coaches through football coaching qualifications	Coaches with university studies related to sport	4.09	2.52	0.020	0.99
	Coaches with Secondary Education, Vocational Training or Upper Secondary studies	5.70	3.70		

education throughout the year on extra-sporting aspects (use of social networks, values education, communication skills, etc.) (91.5%; M=8.23±1.87). They also considered it fundamental to have official conferences and forums where coaches from various schools and clubs could share their experience and knowledge (93.5%; M= 8.35 ± 1.70). Finally, respondents considered it important that, during the official courses leading to coaching qualifications, coaches at these levels could exchange training experiences with clubs and football schools from other cultures, territories and countries (97.4%; M=8.73±1.38) (see Table 5).

Discussion and conclusions

The aim of the study was to find out the profile and education of grassroots football coaches (working with 8-12-year olds) of Spanish professional clubs (first and second male division, and first female division), as well as the qualities and characteristics they should have. Bearing in mind the socio-demographic variables analysed, the results showed that most of the coaches belonged to the male gender. However, these data were reduced in the female teams, where 40% of the coaches were female, against the 60% of them who were male. These data coincide with those obtained in other studies (Abad, et al., 2011a; Paixão, et al., 2021), which highlighted the predominance of male coaches in the initiation football categories.

In terms of age, there was a significant number of coaches aged between 20 and 30 years, with an average age of 31 years, data which are in line with other similar studies (Abad, et al., 2011a; Lledó & Huertas, 2012). In terms of work experience as a grassroots football coach, the highest percentage was found to be between four and seven years of experience in coaching the mentioned educational categories. Furthermore, most of the coaches had around two years of experience coaching in the *alevin* (U12) category, the result that matched the number of years coaching in the *benjamin* (U10) category. These data are similar to the results obtained by Abad, Benito, Giménez, and Robles (2011b), who indicated in their study on grassroots football coaches in the province of Huelva that the vast majority had little experience training as coaches in these age categories (three and five years). These data are also reflected in the research by Álamo, Amador, and Pintor (2002) who also reported that in Gran Canaria and Tenerife, football coaches working at the grassroots level were mostly inexperienced. Paixão et al. (2021) also showed that most of the coaches in the educational categories in Beja (Portugal) had less than two years of experience.

As for specific training as a coach, most of the coaches had obtained level II or UEFA A coaching qualifications, with level III or UEFA PRO coaches being the second most represented. These findings do not coincide with the study by Feu, Ibáñez, and Gozalo (2007), where the majority of coaches had a level I (UEFA A license) or even just a Leisure and free time counsellor qualification. However, it seems that professional clubs want to avoid the lack of training of their coaches, considering that those with specific qualifications had a greater capacity to develop an adequate education of the player (Camiré, Forneris, & Trudel, 2012).

The data on the academic education of the coaches reveal that the vast majority had university studies related to sports. These results confirm what was indicated by Lledó and Huertas (2012) in their research on coaches in the initiation stage of professional clubs in the Community of Valencia, in which they obtained very similar findings to those of this research. Professional clubs seem to be aware of the importance of grouping their technical staff with professionals who have a sport-related university education. On the contrary, these results are not in line with those achieved by Feu et al. (2007) and Abad et al. (2011b), who suggested that the majority of grassroots coaches had a low or medium-low academic profile, with a predominance of non-university studies.

As for the sporting experience, it was revealed that the highest percentage of the coaches analysed had been former amateur or grassroots football players in non-professional clubs. On the other hand, very few ex-professional players were found to coach in these categories; it may be due to the fact that they do not show great interest in coaching at the initiation level, their priorities as coaches being elsewhere. Studies conducted by Abad et al. (2011a) also pointed out that the majority of the coaches surveyed had experience as football players. Furthermore, Paixão et al. (2021) deemed that the influence of the coach's playing experience on the development of their trainees seemed not to have been addressed yet by the scientific community.

Respondents reported that they agreed with the fact that the adaptations they made in relation to children's abilities were insufficient. The coach must understand that the main focus should be on the child and, therefore, the sport must be adapted to the child from all points of view. On the other hand, the study by Lledó and Huertas (2012) concluded that the initiation coaches did not carry out sufficient adaptations in relation to the competition and the training methods used. On the contrary, Abad et al. (2011a) and Paixão et al. (2021) showed that coaches claimed to have carried out adaptations appropriate to the child's abilities, which coincides with the results obtained in this study. Conversely, the coaches of these categories, when asked about some qualities they observed in themselves, highlighted the use of teaching methods enabling autonomy and initiative in decision-making in their players and the ability to manage the competition as a part of the training process and not as the sole purpose of the game. The foregoing can be questioned because respondents also felt that coaches prioritised their promotion as a coach over the development of the player. Respondents also strongly agreed that coaches should have pedagogical skills and master the use of methods favouring learning over performance and the use of social networks. Regarding teaching methods, Cecchini, Contreras, and Méndez (2005) considered it fundamental to use methods influencing not only the preparation of the player but also the adherence to the sports practice among youngsters, being able to have a considerable level of pedagogical skill (Light & Harvey, 2017).

Finally, as for the availability of specialist coaches at the initiation stage of football, the respondents showed a high degree of agreement in relation to this issue. No studies have been found in this regard, so it might be an interesting aspect to investigate whether clubs do take into account when hiring coaches the fact that they are specialists in this initiation stage. Moreover, coaches at the initiation stage should not be understood from a generic perspective as sports coaches, but the use of the term educator or sports trainer is recommended (Wein, 2005). This idea may suggest, as the results obtained have shown, that it is important to have specialists who know the needs of children at this age, who know how to adapt the sport to children's characteristics and who are capable of putting into practice the integral education of the sportsperson, trying to teach through sport in order to shape good athletes and better people.

On the issue of the coach's education for working at this stage, when asked if they considered that coaches were well educated, it was observed that many coaches disagreed with this statement. Along these lines, Abad et al. (2011a) found in their study that coaches who did not hold a football qualification and who had basic-level studies predominated. On the other hand, regarding the preparation to be a coach, the respondents showed a low degree of agreement on the question of whether the training they had received through football coaching qualifications was sufficient to be able to carry out the correct sporting and human education in a group of players of these age categories. These data were consistent with those of Abad et al. (2011b). The research studies mentioned above, and the high degree of agreement obtained when coaches were asked if they would modify the contents offered by coaching courses so that they would be more in line with the requirements of this stage, showed that coaches considered that they did not find a programme in official qualifications that would truly be adjusted to offer the knowledge necessary to produce good coaches for football initiation stage. The coaches' perceptions of coaching courses were not aligned with the recommendations by McCullick, Belcher, and Schempp (2005), who believed it was very important for courses to be of good quality and with a clear practical application to coaching. Finally, as far as the contents of the coaching courses are concerned, the respondents agreed that the practical training period within these qualifications for coaching in the categories of *alevin* (U12) and *benjamin* (U10) was insufficient. It should be noted that this period becomes a fundamental part of the training of coaches since during this time coaches gain experience in training and competition, being, moreover, highly valued by the trainees (Lledó & Huertas, 2012). In this way, the figure of the mentor is necessary to increase the quality of the internship period (Cushion, 2006), as well as the education of the coaches.

On the issue of continuing and complementary education, they considered it essential to have official conferences and forums where coaches in these age categories of different schools and clubs could share their experiences and knowledge. The data compiled by Abad et al. (2011a) suggested it was very important that continuing education should exist and be promoted, as many coaches showed a lack of education. In this line, Nash and Collins (2006) and Côté et al. (2013) highlighted the importance of continuing education for football coaches. Furthermore, coaches are interested in and predisposed to this type of education and tend to demand learning of contents related to the training process, didactics and teaching methodology (Paixão, et al., 2021).

In light of the foregoing, in order to overcome the educational problems of grassroots football coaches, it would be advisable for football federations and other training bodies to encourage and facilitate courses and workshops of a practical nature (Abad, et al., 2011a). Along these lines, Werthner and Trudel (2006) stated that sports federations should stimulate training strategies with a non-formal character. Nonetheless, Lledó and Huertas (2012) highlighted the precarious employment situation of many grassroots football coaches, who work without an employment contract and receive very low or no financial compensation. This situation means that the weekly time dedication of grassroots football coaches is insufficient to provide some continuity in continuing education programmes since they have to combine their work as a coach with another job.

In conclusion, the profile of the football coach of professional clubs of Spanish male and female leagues in the educational categories of *benjamin* (U10) and *alevin* (U12) is as follows: male between 20 and 30 years of age, with work experience in grassroots football from four to seven years, but with little experience in the educational stage of initiation (two years) in the *alevin* (U12) and *benjamin* (U10) categories, with a specific football qualification of level II or UEFA A license, having a degree from university studies related to the sport who has been a former player in grassroots or amateur football. Furthermore, for the respondents, it is very important that coaches have pedagogical skills, that they use methods prioritising learning over performance and that they use social networks appropriately. In addition, coaches consider it essential to be specialists in coaching the educational stage of players.

Concerning the perception of coach-specific education received, the respondents consider that the training received in the official football coaching courses is not sufficient to be able to carry out the correct sporting and human education of the players in these specific educational categories. They also believe that it is advisable to modify the contents of the football coaching courses in order to adjust them to the training needs necessary to coach children at the initiation stage. Additionally, they consider the academic requirements to access the coaching courses to be insufficient and demand more training and qualification to be able to coach players at the initiation stage. They also deem that the practical training period proposed in the coaching courses' practical training block is insufficient to perform their work with the categories of *benjamín* (U10) and *alevin* (U12).

With regard to continuing education, they express their support for exchanging training experiences with clubs and football schools from other cultures, territories and countries during their training in coaching courses and they also express that it is very important that the coaches of players at the initiation stage receive education throughout the year on extra-sporting aspects, indicating that training courses, conferences and official forums are a good opportunity for continuing education to share their experiences and knowledge. As to the limitations of this study, it can be pointed out that there are few similar studies, due to the particularity of the context investigated. In addition, the instrument used, the questionnaire, is always subject to the honesty and interest of the individuals surveyed, which means that the results should be considered cautiously and that further research is needed in this respect. It would therefore be interesting to perform the same study with coaches working in non-professional clubs (both male and female) and compare the data collected with the findings of this study.

Practical implications

The data collected in this research, on the one hand, can help professionals who manage football clubs to establish criteria in the selection processes that facilitate the identification of coaches with the right profile, training and qualities to give stability to the projects in the initiation stage, being interesting that those responsible for the methodology of the clubs can establish criteria to evaluate both new coaches and those who already belong to the club. On the other hand, knowledge about the skills and training that coaches have provides information that can be used by the training entities (federations and training centres) to establish new strategies in the official training programmes, as well as to develop new programmes that promote the continuous training of coaches.

Finally, it is considered that this work can help coaches to know about and reflect on skills and abilities they have in the light of the presented criteria, thus being a way of self-evaluation.

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TRAINING PRACTICES OF FILIPINO ATHLETES DURING THE EARLY COVID-19 LOCKDOWN

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Abstract:

The imposition of COVID-19 lockdown restricted the daily activities of many people, including athletes. This study investigated the training practices of athletes in the Philippines during the early COVID-19 lockdown. A total of 442 athletes answered an online survey (May-July 2020), with questions pertaining to training practices, such as training frequency and duration. Data were analyzed according to: athlete classification (world-class, international, national, state, or recreational), sport category (individual or team), and sex (male or female). During lockdown, significant reductions in training frequency (except recreational, i.e., lower pre-lockdown training) and duration were observed for all athletic classifications. Similarly, training frequency and duration decreased significantly irrespective of sport category and sex. World class athletes appeared to be less affected by lockdown (types of exercise and specific training) as compared to lower-classification athletes. Athletes grouped in accordance with sex and sport category demonstrated little to no difference in training practices during the COVID-19 lockdown. The findings of the current study highlight the challenges experienced by athletes during lockdown, which may aid policy makers in the development of guidelines related to lockdown or lockdown-like situations to establish appropriate support for affected athletes.

Key words: *movement restriction, home training, remote training, sports training, SARS-CoV-2*

Introduction

In December 2019, the novel coronavirus (COVID-19) was reported in Hubei Province, China (Zhu, et al., 2020). The high person-to-person transmission capacity of COVID-19 resulted in a pandemic, affecting 600 million individuals to August 2022 (www.who.int). The pandemic resulted in social restrictions (Ammar, et al., 2020a), including residential isolation and lockdowns, affecting the ability to participate in sports and exercise (Keshkar, et al., 2021; Trabelsi, et al., 2021; Washif, et al., 2022a). These restrictions also resulted in cancellation or postponement of major sporting events (Bok, Chamari, & Foster, 2021; Dergaa, et al., 2021), including the Philippine National Games, Southeast Asian Games, and Association of Southeast Asian Nations Para Games.

The pandemic has presented mental, social, and physical challenges for both athletic groups and wider population (Ammar, et al., 2020b; Pillay, et al., 2020). For example, the time spent completing all physical activity (i.e., vigorous, moderate, and walking) and the metabolic equivalent tasks among the worldwide population has decreased (>25%), during lockdowns (Ammar, et al., 2020c). For athletes, daily routines such as training and recovery were limited or impeded (Romdhani, et al., 2022a; Washif, et al., 2022a), resulting from limited access to specialized facilities, technical coaching, sports science support, and medical professionals (Pillay, et al., 2020; Washif, et al., 2022a, 2022b).

During lockdown, significant changes in training practices were reported among athletes (Pillay, et al., 2020; Washif, et al., 2022a). Team sports activities, where athletes routinely interact with opponents, were no longer possible (Washif, et al., 2022c). Therefore, athletes resorted to home-based physical training (e.g., bodyweight and cardiorespiratory training) to maintain fitness (Hammami, Harrabi, Mohr, & Krustrup, 2020; Washif, Mohd Kassim, Lew, Chong, & James, 2021). Among elite and sub-elite athletes in South Africa, Pillay et al. (2020) reported alterations in training practices that resulted in greater moderate intensity training, compared with typical higher intensities, which may be considered sub-optimal. For highly trained kayakers and canoeists, the lockdown reduced weekly training time, decreased light-to-moderate physical activity, and increased weekly home-based strength training sessions (Hammami, et al., 2020). Manipulation of key training variables to attain training stimulus similar to pre-lockdown during pandemic and lockdown situations and the increased risk of injuries (Seshadri, Thorn, Harlow, Drummond, & Voos, 2021), might have contributed to reduction in neuromuscular performance (Spyrou, et al., 2021). For these reasons, caution must be taken when considering modified training during lockdown.

Furthermore, lockdowns appear to have been particularly challenging to lower classification athletes and male athletes due to limited/precluded facility access (Washif, et al., 2021), and lower frequency of vigorous-intensity training (Hermassi, et al., 2021), respectively. This modification has been associated with increased stress levels (di Fronso, et al., 2022; Washif, et al., 2022b). Compared to males, female athletes reported greater mood disruptions associated with increased perceived stress, and dysfunctional psycho-biosocial states (di Fronso, et al., 2022). Also, more females reported increased anxious feelings and mental vulnerability during lockdown compared to males (Washif, et al., 2022c). Similar outcomes were reported amongst young individuals in the Philippines during the early pandemic (Tee, et al., 2020). The findings mentioned emphasize the importance of understanding the challenges experienced by athletes of different classifications and sexes during lockdown, which can help to provide data-driven assistances in future lockdown situations and post-lockdown training resumption.

The Philippines was one of the countries that implemented a 'late' lockdown (i.e., locally termed as *community quarantine*), which also affected the preparation of athletes for the Tokyo 2020 Olympics (Edrada, et al., 2020; Official Gazette Philippines, 2020), performed one year later (Bok, et al., 2020). Despite this, the Philippines posted the greatest medal output in the Tokyo 2020 Olympics, since its participation in the quadrennial event. Given the unique situations in the Philippines described above, there is currently limited information regarding athletes' practices during lockdown among different classification athletes (e.g., world class, national, state athletes), sport category (team and individual), and sex (male and female). Such information will help policy makers to consider evidence-informed guidelines related to the training management, and also establish guidance on return to sport and competition preparation during lockdown-like situations. Thus, the current study investigated athletes' training practices in the Philippines during lockdown, including changes in the training frequency and duration (pre-lockdown vs. lockdown) with reference to athlete classification, sport category, and sex.

Methods

Participants

A total of 442 recreational, amateur and elite athletes (≥18 years) from the Philippines, who had experienced lockdown for at least two weeks between March to June 2020, volunteered to participate in the study. All athletes did not miss more than seven days of technical/tactical/physical training due to sickness and/or musculoskeletal injury between March to June 2020. To identify a difference in training practice variable, training frequency, and duration, sample size was calculated using the formula $n = (Z\alpha/2)^2 s^2/d^2$, where "s" is the standard deviation (SD = 4.00%) and "d" is the accuracy of estimate or how close it is to the true mean (= 0.65%) (Kang, Ragan, & Park, 2008). The "s" was collected from a previous related literature (Washif, et al., 2022a), where athletes performing ≥5 sessions/week before lockdown reduced their training volume by -23±4% during lockdown. "Zα/2" is the normal deviate for a two-tailed alternative hypothesis at a level of significance (Zα/2 equal to 3.29 at an error rate of 0.001%). The sample size as N= (3.29)2 42/(0.65) indicated a sample of 410 participants. Athletes were classified based on competition levels with specific criterion outlined elsewhere (Washif, et al., 2022a): (a) world class (WC); (b) international (INT), (c) national (NAT); (d) state (ST); (e) recreational (REC). Athletes were also classified by sport types (individual: e.g. boxing, fencing, athletics, badminton; team: e.g. basketball, handball, soccer, volleyball), and sex (female and male). All participants gave informed consent and proceeded with answering an online survey to establish the training practices of athletes under the first lockdown. The study protocol aligns with the Declaration of Helsinki for Human Experimentation and was approved by Institutional Ethics Committee (Washif, et al., 2022a).

Procedures

This study was part of a global study examining athletes' training practices during lockdown (Washif, et al., 2022a). An online survey using Google Form, disseminated through different platforms (email, personal/group messaging, social media), was answered by the participants between May 17 to July 5, 2020. Data from questions with pre-defined answers (e.g., yes or no) were converted to standardized codes/numbers, with the use of the automated/customized setting in the Excel spreadsheet (Microsoft, USA), for analysis.

Survey. The English version of the "ECBATA survey" (Washif, et al., 2022a) was used in this study. The ECBATA survey was initially developed by sports scientists from the National Sports Institute of Malaysia and ASPETAR (Qatar), and further reviewed by a steering group of >100 researchers and sports scientists from >60 countries. In the current study, the researchers focused on training practices pertaining to questions related to purpose of training, training prescription, training administration, type of exercise, type of specific training, and recovery strategy. Each question contained items answerable by a single response (1 = yes; 0 = no). However, multiple responses can be selected from each training practice theme. Any missing sub-item response or athlete grouping datum were excluded from the analysis.

This study also examined the training frequency and duration before and during lockdown. Training frequency was assessed using a rating scale from 1 to 11, where one answer corresponded to once-a-week training frequency and 11 depicted more than 10 sessions a week. Training duration was categorized according to: (a) 1 = <30 min; (b) 2 = 30-59 min; (c) 3 = 60-89 min; (d) 4 = 90-119 min; (e) 5 = >120 min). Any missing datum in training frequency/duration or classification/sex/category were excluded from analysis of training frequency/duration. Each parameter in this study is answerable by single response. Test-retest reliability of the survey questionnaire was rated as good-excellent (Washif, et al., 2022a).

Statistical analysis

The non-parametric Kruskall-Wallis test was carried out to determine any significant between-group differences in training practices, frequency, and duration in the athletic level. Subsequent inter-group pairwise comparisons with a significance level adjusted for the Bonferonni correction were also administered. The Mann-Whitney U test was used to examine any significant intergroup differences in sport category (individual vs. team) and sex (males vs. females). Additionally, within-group analyses of training frequency and duration before and during lockdown in athlete classification, sport category, and sex were conducted using the Wilcoxon-Signed rank test. Any missing/*unclear* categorical variables were not included in the analysis. Statistical analyses were carried out using a commercial statistical package (SPSS version 25, IBM Corp, USA) with an alpha set at 0.05 level.

Results

Athlete classification

Training frequency

Athletes from WC (n = 55, *p* =.000) and INT (n = 90, *p* =.000), NAT (n = 85; *p* =.000), and ST (n = 116, *p* =.000) demonstrated significant reductions in training frequency. No difference in training frequency was seen in REC (n = 11, *p* =.787). Before lockdown, there was a significant between-group difference in training frequency (*p* =.000), with the training frequency of WC > INT (*p* =.000), WC > NAT (*p* =.001), WC > ST (*p* =.000), and WC > REC (*p* =.013). During lockdown, a significant between-group difference in training frequency existed (p =.000). The WC > INT (*p* =.000), WC > NAT (*p* =.006), and WC > ST (*p* =.034). The training frequency of ST was also significantly higher than INT (*p* =.026). Figure 1 depicts the training frequency of athletes by classification pre and during lockdown.

Training duration

The training duration of WC (n = 64; *p* =.000), INT (n = 103; *p* =.000), NAT (n = 98; *p* =.000), ST (n = 138; p =.000), and REC (n = 15, *p* =.035) decreased during lockdown (Figure 2). Before lockdown, there was a significant between-group difference in training duration (*p* =.001), with pairwise comparisons depicting with significant pairwise differences found in WC > INT (*p* =.001) and INT > ST (*p* =.029). There was also a significant between-group difference during lockdown (*p* =.000) in WC > INT (*p* =.000) and WC > NAT (*p* =.021). Figure 2 shows the training duration of athletes according to classification before and during lockdown.

Training practices

Table 1 displays the training practices of athletes in accordance with athlete classification during lockdown.

Training purpose

There was a significant intergroup difference for maintaining/developing skills/technique (*p* =.028), with NAT > INT (*p* =.027) at *post hoc*. There was also a significant between-group difference for maintaining/developing power (*p* =.001), with *post hoc* INT < NAT (p =.029), INT < ST (*p* =.008), and INT < REC (*p* =.004). A significant intergroup difference was identified for maintaining/developing muscle balance (*p* =.033), with *post hoc* NAT > ST (*p* =.033). While a significant intergroup difference was found in maintaining/developing flexibility (*p* =.014), subsequent pairwise comparisons exhibited non-significant differences.

Training prescription

A significant between-group difference was identified for own training program (*p* =.000), with *post hoc* WC < INT (*p* =.014), WC < ST (*p* =.002), WC< REC (*p* =.011), NAT < INT (*p* =.003), NAT

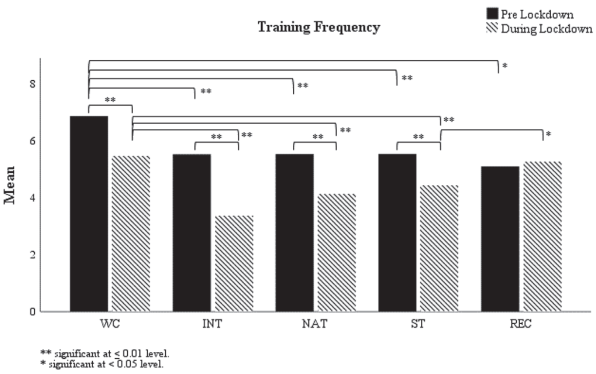

Figure 1. Training frequency of various athletes before and during lockdown. WC – world class; INT – international; NAT – national; ST – state; REC – recreation.

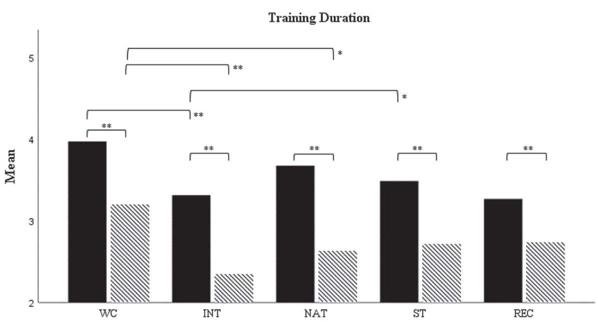

Figure 2. Training duration before and during lockdown of athletes.

Table 1. Training practices of athletes during lockdown (mean rank)

	WC	INT	NAT	ST	REC	p
Q1. What are/were your general purpose(s) of training during lockdown? (n = 438; missing = 4)						
	n=65	n=104	n=109	n=143	n=17	
Q1.1. To maintain or develop general fitness and health	212.3	237.6	213.9	215.4	207.4	.062
Q1.2. To maintain or develop skills/technique	230.8	198.8	243.6	210.3	226.1	.028
Q1.3. To maintain or develop strength and power	225.3	183.2	227.1	229.9	283.7	.001
Q1.4. To maintain or develop muscular endurance	230.5	201.5	233.1	214.3	244.2	.174
Q1.5. To maintain or develop abdominal strength	223.5	209.6	231.5	218.6	196.3	.551
Q1.6. To maintain or develop aerobic fitness	228.0	203.5	230.0	215.4	252.3	.249
Q1.7. To maintain or develop general flexibility	249.9	211.2	235.0	204.3	182.9	.014
Q1.8. To improve muscle balance	222.2	209.6	246.5	206.9	202.4	.033
Q1.9. Weight management	205.5	205.9	240.5	218.4	231.1	.133
Q2. Who is prescribing/prescribed the training program during lockdown? (n = 437; missing: n = 5)						
	n=65	n=104	n=109	n=142	n=17	
Q2.1 Own training program	183.1	236.9	184.1	242.2	277.4	.000
Q2.2 Training program from my coach or trainer	243.9	225.4	235.2	193.0	197.3	.004
Q2.3 Combination of own training and my coach/trainer	236.4	206.9	225.7	218.6	186.9	.282
Q2.4 Found training material from an external source: online, TV, a friend, etc.	189.2	219.4	225.1	227.5	220.4	.073
Q3. Do/did you train? (n = 435, missing: n = 7)						
	n= 64	n=103	n=108	n=143	n=17	
Q3.1 Alone	232.5	190.5	216.2	231.5	228.1	.006
Q3.2 In a small group of partners of equal athletic capacity	233.7	259.0	197.8	199.6	193.9	.000
Q3.3 With family members or friends with little athletic capacity	206.6	224.6	226.4	214.0	201.6	.452
Q4. What are the types of exercises that you have been doing consistently (at least twice a week) during lockdown? (n = 432; missing: n = 10)						
	n=64	n=104	n=105	n=142	n=17	
Q4.1. Body-weight based exercises with limited equipment	237.1	206.2	239.9	203.4	166.7	.002
Q4.2. Strength training with appropriate equipment (dumbbells, weights, etc.)	243.5	214.4	191.3	227.9	187.9	.002
Q4.3. Technical skills (sport specific skills training)	210.1	243.6	217.7	202.7	182.5	.028
Q4.4. Imitation or simulation of the techniques of my sport	244.8	205.8	217.8	208.5	234.0	.043
Q4.5. Cardiovascular training (running, cycling, rowing, etc.), including HIIT	240.0	237.9	189.1	211.9	205.1	.004
Q4.6. Plyometric training	226.6	203.0	231.3	215.9	174.4	.098
Q5. What are the types of specific training you could do with the same intensity during lockdown (very similar to pre-lockdown)? (n = 432; missing: n = 10)						
	n=65	n=104	n=106	n=140	n=17	
Q5.1. Warm-up and stretching	212.6	232.1	214.0	208.6	217.1	.124
Q5.2. Weightlifting (strength) training	225.5	204.7	205.9	233.1	184.4	.048
Q5.3. Plyometric training (e.g., repeated jumping)	228.9	200.7	234.2	215.0	167.9	.034
Q5.4. Technical skills (sport-specific)	235.9	197.3	235.1	208.1	213.0	.027
Q5.5. Speed training	253.9	203.2	206.4	219.2	195.6	.008
Q5.6. Speed endurance	224.6	245.4	196.5	210.9	179.6	.004
Q5.7. Long endurance	246.1	255.3	197.8	191.3	190.0	.000
Q5.8. Interval/intermittent training	260.1	213.2	203.7	208.4	216.7	.007
Q5.9. Change of direction	222.7	208.2	228.2	214.2	189.5	.120

Q6. What are the modes of physical recovery that you use consistently (at least once a week) during lockdown? (n = 442)						
	n= 65	n = 104	n = 110	n = 144	n = 19	
Q6.1. Not applicable	207.7	263.4	194.6	212.7	261.9	.000
Q6.2. Ice bath	226.9	219.3	228.6	217.2	206.5	.309
Q6.3. Massage	260.3	213.1	219.7	214.7	197.1	.001
Q6.4. Acupuncture	220.5	222.6	220.5	222.0	220.5	.797
Q6.5. Sauna	249.8	223.9	215.0	213.6	209.0	.000
Q6.6. Stretching	230.1	195.3	236.3	230.8	179.8	.006
Q6.7. Meditation/relaxation	230.0	208.8	229.4	224.8	191.5	.373
Q6.8. Foam rolling	225.7	219.8	217.5	224.7	215.5	.384
Q6.9. Electronic pulse therapies	227.6	220.4	220.0	220.1	225.6	.716

WC - world class; INT - international; NAT - national; ST - state; REC - recreational; HIIT - high intensity interval training.

< ST (p =.000), and NAT < REC (p =.008). Similarly, a significant intergroup difference was also detected for the training program from the coach/trainer (p =.004), with *post hoc* NAT > ST (p =.019) and WC > ST (p =.015).

Training administration

The intergroup difference for training alone was significant (p =.006), with *post hoc* ST > INT (p =.005) and WC > INT (p =.036). There was also a significant between-group difference for training in a small group of partners of equal athletic ability (p =.000), with *post hoc* INT > NAT (p =.000) and INT > ST (p =.000).

Type of exercise

A significant between-group difference in weightlifting (strength) training with appropriate equipment (p =.002) existed, with *post hoc* ST > NAT (p =.024) and WC > NAT (p =.004). A significant intergroup difference for technical skills (p =.028) was also identified, wherein INT > ST (p =.032) at *post hoc*. A significant intergroup difference was seen in for cardiovascular training (p =.004), with *post hoc* WC > NAT (p =.020) and INT > NAT (p =.007). Significant group differences in bodyweight exercises with limited equipment (p =.002) and imitation or simulation of techniques of my sport (p =.043) were found, but *post hoc* revealed no significant differences.

Type of specific training

There was a significant intergroup difference for speed training (p =.008), with *post hoc* WC > INT (p =.009) and WC > NAT (p =.018). Also, a significant between-group difference for speed endurance (p =.004) was seen, with INT > NAT (p =.006) at *post hoc*. A significant intergroup difference was found for long endurance (p =.000), with *post hoc* WC > ST (p =.006), WC > NAT (p =.040), INT > ST (p =.000), and INT > NAT (p =.001). The interval/intermittent training was significantly different across groups (p =.007), with *post hoc* WC > NAT (p =.005), WC > ST (p =.008), and WC > INT (p =.040). While significant between-group differences were demonstrated in weightlifting (p =.048), plyometric training (p =.034), and technical skills (p =.027), no significant pairwise difference was identified.

Recovery strategy

In modes of physical recovery, there was a significant intergroup difference in not applicable (p =.000), with *post hoc* REC > NAT (p =.016) and INT > NAT (p =.000). The massage was also significant across groups (p =.001), with *post hoc* WC > REC (p =.030), WC > INT (p =.003), WC > ST (p =.002), and WC > NAT (p =.015). Significant between-group differences were also identified for sauna (p =.000), with *post hoc* WC > REC (p =.022), WC > ST (p =.000), WC > NAT (p =.000), and WC > INT (p =.013). The stretching was significantly different between groups (p =.006), with *post hoc* NAT > INT (p =.027).

Sport category

Training frequency

Training frequency of individual (n = 164; p =.000) and team sports athletes (n = 133; p =.000) decreased during lockdown. No group differences were observed between individual and team sports for training frequency before (p =.903) and during (p =.618) lockdowns.

Training duration

The training duration for individual (n = 155; p =.000) and team athletes (n = 142; p =.000) significantly reduced during lockdown. No group differences were observed between individual and team sports for training duration before (p =.307) and during (p =.384) lockdowns.

Training practices

Training prescription

Team sports athletes reported a significantly greater propensity for combination of own training program and from coach/trainer than individual sports athletes (p =.001).

Sex

Training frequency

The training frequency of females (n = 139; *p* =.000) and males (n = 161; *p* =.000) decreased during lockdown (Figure 3). No between-group differences were observed in training frequency before (*p* =.465), and during lockdown (*p* =.695).

Training duration

The training duration of females (*p* =.000) and males (*p* =.000) decreased during lockdown. Comparison between sexes demonstrated non-significant differences before (*p* =.079) and during (*p* =.241) lockdowns.

Training practices

Training purpose

Females demonstrated higher scores for improving muscle balance compared to males (*p* =.007).

Table 2 displays the practices of athletes during lockdown, in accordance with sport category and sex.

Table 2. Training practices of individual and team, and female and male athletes during lockdown (mean rank)

	Ind	Team	p	Female	Male	*p*
Q1. What are/were your general purpose(s) of training during lockdown?						
	n=220	n=200		n=192	*n=243*	
Q1.1. To maintain or develop general fitness and health	209.3	211.8	.716	220.7	215.9	.480
Q1.2. To maintain or develop skills/technique	201.1	220.9	.052	221.1	215.6	.600
Q1.3. To maintain or develop strength and power	204.5	217.1	.214	224.8	212.6	.239
Q1.4. To maintain or develop muscular endurance	207.0	214.4	.468	227.2	210.7	.115
Q1.5. To maintain or develop abdominal strength	206.6	214.8	.428	228.4	209.8	.076
Q1.6. To maintain or develop aerobic fitness	215.5	205.1	.306	221.6	215.2	.542
Q1.7. To maintain or develop general flexibility	208.5	212.8	.675	226.9	211.0	.129
Q1.8. To improve muscle balance	202.7	219.1	.099	233.3	205.9	.007
Q1.9. Weight management	208.4	212.9	.659	224.4	212.9	.268
Q2. Who is prescribing/prescribed the training program during lockdown?						
	n=219	n=202		n=192	n=242	
Q2.1 Own training program	216.5	205.0	.251	216.9	218.0	.912
Q2.2 Training program from my coach or trainer	206.9	215.5	.389	215.6	219.0	.744
Q2.3 Combination of own training and my coach/trainer	195.4	227.9	.001	220.9	214.8	.550
Q2.4 Found training material from an external source: online, TV, a friend, etc.	215.9	205.7	.240	214.3	220.0	.520
Q3. Do/did you train?						
	n=216	n=201		n=191	n=241	
Q3.1 Alone	209.0	207.9	.897	214.7	217.9	.717
Q3.2 In a small group of partners of equal athletic capacity	207.9	209.2	.890	220.6	213.3	.438
Q3.3 With family members or friends with little athletic capacity	213.1	203.5	.240	214.1	218.4	.601
Q4. What are the types of exercises that you have been doing consistently (at least twice a week) during lockdown?						
	n=215	n=198		n=191	n=238	
Q4.1. Body-weight based exercises with limited equipment	208.5	205.4	.739	217.3	212.8	.607
Q4.2. Strength training with appropriate equipment (dumbbells, weights, etc.)	205.4	208.7	.707	215.4	214.7	.935
Q4.3. Technical skills (sport specific skills training)	202.4	212.0	.343	218.0	212.6	.609
Q4.4. Imitation or simulation of the techniques of my sport	203.4	210.9	.361	220.7	210.5	.233

Q4.5. Cardiovascular training (running, cycling, rowing etc.), including HIIT	214.2	199.2	.122	207.8	220.8	.193
Q4.6. Plyometric training	209.3	204.5	.615	215.4	214.7	.943
Q5. What are the types of specific training you could do with the same intensity during lockdown (very similar to pre-lockdown)?						
	n=217	n=199		n=191	n=238	
Q5.1. Warm-up and stretching	204.3	213.1	.189	214.1	215.8	.801
Q5.2. Weightlifting (strength) training	211.0	205.8	.569	217.4	213.1	.637
Q5.3. Plyometric training (e.g., repeated jumping)	210.8	206.0	.627	220.1	210.9	.352
Q5.4. Technical skills (sport-specific)	205.4	211.9	.485	224.4	207.5	.081
Q5.5. Speed training	208.1	208.9	.926	215.5	214.6	.920
Q5.6. Speed endurance	209.8	207.1	.779	211.9	217.5	.571
Q5.7. Long endurance	207.8	209.3	.879	210.9	218.3	.467
Q5.8. Interval/intermittent training	209.8	207.1	.787	220.4	210.7	.332
Q5.9. Change of direction	211.7	205.0	.324	218.3	212.3	.387
Q6. What are the modes of physical recovery that you use consistently (at least once a week) during lockdown?						
	n=216	n=204		n=193	n=246	
Q6.1. Not applicable	216.7	204.0	.117	228.4	213.4	.067
Q6.2. Ice bath	212.1	208.9	.532	220.9	219.3	.758
Q6.3. Massage	206.1	215.1	.240	222.7	217.9	.543
Q6.4. Acupuncture	211.4	209.5	.169	219.0	220.8	.210
Q6.5. Sauna	212.1	208.8	.461	221.2	219.0	.676
Q6.6. Stretching	205.2	216.1	.229	220.0	220.0	.992
Q6.7. Meditation/relaxation	206.9	214.3	.457	223.6	217.2	.521
Q6.8. Foam rolling	212.3	208.6	.284	218.6	221.1	.452
Q6.9. Electronic pulse therapies	206.9	214.3	0.051	221.6	218.8	.457

Ind- individual; HIIT, high intensity interval training.

Discussion and conclusion

The current study investigated the training practices of athletes in the Philippines during the early COVID-19 lockdown. Compared to before-lockdown, decreased (lower) training frequency and duration was observed during lockdown in all classification athletes (except recreational), sport category, and sex. In the same period, differences within athlete classification were evident in various aspects of training practices (e.g., training purpose, prescription, type of exercise, and specific training) we investigated, favoring world class athletes. During lockdown, team sports athletes used a larger proportion of combination of self-training program and from coach/trainer compared to individual sports athletes. In another light, female athletes appeared to focus more on maintaining muscle balance training than males. These changes highlight the challenges and behavioral responses by Filipino athletes in maintaining their training practices during lockdown.

Lockdown-enforced changes in training practices by athlete classification

Differences in training practices were found between athlete classifications. During lockdown, reduced training frequency was evident in all classification athletes, except recreational athletes (i.e., lower pre-lockdown training). The training duration of all athlete classifications was also lower during lockdown. World class athletes demonstrated the highest training frequency and duration before and during lockdown, which may be linked to their established training routines in preparation for major competitions such as the Olympic Games (Pillay, et al., 2020). It is possible that some of the top Filipino athletes were relatively "unaffected" by the lockdown as compared to lower-classification athletes, as also evidently showed in our global study (Washif, et al., 2022a). In particular, we postulate that a small number of top Filipino athletes (e.g., weightlifters and boxers) were able to effectively organize their lockdown training (including performance supports) during the early COVID-19 lockdown. Around the world, it has been reported that higher classification athletes (e.g., WC) were able to access specialist training and recovery facilities (Washif, et al., 2021), via specific training arrangements including the "bubble" training camps, that enable "normal" training (Washif, et al., 2021) or even "bubble" competitions (Pedersen, et al., 2021). There have also been instances whereby higher-classification athletes acquired "expensive" training equipment for home-based training during lockdown, usually with the provisions of clubs or sponsors (Peña, et al., 2021). These opportunities and assistances from sports organizations might have contributed to reduced training challenges (i.e., amplifies training) during lockdown and likely resulted in positive "post-lockdown" sport performance.

While the comparisons of training practices did not reveal many differences, we found that many training aspects were in favor of world class athletes. For example, world class athletes were the least to use a self-designed training program, as they have received more assistance from their coaching staff. Additionally, a greater number of world class athletes included speed training and intermittent/interval training during their sport-specific activities, during lockdown, which provided a means to improve physiological capacities for competitions (McMaster, Gill, Cronin, & McGuigan, 2013; Pedersen, et al., 2021; Washif, et al., 2022a), and probably also mitigates the risk of injuries upon return to play (Zinner, et al., 2020). Furthermore, world class athletes implemented more recovery strategies, such as massage and sauna, possibly due to increased training demands. It is important that, during lockdown, athletes might have also experienced stress for various reasons (Washif, et al., 2022b). Therefore, optimizing recovery may take on greater importance for performance improvement (Doherty, Madigan, Nevill, Warrington, & Ellis, 2021). These findings agree with other studies reporting the ability of higher classification athletes to preserve their training and recovery during lockdown (Washif, et al., 2021, 2022a). Still, there are discrepancies in training practices, which magnify the need to aid athletes, irrespective of their classifications, to continue training while in lockdown. This would allow athletes to safely prepare for competitions or return to play, while also considering the "welfare" of the athletes who may need support and assistance.

Lockdown-enforced changes in training practices according to sport category

Both individual and team sports athletes displayed reduced training frequency and duration, during lockdown. Such reductions may reflect limited or no access to training facilities, leading to decreased tactical/technical training and other physical training interventions (Haddad, Abbes, Mujika, & Chamari 2021; Pillay, et al., 2020). Even so, team sports athletes utilized the combination of own training program and from coach/trainer to a greater extent than individual athletes. Such discrepancy was not influential in discriminating the physical exercises and sport-specific training carried out by both groups during lockdown. In this study, while both groups exhibited similar training frequency and duration before and during lockdown, information in regard to utility of equipment/facility is unknown. Maintenance of sport-specific training practices was reported to be easier in individual and less equipment-dependent sports (e.g., endurance), compared with more interactive or technically demanding sports (e.g., team; field sports), which were more dramatically impacted during lockdown (Washif, et al., 2022c). Including other factors related to equipment/facility usage of individual and team athletes during lockdown in future studies may help elucidate other valuable information in training practices under pandemic-enforced confinement. Generally, the lockdown affected both individual and team athletes comparably.

Lockdown-enforced changes in training practices according to sex

Males and females demonstrated reduced training frequency and duration in the Philippines. These findings somehow support the global trend during COVID-19 lockdown (Washif, et al., 2022c). In regard to purpose of training, females demonstrated a greater tendency for maintenance of muscle balance as a training priority than males. This result was not observed in a global study (Washif, et al., 2022c) that found more female athletes prioritizing fitness/health maintenance, abdominal strength, and flexibility. These data indicate an influence of country-specific related to training priority when considering sex difference. The training focus of females on muscle balance may be linked to inferior postural control of females as compared to males (Heo, Jeon, Jeon, Cho, & Eom, 2020), which warrants further investigation. Overall, lockdown in the Philippines affected the training practices of male and female athletes similarly.

Limitations

While this study provides novel information for facilitating the levels of support for athlete training during lockdown-like situations, limitations are acknowledged. First, training contents or interventions the athletes performed during lockdown were not documented. Next, questions related to mental health and sleeping habits (Pillay, et al., 2020; Romdhani, et al., 2022b) may offer additional perspectives regarding the impact of COVID-19 lockdown on athletes in the Philippines (Leyton-Román, de la Vega, & Jiménez-Castuera, 2020). Furthermore, Ramadan intermittent fasting, which has taken place during the lockdown, could have influenced the lockdown effects among Muslim athletes, which we addressed elsewhere (Washif, et al., 2022d). Additionally, the data covered the early COVID-19 pandemic, depicting relatively short-term practices and effects. Lastly, despite our efforts to largely spread the survey across the Philippines and a relatively high number of athletes reached, our channels to reach the athletes did not ensure that the sample of athletes was representative of the athletes in the whole country. Results should therefore be interpreted with caution.

In conclusion, the current study highlights differences in training practices of athletes in the Philippines, in terms of athlete classification, sport category, and sex. During lockdown, reductions in training frequency and duration were observed across athlete classification, from state to world class athletes. Decreases (pre- to during-lockdown) in training frequency and duration were not affected (i.e., similar) by sport category and sex. World class athletes preserved their training practices (e.g., specific training, recovery strategies) during lockdown, to a greater extent than lower-classification athletes. Overall, little to no difference in training practices were observed in the comparisons between team and individual sports as well as male and female athletes. Information in the current study may assist policy makers in the Philippines in supporting athletes in managing of training during lockdown (or lockdown-like situations), establishing return to play guidelines, and/or adjusting of competition schedules.

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THE ETIOLOGY OF NEUROMUSCULAR FATIGUE INDUCED BY THE 5-M SHUTTLE RUN TEST IN ADULT SOCCER PLAYERS

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Abstract:

This study investigated the etiology of neuromuscular fatigue induced by a 5-m shuttle run test (5MSRT) in soccer players. Nineteen adult male amateur soccer players (age: 20.0 ± 2.9 years) participated in the present study. Before and after the 5MSRT, they were instructed to complete a maximal voluntary isometric contraction (MVIC) of the knee extensors (KE) during and after which two electrical stimulations were applied at the femoral nerve. Voluntary activation level (VAL), surface electromyography recordings (sEMG), electrophysiological (M_{max}) and potentiated resting twitch (Ptw) responses of the KE were compared between pre- and post-5MSRT. Rating of perception exertion (RPE) was also assessed before, during the test immediately following each sprint repetition and after the test. The distance covered during each sprint significantly decreased as the number of trials performed increased ($p<.05$). The RPE reported following each sprint significantly increased throughout the test. In addition, MVIC (-9%), sEMG (-23%), VAL (-15%), Ptw (-26%) and M_{max} (~22%) of the KE were lowered from pre-to-post 5MSRT ($.001 < p < .01$). The 5MSRT induced a decrease of repeated-sprint running performance and MVIC of the KE. These decrements were accompanied by lowered VAL, sEMG, Ptw and M_{max} values of the KE reflecting the involvement of both the central and peripheral origins in the 5MSRT-induced fatigue. Given the important muscle stress induced by 5MSRT, this strenuous test must be applied with caution, after an inevitable familiarization phase, and not during the competition period to avoid the risk of serious injury.

Key words: *knee extensors, electrical stimulation, electromyography, repeated-sprint ability, perceived exertion*

Introduction

The ability to reproduce maximal efforts with incomplete recovery is a good index of performance in intermittent sports such as soccer (Bradley, et al., 2009; Bradley, Mascio, Peart, Olsen, & Sheldon, 2010; Rampinini, et al., 2007, 2009). Due to the unpredictable nature of the actions in soccer, a myriad of repeated-sprint tests has been designed and used to evaluate the performance of soccer players. Repeated-sprint tests lasting less than 10s with a recovery period not exceeding 60s were the most commonly used during the last two decades (Aziz, Mukherjee, Chia, & The, 2008; Impellizzeri, et al., 2008; Rampinini, et al., 2007, 2009). During these brief repeated-sprint tests, it has been shown that athletes were unable to maintain the same performance level from the beginning to the end of the exercise (Goodall, Charlton, Howatson, & Thomas, 2015; Townsend, Brocherie, Millet, & Girard, 2021). For example, impairment in maximal power output during cycling exercises (Girard, Bishop, & Racinais, 2013; Girard, Mendez-Villanueva, & Bishop, 2011; Kerhervé, Stewart, McLellan, & Lovell, 2020; Tomazin, Morin, & Millet, 2017), an increase in time to cover a given distance (Goodall, et al., 2015; Perrey, Racinais, Saimouaa, & Girard, 2010) or a decrease in distance for a given duration (Townsend, et al., 2021) during running were reported. This performance decrement is commonly related to a combination of multiple factors leading to the development of neuromuscular fatigue (Collins, Pearcey, Buckle, Power, & Button, 2018; Girard, et al., 2011). Hence, maximal voluntary isometric contraction (MVIC) was lowered up to 15% (Girard, et al., 2011, 2013; Tomazin, et al., 2017) following repeated-sprint cycling and between 8 to 20% following repeated-sprint running (Goodall, et al., 2015; Perrey, et al., 2010; Tomazin, et al., 2017; Townsend, et al., 2021). However, the etiology of such impairment differs between studies. While some attributed MVIC decrement mainly to peripheral mechanisms (Girard, et al., 2013; Perrey, et al., 2010), others revealed the involvement of both peripheral and central origins (Goodall, et al., 2015; Tomazin, et al., 2017; Townsend, et al., 2021). Many factors could explain these contradictory results such as the methods used to investigate neuromuscular function, the type of locomotion (Tomazin, et al., 2017; Kerhervé, et al., 2020), the assessed muscular group, the task performed (Collins, et al., 2018; Girard, et al., 2011) or the exercise characteristics (e.g., number of sets and repetitions, duration, distance, recovery period, etc.).

Physical demands in soccer are continually increasing with the evolution of the game. The intense efforts of modern soccer are increasingly longer, more frequent with shorter recovery phases and incorporating more uncertainties into the game requiring more acceleration, blocking, deceleration, and restart actions (Barnes, Archer, Hogg, Bush, & Bradley, 2014; Harper, Carling, & Kiely, 2019). This would lead to higher metabolic demands along with a higher solicitation of eccentric contractions possibly leading to increased peripheral fatigue (Byrne, Twist, & Eston, 2004; Martin, Millet, Lattier, & Perrod, 2005). Indeed, neuromuscular fatigue in response to 90-min and 120-min simulated soccer matches was assessed and demonstrated a greater magnitude (Goodall, et al., 2017; Thomas, Dent, Howatson, & Goodall, 2017) than fatigue reported following the majority of brief repeated-sprint running designs (Kerhervé, et al., 2020; Perrey, et al., 2010; Tomazin, et al., 2017; Townsend, et al., 2021). Thus, the above-mentioned brief repeated-sprint tests might not be representative of real performance in modern soccer. Alternately, one of the least frequently used repeated-sprint tests is the 5-m shuttle run test (5MSRT) which is designed to determine players' match-related-fitness (Pendleton, 1997) in several team sports characterized by intermittent, short duration and high intensity bouts of activity (Boddington, Lambert, Gibson, & Noakes, 2001; Pendleton, 1997). This test, adopted by the Welsh Rugby Union and modified by the Sports Science Institute of South Africa (Boddington, et al., 2001), consists of six 30-second repeated sprints carried out in a shuttle way over distances increased by 5-m each shuttle, interspersed by 35 s of passive rest periods. Some of the interesting features of the 5MSRT that make it quite different from more popular brief repeated-sprint tests are its long-lasting duration per sprint with a near 1:1 exercise/recovery (E/R) ratio and its shuttle activity requiring repeated accelerations, decelerations and changes of direction. Although these characteristics of the 5MSRT makes it more specific to major team sports including soccer, the fatigue induced by such a test has been overlooked. Yet, understanding the neuromuscular etiology associated with the 5MSRT could be very useful to adequately guide the implementation of training aimed at both reducing fatigability and increasing performance during the 5MSRT and consequently physical performance in soccer competition. Thereafter, the study of the neurophysiological mechanisms underlying reduced fatigability / improved performance following a specific training program becomes therefore feasible and its transfer in the physical activity performance could also be investigated. Although perception of fatigue increased after the 5MSRT (Boukhris, et al., 2020), to the best of our knowledge, no previous study investigated the neuromuscular fatigue induced by a 5MSRT.

Hence, the purposes of the present study were: i) to assess the performance of adult soccer players during a 5MSRT and ii) to investigate the etiology of neuromuscular fatigue induced by the 5MSRT. Due to the all-out sprint duration, overall distance covered and shuttle nature of the 5MSRT, we hypothesized that both central and peripheral factors may account for the performance decrement during the 5MSRT.

Materials and methods

Participants

Nineteen amateur adult male soccer players (age: 20.0 ± 2.9 years, body height: 172.8 ± 6.5 cm, body mass: 67.4 ± 6.4 kg) competing in the third division of the Tunisian championship volunteered to contribute to this study. Participants trained two days a week for an average of 2h per training session plus the competition. They were informed about the possible risks and discomforts associated with the experimental procedures and gave their written informed consent. The study was conducted according to the Declaration of Helsinki and the protocol was fully approved by the Institute Research Ethics Committee. The inclusion criteria were the following: no smoking, no alcohol consumption, no injury for at least six months before participation in the study, tolerance to the study protocol and training routine for at least one hour during two days per week.

Experimental design

One week after two prior visits aiming at getting familiar with the experimental procedures (i.e., neuromuscular measures and 5MSRT), participants were enrolled in the experimental session. After a warm-up, an assessment of neuromuscular function was carried out before and following the 5MSRT. During the 5MSRT, perceived exertion was also rated immediately following each of the all-out 30-second repeated sprints (Figure 1).

The warm-up consisted of a 5-min jog at a self-selected comfortable pace followed by a 5-min series of dynamic stretching (e.g., hip flexion/extension, hip abduction/adduction, butt kicks) and five progressive sprints over different distances with and without change of direction. The assessment of neuromuscular function included three and one 3-s maximal voluntary isometric contractions (MVIC) of the knee extensor muscles (KE) performed before (PRE) and immediately after (POST) the 5MSRT, respectively. Superimposed (over the 3-s MVICs) and potentiated (3s after the contraction) twitches were delivered by electrical nerve stimulation. The highest MVIC value among the three trials at PRE and the single trial at POST was taken into account for subsequent analysis. To exclude the confounding effect of fatigue induced by repeated muscular contractions, the MVICs performed at PRE were separated by a 2-minute recovery period. During each MVIC, surface electromyography (sEMG) activity of KE muscles was measured.

MVIC. MVIC was measured using an isometric dynamometer (Good Strength, Metitur, Finland) equipped with a cuff connected to a strain gauge. This cuff was attached to the anterior aspect of the shank ≈2 cm above the lateral malleolus using a Velcro strap. During testing, the participants were seated with the hip and knee angles set at 90° (knee full extension = 0°). Safety belts were strapped across the participants' chest, thighs and hips to avoid lateral, vertical and frontal displacements. All measurements were taken from the right lower limb. Participants were instructed to exert maximal voluntary knee extension against the lever arm. Participants were strongly encouraged while performing the MVIC.

Surface electromyography recordings. The sEMG signals of the *vastus lateralis* (VL), *vastus medialis* (VM) and *rectus femoris* (RF) muscles were recorded using bipolar silver chloride surface electrodes (Blue Sensor N-00-S, Ambu, Denmark) during MVIC and nerve stimulations. The electrodes were taped lengthwise on the skin over the muscle belly following SENIAM recommendations, with an inter-electrode distance of 20 mm. A reference electrode was attached to the patella of the same leg. Low impedance (Z<5kΩ) at the skin-electrode surface was obtained by shaving, abrading the skin with thin sandpaper and cleaning with alcohol. sEMG signals were amplified (Octal Bio Amp ML 138, ADInstruments, Australia) with a bandwidth frequency ranging from 10 Hz to 1 kHz (common mode rejection ratio > 96 dB, gain = 1000) and simultaneously digitized together with the force signals using an acquisition card (Powerlab 16SP, AD Instruments, Australia) and Labchart 7.0 software (AD Instruments, Australia). The sampling frequency was 2 kHz. The root mean square (RMS) values of the VL, VM and RF sEMG recordings were calculated over a 0.5-second period of the MVIC plateau, just before the superimposed stimulation and averaged. The RMS values were normalized to the respective peak-to-peak M-wave amplitudes (M_{max}) of each muscle.

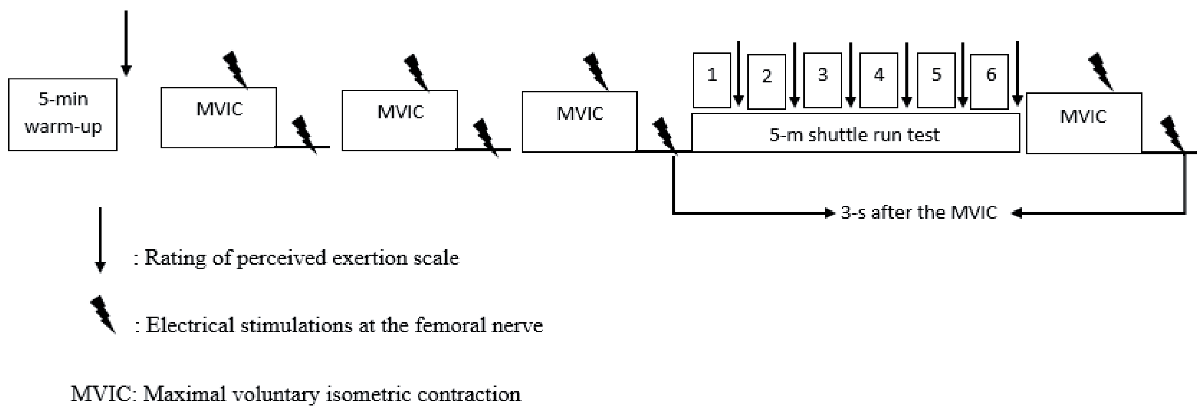

Figure 1. Schematic representation of the experimental design.

Electrical nerve stimulation. The femoral nerve was stimulated percutaneously with a single square-wave stimulus of 1-ms duration with maximal voltage of 400 V delivered by a constant current stimulator (Digitimer DS7A, Hertfordshire, United Kingdom). The cathode (self-adhesive electrode: Ag–AgCl, 10 mm diameter) was positioned in the femoral triangle and pressed firmly into place by an experimenter. The anode, a 10 × 5 cm self-adhesive stimulation electrode (Medicompex SA, Ecublens, Switzerland), was placed midway between the greater trochanter and the iliac crest. Optimal stimulation intensity was determined from M-wave and twitch force measurements before the testing session. Briefly, the stimulation intensity was increased by 5 mA until there was no further increase in either potentiated resting twitch (Ptw) or in concomitant VL, VM and RF M-wave peak-to-peak amplitudes. During the subsequent testing procedures, the intensity was set at 150% of the optimal stimulation intensity to overcome the potential confounding effect of axonal hyperpolarization.

The contractile properties of the KE muscles were evaluated by analyzing the Ptw and the M_{max} peak-to-peak amplitude of VL, VM and RF muscles. VAL was computed using the following corrected formula (Strojnik & Komi, 1998), as the superimposed stimulus was not always delivered over the MVIC plateau:

VAL (%) = [1 – superimposed twitch × (superimposed twitch / MVIC) / potentiated resting twitch] × 100.

5-m shuttle run test (5MSRT)

The 5MSRT consisted of six all-out maximal sprints separated by 35-s of recovery. Each sprint lasted 30 s and consisted of a maximal shuttle run over increasing distances of 5 m, 10 m, 15 m, 20 m, etc. (Boddington, et al., 2001). Participants started the test in line with the first beacon and began sprint shuttling at auditory signal over 5m, 10m, 15m, etc., until finishing the 30s duration. The distance covered (measured by a precision of 5m) during each all-out sprint was registered and the following indices were recorded:

- Higher distance (HD) (m): the greatest distance covered during a 30-s shuttle
- Total distance (TD) (m): the total distance covered over the six 30-s shuttles
- Fatigue index (FI): calculates the drop-off in performance from the best to the worst performance
  FI (%) = [(shuttle(1) 1 + shuttle 2) – (shuttle 5 + shuttle 6) / (shuttle 1 + shuttle 2)] × 100
  (1) Shuttle consists of the covered distance for the corresponding trial (from the first to the sixth trial)
- The percentage of decrement (PD):
  PD (%) = [(HD × number of sprints) – TD / (HD × number of sprints)] × 100

Rating of perceived exertion scale (RPE)

Participants were asked to rate their overall RPE, that is the combination of chest RPE (i.e., breathlessness) and leg RPE (i.e., local perception of effort) before (i.e., after the warm-up), during (i.e., after each all-out sprint) and immediately after the 5MSRT. The validated French version of the RPE scale was used (Haddad, et al., 2013). The RPE is an 11-points scale ranging from “0 (nothing at all)” to “10 (maximal)”. The RPE score increased for higher ratings of perceived exertion.

Statistical analysis

Statistical tests were performed using the STATISTICA software (StatSoft, France; version 10) and data are presented as means ± standard deviation (SD). The Shapiro-Wilk test confirmed that the data were normally disturbed. The six calculated distances and the assessed RPE during the 5MSRT were analyzed using repeated measures ANOVA (6 all-out sprints). MVIC, RPE, RMS, M_{max}, RMS/M_{max}, Ptw and VAL were analyzed by repeated measures ANOVA to investigate differences between before and after the 5MSRT. When appropriate, significant differences between means were tested using the Bonferroni *post-hoc* test. Effect sizes were calculated as partial eta-squared (η^2_p) to estimate the meaningfulness of significant findings. η^2_p values of 0.01, 0.06 and 0.13 represent small, moderate, and large effect sizes, respectively. A Pearson correlation coefficient was used to assess the relation between the performance variables (HD, TD, FI and PD), RPE and delta of neuromuscular parameters (MVIC, Ptw, VAL, M_{max}, RMS and RMS/M_{max}). Significance was accepted for all analyses at the level of $p \leq .05$ and was reported as $p<.05$, $p<.01$ and $p<.001$.

Results

The 5-m shuttle run test (5MSRT) performance and RPE

The values measured for the HD, TD, FI and PD were 119.8 ± 7.7m, 659.8 ± 43.9m, 12.3 ± 4.9% and 8.2 ± 4.1%, respectively, and the distance covered during each all-out sprint is presented in Figure 2. During the 5MSRT performance, a significant effect of the sprints was observed for HD ($F_{(5,90)}$ = 63.7, $p<.001$, η^2_p = 0.78), as well as for RPE ($F_{(5,90)}$ = 289.8, $p<.001$, η^2_p = 0.94). The HD of the 1st sprint was significantly higher than the five other sprints ($p<.001$). Thereafter, the covered distance decreased progressively over sprints (.001 < p <

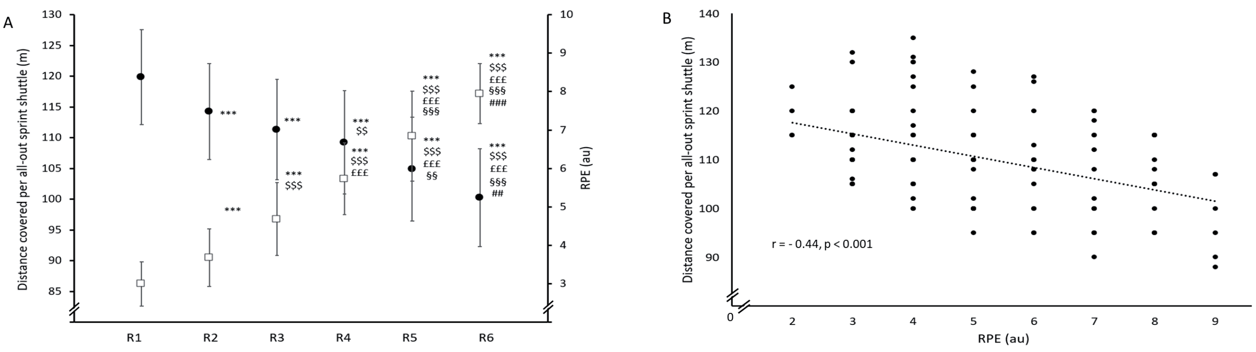

Figure 2.
*(A) Evolution of the covered distance and the rating of perceived exertion (RPE) during each sprint (from S1 to S6) of the 5-m shuttle run test (mean ± SD). *** (p<.001): significantly different from the 1st sprint; $$ (p<.01) and $$$ (p<.001): significantly different from the 2nd sprint; £££ (p<.001): significantly different from the 3rd sprint; §§ (p<.01) and §§§ (p<.001): significantly different from the 4th sprint; ## (p<.01) and ### (p<.001): significantly different from the 5th sprint.*
(B) Correlation between the covered distance by each sprint and the averaged rating of perceived exertion (RPE).

Table 1. Neuromuscular measurement and electromyographic responses recorded before (PRE) and after (POST) the 5-m shuttle run test (mean ± SD)

	PRE	POST	DELTA (%)
MVIC (N)	688.6 ± 137.4	628.3 ± 152.3***	-9.3 ± 9.2
Ptw (N)	5.4 ± 1.7	4.3 ± 1.5***	-26.1 ± 13.3
VAL (%)	5.4 ± 1.7	4.3 ± 1.5***	-14.9 ± 9.3
M_{max} (mV)			
vastus lateralis	5.4 ± 1.7	4.3 ± 1.5***	-21.2 ± 14.4
vastus medialis	3.4 ± 1.4	2.7 ± 1.5***	-22.0 ± 18.0
rectus femoris	3.7 ± 1.6	2.9 ± 1.5***	-21.7 ± 17.8
RMS (mV)			
vastus lateralis	0.38 ± 0.09	0.33 ± 0.10***	-13.5 ± 11.4
vastus medialis	0.37 ± 0.11	0.30 ± 0.09***	-18.0 ± 8.9
rectus femoris	0.47 ± 0.21	0.32 ± 0.08**	-27.2 ± 16.6
RMS/M_{max} (mV)			
vastus lateralis	0.08 ± 0.03	0.09 ± 0.06	14.5 ± 31.4
vastus medialis	0.12 ± 0.05	0.14 ± 0.07	12.7 ± 38.6
rectus femoris	0.17 ± 0.14	0.15 ± 0.11	-0.9 ± 37.8

Note. MVIC: Maximal voluntary isometric contraction; Ptw: potentiated resting twitch; VAL: voluntary activation level; M_{max}: peak-to-peak M-wave amplitude; RMS: Root mean square. ** (p<.001) and *** (p<.001) indicate a significant difference between PRE and POST values.

.01; Figure 2A). In parallel, RPE was significantly increasing progressively from sprint one to the following throughout the test (p<.001; Figure 2A). A significant inverse correlation was found between HD covered and RPE values of each all-out sprint (r = -0.44, p<.001; Figure 2B).

Neuromuscular responses to the 5MSRT

MVIC ($F_{(1,18)}$ = 26.3, p<.001, η^2_p = 0.59, -9.3 ± 9.2%), Ptw ($F_{(1,18)}$ = 46.4, p<.001, η^2_p = 0.72, -26.1 ± 13.3%) and M_{max} values of each KE muscle (VL, $F_{(1,18)}$ = 40.7, p<.001, η^2_p = 0.64, -21.2 ± 14.4%; VM, $F_{(1,18)}$ = 25.3, p<.001, η^2_p = 0.58, -22.0 ± 18.0%; RF, $F_{(1,18)}$ = 26.0, p<.001, η^2_p = 0.60, -21.7 ± 17.8%) significantly decreased after the 5MSRT (Table 1).

VAL ($F_{(1,18)}$ = 57.8, p<.001, η^2_p = 0.76, -14.9 ± 9.3%), RMS values of each KE muscle (VL, $F_{(1,18)}$ = 27.1, p<.001, η^2_p = 0.60, -13.5 ± 11.4%; VM, $F_{(1,18)}$ = 47.5, p<.001, η^2_p = 0.73, -18.0 ± 8.9%; RF, $F_{(1,18)}$ = 14.2, p<.01, η^2_p = 0.45, -27.2 ± 16.6%) were significantly impaired after the 5MSRT, whereas no significant change was noted for the RMS/M_{max} values of each KE muscle (p>.05; Table 1). No significant correlation was found between any of the performance variables and neuromuscular parameters.

Discussion and conclusions

The aim of the present study was twofold: (1) to assess the evolution of the performance during the 5MSRT in adult soccer players and (2) to quantify the degree of peripheral and central factors contributing to neuromuscular fatigue elicited by this all-out repeated-sprint test. The main findings were (*i*) the progressive performance decrement throughout the 5MSRT was accompanied by force production impairment at the termination of the test and (*ii*) both peripheral and central factors accounted for the neuromuscular fatigue observed.

HD and TD covered in the present investigation are in agreement with previous studies (Belkhir, Rekik, Chtourou, & Souissi, 2019; Boddington, et al., 2001; Boukhris, et al., 2020) although the characteristics of the participants differed (i.e., physically active male, amateur male team sports players, female field hockey players, male soccer players). More specifically, we found a progressive performance decrease induced by the 5MSRT when comparing the covered distances throughout the test (i.e., -5% between the first and the second sprint reaching -17% in the last all-out sprint in comparison with the first one, leading to a PD of ~8%). The fatigue index (FI) in our participants reached 12.3%, which was slightly greater than a previous observation in male soccer players (~8%; Belkhir, et al. 2019). Finally, the 5MSRT-performance decrements were accompanied by a progressive increase of RPE indicating the occurrence of greater effort perception throughout the test (Boddington, et al., 2001; Kerhervé, et al., 2020; Townsend, et al., 2021). Originally, a correlation was found between HD decreases and RPE increases (Figure 2B). Taken together, these observations suggest the development of fatigue throughout the test, but no study was previously conducted to investigate neuromuscular fatigue and the associated underpinning mechanisms induced by a 5MSRT.

After the 5MSRT, a 9% decrease of KE MVIC was observed confirming that fatigue occurred. Comparable KE MVIC impairment was reported after short duration (i.e., < 6s) repeated sprint running (Goodall, et al., 2015; Tomazin, et al., 2017; Townsend, et al., 2021). Concomitantly to the decrease of the MVIC, both the resting potentiated twitch (Ptw) and the M_{max} values of the KE muscles were reduced. M_{max} decreases indicate a neuromuscular transmission failure, arising probably from ionic disturbance of the Na^+-K^+-ATPase activity resulting in extracellular K^+ accumulation (Clausen, Nielsen, Harrison, Flatman, & Overgaard, 1998). Such alterations of sarcolemma excitability were highlighted after maximal dynamic contractions of the knee extensors muscles leading to fatigue (Fraser, et al., 2002). After repeated sprint running protocols, inconsistent observations were reported in the literature. To date, M_{max} of the KE muscles was unaffected after short sprint duration (i.e., < 7s; Goodall, et al., 2015; Tomazin, et al., 2017; Townsend, et al., 2021), whereas M_{max} of the *soleus* muscle was impaired for similar short sprint duration (Perrey, et al., 2010). Although many factors (i.e., differences in muscle tested, time spent until assessment, recovery time, fitness level of the participants, etc.) could account for these controversial results, the specificity of the 5MSRT (i.e., shuttle form including acceleration, deceleration and change of direction) may contribute to the M_{max} impairment of the KE muscle in our participants. Future studies are needed to determine the contribution of influencing factors in muscle excitability impairment after all-out repeated sprint running protocols.

An alteration of sarcolemma excitability is often associated with diminished Ca^{2+} release and/or decreased myofibrillar Ca^{2+} sensitivity leading to reduced actin-myosin bridge formation and consequently Ptw impairment (Allen, Lamb, & Westerblad, 2008). Other factors, like accumulations of Pi and H^+ associated with elevated blood lactate concentration, generally observed after repeated-sprint running protocols (Goodall, et al., 2015; Perrey, et al., 2010), may have impeded the excitation-contraction coupling through inhibition of Ca^{2+} handling within the KE muscles. In addition, a recent study showed that immediately after a 5MSRT, important perception of muscle soreness and increased biomarkers of muscle damage and inflammation were present in amateur male sports players (Boukhris, et al. 2020). These observations could be ascribed to the stretch-shortening cycle (SSC) actions and the eccentric contractions due to repeated accelerations, decelerations and changes of direction associated with the shuttle form of the 5MSRT. Indeed, Ptw impairments of the KE muscles are commonly reported after intense exercises involving either SSC (Strojnik & Komi, 2000) or eccentric contractions (Souron, Nosaka, & Jubeau, 2018). Hence, possible muscle damage may have led to changes in sarcoplasmic reticulum structure participating in the reduced Ca^{2+} release and uptake observed after intense exercise (Byrd, McCutcheon, Hodgson, & Gollnick, 1989). The 26% reduction of Ptw after our 5MSRT agrees with twitch impairments of the KE muscles observed in the literature after repeated sprint running (Goodall, et al., 2015; Townsend, et al., 2021) and 90min (23%) and 120min (23%) simulated soccer match (Goodall, et al., 2017), while muscle excitability remained unaffected in these studies. This further reinforced the important specificity of the shuttle form of the 5MSRT associated with the higher metabolic demand induced by the duration of each all-out sprint (i.e., 30s) compared to shorter (i.e., < 7s) sprint durations (Duffield, Dawson, & Goodman, 2004), leading to concomitant muscle excitability and excitation-contraction coupling impairments. Given the great peripheral fatigue and important muscle stress induced by 5MSRT, this strenuous test must be applied with caution, after an inevitable familiarization phase, and not during the competition period to avoid the risk of serious injury.

Central mechanisms also seem to play a determinant role in the KE MVIC reduction. Our findings demonstrated a -15% decrease of voluntary activation between PRE and POST measures. Interestingly, the VAL reduction in the present study was greater than voluntary activation alterations of the KE muscles reported in the literature (~6.5-9%) after repeated sprint running protocols (Goodall, et al., 2015; Tomazin, et al., 2017; Townsend, et al., 2021) but similar to those reported after 90-min (15%) and 120-min (18%) of simulated soccer match (Goodall, et al., 2017). While a single 200-m sprint of performance duration similar (i.e., ~31s) to that of the 5MSRT did not impair voluntary activation (Tomazin, Morin, Strojnik, Podpecan, & Millet, 2012), two short duration sprints (i.e., < 4.4s) led to a decrement in voluntary activation by ~6.5% (Goodall, et al., 2015). A review of the literature indicated that increasing the number of short duration (i.e., < 6s) sprints led to more pronounced impaired voluntary activation by ~7% after eight (Townsend, et al., 2021) or ten (Tomazin, et al., 2017) sprints and up to ~9% after twelve (Goodall, et al., 2015) or twenty sprints (Tomazin, et al., 2017). With six repetitions, the longer duration per all-out sprint might therefore explain the greater voluntary activation impairment observed after our 5MSRT. In fact, the reduction of voluntary activation by up to 30% was observed after a maximal all-out cycling sprint lasting 30 s (Fernandez-del-Olmo, et al., 2013). Although the tested locomotion was different here, one can argue that central fatigue may have occurred after the first all-out 30-s sprint of the 5MSRT. Further studies are needed to ascertain this suggestion since we did not assess the time course of neuromuscular fatigue after each sprint.

Central fatigue was also investigated through the measure of RMS and RMS/M_{max} values of the KE muscles. Like previous repeated sprint protocols (Hader, Mendez-Villanueva, Ahmaidi, Williams, & Buchheit, 2014), KE muscles' RMS values were significantly lowered after the 5MSRT, but RMS/M_{max} values remained unaffected by the exercise. To date, only two studies have reported impaired RMS/M_{max} values of the *vastus lateralis* (Tomazin, et al., 2017) or *rectus femoris* (Townsend, et al., 2021) muscle after repeated sprints of short duration. Heterogeneity of the experimental designs might contribute to the inconsistencies observed but caution is required when interpreting RMS/M_{max} values due to its lower reproducibility than voluntary activation measures during fatigue (Place, Maffiuletti, Martin, & Lepers, 2007) and amplitude cancellation phenomena in sEMG signals. Indeed, the concomitant decrease of both RMS and M_{max} values could explain, at least in part, the unchanged RMS/M_{max} observed in our study. This could explain why the evolution of RMS/M_{max} values and VAL differed after our 5MSRT.

Notwithstanding these concerns, the altered VAL after our 5MSRT indicates that the MVIC decrease may in part be due to neural drive failure leading to inhibitory effects onto motoneurons. As discussed above, repeated sprint running provokes metabolic by-product accumulation (Goodall, et al., 2015; Perrey, et al., 2010), which is involved in the enhanced inhibitory feedback from group III and IV afferences (Pollak, et al., 2014) that could occur at both the spinal and supraspinal levels. Although motor nerve stimulation does not allow to differentiate between the spinal and supraspinal inhibition, supraspinal fatigue was recently evidenced through the use of transcranial magnetic stimulation after a 30-s maximal all-out cycling sprint (Fernandez-del-Olmo, et al., 2013), repeated sprint running (Goodall, et al., 2015) and 90min and 120min simulated soccer match (Goodall, et al., 2017). Therefore, it is likely that supraspinal factors are involved in the VAL impairment observed here.

As recently observed after a 5MSRT (Boukhris, et al. 2020), important muscle soreness and inflammation suggesting muscle damage may also participate in the elevated inhibitory influence of group III and IV afferents (Hoheisel, Unger, & Mense, 2005). Both the duration of each maximal all-out sprint and the shuttle form of the 5MSRT requiring accelerations, decelerations and changes of direction could account for this possible muscle damage. Albeit muscle soreness was not investigated here, a progressive increase in perceived exertion was found. In addition, we have highlighted that perceived exertion increases were correlated to performance decrements. Perception of muscle soreness, or pain (Pollak, et al., 2014) and perception of exertion (de Morree, Klein, & Marcora, 2012) have different neurophysiology constructs; nonetheless, both may have contributed to unpleasant sensations impairing the 5MSRT performance.

From a practical point of view, this information on the neuromuscular fatigue etiology related to the 5MSRT as a specific repeated-sprint test characterized by its long duration with a near 1:1 E/R ratio and its shuttle form could better orientate the coaches and/or physical trainers in their evaluation and training choice. The similar magnitude of peripheral and central fatigue development after 5MSRT and simulated soccer matches could reflect a better representativeness of real efforts and fatigue induced in modern soccer by this test in comparison with the brief repeated-sprint protocols classically used. Further investigations should thus be carried out to evaluate the relationship between fatigability and performance exerted during 5MSRT and a simulated soccer match. Then, adequate training protocols could be implemented aimed at reducing both central and peripheral fatigability and therefore improving the performance during the 5MSRT and consequently in competition.

One important limitation of the present study was the use of a single stimulus rather than two stimuli to investigate neuromuscular function. The use of a single stimulus may have underestimated the voluntary activation level (Place, et al., 2007; Shield & Zhou, 2004;). However, Goodall et al. (2015) found similar central and peripheral impairments after short duration repeated-sprint running with the use of a single twitch. Nevertheless, future investigations of neuromuscular function after fatigue-induced 5MSRT should use doublet stimuli to confirm our observations. Second, the distinction between the contribution of supraspinal and spinal aspects of the amount of fatigue and 5MSRT-induced performance impairment is limited with the voluntary activation measure. Future transcranial magnetic stimulation and/or reflex studies could assess this issue more precisely. Third, we cannot exclude a possible alteration of antagonist muscles' coactivation to performance decrements with fatigue, especially when changes of direction are part of the exercise (Hader, et al., 2014). Finally, the initial level of the tested athletes may have influenced the obtained results. Thus, their generalization to other populations with different physical levels should be done with caution.

The present study originally studied the neuromuscular fatigue and underlying mechanisms following the 5MSRT. Although no correlation was observed, there were similar performance (i.e., 8%) and force production (i.e., 9%) decreases after the 5MSRT. We originally demonstrated that the 5MSRT-performance impairment was associated with neuromuscular fatigue involving both peripheral and central factors. Such findings have practical implications for scientists, coaches and/or physical trainers for training and testing purposes. Adequate training protocols such as endurance training (Zghal, et al., 2015), concurrent strength and endurance training (Eklund, et al., 2014) or high-intensity interval training (Lee, Hsu, & Cheng, 2017; Milioni, et al., 2019), which have already been shown to be effective in limiting the development of central and peripheral fatigue, could be implemented to reduce the 5MSRT-induced neuromuscular fatigue and to improve the physical performance of athletes during competitions.

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NEUROMUSCULAR AND FUNCTIONAL RESPONSES TO CONCENTRIC AND ECCENTRIC STRENGTH TRAINING IN OLDER ADULTS: A SYSTEMATIC REVIEW

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Review
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Abstract:

The type of muscle action is important when designing exercise interventions for older individuals and may result in different effects. In this study we performed a systematic review of controlled trials comparing the effects of concentric and eccentric resistance training, performed on isokinetic dynamometers, on lower extremity muscular and functional performance in older adults (CDR42017075316). Six databases (Pubmed, CINAHL, SPORTDiscus, PEDro, Cochrane Central, and Embase) were searched. Outcomes of interest concerned neuromuscular and functional performance. Trials should consider 65 years or older individuals participating in concentric and/or eccentric training on isokinetic dynamometers, at least twice a week, during at least four weeks. Results should be compared to a control group or between different contraction types. A qualitative analysis of data was done. Quality assessment considered the Cochrane Risk of Bias Tool. The initial search returned 10376 studies and four trials were considered for inclusion. Three trials compared the effects of concentric training with the ones of control groups, and one compared the effects of concentric with the ones of eccentric training. All trials focused on knee extensor and flexor muscles, and one also focused on ankle dorsiflexors and plantarflexors. Training programs included three sessions/week lasting 8-12 weeks. Concentric training improved strength, power, and muscle antagonist coactivation compared to the control. Concentric and eccentric training improved knee isometric, concentric and eccentric strength and scores on self-paced step test, with no effect on gait speed. They did not consider muscle structural parameters. The findings of beneficial effects of isokinetic concentric and eccentric resistance training on muscle strength and power in older adults were consistent. However, there is a lack of trials addressing the effects of isokinetic strength training on muscle structure and functionality.

Key words: *aged, aging, resistance training, lower extremity, physical examination*

Introduction

Life expectancy at 60 years of age is gradually increasing, changing from 18.8 years to 20.5 years from 2000 to 2016 (WHO, 2018). Aging is accompanied by several adaptations in the musculoskeletal system structure and function. These changes include reduced muscle mass and strength (Kamel, 2003; Nilwik, et al., 2013), which might be associated with sarcopenia and dynapenia (Clark & Manini, 2008), resulting in impaired functionality and increasing the risk of falls (Kamel, 2003).

The importance of muscle strength for maintenance of the elderly's functionality is recognized in the literature (Schaap, Koster, & Visser, 2013). Losses in muscle mass have the onset at the age of 25 years, and gradually increase as the age advances (Lexell, Taylor, & Sjostrom, 1988). Around the 4th decade of life, muscle strength reduction initiates (Akima, et al., 2001; Amaral, et al., 2014; Trudelle-Jackson, Ferro, & Morrow, 2011), and by the age of 80 years an individual may lose up to 40% of muscle mass in comparison to a young adult (Lexell, et al., 1988). These losses result from reduced size (hypotrophy) of type II muscle fibers (Nilwik, et al., 2013), and, to a lesser extent, from reduced number (atrophy) of both fiber types I and II (Lexell, et al., 1988). However, there are other neuromuscular parameters that determine musculoskeletal system adaptations to aging, which include a decline in the neuromuscular activation capacity, an increased antagonist co-contraction (Arnold & Bautmans, 2014), and alterations in muscle architecture (Narici, Maganaris, Reeves, & Capodaglio, 2003). Taken together, these adaptations limit functional tasks' performance, including those required for daily life independence.

Many types of training programs lead to successful improvements of muscular parameters (e.g. strength, power, echo intensity, cross-sectional area) and functionality (e.g. gait speed, sit-to-stand) (Hortobagyi, et al., 2015; Labata-Lezaun, et al., 2023; Lopez, et al., 2022) in older adults. However, it is still not clear which muscular parameters are related to the functional improvements (Beijersbergen, Granacher, Vandervoort, DeVita, & Hortobagyi, 2013). One of the most advocated strategies to slow down or reverse sarcopenia, and to improve elderly's functionality and independence based on physical exercise, is the resistance training including concentric and eccentric muscle actions (Guizelini, de Aguiar, Denadai, Caputo, & Greco, 2018; Kamel, 2003; Lopez, et al., 2017). Concentric training increases the pennation angle of trained muscles compared to eccentric training (Reeves, Maganaris, Longo, & Narici, 2009). Eccentric training increases fascicle length more than concentric training (Reeves, et al., 2009). Therefore, both training modalities can produce different effects on strength, muscle structure, and functionality (Katsura, Takeda, Hara, Takahashi, & Nosaka, 2019). On the other hand, both types of muscle contractions are required during the performance of daily life tasks, and, consequently, are functionally important. Activities like rising from a chair, climbing stairs, and walking uphill require mainly concentric actions from the hip and knee extensors. Eccentric actions are particularly required when sitting down on a chair, stair descending, and downhill walking/running.

Exercise training for one or more muscle groups can improve strength and functionality (Lee & Park, 2013; Symons, Vandervoort, Rice, Overend, & Marsh, 2005; Tracy, et al., 1999; Yoshiko & Watanabe, 2021). Strength, power, and muscle structural characteristics of different muscles are related to the functionality of older individuals (Rech, et al., 2014; Silder, Heiderscheit, & Thelen, 2008; Spink, et al., 2011). Thus, one can expect that improving these muscular parameters from one or more muscles can lead to gains in functionality. However, it is still unclear if different training configurations or modalities can generate specific functionality gains in older individuals. Therefore, it is important to systematically investigate whether concentric and eccentric strength training programs generate different improvements in different functional tasks.

Strength exercises can be performed on isokinetic dynamometers, with body weight-bearing exercises, and using traditional weight-lifting machines. Among these modalities, the isokinetic dynamometer training allows for strict load control (Kuruganti, Parker, Rickards, & Tingley, 2006), with the exercise being performed at constant angular velocity (Hislop & Perrine, 1967) and the possibility to monitor performance outcomes related to muscle strength such as the peak torque. Force production is dependent on contraction velocity, and, during body weight-bearing exercises and traditional weight-lifting machine exercises, angular velocity is not constant along the total joint range of motion. This change in angular velocity throughout the total range of motion reduces the mechanical load to the muscle (Malliou, et al., 2003) as well as underestimates its true capacity to generate force during both concentric and eccentric phases (Reeves, et al., 2009). Therefore, isokinetic strength exercises allow for a maximal effort from the target muscles through the entire joint range of motion and dynamic contraction modalities, thereby generating better skeletal muscle adaptations in older adults that might produce greater functional gains or smaller functional losses due to the natural aging process.

When designing exercise interventions for the elderly, it is important to have clear information regarding what type of muscle action may result in larger strength gains and larger effects on neuromuscular and functional performance. However, while previous studies have established the benefits of resistance training, differences between training programs based on concentric and eccentric actions remain unclear, independent if administrated isolated or combined. Thus, the aim of the present study was to perform a systematic review of controlled trials that compared the effects of concentric and eccentric resistance training on the lower extremity muscular and functional performance in older adults. The two training modalities could be performed either isolated or in combination, but only on isokinetic dynamometers.

Methods

This is a systematic review of controlled trials following the PRISMA Statement recommendations and registered in the International Prospective Register of Systematic Reviews – PROSPERO (CRD42017075316, available at https://www.crd.york.ac.uk/prospero).

Search strategy

Controlled trials, indexed in Medline (via Pubmed), CINAHL, SPORTDiscus, PEDro, Cochrane Central, and Embase, published until August 13th 2022, were searched. Reference lists from the studies included in this review were also searched to find other potential studies to be included.

Mesh terms, Emtree terms, and keywords related to the subject of interest (older individuals, strength training, and lower limbs) and the outcomes of interest (strength, rate of torque development, muscle activation, pennation angle, fascicle length, muscle thickness, echo intensity, and functional tests) were utilized combined with the Boolean operators "AND" and "OR". The complete description of the search strategy used in Medline via Pubmed database is available in Table 1. Searches in the remaining databases were adapted to the databases criteria and are available upon request.

Eligibility criteria

To be included, the controlled trials should address the effects of concentric or eccentric (either isolated or combined) training for the lower limbs and compare outcomes between different trainings and/or with a control group. Participants should be elderly (men or women, 65 years old or more), without severe pathologies, community dwelling or residents in geriatric institutions.

The training should last at least four weeks, with a frequency of two or more sessions per week (at least eight sessions in total), performed on isokinetic dynamometer with the angular velocity control. To be included, a description of the training characteristics should be available in the manuscript. Studies

Table 1. Complete description of the search strategy used in Medline via Pubmed database

	Mesh Terms
Participants	(Aged OR Elderly OR Aging OR Senescence OR Biological Aging OR Aging, Biological OR Aged, 80 and over OR Oldest Old OR Nonagenarians OR Nonagenarian OR Octogenarians OR Octogenarian OR Centenarians OR Centenarian OR Ageing OR Older OR Old)
Training	(Resistance Training OR Training, Resistance OR Strength Training OR Training, Strength OR Weight-Lifting Strengthening Program OR Strengthening Program, Weight-Lifting OR Strengthening Programs, Weight-Lifting OR Weight Lifting Strengthening Program OR Weight-Lifting Strengthening Programs OR Weight-Lifting Exercise Program OR Exercise Program, Weight-Lifting OR Exercise Programs, Weight-Lifting OR Weight Lifting Exercise Program OR Weight-Lifting Exercise Programs OR Weight-Bearing Strengthening Program OR Strengthening Program, Weight-Bearing OR Strengthening Programs, Weight-Bearing OR Weight Bearing Strengthening Program OR Weight-Bearing Strengthening Programs OR Weight-Bearing Exercise Program OR Exercise Program, Weight-Bearing OR Exercise Programs, Weight-Bearing OR Weight Bearing Exercise Program OR Weight-Bearing Exercise Programs OR Eccentric OR Eccentric Training OR Eccentric Exercise OR Eccentric Contraction OR Concentric OR Concentric Training OR Concentric Exercise OR Concentric Contraction OR Eccentric OR Lengthening Contraction OR Negative Work OR Positive Work OR Shortening Contraction OR concentric eccentric OR eccentric concentric)
Lower extremity	(Lower Extremity OR Extremities, Lower OR Lower Extremities OR Lower Limb OR Limb, Lower OR Limbs, Lower OR Lower Limbs OR Membrum inferius OR Extremity, Lower OR Hip OR Hips OR Coxa OR Coxas OR Hip Joint OR Hip Joints OR Joint, Hip OR Joints, Hip OR Acetabulofemoral Joint OR Acetabulofemoral Joints OR Joint, Acetabulofemoral OR Joints, Acetabulofemoral OR Knee OR Knee Joint OR Joint, Knee OR Joints, Knee OR Knee Joints OR Superior Tibiofibular Joint OR Joint, Superior Tibiofibular OR Joints, Superior Tibiofibular OR Superior Tibiofibular Joints OR Tibiofibular Joint, Superior OR Tibiofibular Joints, Superior OR Ankle OR Ankles OR Regio tarsalis OR Tarsus OR Ankle Joint OR Ankle Joints OR Joint, Ankle OR Joints, Ankle OR Inferior Tibiofibular Joint OR Inferior Tibiofibular Joints OR Joint, Inferior Tibiofibular OR Joints, Inferior Tibiofibular OR Tibiofibular Joint, Inferior OR Tibiofibular Joints, Inferior OR Articulation talocruralis OR Tibiofibular Ankle Syndesmosis OR Ankle Syndesmoses, Tibiofibular OR Ankle Syndesmosis, Tibiofibular OR Syndesmoses, Tibiofibular Ankle OR Syndesmosis, Tibiofibular Ankle OR Tibiofibular Ankle Syndesmoses OR Tibiofibular Syndesmosis OR Syndesmoses, Tibiofibular OR Syndesmosis, Tibiofibular OR Tibiofibular Syndesmoses OR Ankle Syndesmosis OR Ankle Syndesmoses OR Syndesmoses, Ankle OR Syndesmosis, Ankle OR Thigh OR Thighs OR Leg OR Legs OR Foot OR Feet)
Outcomes	(Muscle Strength OR Strength, Muscle OR Torque OR Torques OR Walking Speed OR Speed, Walking OR Speeds, Walking OR Walking Speeds OR Gait Speed OR Gait Speeds OR Speed, Gait OR Speeds, Gait OR Walking Pace OR Pace, Walking OR Paces, Walking OR Walking Paces OR Postural Balance OR Balance, Postural OR Musculoskeletal Equilibrium OR Equilibrium, Musculoskeletal OR Postural Equilibrium OR Equilibrium, Postural OR force OR power OR rate of torque development OR rate of torque production OR rate of force production OR rate of force development OR muscle activation OR muscular activation OR pennation angle OR fascicle length OR muscle thickness OR echo intensity OR echo-intensity OR muscle quality OR muscular quality OR functionality OR functional OR mobility OR gait velocity OR timed up and go test OR timed up and go OR TUG OR TUG test OR sit to stand OR sit to stand test OR 30 second sit to stand test OR 30 second sit to stand OR sit-to-stand OR sit-to-stand test OR five times sit-to-stand OR five times sit-to-stand test OR five-repetition sit-to-stand OR five-times-sit-to-stand OR five-times-sit-to-stand test OR jump OR vertical jump OR balance OR Stair Climbing OR Climbing, Stair OR Stair Navigation OR Navigation, Stair OR 6 min walk test OR 6 min walking test OR 6-min-walk-test OR 6-min-walking-test OR 6 minutes walk test OR 6 minutes walking test OR 6-minutes-walk-test OR 6-minutes-walking-test OR six min walk test OR six min walking test OR six six-min-walk-test OR six-min-walking-test OR six minutes walk test OR six minutes walking test OR six-minutes-walk-test OR six-minutes-walking-test)

investigating at least one of the outcomes of interest were included in the study.

Non-randomized or non-controlled trials, studies including hospitalized individuals, and/or individuals with some pathologies were not included. Studies including participants performing other physical exercise type concomitantly to the training program were not included. Finally, only articles written in English, Spanish or Portuguese were considered.

Study selection

Results from each database were exported for further analysis of titles and abstracts by two independent raters. Duplicated studies were excluded. Titles and abstracts were analyzed to select potential studies to be included in the review, and to exclude manuscripts that did not fill the eligibility criteria. Studies, selected by at least one rater, were downloaded and the eligibility criteria were applied. Two independent raters performed full-text analyses, and discrepancies were solved by consensus.

Outcomes

The considered outcomes were the following: lower limb strength, rate of torque development, muscle activation, pennation angle, fascicle length, muscle thickness, echo intensity, and performance in functional tasks. Functional tasks were considered for the assessment of gait speed (determined for different distances), stair ascent (time to climb different number of stairs), stair descent (time to step down different number of stairs), sit-to-stand (number of repetitions in different times or time to perform a determined number of repetitions), timed up and go test (time to perform the test), balance (static balance, bipodal or unipodal, time to maintain the position or center of pressure displacement), vertical jump (jump height) and 6-min walking test (distance walked in 6-min).

Quality assessment

Two independent reviewers evaluated the methodological quality of the included studies using the Cochrane Risk of Bias Tool, which considers the sequence generation, allocation concealment, blinding of participants and personnel, blinding of outcomes assessment, incomplete outcome data, selective outcome reporting, among other sources of bias. Each item was assessed as either a low risk of bias, high risk of bias or unclear in each of the included studies. Discrepancies were solved by consensus, and the methodological quality results were considered in the discussion.

Data extraction

Two reviewers used a standardized spreadsheet to extract data, and discrepancies were solved by consensus. Data extracted included publication info (author, year), participants' characteristics (number of participants and dropouts in each of the groups, sex, age, body mass, and body height), training characteristics (number of sessions, weekly frequency, exercises performed, volume, intensity, movement velocity, sets and repetitions), mean and standard deviation/standard error of outcome variables determined before and after training, and statistical results. If the study had more groups of study (other age group or training type), only the data about the groups of interest were extracted. When the data were presented in figures, raw data were requested by e-mail from the first author of the study in question.

Statistical analyses

Data analyses were planned to consider qualitative and quantitative approaches. However, the small number of included trials and the variety of outcomes described limited a quantitative assessment. Therefore, a qualitative analysis was performed considering the main characteristics, results, and limitations of each study in addition to the already mentioned quality assessment. Data described in the Results section regarding the effects of training are presented in the way each study informed them (e. g. mean, delta value, effect size).

Results

Yield

The initial search returned 10376 studies retrieved from the databases. Duplicates were removed and, after title and abstract analysis, 440 full texts were downloaded for analysis. After inclusion and exclusion criteria analysis, four trials fulfilled the eligibility criteria for inclusion in this systematic review of controlled trials. Figure 1 depicts the flowchart of the studies' search and inclusion.

Characteristics of the included trials

Table 2 shows the main characteristics of the participants and training programs. All trials considered older women (Laroche, Roy, Knight, & Dickie, 2008; Malliou, et al., 2003; Signorile, et al., 2002; Symons, et al., 2005), with two of these trials including only women (Laroche, et al., 2008; Signorile, et al., 2002). The mean age of the participants was 69.7 years. Three trials compared effects of a concentric training with a control group (Laroche, et al., 2008; Malliou, et al., 2003; Signorile, et al., 2002) and one trial compared groups performing a concentric versus an eccentric training (Symons, et al., 2005). All trials considered a weekly frequency of three sessions, with a total program duration

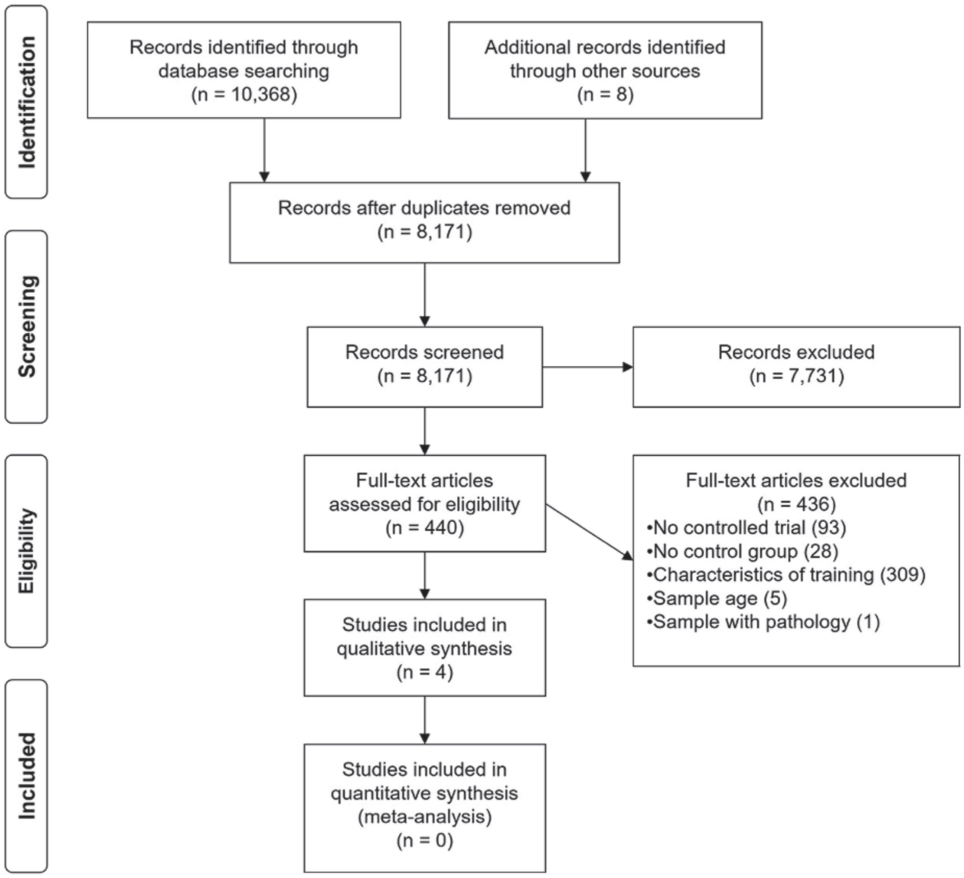

Figure 1. Flowchart of search and selection of the studies included in this systematic review.

ranging from eight to 12 weeks (Laroche, et al., 2008; Malliou, et al., 2003; Signorile, et al., 2002; Symons, et al., 2005), and were focused on knee extensor and knee flexor muscles. Ankle dorsiflexor and plantarflexor muscles were also considered in one study (Signorile, et al., 2002).

Training effects

Table 3 describes the studies' results and outcomes. Concentric training alone improved concentric strength, power, rate of torque development, and muscle activation in comparison to control groups (Laroche, et al., 2008; Malliou, et al., 2003; Signorile, et al., 2002). Functional parameters were not considered in these trials.

Concentric and eccentric trainings improved isometric, concentric and eccentric strength and results on the self-paced step test (stair test), without improvement in gait speed (Symons, et al., 2005). Muscle structural parameters (echo intensity, thick-

Table 2. Main characteristics of participants and training programs from the included trials

Participants				Characteristics of training							
Study	Groups	Age	Number/ Gender	Weekly frequency	Program duration	Muscular group	Lower limb	Intensity (%)	Velocity ($^{\circ}\cdot s^{-1}$)	Range of motion	Number of series x repetitions
Laroche et al., 2008	Control Concentric	73.7±4.6 71.3±6.3	12 F 12 F	3	8 weeks	knee extensors and flexors	L/R	100	45 and 200	90º to 180º	3x8 (each velocity)
Malliou et al., 2003	Control Concentric	69.9±4.3/65.7±4.3 69.7±2.2/68±5.1	10 M/F 12 M/F	3	10 weeks	knee extensors and flexors	NI	NI	150, 150 and 180	NI	3x12 (each velocity)
Signorile et al., 2002	Control Concentric HS Concentric LS	69.0±1.76 68.4±1.4 68.8±1.6	7 F 9 F 8 F	3	12 weeks	knee extensors and flexors; ankle plantarflexors and dorsiflexors	NI	NI	knee and ankle: HS: 270 and 180 LS: 60 and 60	NI	knee and ankle: HS: 10x1 and 8x1 LS: 6x1 and 6x1
Symons et al., 2005	Concentric Eccentric	71.8±3.1 70.5±5.2	10 M/F 9 M/F	3	12 weeks	knee extensors	L/R	100	NI	NI	3x10

Note. F: female; M: male; L: left; R: right; HS: high-speed training group; LS: low-speed training group; NI: not informed.

Table 3. Outcomes measured and results extracted from each included study as presented by the authors

Study	Outcome	Pre		Post		Effect of time		
		Control (mean±SE)	Concentric (mean±SE)	Control (mean±SE)	Concentric (mean±SE)	Control	Concentric	
Laroche et al., 2008	Knee extensor isometric peak torque (105º) (N·m·kg^{-1})	1.3±0.1	1.6±0.1	1.3±0.1	1.7±0.1	(~) p>0.05; ES=0.17	(↑) p=0.03; ES=0.25	
	Rate of torque development (105º) (N·m·s^{-1}·kg^{-1})	6.2±0.8	7.2±0.9	6.7±0.7	7.1±0.9	(~) p>0.05; ES=0.19	(~) p>0.05; ES=-0.02	
	Antagonist coactivation (%pEMG)	22.3±2.4	24.3±2.9	25.7±3.9	21.2±1.9	(~) p>0.05; ES=0.32	(↓) p=0.02; ES=-0.39	
	Onset EMG amplitude (%pEMG)	92.7±3.6	85.5±4.3	86.1±3.7	79.7±3.5	(~) p>0.05; ES=-0.54	(~) p>0.05; ES=-0.44	
	Rate of EMG rise (%pEMG)	1152.3±98.5	1079.4±95.6	1153.9±73.7	1001.1±76.6	(~) p>0.05; ES=0.01	(~) p>0.05; ES=-0.27	
		Control (mean±SD)	Concentric (mean±SD)	Control (mean±SD)	Concentric (mean±SD)	Control	Concentric	
Malliou et al., 2003	Knee extensors concentric peak torque 60º·s^{-1} (N·m)	109.6±10.8	106.3±12.2	107.9±9.2	118.3±12.8	(~) p>0.05	(↑) p<0.05	
	Knee extensors concentric peak torque 180º·s^{-1} (N·m)	66.3±6.8	68.4±9.2	65.9±5.2	81.3±5.8	(~) p>0.05	(↑) p<0.05	
						Control	HS	LS
Signorile et al., 2002	Knee extension average power 60º·s^{-1} (W)	*Data were presented only as figures.		*Data were presented only as figures.		(~) p>0.05	(~) p>0.05	(~) p>0.05
	Knee extension average power 180º·s^{-1} (W)					(~) p>0.05	(↑) Δ25.96±5.06 p=0.0007	(~) p>0.05
	Knee extension average power 300º·s^{-1} (W)					(~) p>0.05	(↑) Δ32.49±6.34 p=0.0004	(~) p>0.05
	Knee flexion average power 60º·s^{-1}s (W)					(~) p>0.05	(~) p>0.05	(~) p>0.05
	Knee flexion average power 180º·s^{-1} (W)					(~) p>0.05	(~) p>0.05	(~) p>0.05
	Knee flexion average power 300º·s^{-1} (W)					(~) p>0.05	(~) p>0.05	(~) p>0.05
	Ankle dorsiflexion average power 60º·s^{-1} (W)					(~) p>0.05	(↑) Δ2.51±0.55 p=0.0036	(↑) Δ3.50±0.36 p=0.0003
	Ankle dorsiflexion average power 180º·s^{-1} (W)					(~) p>0.05	(↑) Δ6.31±1.06 p=0.0001	(↑) Δ6.66±1.01 p=0.0001
	Ankle dorsiflexion average power 300º·s^{-1} (W)					(~) p>0.05	(↑) Δ5.65±0.82 p=0.0001	(↑) Δ7.60±0.65 p=0.0001
	Ankle plantarflexion average power 60º·s^{-1} (W)					(~) p>0.05	(~) p>0.05	(↑) Δ9.12±2.63 p=0.0132
	Ankle plantarflexion average power 180º·s^{-1} (W)					(~) p>0.05	(~) p>0.05	(↑) Δ12.47±3.53 p=0.0310
	Ankle plantarflexion average power 300º·s^{-1} (W)					(~) p>0.05	(~) p>0.05	(~) p>0.05
		Concentric (mean±SD)	Eccentric (mean±SD)	Concentric (mean±SD)	Eccentric (mean±SD)	Concentric	Eccentric	
Symons et al., 2005	Knee extensors peak isometric torque (90º)	130.6±54.0	142.0±39.8	151.8±61.2	176.0±44.7	(↑) p<0.01; Δ%: 17.3	(↑) p<0.01; Δ%: 25.5	
	Knee extensors peak concentric torque (90º·s^{-1})	93.6±40.4	107.5±30.7	113.9±48.3	116.3±26.1	(↑) p<0.01; Δ%: 22.1	(↑) p<0.01; Δ%: 10.0	
	Knee extensors peak eccentric torque (-90º·s^{-1})	161.9±62.6	168.5±40.0	191.4±76.8	207.1±35.6	(↑) p<0.01; Δ%: 17.9	(↑) p<0.01; Δ%: 26.0	
	Knee extensors concentric power (W)	75.5±37.2	83.5±32.8	104.4±41.0	98.1±28.7	(↑) p<0.01; Δ%: 51.8	(↑) p<0.01; Δ%: 23.3	
	Self-paced gait speed (80m) (m/s)	NI	NI	NI	NI	(~) p>0.05	(~) p>0.05	
	Self-paced step test (20 two-step cycles) (s)	NI	NI	NI	NI	(↓) p<0.03 ➔ ≈ -7%	(↓) p<0.03 ➔ ≈ -6%	

Note. SE: standard error; SD: standard deviation; ES: effect size; NI: not informed; ↑: increase; ↓: decrease; ~: not altered; pEMG: EMG seen at peak torque; HS: high-speed training group; LS: low-speed training group.

Table 4. Quality assessment

	Laroche et al., 2008	Malliou et al., 2003	Signorile et al., 2002	Symons et al., 2005
Random sequence generation	Low	Unclear	Low	Low
Allocation concealment	Unclear	Unclear	Unclear	Unclear
Blinding of participants and personnel	Low	Low	Low	Low
Blinding of outcome assessment	Unclear	Unclear	Unclear	High
Incomplete outcome data	Unclear	Low	Low	High
Selective reporting	Low	Low	Low	Low
Other sources of bias	Low	Unclear	Low	Unclear

ness, pennation angle and fascicle length) were not outcomes of interest in the selected trials.

Quality assessment

Table 4 presents the results of the methodological quality assessment by two reviewers. None of the included trials presented a low risk of bias in all assessed items. In addition, two trials (Laroche, et al., 2008; Signorile, et al., 2002) presented most of the assessed items with a low risk of bias and two trials (Malliou, et al., 2003; Symons, et al., 2005) present most of the items with a high risk or unclear.

Discussion and conclusions

In this systematic review, we analyzed controlled trials addressing the effects of concentric and eccentric resistance training, either isolated or in combination, on lower extremity neuromuscular and functional parameters in older adults. To ensure a proper control of the muscle action performed, as well as control of load intensity and contraction velocity, randomized trials with resistance training performed on an isokinetic dynamometer were revised. Our main findings revealed a small number of controlled trials that allowed us to discuss the effects of concentric and eccentric resistance training programs on the elderly's muscular and functional performances. Furthermore, quality assessment revealed a low risk of bias in two studies (Laroche, et al., 2008; Signorile, et al., 2002) and a high risk of bias in the other two (Malliou, et al., 2003; Symons, et al., 2005) studies, making it difficult to determine the training programs exact effects. Nevertheless, a positive training effect on knee muscles' performance, and a lack of consideration to functional performance, were common observations among the included trials.

When aiming to determine training adaptations, the use of isokinetic dynamometer is fundamental since it permits to identify different stimuli from concentric and eccentric muscle actions. One could argue that isokinetic training is hard to be applied in the general population due to the need for the specific instrumentation. We understand that among the advantages of this type of equipment are the safe control of the load (Kuruganti, et al., 2006) (which is important for older individuals), the constant angular velocity (Hislop & Perrine, 1967) (which controls the effect of velocity on force production, as demonstrated by the force-velocity curve). Additionally, it is possible to accommodate the maximal muscle potential along the entire joint range of motion (Malliou, et al., 2003), and to set the load separately to elicit similar effort for both the concentric and eccentric phases of the movements (which is important considering that eccentric action elicits greater strength (Reeves, et al., 2009). Therefore, the isokinetic dynamometer allows for controlling several of the intervening parameters on muscle force-production capacity, which can have a confounding effect on the training outcomes and mechanisms of neuromuscular adaptation.

The analyzed trials' results remain unclear whether functionality and strengthening outcomes in older people differ between training stimuli that involve concentric, eccentric, or concentric and eccentric actions combined into a training program. The concomitant assessment of muscular and functional performances from the training programs was not common in the trials, and many of the available studies in the searched literature were limited due to the lack of a control group or other comparative group, which led to their exclusion from the present review.

Concentric training was the most popular configuration of isokinetic training among the included trials. Isokinetic concentric (knee extensors and flexors) training compared with a control group was performed in three of the four included trials (Laroche, et al., 2008; Malliou, et al., 2003; Signorile, et al., 2002). All trials reported improvement in neuromuscular parameters, but none considered functional capacity assessment in the trained elderly. The training programs improved knee extensor isometric (Laroche, et al., 2008) and concentric torques (Malliou, et al., 2003), and reduced antagonistic coactivation (Laroche, et al., 2008). This reduced coactivation may benefit movement coordination (Kuruganti, et al., 2006), improving efficiency during activities of daily life (e.g. rising from a chair, climbing stairs). Although power is an important functionality component for the older adult, no modifications in the rate of torque development and neuromuscular activation were observed in response to training, despite of the adopted training velocities (Laroche, et al., 2008).

Signorile et al. (2002) developed a concentric training program at two different angular velocities (knee: $60 \cdot s^{-1}$ and $270^{o} \cdot s^{-1}$; ankle: $60 \cdot s^{-1}$ and $180^{o} \cdot s^{-1}$), and found that knee flexors power had no improvement at the assessed velocities ($60^{o} \cdot s^{-1}$, $180^{o} \cdot s^{-1}$ and $300^{o} \cdot s^{-1}$). Knee extensors power did not change for the lower-velocity training group. Conversely, a high-velocity training improved knee extensor power at the two greater angular velocities ($180^{o} \cdot s^{-1}$ and $300^{\circ} \cdot s^{-1}$). The use of high-velocity training can be a strategy for improving rapid reactions to perturbations (e.g., reaction during an imminent fall, a change of direction or to stop or initiating a movement when an unexpected event occurs), which is an ability that decreases with aging.

When the ankle muscles were trained, there were improvements in dorsiflexion torque at the different tested velocities, regardless of the training velocity (Signorile, et al., 2002). Results were different for ankle plantarflexors. While the high-training velocity did not improve performance, the low-training velocity improved power performance at lower angular velocities, showing evidence for the training velocity specificity. These results suggest that combining explosive movements for the lower extremity can selectively benefit different muscular groups.

Trainings focusing on ankle muscles are also important. The capacity to activate the dorsiflexor muscles and generate greater dorsiflexion during the swing phase of gait leads to a reduced risk of toe contact with obstacles (Begg & Sparrow, 2006), preventing trips and subsequent falls. Moreover, ankle plantarflexor strength is important during the propulsion phase of walking. However, most of the weight bearing exercises and weight-lifting machines rely on the participant's ability to perform full range of motion at the ankle throughout the exercise, which is different from the isokinetic dynamometer where the exercise performance can be determined throughout the joint's full range of motion.

Concentric and eccentric contractions can lead to different muscle structural adaptations (Franchi, Reeves, & Narici, 2017). Concentric contractions lead to greater improvements in the pennation angle, due to the parallel addition of sarcomeres (Reeves, et al., 2009). On the other hand, eccentric actions lead to greater improvements in fascicle length, due to the addition of in-series sarcomeres (Reeves, et al., 2009). However, the included studies did not investigate muscle structural parameters, and therefore there is still a lack of muscle structural parameters adaptations in the literature of controlled resistance training trials.

Only one study compared the effects of concentric versus eccentric training, performed on the isokinetic dynamometer, on muscular and functional parameters in older adults (Symons, et al., 2005). In this study, both training modalities improved knee extensors strength (isometric, concentric and eccentric strength), knee extensors concentric power (which was higher in the concentric than in the eccentric group), and performance in self-paced step test (Symons, et al., 2005). However, a training specificity seems to exist, because eccentric training increased 8% more eccentric torque than the concentric training, with the same occurring in the concentric torque, which was 12% greater in the concentric group compared to the eccentric training group. One practical application of this result is the identification of which muscle action type is more impaired in the older adult and choosing the equivalent resistance training for his/her specific needs. Furthermore, the results suggest that, if both muscle actions need attention, a combined training could be more adequate. However, the load control for concentric and eccentric actions in the same training session can be difficult to be determined due to the known different capacities of force production during concentric and eccentric contractions.

Gait speed did not change in response to different trainings, most likely because only knee extensors were trained. Hip extensors and ankle plantarflexors have significant correlation with preferred gait speed, but the knee extensors do not (Muehlbauer, Granacher, Borde, & Hortobagyi, 2018), which suggest that older adults strength training should also focus on hip and ankle muscles.

All trials reported neuromuscular parameters improvement, but only one considered the assessment of functional capacity (Symons, et al., 2005). None considered muscle structure. Structural parameters can elucidate the strength gain mechanisms, and therefore need to be investigated in controlled trials.

Another important aspect is the methodological quality of the included trials. Despite the fact that some parameters were well controlled, allocation concealment, for example, was unclear in all studies, and blinding of outcome assessment was also unclear or classified with a high risk of bias. These results, combined with the low number of trials about the topic of interest, show the urgent need for controlled trials with a high methodological quality.

From the trials included in this review, it is possible to observe that all training programs improved lower limb strength. However, the improvements are dependent on the training velocity, trained muscular groups, and muscle action. As the influence of these exercise configuration parameters are difficult to control in exercises performed with free weights or with weightlifting machines, understanding the mechanisms using controlled conditions is still necessary.

When structuring training programs for older individuals, the advantages of each of these parameters should be considered, aiming at improving several aspects that are impaired by aging. For example, training programs with different angular velocities improve the capacity to perform daily tasks requiring slow or rapid movements, contributing to the maintenance of older adults' physical independence. Additionally, if older people have impairment concerning a specific task, physicians should use the most helpful training modality for that impairment (with specific characteristics of velocity, load, muscular groups and contraction type). Moreover, if there is a global mobility difficulty, trainings that are more comprehensive might be more efficient (e.g., combining two velocities).

In conclusion, positive effects of concentric training compared to a control condition were consistent across the studied trials. Similar effects of concentric and eccentric training were found on neuromuscular parameters, but only one study addressed this issue. A common characteristic across the included trials is the lack of consideration of the effects from different training configurations on functional performance related to the elderly's independence. Due to the low number of studies, there is a need for new controlled trials, with high methodological quality, comparing the effects of concentric and eccentric training programs on neuromuscular (including muscle structure) and functional parameters in older adults.

When designing training programs for older adults, an isokinetic concentric training for knee extensors and flexors and ankle plantarflexors and dorsiflexors leads to improvements of neuromuscular factors (concentric strength, power, rate of torque development and muscle activation). Furthermore, a comparison between an isokinetic concentric and an eccentric strength training shows that they present similar results on neuromuscular parameters (isometric, concentric and eccentric torque and concentric power). Most of the included studies did not focus on functional parameters and none of them focused on muscle structural parameters. Therefore, the effects of these two isokinetic training modalities on the older adults' functional tasks and muscle structure remain unknown.

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GUIDELINES FOR CONTRIBUTORS

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Undeclared financial conflicts may seriously undermine the credibility of the journal, the authors and the science itself. The most obvious conflicts of interest are financial relationships such as: employment, stock ownership, grants, patents. Conflicts can also exist as a result of personal relationships, academic competition, and intellectual passion. All authors are requested to disclose any actual or potential conflict of interest including any financial, personal or other relationships with other people or organizations that could inappropriately influence or be perceived to influence, their work.

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Ethics is given the highest priority so all activities in conducting research must comply with ethical principles and relevant national, EU and international legislation, for example. the Charter of Fundamental Rights of the European Union and the European Convention on Human Rights. The most common ethical issue usually include: the protection of children, patients and other vulnerable populations, privacy and data protection. We encourage the publishing of research results of a study in which all research participants have signed informed consent and have been given full information on the possible effects of research intervention.

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Editorial policy relies on guidelines of the Committee on publication Ethics regarding redundant publication, which is also considered scientific misconduct.

AUTHOR GUIDELINES

In preparing manuscripts for publication in Kinesiology, the authors should strictly adhere to the guidelines based on the Publication Manual of the American Psychological Association, 6th ed. The manuscripts that have been submitted in accordance with these instructions, and providing they are of interest to the journal, will enter the reviewing procedure. Any manuscript should not ordinarily exceed 25 pages including the abstract, references, and all tables and illustrations. Discursive treatment of the subject matter is discouraged.

Accompanying document

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The journal Kinesiology generally accepts original scientific papers, review articles, but takes into consideration meta-analyses, case studies, brief reports, narrative reviews, commentaries and letters to editors.

The original scientific paper must be an original contribution to the subject treated and divided into the following sections: Introduction, Methods, Results, Discussion and conclusions. The review article should discuss a topic of current interest and have the latest data in the literature. It should outline knowledge of the subject and analyse various opinions regarding the problem. As a rule, these articles are commissioned, but any initiative from any competent author is welcome.

Please, use font Times New Roman, 12-point font size, double space.

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The title page of the manuscript should contain the following information: a concise, but informative title; the full first and family names of the author(s) (do not include degrees); the last author is introduced by “and”; the affiliation of the authors (affiliated institutions and their locations); the name and address of the corresponding author (must include title, degree and position of the corresponding author, phone and fax numbers – zip code for the country and city, and email address). The title of the article must be short and clear, abbreviations are discouraged. The abstract should be informative and self-explanatory without reference to the text of the manuscript. It should include essential results that support the conclusions of the work. Three to six key words, not used in the title, should also be provided. Authors are advised not to use abbreviations in the abstract. The abstract should contain between 100-250 words.

Text of the paper

The text must comprise of:

Introduction

This describes the present state of knowledge of the subject and the aim of the research.

Methods

This section identifies methodologies, equipment and procedures with sufficient details to allow other researchers to reproduce the results; specifies well-known methods including statistical procedures; mentions and provides a brief description of the published methods which are not yet well known; describes new or modified methods at length; justifies their use and evaluates their limits. Units of measurement, symbols and abbreviations must conform to international standards. Measurements of length, height, weight and volume should be given in metric units (metre, kilogram, litre) or their decimal multiples.

Results

The results should be reported as tables and graphs, possibly processed statistically and concisely presented in the text.

Discussion and conclusions (do NOT separate discussion and conclusions)

The authors are expected here to comment on the results and compare them with literature data. The discussion must be rigorous and correspond to experimental data. Practical implications are welcome.

References

The journal uses the APA reference system **(Publication Manual of the American Psychological Association, 6th ed.)**. The list of references may contain only the authors cited in the text. Authors are obliged to include DOIs in their reference lists, if possible.

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The study should be documented throughout the text by citing the author(s) and date (within parentheses) of the works used in the research, i.e. "… The recent comparison (Hughes, 2001) showed…", or "… Hughes (2001) compared…".

When there are two authors, always cite both names every time the reference occurs in the text. In the text, the surnames should be joined by "and" (Vuleta, Milanović and Jukić (2004) reported...), whereas within parentheses the sign "&" should be used. The same is valid for three and more authors (up to six). Three, four, or five authors should be cited the first time the reference appears in the text; in subsequent referencing, cite only the family name of the first author followed by "et al." – 1st time (Vuleta, Milanović, & Jukić, 2004); 2nd time: (Vuleta, et al., 2004). Six and more authors should always be cited like: the surname of the first author followed by ", et al.". Be sure when shortening two or more references of the same primary author, to keep enough information to distinguish these citations (by citing as many of the subsequent authors as necessary).

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Alphabetical order of references in the list should be followed. References should be complete and contain all the authors (up to and six) that have been listed in the title of the original publication. Titles of references written in languages other than English should be additionally translated into the English language and enclosed within square brackets. Full titles of journals are required (not their abbreviations). The author of the article is responsible for the accuracy of data and references.

The style of referencing should follow the examples below:

Books

Arnold, P.J. (1979). *Meaning in movement and sport and physical education*. London: Heinemann. Bartoluci, M. (2003). *Ekonomika i menedžment sporta* (2nd ed.). [Economics and management of sport. In Croatian.] Zagreb: Informator, Kineziološki fakultet Sveučilišta u Zagrebu.

Journals

Sallis, J.F., & McKenzie, T.L. (1991). Physical education's role in public health. *Research Quarterly for Exercise and Sport*, *62*(2), 124–137. Trstenjak, D., & Žugić, Z. (1999). Sport as a form of social involvement – the case of tennis. *Kinesiology, 31*(2), 50–61.

Chapters in books

Sparkes, A.C. (1997). Reflections on the socially constructed self. In K. Fox (Ed.), *The physical self: From motivation to well-being* (pp. 83–110). Champaign, IL: Human Kinetics.

Rossi, T., & Cassidy, T. (in press). Teachers' knowledge and knowledgeable teachers in physical education. In C. Hardy & M. Mawer (Eds.), *Learning and teaching in physical education*. London: Falmer Press

Chapters in published books of conference proceedings

Siedentop, D. (1998). New times in (and for) physical education. In R. Feingold, R. Rees, G. Barrette, S. Fiorentino, S. Virgilio & E. Kowalski (Eds.), *AIESEP Proceedings, "Education for Life" World Congress* (pp. 210–212). New York: Adelphi University.

Kasović, M., Medved, V., & Vučetić, V. (2002). Testing of take-off capacities in the lower extremities of top football players. In D. Milanović & F. Prot (Eds.), *Proceedings Book of 3rd International Scientific Conference "Kinesiology – New Perspectives"* (pp. 677–680). Zagreb: Faculty of Kinesiology, University of Zagreb.

Electronic resources (computer software, computer and information services, on-line sites)

U.S. Department of Education. (1997). *Title IX: 25 years of progress* /on-line/. Retrieved April 15, 1999 from: www.ed.gov/pubs/TitleIX/title.html

Yi Xiao, D. (2000). Experiencing the library in a panorama virtual reality environment. *Library Hi Tech*, 18, 2, 177–184. Retrieved July 30, 2001 from: http://isacco.anbar.com/vl=666630/cl=8/nw=1/rpsv/cw/ mcb/07378831/v18n2/s9/p177.html

Nonprinted media (Abstract on CD-ROM)

Meyer, A.S., & Bock, K. (1992). The tip-of-the-tongue phenomenon: Blocking or partial activation? /CDROM/. *Memory & Cognition*, *20,* 715–726. Abstract from: SilverPlatter File: PsycLIT Item: 80-16351.

Theses

Marelić, N. (1998). *Kineziološka analiza karakteristika ekipne igre odbojkaša juniora*. [Kinesiological analysis of the junior volleyball team play characteristics. In Croatian.] (Unpublished doctoral dissertation, University of Zagreb) Zagreb: Fakultet za fizičku kulturu Sveučilišta u Zagrebu.

Horvatin-Fučkar, M. (2002). *Povezanost ritma i uspjeha u sportskoj i ritmičkoj gimnastici.* [Relationship between rhythm and success in artistic gymnastics and rhythmic gymnastics. In Croatian.] (Unpublished Master's thesis, University of Zagreb) Zagreb: Kineziološki fakultet Sveučilišta u Zagrebu.

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Tables and figures should be placed at the end of the manuscript, in one document. The position of tables and figures in the text should be indicated with the words ''Insert Table 1 here''.

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Reviews of books are usually written at the invitation of the Editorial Board of Kinesiology. The Editorial Board generally defines the length of the review. The author of a review should answer the following questions: should the book have been published, is this book better or worse than other similar ones, if these do exist, and who this book can be useful for. Elements of the review should follow this logical order – asking questions, analysis of the arguments "for" and "against" and answers to the questions.

Style and language

The Editorial Board accepts manuscripts written in English only. The language of Kinesiology is either American English or British English. Manuscripts may be rejected if written in poor English. The author is fully responsible for the style (formal, unbiased in any sense), language, and content of the paper. Yet, the Editorial Board has the right to comment on the form and language of the paper before it is accepted for publication. A good, standard command of grammar is expected in written English. Please, avoid nonstandard abbreviations.

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