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Contents

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ACCURACY OF THE 20-M SHUTTLE RUN TEST FOR INDIVIDUALIZING EXERCISE INTENSITY OF HIGH-INTENSITY INTERVAL TRAINING

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Abstract:

The aim of the study was to investigate the accuracy of the 20 m shuttle run test (20mSRT) for the prescription of high-intensity interval training (HIIT) and to examine the appropriate intensity, prescribed by the 20mSRT end-test speed, for the execution of HIIT. Twenty physical education students (age: 22.4 ± 0.8 years, body height: 175.7 ± 8.9 cm, body weight: 73.8 ± 13.4 kg) participated in the study. On two separate occasions, the participants were first tested with a maximal incremental exercise test and the 20mSRT. On another two occasions, they were required to perform a 10-minute HIIT session comprised of 15-s runs interspersed with 15-s passive recovery. The intensities of the HIIT sessions were either 100% (T100%) or 110% (T110%) of the end-test speed reached in the 20mSRT. Mean oxygen uptake (VO_2) (84.4 ± 5.5% vs. 77.8 ± 6.9% of VO_{2max}), mean heart rate (HR) (93 ± 2.8% vs. 87.6 ± 4.6% of HR_{max}), blood lactate concentration (12.6 ± 2.1 vs. 5.4 ± 2.6 mmol/l), and ratings of perceived exertion (9.5 ± 0.5 vs. 6.7 ± 1) were all significantly ($p<.01$) higher during T110% vs. T100%. The percentage of the total exercise time spent ≥ 90% VO_{2max} (37.6 ± 25.3 vs. 18.6 ± 18.0%, $p<.05$) and ≥ 90% HR_{max} (73.9 ± 17.7% vs. 37.5 ± 33.3, $p<.001$) were also significantly higher during T110%. The mean VO_2 and HR coefficient of variation during T110% were 6.5 and 3%, respectively. The cardiorespiratory, metabolic, and perceptual responses to T110% were reflective of the responses typical for HIIT, while T100% induced insufficient physiological stress to enable optimal cardiorespiratory adaptation. Therefore, the intensity of 110% 20mSRT is preferable for inducing the appropriate acute physiological responses and the 20mSRT can be used to accurately prescribe HIIT.

Key words: *exercise testing, aerobic endurance, beep test, maximal oxygen uptake, heart rate, acute exercise responses*

Introduction

High-intensity interval training (HIIT) is comprised of short (10-60 seconds) or long (1-5 minutes) work intervals performed at intensities close to velocity associated with attainment of maximal oxygen uptake (vVO_{2max}) interspersed with active or passive recovery periods of similar or shorter duration (Buchheit & Laursen, 2013a). Studies have shown that HIIT is the optimal training programme for enhancing cardiorespiratory and metabolic function as it enables athletes to spend several minutes per session at ≥ 90% of maximal oxygen uptake (VO_{2max}) (Buchheit & Laursen, 2013a, 2013b). Such an acute training stimulus maximally stresses the cardiorespiratory system and therefore may be very effective for improving the VO_{2max} (Dolci, Kilding, Chivers, Piggott, & Hart, 2020; Midgley, McNaughton, & Wilkinson, 2006).

The short interval HIIT is very often utilized in team sports as its intermittent nature closely mimics the activity patterns seen in team sports and its implementation in gym conditions with restricted space available is much easier than the implementation of the long interval HIIT. Studies have shown that the execution of the short interval HIIT, consisting of 15-second work interval at intensities above the vVO_{2max} alternated with 15-second recovery intervals (15 s/15 s), enable athletes to accumulate several minutes in the zone ≥90% VO_{2max} (Buchheit & Laursen, 2013a; Midgley & McNaughton, 2006). The training intensity individualization in these studies was done by using maximal aerobic speed (MAS) or vVO_{2max} attained in maximal incremental exercise tests (IET) performed in the laboratory conditions on the treadmill (de Freitas, et al., 2019; Rozenek, Funato, Kubo, Hoshikawa, & Matsuo, 2007; Twist, Bott, & Highton, 2023) or in the field (Billat, et al., 2001; Collison, et al., 2022; Dupont & Berthoin, 2004; Dupont, Blondel, Lensel & Berthoin, 2002; Julio, et al., 2020), and the training protocols were all conducted in a form of straight-line running. Although a number of objective (Jamnick, Pettitt, Granata, Pyne, & Bishop, 2020) and subjective (Bok, Rakovac, & Foster, 2022) methods can be used for exercise prescription, the translation of exercise test responses to an accurate individualization of training sessions is still an extremely complex task (Bok & Foster, 2021; Foster, et al., 2020). Specifically, physiological responses can be very heterogeneous if training protocols are individualized through MAS or vVO_{2max} assessed with IET and then conducted in-doors in the form of shuttle running (Buchheit, 2008; Sandford, Laursen, & Buchheit, 2021). Therefore, a 30-15 intermittent fitness test (30-15IFT) was developed more than a decade ago in order to provide end-test speed (vIFT) that is more accurate for prescribing such intermittent training protocols (Buchheit, 2010; Buchheit, Dikmen & Vassallo, 2021). Indeed, when the prescription was based on the vIFT, the execution of 15 s/15 s training session showed low level of interindividual variability in cardiorespiratory responses suggesting that this procedure might be the best solution for prescribing the short format HIIT (Buchheit, 2008; Buchheit, et al., 2021). It was subsequently reported that performing 15 s/15 s training sessions prescribed through the vIFT enabled athletes to spend around 45% of an 8-minute total exercise time in the zone ≥90% VO_{2max} (Buchheit, et al., 2009).

However, aerobic fitness in team sports players is often assessed by different aerobic field tests such are the 20-metre shuttle run test (20mSRT) (Léger & Lambert, 1982; Mayorga-Vega, Aguilar-Soto, & Viciana, 2015) and the YoYo intermittent recovery test (YoYoIRT) (Bangsbo, Iaia, & Krustrup, 2008) mostly due to the claims that these tests possess high ecological validity for team sports (Bok & Foster, 2021; Castagna, Manzi, Impellizzeri, Weston, & Alvarez, 2010). Unfortunately, the end-test speeds between all these aerobic field tests are markedly different due to the disparate nature of the test protocols and, therefore, can hardly be used interchangeably for exercise prescription (Bok & Foster, 2021; Buchheit, 2008; Dupont, et al., 2010). It is currently unknown whether the v20mSRT can be used to accurately prescribe the short interval HIIT and what is the appropriate intensity for yielding the greatest accumulation of time spent ≥90% VO_{2max}. Namely, when 10 minutes of 15 s/15 s HIIT session at the intensity of 140% v20mSRT was performed, young team sports athletes exercised at 89.5% of their maximal heart rate reserve (HR_{res}), with a coefficient of variation (CV) of 10.6% (Buchheit, 2008). This rather high CV indicated poor practical validity of the test for the accurate individualization of HIIT sessions (Buchheit, 2008, Buchheit, et al., 2021). However, time spent in the zone ≥90% VO_{2max} was not reported in the study and the fact that the training session was performed on the 40 m court, which was double the distance used in the 20mSRT, can provide a partial explanation for the rather high CV of the heart rate response. Executing HIIT session through 20 m shuttle running, which makes the training session more similar to the testing protocol, could provide a more stable physiological response.

Therefore, the aims of the present study were: 1) to investigate whether the 20mSRT can be used for HIIT prescription if performed using 20-m shuttle runs by assessing the time spent ≥90% of maximal heart rate (HR_{max}) and VO_{2max}, and 2) to compare the cardiorespiratory, metabolic and perceptual responses to 15 s/15 s HIIT sessions performed at 100% and 110% of v20mSRT with the purpose to determine the appropriate intensity for the execution of the short format HIIT session.

Methods

Participants

Twenty physical education students (seven females and 13 males; age: 22.4 ± 0.8 years, height: 175.7 ± 8.9 cm, weight: 73.8 ± 13.4 kg, % body fat: 17.4 ± 4.9 %) volunteered to participate in the study. All participants were physically active individuals with training background from different individual and team sports. Five participants were still active national level competitors in their respective sports, whereas the rest of the participants practiced their sport and other physical activities several times a week for the purpose of physical recreation while pursuing a healthy lifestyle. The participants were aware that they could withdraw from the study at any point without any consequences. The study protocol was approved by the Ethics Committee of the Faculty of Kinesiology University of Zagreb (protocol # 2/2021, approved on 28th January 2021) and conformed to the recommendations of the Declaration of Helsinki.

Experimental design

The participants were required to undertake two testing and two training sessions over a two-week period. All testing and training sessions were performed at the approximately same time of the day to avoid circadian rhythm influence on performance. Participants were familiarized with both tests and the training sessions before the study commencement, and they all had recent experience in the execution of testing and training as this was part of their practical academic requirements. First, the participants performed the 20mSRT and maximal IET on two different occasions separated by at least 48 hours. The 20mSRT was performed for the purpose of determining the end-test speed (v20mSRT), while the maximal IET was performed in order to assess the VO_{2max} and HR_{max} of the participants. Subsequently, on another two occasions, separated by at least 72 hours, the participants performed a 10-minute HIIT session comprised of 15-second shuttle running at either 100% or 110% of the v20mSRT interspersed with 15-second passive recovery. To ensure running at the appropriate intensity, the total distance for 15 s run was calculated based on each participant's v20mSRT. Both training sessions were performed indoors, and the participants were required to run back and forth between two lines set 20 metres apart. Heart rate and respiratory gas exchange were continuously monitored and recorded during the training sessions. Ratings of perceived exertion (RPE) were collected immediately after, whereas blood lactate concentration (La) was determined three minutes after the end of each training session. The participants refrained from any strenuous exercise for 24 hours preceding the test and had consumed their last meal at least 2.5 hours before each testing or training session to avoid any undue fatigue or possible gastrointestinal discomfort. They were also required to maintain their regular diet and habitual lifestyle during experimental procedure to reduce the influence of the uncontrolled variables.

Procedures

Maximal incremental exercise test. For the assessment of VO_{2max}, a maximal IET was performed on a motor-driven treadmill (h/p Cosmos, Nussdorf-Traunstein, Germany) in laboratory conditions. At the beginning of the test, the participants walked for two minutes at 3 km/h. The treadmill speed was thereafter increased by 0.5 km/h every 30 seconds until volitional exhaustion. The grade of the treadmill was set to 1%. Respiratory gas exchange and heart rate were continuously recorded with an automated breath-by-breath portable metabolic system (Metamax 3b, Cortex Biophysik, Leipzig, Germany). The metabolic system was calibrated according to the manufacturer guidelines. The collected raw data were manually filtered and averaged on a 5-second interval basis, while VO_2 data were additionally averaged across 30-second time epochs for the purpose of VO_{2max} determination. The highest VO_2 response recorded during a 30-second time epoch was defined as VO_{2max}. A plateau in VO_2 and HR response despite an increase in running speed and/or RPE $\geq$8 on the Borg's category ratio scale (Borg, 1982) were used as criteria for attainment of the VO_{2max} (Mezzani, et al., 2012). A verification exercise bout was not performed.

20-m shuttle run test. For the assessment of the end-test velocity, the 20mSRT was performed indoors on a handball court (Léger, Mercier, Gadoury, & Lambert, 1988). The initial speed was set at 8.5 km/h for the first minute and increased by 0.5 km/h for each subsequent minute thereafter. The participants were required to run back and forth between two lines set 20 m apart at a pace dictated by the pre-recorded audio track. This pacing strategy assisted participants in adjusting their running speed so that they entered the 3-m zone demarcating the end-court lines at each beep. The participants were instructed to complete as many stages as possible. The test stopped when the participant was no longer able to maintain pace or was unable to reach the 3-m zone at each end of the court for three consecutive times. The HR was recorded during the test (Polar Team App, Polar Electro, Kempele, Finland) and the velocity of the last stage successfully completed was recorded as the v20mSRT. The test-retest reliability (r=0.975) for v20mSRT in adults has been reported to be excellent (Léger & Lambert, 1982).

HIIT sessions. To investigate whether the v20mSRT can be used for HIIT training prescription, the participants performed two 10-minute 15 s/15 s HIIT sessions comprised of shuttle running over a 20-metre distance at 100% (T100%) and 110% (T110%) of the v20mSRT interspersed with passive recovery. Both training sessions were performed indoors and were scheduled so as to allow at least 72 hours recovery for each participant. A 20-m distance was used for the execution of both training sessions to replicate the locomotor activity of the testing protocol and to induce physiological responses with minimal between-subject variability. The targeted distance of the 15-second run for each participant was calculated based on the v20mSRT and was demarcated with cones on the 20-m course. A short warm-up consisting of 5-minute low-intensity continuous running and 3-minute lower-body dynamic stretching was performed before the commencement of the HIIT sessions. The participants were required to adjust their running speed in accordance with the 15-second beeps which demarcated running and recovery intervals. The two intensities chosen for the execution of the training sessions were selected based on the fact that the 20mSRT was a continuous incremental aerobic field test and therefore intensities of at least 100% of the end-test speed and higher have to be used for the prescription of short format HIITs (Buchheit & Laursen, 2013a). Pilot tests conducted before the commencement of the study with just one participant confirmed the correctness of such decisions. Heart rate was recorded throughout the training sessions for all the participants (Polar Team App, Polar Electro, Kempele, Finland), while respiratory gas exchange values were collected only for eleven participants due to the time and equipment constraints (only one portable gas analyser Metamax 3b, Cortex Biophysik, Leipzig, Germany was available for the study). Collected data were analysed as for the maximal IET. The time spent in the zone ≥90% of VO_{2max} (t@90% VO_{2max}) and HR_{max} (t@90% HR_{max}) was calculated using the 5-second averaged data. Three minutes after the end of each training session, fingertip blood samples were collected for the La assessment (Lactate Scout+, EKF Diagnostics, Cardiff, UK). Immediately upon finishing the training session the participants also reported their RPE using a modified Category Ratio 0-10 Borg's scale (Borg, 1982; Foster, et al., 2001).

Statistical analysis

All the data are presented as mean ± standard deviation. Normality assumptions were verified using the Kolmogorov-Smirnov test. Differences between T100% and T110% in peak and mean values for VO_2, HR, and La were evaluated by one-way analysis of variance (ANOVA) for repeated measures. Wilcoxon matched pairs test was used for assessing differences in RPE between the HIIT sessions as the variables were not normally distributed. Statistical significance was accepted at $p<.05$. Statistical analyses were performed with Statistica (v 13.2; Dell Inc, Tulsa, OK).

Results

The results obtained at the maximal IET and 20mSRT are presented in Table 1. The v20mSRT corresponded to 81.1% of vIET.

Peak VO_2 during T110% and T100% corresponded to 100.5 ± 4.8% and 94.6 ± 7.4% of VO_{2max}, while mean VO_2 corresponded to 84.4 ± 5.5% and 77.8 ± 6.9% of VO_{2max}, respectively. The CV of the mean VO_2 was 6.5% and 8.9% for T110% and T100%, respectively. The participants spent 18.6 ± 18% and 37.6 ± 25.3% of total exercise time in the zone ≥90% VO_{2max} during T100% and T110%, respectively. Peak HR corresponded to 98.5 ± 2.3% and 93.6 ± 3.9% of HR_{max}, while mean HR corresponded to 93 ± 2.8% and 87.6 ± 4.6% of HR_{max} during T110% and T100%, respectively. The mean HR response had CV of 3.0% and 5.3% for T110% and T100%, respectively. The participants spent 37.5 ± 33.3% and 73.9 ± 17.7% of total exercise time in the zone ≥90% VO_{2max} during T100% and T110%, respectively. All the participants completed the T100%, whereas three subjects were unable to finish the T110% session and terminated their running after having completed 9, 16 and 18 intervals. An individual example of oxygen uptake (VO_2) and heart rate (HR) responses to T110% and T100%, expressed as percentage of VO_{2max} and HR_{max}, are presented in Figure 1.

Table 1. Anthropometric and physiological characteristics of the subjects

Characteristics	Value (mean ± SD)
Age (years)	22.4 ± 0.8
Height (cm)	175.7 ± 8.9
Weight (kg)	73.8 ± 13.4
% body fat (%)	17.4 ± 4.9
VO_{2max} (l/min)	4.0 ± 1.0
VO_{2max} (ml/kg/min)	53.3 ± 6.4
HR_{max} (IET) (bpm)	195.2 ± 8.8
vIET (km/h)	15.9 ± 1.4
HR_{max} (20mSRT) (bpm)	197.9 ±8.7
v20mSRT (km/h)	12.9 ± 1
20mSRT (distance) (m)	1730 ± 428.3

Note. VO_{2max} – maximal oxygen uptake; HR_{max} – maximal heart rate; IET – maximal incremental exercise test; vIET – final velocity achieved in IET; 20mSRT – 20-metre shuttle run test; v20mSRT – final velocity achieved in 20mSRT.

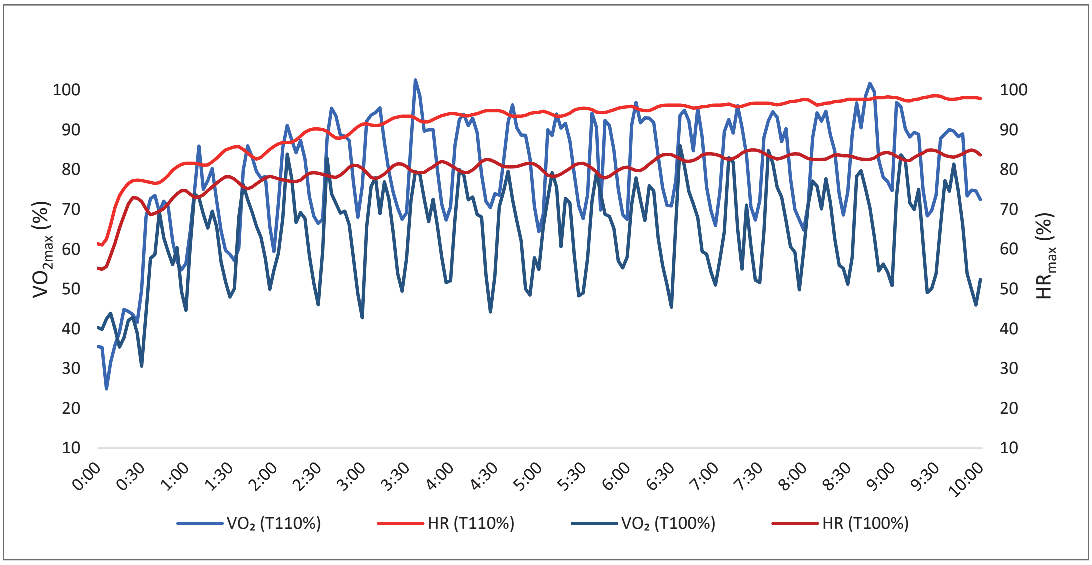

Figure 1. An individual example of oxygen uptake (VO_2) and heart rate (HR) responses to T110% and T100% expressed as the percentage of VO_{2max} and HR_{max} obtained in the maximal incremental exercise test.

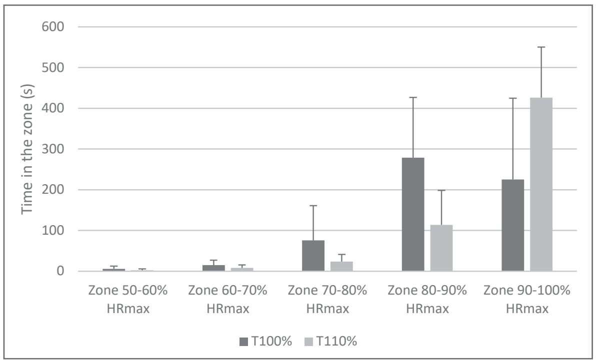

Figure 2. Time spent (mean ± standard deviation) in the particular heart rate intensity zones during the training sessions.

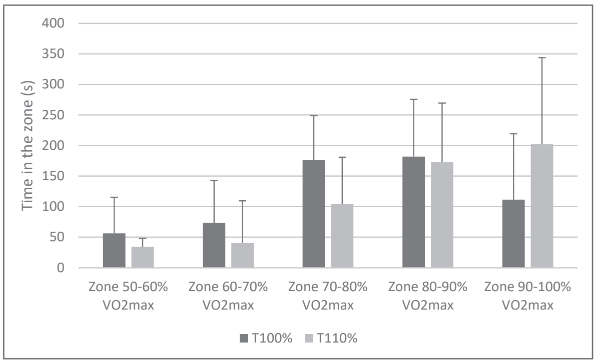

Figure 3. Time spent (mean ± standard deviation) in the particular oxygen uptake intensity zones during the training sessions.

Peak VO_2 (p=.03), mean VO_2 (p<.01), peak HR (p<.001) and mean HR (p<.001) during T110% were all significantly higher than during T100%. Time spent in the zone ≥90% HR_{max} was significantly greater during T110% (p<.001) (Figure 2), but time spent in the zone ≥90% VO_{2max} was not significantly (p=.07) different between the sessions (Figure 3). On the other hand, the percentage of total exercise time spent in the zone ≥90% VO_{2max} (p=0.02) and HR_{max} (p<.001) were both significantly different between the sessions. For the subjects that did not complete the full training session the percentage of time spent ≥90% of VO_{2max} and HR_{max} was calculated using their respective total exercise time. Significant differences between the sessions were also found in La (p<.001) and RPE (p<.001) (Table 2).

Table 2. Participants' cardiorespiratory, metabolic and perceptual responses recorded during the training sessions

	T100%	T110%
VO_{2peak} (ml/kg/min)	50.5 ± 6.4	53.8 ± 6.8*
VO_{2mean} (ml/kg/min)	41.6 ± 5.2	45.2 ± 5.9**
HR_{peak} (bpm)	182.8 ± 10.4	192.4 ± 9.5***
HR_{mean} (bpm)	171.1 ± 11.4	181.5 ± 9.4***
La (mmol/l)	5.4 ± 2.6	12.4 ± 2.1***
RPE (a.u.)	6.7 ± 1.0	9.5 ± 0.5***
t@90% VO_{2max} (s)	111.4 ± 107.8	202.3 ± 141.4
t@90% HR_{max} (s)	225.2 ± 199.5	426.1 ± 124.3***
%t@90% VO_{2max} (%)	18.6 ± 18.0	37.6 ± 25.3*
%t@90% HR_{max} (%)	37.5 ± 33.3	73.9 ± 17.7***

Note. T100% – training session performed at 100% v20mSRT; T110% – training session performed at 110% v20mSRT; VO_{2peak} – peak oxygen consumption; VO_{2mean} – mean oxygen consumption; HR_{peak} – peak heart rate; HR_{mean} – mean heart rate; La – blood lactate concentration; RPE – rating of perceived exertion; t@90%VO_{2max} – time spent in the zone ≥90% of VO_{2max}; t@90%HR_{max} – time spent in the zone ≥90% of HR_{max}; %t@90%VO_{2max} – percentage of total exercise time spent in the zone ≥90% of VO_{2max}; %t@90%HR_{max} – percentage of total exercise time spent in the zone ≥90% of HR_{max}. * Significant difference between the sessions (p<.05); ** Significant difference between the sessions (p<.01); *** Significant difference between the sessions (p<.001).

Discussion and conclusions

This study is the first to report the cardiorespiratory, metabolic, and perceptual responses to the short interval HIIT prescribed based on the v20mSRT. The main findings of the study were the following: 1) 20mSRT can be used effectively for the prescription of HIIT; 2) the intensity of 110% v20mSRT is more appropriate for creating the optimal acute training stimulus required for the enhancement of VO_{2max}; and 3) not all athletes were able to complete the intended duration at 110% v20mSRT.

Peak VO_2 and peak HR were both above 90% of their respective maximal values during both training sessions suggesting the potential of each session intensity to elicit a high enough acute cardiovascular stress necessary for VO_{2max} enhancement. However, even though the percentages of peak VO_2 and peak HR values reached during both sessions were very similar to each other, the mean VO_2 and HR values were rather different. Namely, the mean HR values were above the 90% of HR_{max} during both training sessions, whereas the mean VO_2 values were only 84.4% and 77.8% of VO_{2max} during T110% and T100%, respectively. This indicates lower association between HR and VO_2 dynamics during a short format HIITs and suggests that during this type of training sessions HR cannot be used to accurately estimate VO_2 responses. The dissociation is due to the fact that VO_2 kinetics is much faster than HR in response to the changes in exercise intensity (Midgley, McNaughton, & Carroll, 2007) and this is especially evident in training sessions comprised of very short intervals incorporating large amplitudes between work and recovery intensities (Billat, et al., 2001; Borel, et al., 2010) (Figure 1). This discrepancy between mean VO_2 and mean HR is also reflected in the time spent ≥90% of VO_{2max} and HR_{max} during the training sessions (Figures 2 and 3). Therefore, the mean intensity of the training session as well as the time spent in the zone ≥90% of VO_{2max} could easily be overestimated if only HR is monitored and used for the interpretation.

Time spent ≥90% of VO_{2max} was 202.3 seconds or 37.6% of total exercise time for T110%, which was significantly greater than 111.4 seconds or 18.6% of total exercise time obtained for T100%. This, along with the higher mean VO_2 and mean HR registered during T110%, indicates that intensity of 110% v20mSRT should be used for the prescription of 15 s/15 s HIIT. This is congruent with the general recommendation that intensities between 100% and 120% of vVO_{2max} obtained through continuous IET are used for the execution of the short format HIIT (Buchheit & Laursen, 2013a). More specifically, when acute responses to different intensities applied to 15 s/15 s HIIT were investigated, it was shown that the intensity of 110% MAS in particular enabled the longest time to exhaustion and the greatest time spent ≥90% VO_{2max} (Dupont, et al., 2002). So, even though only two intensities were investigated in this study, it appears that, similar to when continuous straight-line IET is used for training prescription, the percentage of 110% of v20mSRT is optimal for the execution of 15 s/15 s HIIT.

It was previously reported that, when total exercise time was predetermined to eight minutes, the 15 s/15 s training session performed at intensity of 95% vIFT resulted in 216.1 seconds or 45% of total exercise time spent ≥90% of VO_{2max} (Buchheit, et al., 2009). When three sets of 6-minute 15 s/15 s bouts, performed at the intensity of 120% vVO_{2max}, were executed on the treadmill, the total exercise time spent ≥90% of VO_{2max} was 288 s or 26.7% of the total working exercise time (Twist, et al., 2023). On the other hand, when exercise was performed until exhaustion, participants managed to spend 383 seconds or 54.9% (Dupont, et al., 2002), 335.5 seconds or 25% (de Freitas, et al., 2019), and 317 seconds or 43.2% of total exercise time (Dupont & Berthoin, 2004) ≥90% of VO_{2max} during sessions performed on an indoor track or on the treadmill. As optimal time spent ≥90% VO_{2max} for team sport athletes is estimated to be around five minutes (Buchheit & Laursen, 2013a), the T110% fell just a bit short to reach that goal. Therefore, the total session time needs to be prolonged in order to accumulate five or more minutes in the zone. However, as exhaustion during HIIT sessions, when performed as on-ground straight-line running, was reached after 745 (Dupont & Berthoin, 2004) and 698 seconds (Dupont, et al., 2002), it is obvious that such a prolonged training session would need to be broken into sets if exhaustion is likely to be avoided. This is further supported by the fact that even the 10-minute training session in this study was not completed by all the participants since three subjects quit running after having executed 9, 16 and 18 intervals. Therefore, prescribing the 10-minute short interval HIIT based on the 20mSRT appears less effective in terms of the cardiorespiratory response when compared to a shorter 8-minute session prescribed through vIFT (Buchheit, et al., 2009).

Practical validity and accuracy of the fitness test for individualizing HIIT can be evaluated by assessing interindividual variation in acute cardiorespiratory responses (Buchheit, 2008, 2010). Previous study reported a rather high CV (10.6%) for mean $\%HR_{res}$ when 10-minute 15 s/15 s HIIT session was performed based on the 20mSRT, while much lower CV (2.9%) was found when identical training session was performed based on the 30-15IFT (Buchheit, 2008). Conversely, lower CVs of 3% and 6.5% for mean %HR and mean $\%VO_2$, respectively, were obtained in our study. So, even though different variables were analysed, it does appear that interindividual variation in cardiorespiratory responses was lower in this study, which indicates better precision for training prescription. These lower CVs found in this study could be due to the fact that training sessions were performed on a 20 m distance course as opposed to the 40 m running course and at training intensity of 140% v20mSRT that were used in the other study (Buchheit, 2008). Making the locomotor activity of the training session more similar to the testing procedure obviously enables more homogenous cardiorespiratory responses during the session. Namely, when the session was executed on a longer running course, the smaller number of changes of direction (COD) and the higher running speed selected for each work interval during the session probably caused greater deviation from the physiological responses captured during the testing procedure, creating more heterogeneous responses between participants (Buchheit, 2008). On the other hand, when the training session is organized as to be more similar to the testing procedure, the physiological responses and energy cost of running can be more closely matched (Buchheit, et al., 2021). In this latter case other physiological capacities, such as the COD ability, anaerobic capacity, and power, which also contribute to the performance of the 20mSRT aside from the VO_{2max}, had been utilized in similar extension during the session as they were during the final stage of the test. So, using the 20 m running course and exercise intensities relatively close to the v20mSRT (i.e., 110% v20mSRT) enabled higher practical validity and greater accuracy of the test for individualizing the short format HIIT.

However, it must be acknowledged that three subjects were not able to finish the entire 10-minute session. One of the limitations of the study was the fact that participants were physical education students with different sports background making the 20mSRT more or less specific for each person. Therefore, the contribution of anaerobic capacity, as well as neuromuscular and COD abilities to the performance of the test probably differentiated more among the participants in such a heterogenous group of people than it would have had if the group was comprised of players from a single sport. In this case similar or even identical v20mSRT could have been reached by subjects presenting with greatly different physiological profiles (Buchheit, et al., 2021). In addition, in terms of their practical validity, continuous maximal aerobic tests are inferior to the intermittent ones (e.g., 30-15IFT) as their end-test speeds do not incorporate the ability of inter-effort recovery which is extremely important for performing intermittent exercise (Haydar, Al Haddad, Ahmaidi, & Buchheit, 2011). All this may enable participants with very high aerobic capacity and the ability to tolerate acidosis, but with lower leg power and COD abilities, to reach high v20mSRT; however, they may exhibit poor performance during intermittent shuttle exercise. Indeed, the participant that ceased exercising after having completed only nine intervals was a top-level rower who reached top scores in both maximal IET and 20mSRT. Probably, his pronounced aerobic profile and the ability to tolerate high levels of acidosis enabled him to reach high v20mSRT, but his poorer COD abilities and lower running economy, associated with the execution of the unfamiliar and prolonged shuttle running, prevented him from maintaining exercise at this intensity for longer. Namely, frequent decelerations and accelerations at such high speed taxed his aerobic capacity very heavily early into the exercise, mostly due to the impaired running economy during shuttle running, and consequently increased the contribution from the anaerobic capacity leading to the early exhaustion. This was probably even further emphasized by the participant's high body mass and height as it was previously shown that subjects of high stature might present with greater running economy deterioration during COD running (Buchheit, Haydar, Hader, Ufland, & Ahmaidi, 2011). Lower training and competition volumes were also associated with greater deterioration of running economy during shuttle running (Buchheit, et al., 2011) and this, along with their high stature, may explain premature exhaustion of the other two participants who recently stopped competing in basketball and soccer and became recreational players. Finally, the requirement to carry the portable metabolic analyser during the training sessions, while this was not the case during testing, may have further amplified the energy cost of shuttle running.

Blood lactate concentration and RPE were also significantly different between the T110% and T100% sessions. Namely, when 15 s/15 s HIIT session was performed for eight minutes, it elicited blood lactate concentration of 11.6 mmol/l and RPE of 6.6 (Buchheit, et al., 2009), while a bit shorter predetermined session lasting ≈445 seconds resulted in blood lactate concentration of 9.2 ± 1.4 mmol/l (Dupont, Blondel, & Berthoin, 2003). In addition, the same HIIT exercise performed in the format of four 4-minute bouts separated with 3-minute passive recovery elicited blood lactate concentration of 4.7 ± 0.6 mmol/l and RPE of 7.1 ± 1 (Selmi, et al., 2017), while three sets of 6-minute running separated with 5-minute passive recovery elicited blood lactate concentration of 5.9 ± 2.5 mmol/l (Twist, et al., 2023). On the other hand, performances to exhaustion elicited blood lactate concentration of 11.7 ± 2.1 mmol/l after 745 ± 171 seconds (Dupont & Berthoin, 2004), 11.1 ± 2.5 mmol/l after 698 ± 355 seconds (Dupont, et al., 2002), 9.5 ± 2.6 mmol/l after 495 ± 124 seconds (Buchheit, Laursen, Millet, Pactat, & Ahmaidi, 2008) and 5.5 ± 2.6 mmol/l with RPE of 18 ± 1 after 1342 ± 446 seconds of exercise (de Freitas, et al., 2019). Also, delta of blood lactate concentration was around 9 and 6 mmol/l with RPEs around 16 and 18 for long-distance runners and rugby players, respectively, after performing exercise to exhaustion that lasted approximately six minutes on average for both groups (Julio, et al., 2020). It does seem that performing this type of HIIT session through 20-m shuttle running elicits higher perceptual responses for the corresponding blood lactate concentration than when it is performed over a 40-m course (Buchheit, et al., 2009) or in the form of the straight-line running (Dupont, et al., 2003). Even the sessions performed until volitional exhaustion that lasted for longer caused lower blood lactate concentrations than the T110%. More frequent decelerations and accelerations obviously outweigh lower running speeds utilized in sessions based on the 20mSRT. So, the accumulation of 37.6% or 202.3 seconds of total exercise time in the zone ≥90% VO_{2max} comes with rather high metabolic and perceptual stress making this particular format of 15 s/15 s training session less efficient in comparison to the ones prescribed on 30-15IFT or maximal IET. However, as studies in which HIIT exercise was performed in multiple 4- to 6-minute sets generally report lower metabolic and perceptual stress (Selmi, et al., 2017; Twist, et al., 2023) in comparison to longer duration bouts (Buchheit, et al., 2009) and especially exercise to exhaustion (Dupont & Berthoin, 2004; Julio, et al., 2020), it is prudent to assume that optimal acute physiological and perceptual responses could be obtained by performing the HIIT session within a few shorter bouts.

Generally, the results of this study suggest that 20mSRT can be used effectively for the prescription of short format HIIT and that the intensity of 110% v20mSRT seems to be appropriate for creating the optimal acute training stimulus required for the enhancement of VO_{2max}. Performing HIIT on a 20-m running course and executing locomotor activity of the training session most similar to the testing procedure leads to less interindividual variation in cardiorespiratory responses and more accuracy in individualization. It does, however, seem that performing the session on such a short distance course elicits higher metabolic and perceptual responses in comparison to the sessions performed over longer distances and based on maximal IET or 30-15IFT. This should be kept in mind when this type of HIIT session is integrated into a periodized weekly training regime. Additionally, future research should aim to determine the exact magnitude of the neuromuscular stress imposed by performing frequent COD during these sessions in order to enable better training periodization. Finally, athletes who are not accustomed to shuttle running and who possess rather high levels of VO_{2max} might be susceptible to early exhaustion during HIIT, probably due to the deterioration of running economy and an increase in energy cost of running associated with COD. Therefore, caution should be exercised when 20mSRT is used to prescribe HIIT for a very heterogeneous group of people.

The main limitation of the study was the fact that the VO_2 was not collected for all participants during the sessions. However, comparing the HR responses of the participants for whom VO_2 was measured with HR responses of the participants for whom VO_2 was not measured revealed that no significant differences existed between them. Therefore, it is prudent to assume that VO_2 responses collected on a subsample can be considered as representative for the entire sample.

The study results show that 20mSRT can effectively be used to prescribe a short format HIIT when the session is performed over a 20-m running distance. To elicit the appropriate cardiorespiratory response, the intensity of 110% v20mSRT should preferably be used. However, very high peak VO_2 and HR responses during the 10-minute session, along with the early exhaustion of three subjects, point out that shortening of the exercise time could be beneficial. Namely, performing the training session in two to three shorter, e.g., 6- to 8-minute bouts, could possibly reduce the metabolic and perceptual responses, while also mitigate the risk of reaching exhaustion in athletes with poor shuttle running economy. However, the exact optimal duration of the set/bout should be experimentally determined through future studies. Additionally, performing the session in the form of several shorter bouts could provide for greater accumulation of time in the zone ≥90% VO_{2max}.

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ACUTE EFFECTS OF ANKLE WEIGHT LOADING ON REGIONAL ACTIVITY OF RECTUS FEMORIS MUSCLE AND LOWER-EXTREMITY KINEMATICS DURING WALKING IN OLDER ADULTS

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Abstract:

Ankle weight loading is a straightforward and easily applicable method to increase the physiological burden during walking in older adults. The current study investigated the acute effects of ankle weight loading on the regional activity of rectus femoris (RF) muscle and lower-extremity joint angles during walking in twenty-nine healthy older adults. Neuromuscular activities of proximal (RFP) and distal (RFD) regions of the RF into averaged rectified values (ARV) and kinematics of left lower extremities were measured during walking with and without ankle weight on a treadmill using surface electromyography (EMG) and motion capture, respectively. Significant differences in normalized ARV between RFP and RFD with ankle weight loading were found in longer periods of the stance phase (30-55 and 5-15%) and swing (70-90 and 95-100%) phases compared to without weight condition (30-40, 50, and 75-85%) ($p<.05$). The hip flexion angle at (10-25 and 60-90%), knee extension at (5%, 15%, 25-35%, and 100%), and ankle dorsiflexion at (30-55% and 75%) of the gait cycle were increased with ankle weight loading more than without it ($p<.05$). Ankle weight loading could change the neuromuscular activity pattern of RFP and improve lower-extremity kinematics during walking in older adults.

Key words: *the elderly, ankle weight, rectus femoris, surface electromyography, joint angle*

Introduction

The rectus femoris (RF) muscle is activated regionally based on anatomical characteristics during gait phases (Watanabe, Kouzaki, & Moritani, 2014). The most important role of the RF muscle involves its proximal region (RFP) in the swing phase (Watanabe, Kouzaki, & Moritani, 2012). The RF muscle contracts in the stance to swing and terminal swing to extend the knee through concentric and eccentric contractions, respectively (Nardo & Fioretti, 2013). Also, RFP is activated in swing and stance to swing phases to flex the hip joint during gait (Watanabe, et al., 2014). The activity of RFP and the distal regions of RF (RFD) as a bi-articular muscle is affected by various hip and knee joint angles during walking (Savelberg & Meijer, 2004).

Previous studies showed that hip and knee joint range of motion was reduced during gait in older adults (Kirkwood, Gomes, Sampaio, Culham, & Costigan, 2007). Aging impairs the control of lower-extremity motion during the swing phase and increases the risk of falls (Tanimoto, et al., 2017). Older adults often show reductions in the swing duration and lower-extremity joint motions to prevent falling (Hahn & Chou, 2004). Furthermore, the impairment of lower-extremity kinematics during the swing phase increases the risk of falls in older adults (Kobayashi, Hobara, Matsushita, & Mochimaru, 2014; Watanabe, 2018). The baseline of an age-related decline of lower-extremity motion in healthy older adults is a decrease in knee extensor neuromuscular activity (Reid, et al., 2014).

Neuromuscular activation of the RF muscle to control knee extension and flexion movements within the swing phase is necessary (Tanimoto, et al., 2017). Also, resistance exercise increases electromyography (EMG) activity of RF and vastus lateralis muscles and improves functional activities in young and old subjects (Aagaard, Suetta, Caserotti, Magnusson, & Kjaer, 2010; Angst, et al., 2015). The researchers reported that resistance exercise increases muscle force production in older adults (Angst, et al., 2015; Carroll, Barry, Riek, & Carson, 2001; Mayer, et al., 2011). Moreover, resistance training recruits muscle fibers and increases motor function in older adults (Bellew, 2002; Carroll, et al., 2001; Mayer, et al., 2011).

Muscle activation between younger and older adults is not the same (Aagaard, et al., 2010). In addition, the age-related declines of lower-extremity muscle activity at different lower-extremity joint angles (Savelberg, et al., 2004) and neuromuscular activities of RFD and RFP in the swing phase are different (Watanabe, et al., 2012). Also, the regional activity of the RF muscle on weight loading while walking in older adults had never been clarified. Therefore, the purpose of the present study was to determine the acute effects of ankle weight loading on the regional RF muscle activity and lower-extremity joint angles during walking in older adults. Regarding previous studies (Watanabe, et al., 2012), the superiority of increased RFP activity in the swing phase could have induced increases in hip flexion and improvements in gait variables in older adults. Thus, we hypothesized that RFP activity would be increased with weight loading and lead to improved older adults' lower-extremity kinematics while walking.

Methods

Participants

Twenty-nine healthy older adults (female: 22, male: 7; age: 67.96±6.86 years, body height: 157.63 ± 8.48 cm, body weight: 53.78 ± 9.04 kg, body mass index: 21.55 ± 2.38 kg/m^2) participated in this study at the Neuromuscular Biomechanics Lab of Chukyo University. The participants gave written informed consent after receiving a detailed explanation about the purposes, potential benefits, and risks of their participation. The older adults who had no medical limitations to the exercise were included as healthy participants and recruited in the local community center in Nagoya city. All the participants were without a history of musculoskeletal or neurological disorders, and none had any exercise limitation advised by a physician. All study procedures were conducted according to the Declaration of Helsinki and the research code of Ethics of Chukyo University, and were approved by the Committee of Human experiment at Chukyo University (2019-002).

Experimental design

Before starting the experiment, the preferred gait speed of subjects was measured while walking a distance of 10 m normally on flat ground. The subjects walked on a treadmill (TAKEI S-16075, Takei Kiki Kogyo Co., LTD, Japan) at their preferred gait speed in two trials for 150 s per trial. We used a harness attached to a belt around the participant's waist to prevent falling. Before the start of walking, lower-extremity joint kinematics were captured in a standing position for 5 s. The subjects were familiarized with walking with and without weights on a treadmill for 30 s before starting each trial. Neuromuscular activation of the RF muscle and lower-extremity kinematics were recorded in every trial. The left lower extremity was used to record RF activity and joint kinematics in all trials based on the measurement in the sagittal plane. We recorded muscle activity and joint kinematics 30 s after starting the trial with/ without weight loading. Also, we synchronized EMG and motion capture systems 30 s after recording data. A five-minute rest interval was given between each trial. We applied the weights above the ankle for both legs in the trial with weight loading. The amount of weight loaded was selected from 0.5, 1, 1.5 and 2 kg approximated to 2% of body weight for each participant, determined as the maximum load with which the participant could walk normally on a treadmill. We decreased the weight load and speed of walking when participants experienced difficulty in the familiarization stage of walking on the treadmill.

Lower-extremity kinematics

A three-dimensional motion capture system with six cameras coordinated by reflective markers on the left lower extremity in the sagittal plane with a sampling rate of 100 HZ was used (Vicon Bonita3, Vicon Motion Systems Ltd., Oxford, United Kingdom). Reflective markers were attached on the left acromion, greater trochanter, lateral femoral condyle, lateral malleolus, fifth metatarsal, toe, and center of the heel. Toe and heel markers were used to detect toe-off and heel contact. Vertical coordinates of the toe and heel were measured before walking in the standing phase to detect heel contact and toe-off timing.

We determined the timing of heel contact as the start of the stance phase minus vertical coordinates and that of toe-off as the start of the swing. The detected coordinates for each marker in the sagittal plane were filtered using a fourth order Butterworth low-pass filter (6 HZ). Also, we synchronized EMG and motion capture data using an infra-radiation light-emitting diode with electrical signals.

Surface EMG recording

Neuromuscular activity of the RF muscle in the left lower extremity was recorded using surface EMG. The electrodes were attached along a line between ASIS and the midpoint of the superior pole of the patella. The bipolar surface Ag/Agcl (Dual electrodes, 15770 N, Greenway-Hayden Loop, Scottsdale, AZ 85260, Noraxon, USA, Inc.) electrodes were placed at 20% and 50% from ASIS along the line for RFP and RFD, respectively. The inter-electrode distance was 20 mm and input impedance exceeded 200 Ω. The sampling rate was 1000 HZ and the signals were filtered with a 4th order Butterworth filter (band width 20-400 Hz) (FA-DL-141, 4 assist, Tokyo, Japan). We shaved the skin on the location of the electrodes, cleaned it with alcohol, and attached the electrodes for RFP and RFD along a line with a common reference electrode on the left iliac crest. Also, we confirmed the electrode locations and muscle activity with isometric contractions of muscles.

Data analysis

Neuromuscular activity levels of RFP and RFD and hip, knee, and ankle joint values in the sagittal plane were dependent variables. The average rectified values (ARV) of RFP and RFD were analyzed in ten consecutive gait cycles for 120 s after starting each trial for the left lower extremity. ARV of RFP and RFD were normalized by maximum values of ARV during a gait cycle and mean ARV calculated for each 5% of ten gait cycles. The hip joint angle was defined between the greater trochanter of the femur and along the trunk and thigh as hip joint flexion, the knee joint angle was between the lateral condyle and along the thigh and shank as knee flexion, and the ankle joint angle was between the lateral malleolus and condyle of the fifth metatarsal bone as ankle dorsiflexion. The trunk angle was defined between the trunk alignment and vertical axis as the trunk forward flexion angle. Also, the thigh angle was between the anterior side of the thigh and the horizontal axis as the thigh flexion angle.

Statistical analysis

Data analysis was performed using SPSS (version 20, Tokyo, Japan). We assessed the distribution of data using the Kolmogorov-Smirnov test and analyzed data with nonparametric tests. Also, we compared the acute effect of weight loading on RFP and RFD muscle activity, and hip, knee, ankle, trunk, and thigh joint angles with the Wilcoxon rank sum test between two trials. Every gait cycle was divided into twenty 5% segments and the start and end of every gait cycle were determined as 0 and 100%, respectively. The significance level was set at 0.05.

Results

There were no significant differences in gait parameters between with and without weight loading, with trials shown in Table 1 ($p>.05$). The average amount of weight loaded was 0.019 ± 0.002 kg and the preferred gait speed was 4.68 ± 0.62 (km/h). The mean ARV of RFP in 70% of the gait cycle with was greater than without loading ($p<.05$) (Fig. 1). There were significant differences between trials in mean ARV of RFP at 10, 20, and 95% of the gait cycle ($p<.05$) (Fig. 1) and mean ARV of RFD at 20-30 and 75% ($p<0.05$) (Fig. 2). Mean ARV of RFP with weight loading was more than that of RFD at

Table 1. Gait parameters during walking with and without weight loading

	With loading	Without loading	p-value
Cadence (Step number/min)	127.33 ± 7.47	125.52 ± 18.68	0.059
Toe off timing (%)	63.30 ± 1.62	63.70 ± 2.02	0.125

Note. p<.05 is significant.

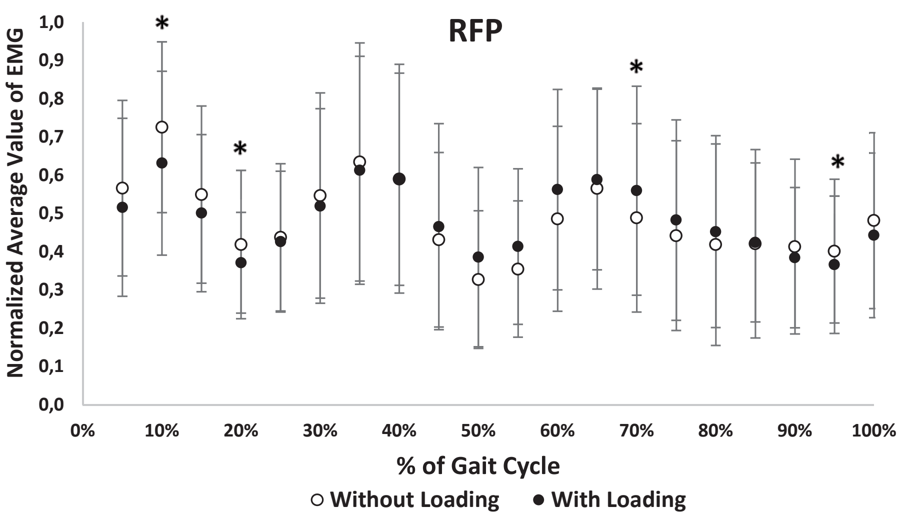

*Fig. 1. Mean normalized absolute rectified values (mean and standard deviation) of the proximal region of the rectus femoris (RFP) muscle during walking with and without weight loading. * indicates p<.05.*

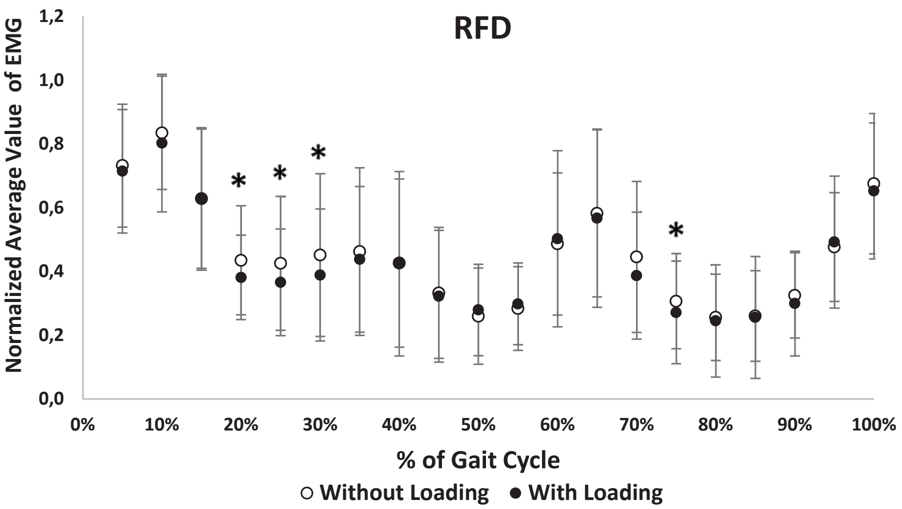

*Fig. 2. Mean normalized absolute rectified values (mean and standard deviation) of the distal region of the rectus femoris (RFD) muscle during walking with and without weight loading. * indicates p<.05.*

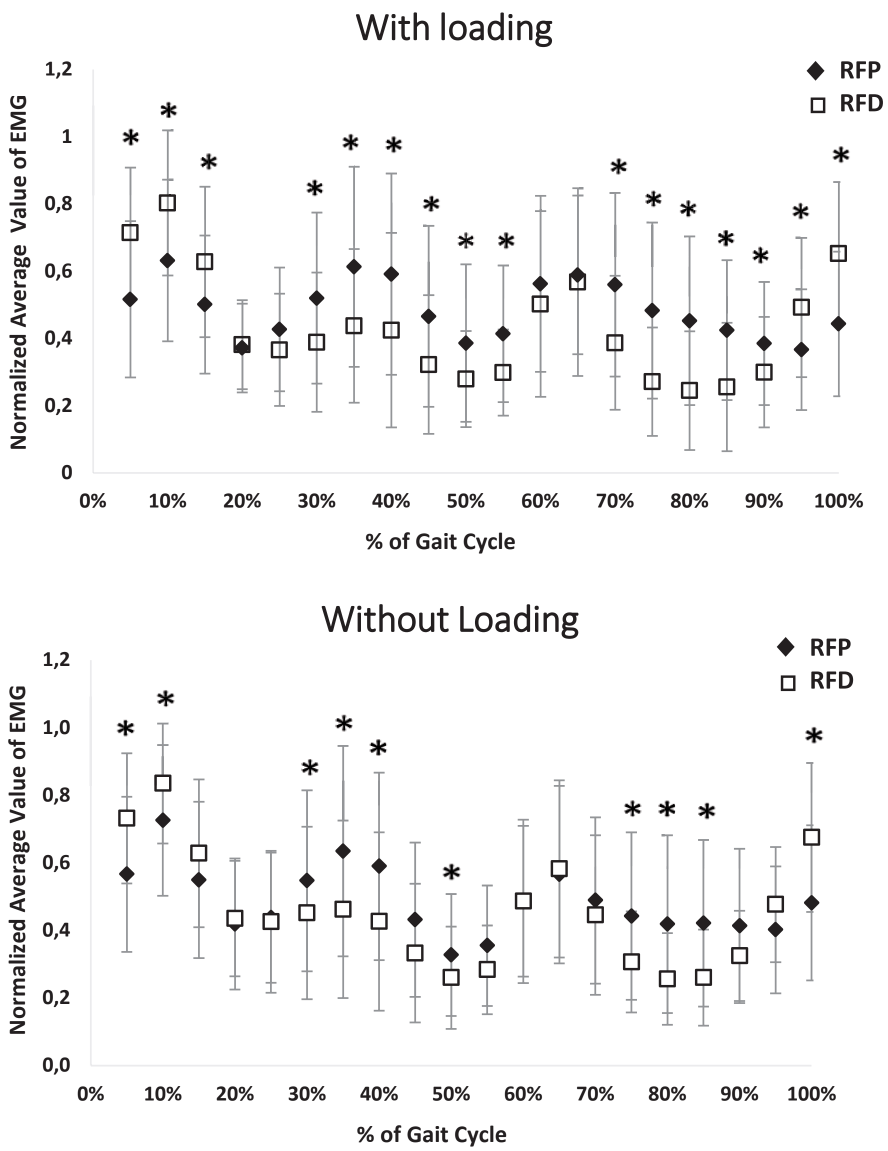

*Fig. 3. Mean normalized absolute rectified values (mean and standard deviation) of the proximal (RFP) and distal (RFD) regions of the rectus femoris muscle during walking with and without weight loading. * indicates p<.05.*

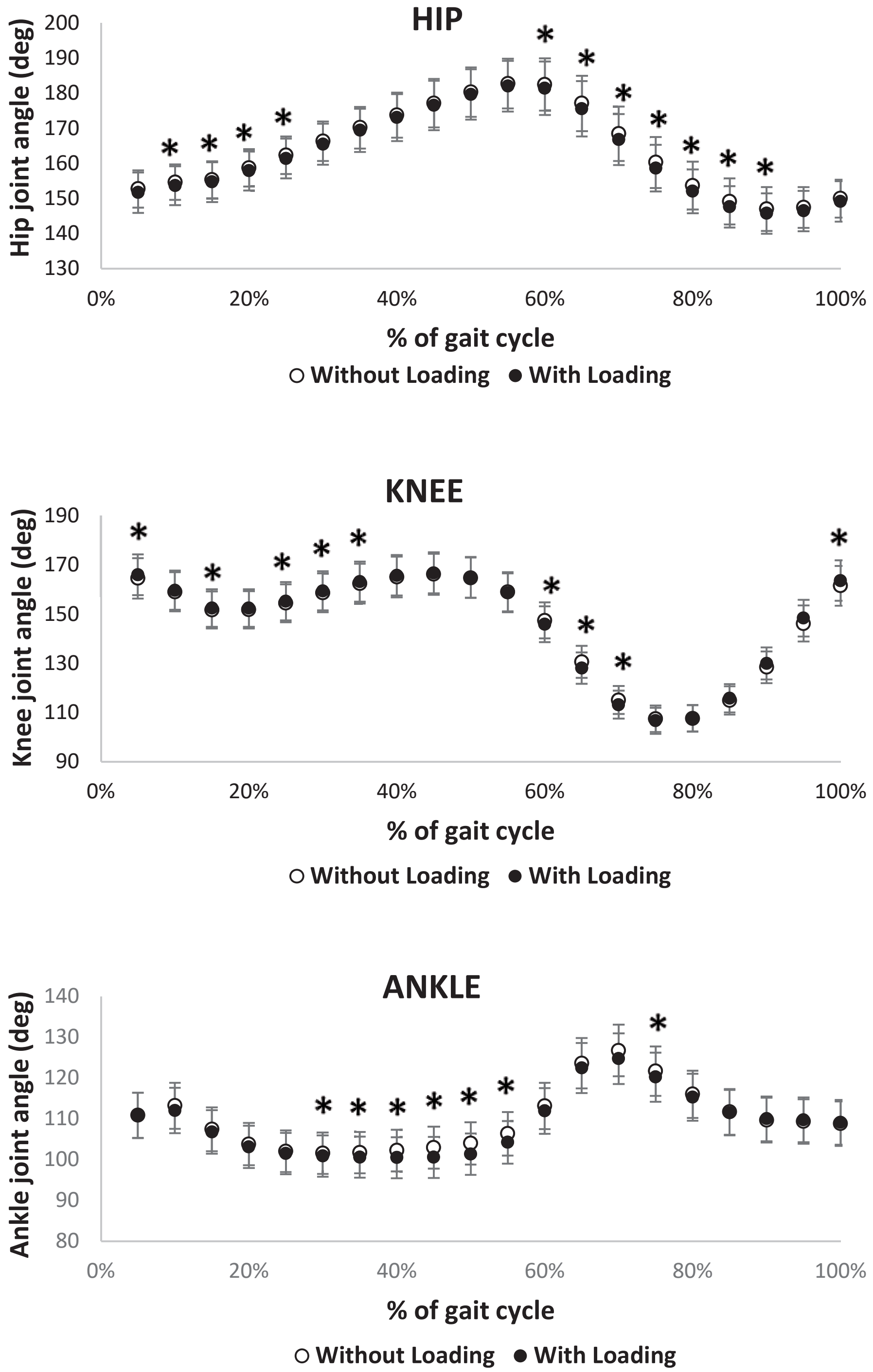

Fig. 4. Hip, knee, and ankle joint range of motion (degrees) in the sagittal plane during walking with and without loading.
** indicates p<.05.*

30-55 and 70-90% of the gait cycle ($p<.05$) (Fig. 3). Mean ARV of RFP at 30-40, 50 and 75-85% of the gait cycle was more than that of RFD during walking without weight loading ($p<.05$) (Fig. 3). Mean ARV of RFD with weight loading was more than that of RFP at 5-15 and 95-100% ($p<.05$) (Fig. 3). Mean ARV of RFD without weight loading was more than that of RFP at 5-10 and 100% ($p<.05$) (Fig. 3).

There were significant differences in knee joint angles at 25-35 and 60-70, 5, 15 and 100% of the gait cycle between the trials ($p<.05$) (Fig. 4). There were significant differences in hip joint angles at 10-25 and 60-90% and ankle joint angles at 30-55 and 75% between the trials ($p<.05$) (Fig. 4). Hip joint angle ($p=.32$) and thigh angle ($p=.13$) changes were not significant between the trials. Also, trunk angle changes were significant between the trials ($p=.013$).

Discussion and conclusions

The increased resistance enhances the RF muscle activity level in the swing phase during walking on a treadmill in young subjects (Klarner, Blouin, Carpenter, & Lam, 2013). According to our results, the acute use of weight loading during walking could not increase the neuromuscular activity of RFP except at 1% of the gait cycle (Fig. 1). We suggest that the increased activity of RFP at 1% of the gait cycle is negligible and it is inappropriate to come to any conclusion regarding the acute effect of weight loading on RFP activity. The weight load approximating to 1% of the body weight increased gluteus medius activity and improved the quality of walking (Hwang, et al., 2017). Gluteus medius muscle activity with weight loading of 2% was lower than that with 1%, although trunk stabilizer muscle activity was increased with a loading of 2% (Lee, 2013). Thus, there was no positive relationship between increased resistance and muscle activity; it was dependent on the muscle function and direction of the applied resistance (Lee, 2013; Simpson, Munro, & Steele, 2011). In our study, the load was set at 2% of the body weight based on the capability of older adults to walk normally on a treadmill. We suggest that the load was too low to induce significant acute effects on RF muscle activity and, applying such a large load acutely during walking on a treadmill would be difficult for older adults.

Previous findings showed that RFP activity is greater than RFD activity during hip flexion, and RFD activity is greater than RFP activity during knee extension (Watanabe, et al., 2012). Our findings confirmed these results with more detailed data, whereby RFP activities from mid-stance until toe-off (30-55%) and early swing to terminal swing (70-95%) with weight loading were greater than those of RFD (Fig. 3). Neuromuscular activity of RFP without weight loading in pre-swing and mid-swing (30-40, 55, 75-85%) was greater than that of RFD (Fig. 3). It was shown that weight loading more markedly increases RFP activity related to RFD on contraction during gait phases. In pre-swing, when the elevation of the lower extremity demanded marked hip and knee joint flexion, there was no significant difference between the RFP and RFD activity levels (Whittle, 2008). The central nervous system primarily activates the quadriceps femoris muscle during knee flexion in pre-swing and, along with it, quadriceps muscle activity is reduced to extend the knee (Shields, et al., 2005).

Moreover, RFD activity levels with weight loading were greater than those of RFP at the start and end of the gait cycle (0-15 and 95-100%) (Fig. 3). The main function of the RF muscle is the transmission of the lower extremity from stance to swing via changing RFP and RFD contractions. Therefore, it is not possible to completely separate the function of the two regions of the RF muscle. Regarding the importance of the effect of the RF muscle function on the two joints, RFP and RFD activity levels for both joints based on the demand during gait phases should be optimized. RFP and RFD activity levels at more specific percentages of gait phases were increased (Fig. 3), and weight loading could coordinate RF contraction regionally based on the demand in gait phases. Miyamoto, Wakahara, and Kawakami (2012) reported that RFP and RFD activities were increased similarly during knee extension, but RFD was not completely activated during hip flexion (Miyamoto, et al., 2012). Our findings support these results and reveal that RFP was higher than RFD neuromuscular activity in larger percentages of the gait cycle from early swing to terminal swing and mid-stance until toe-off. We clarified that RFP and RFD activity levels at the beginning and end of the gait cycle during knee extension were not similar in either phase. Therefore, our results did not support the presence of similar increases in RFP and RFD activities during knee extension.

From a biomechanical perspective, hip joint flexion should be increased in mid-swing to elevate the lower extremity and move the swinging limb forward in relation to the stance limb accompanied by increased knee joint flexion (Whittle, 2008). In our study, the hip flexion angle with loading was increased in the stance (10-25%) and swing (60-90%) phases (Fig. 4). The maximum performance demand on the hip and knee extensor muscles during walking was increased with aging, and older adults showed higher rates of falling and injury (Samuel, Rowe, & Nicol, 2013). Our results showed that weight loading increased the hip flexion angle in specific percentages of gait phases to guide the body forward and elevate the lower extremity. After further analysis of thigh and trunk joint angle data, we found that the thigh angle was not increased but that the trunk flexion angle was increased with weight loading. Therefore, we suggest that older adults adjusted their specific kinematics with activating hip flexors such as the psoas and abdominal muscles. Although we did not measure the activity of these muscles, the increased trunk flexion angle suggests the contribution of hip flexors to the increased hip flexion angle. Thus, the increased hip flexion angle that we observed could have been the result of the contributions of the abdominal and psoas muscles.

Changing the knee and hip joint angles during lower-extremity movements affects the activation of synergist muscles of the trunk and pelvis (Narouei, Imai, Akuzawa, Hasebe, & Kaneoka, 2018). When hip and knee muscles are weak, synergist muscles will be activated during walking to control lower-extremity movement and compensate for function deficiency (Whittle, 2008). RFP was activated in older adults to a lesser extent than in young subjects during walking (Watanabe, Kouzaki, & Moritani, 2016). Although we instructed participants to walk normally and used proper feedback to control the normal kinematics, it was not possible to completely avoid muscle co-activation. The participants flexed their trunk to prevent instability and falling during walking with weight loading. Therefore, we suggest that future studies should evaluate abdominal muscle activity during walking after an intervention period with weight loading. The knee extension angle was increased with weight loading in the stance phase (25-35%), and at the beginning and end of the gait cycle (5, 15 and 100%) (Fig. 4). Resistance training improved the dynamic control and stability of the knee joint during gait (Shields, et al., 2005). Our results confirmed that weight loading improves knee extension during walking in older adults. These results are useful to prevent falling and reduce limitations of knee movement for application in rehabilitation clinics. Also, the ankle dorsiflexion angle with weight loading was increased during the stance and swing phases (30-55 and 75%) (Fig. 4). Although we applied weight loading above the ankle, ankle dorsiflexion was increased to improve foot clearance in toe-off. These results showed that weight loading improves lower-extremity joint kinematics during functional movement.

There were some potential limitations in this study. Greater levels of weight loading may provide clearer results on RF activity (Washabaugh, Augensteina, & Krishnan, 2020; Simpson, et al., 2011), but there were limitations on the weight that could be loaded for older adults during walking on the treadmill. Also, the left lower extremity was assessed in the sagittal plane in twenty-nine older adults; no determination of the differences between the right and left lower extremities and the small sample size could be the other limitations in our study. Moreover, our purpose was to determine the regional activity of RFP and RFD. We did not evaluate the neuromuscular activity of the psoas and trunk muscles, despite the fact these muscles flex the hip during walking. Psoas muscles are the main hip flexors in the swing phase and abdominal muscles are the trunk stabilizers during walking. Due to the contribution of different muscle groups to walking, focusing on changes in the activity of a single muscle activity is difficult. We recommend that future studies investigate the regional activity of the RF muscle regarding co-activation between muscles during walking.

Ankle weight loading increased the neuromuscular activity level of RFP relative to that of RFD in stance and swing phases and RFD activity level relative to that of RFP in early stance and terminal swing phases in more specific percentages of gait phases. Also, ankle weight loading increased knee extension and ankle dorsiflexion angles. Neuromuscular activation and biomechanical changes in our study revealed that weight loading could be useful to guide rehabilitation treatment methods that involve applying ankle weight loading during walking prescribed to improve RF regional activity and range of motion of the knee. We recommend more investigations on the effect of using ankle weight loading in functional rehabilitation programmes since it may prevent limitation of motion and reduce walking impairments in older adults.

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FREE WEIGHT TRAINING VS. ELASTIC BAND TRAINING: WHAT IS A MORE EFFECTIVE STRATEGY FOR INCREASING MAXIMAL VELOCITY ABILITY DURING HANDBALL THROWS?

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Abstract:

The aim of this study was to assess the effectiveness of two resistance training (RT) programmes (free weight [FW] and elastic band [EB]) on velocity variables (handball throwing velocity [HTV] and maximal theoretical velocity [V_0]) using load-velocity (L-V) relationship modelling. Both programmes lasted 6 weeks and consisted of performing bench press and overarm dumbbell pull-over using free weights (FW group) or elastic bands (EB group). Nineteen male sports science students were randomly assigned to EB (n=10) or FW group (n=9). Both RT programmes increased HTV and V_0, although the increment was greater in the FW (>2 m·s^{-1}) compared to the EB group (<1 m·s^{-1}). RT programmes had selective effects on the strength variables being FW more effective in increasing 1-repetition maximum, while EB in increasing maximal isometric force. Very large correlations were observed between two-point (L-V relationship modelled through two pairs of L and V data) and multiple-point methods (L-V relationship modelled through six pairs of L and V data) (V_0: r=0.96; HTV: r=0.93). All coefficients of variation showed high validity both for V_0 and HTV (≤6.2%). Altogether, FW training should be used for increasing the velocity of the throwing performance, while the two-point method for following training-induced changes.

Key words: *load-velocity relationship, resistance training, two-point method*

Introduction

Overhead handball throwing is a complex, discrete, fast movement and the key technical element for successful handball performance (Cuevas-Aburto, Janicijevic, Pérez-Castilla, Chirosa-Ríos, & García-Ramos, 2020; Saavedra, Halldórsson, Kristjánsdóttir, Þorgeirsson, & Geir, 2019). The handball throwing velocity (HTV) has been identified as the crucial variable that can distinguish between skilled and less skilled handball players (Alves & Marques, 2013). It is not surprising then that many researchers have been trying to find the optimal training procedure for increasing HTV. It has been suggested that even short resistance training (RT) programmes are effective at improving throwing ability of different athletes (Baena-Marín, et al., 2022). Many variables should be taken into consideration when programming RT, such as intensity, volume, frequency of training sessions, order of exercises, duration of the rest periods, etc. (Grgic, Schoenfeld, Skrepnik, Davies, & Mikulic, 2018; Mangine, et al., 2015; Wilk, Zajac, & Tufano, 2021). However, there is another variable that is less frequently considered but can significantly influence the outcomes of the RT programmes and it is the type of resistance.

Specifically, previous studies have shown that RT programmes of similar characteristics (i.e., a similar number of repetitions and sets, relative load, and pauses between repetitions) performed using different resistance types led to different musculoskeletal adaptations (Andersen, Fimland, Kolnes, & Saeterbakken, 2015; Rivière, Louit, Strokosch, & Seitz, 2017; Shoepe, Ramirez, & Almstedt, 2010). Nevertheless, free weights (FW) are the most frequently used resistance type for increasing HTV as their utility have been confirmed in many previous studies (Chelly, Hermassi, & Shephard, 2010; Gorostiaga, Izquierdo, Iturralde, Ruesta, & Ibáñez, 1999; Hermassi, Chelly, Fathloun, &

Shephard, 2010; Marques, van den Tilaar, Vescovi, & Gonzalez-Badillo, 2007). To our knowledge, only Cuevas-Aburto et al. (2020) reported that neither FW nor ballistic bench press (BP) RT programme were effective in increasing HTV. Although it is certainly useful and oftenly used RT type, its effectivness should be compared to the other less frequently implemented RT programmes.

For example, another training type frequently used for improving HTV and generally as a part of the strength and conditioning routine is RT using elastic bands (EB) (Bauer, Schwiertz, & Muehlbauer, 2021). Although fewer studies explored the effectiveness of the EB RT on the HTV, their general conclusion was that EB RT programmes were also a feasible solution for incrementing HTV. Of note, only Andersen, Fimland, Cumming, Vraalsen, and Saeterbakken (2018) found no differences in the magnitude of HTV between the control (i.e., the group that performed regular handball training) and the experimental EB group (i.e., the group that performed regular handball plus additional EB training). The possible reason why Andersen et al. (2018) did not find any difference between the control and experimental group might be due to the very general nature of exercises implemented in the experimental group (i.e., six different whole-body exercises). Although the majority of the studies have demonstrated increments in HTV following the EB RT, it is still not clear which characteristics of one EB RT programme should be present to most efficiently increase HTV. And most importantly it is not known whether EB RT is a more effective strategy for increasing HTV than FW RT, or vice versa, although there are some indications that FW could be somewhat more effective for increasing maximal strength, while EB for maximal power development (Djuric, et al., 2016).

Although HTV has been shown to be an important predictor of successful handball performance (Raeder, Fernandez-Fernandez, & Ferrauti, 2015), previous studies have suggested that there is a method that allows assessing the velocity ability of the overhead throwing activity more comprehensively (Sreckovic, et al., 2015). Specifically, Garcia-Ramos et al. (2018c, 2019) and García-Ramos and Jaric (2018) demonstrated that the load-velocity (L-V) relationship modelled using two (i.e., two-point method) or more pairs of loads (multiple-point method) and corresponding velocities were a valid and reliable methods for exploring the maximal theoretical velocity ability during multi-joint movements. This means that recording the throwing velocity performed against two or more different weights allows not only exploring the effectiveness of different training protocols on the HTV (i.e., estimating the velocity associated with the handball ball weight) but also on the maximal theoretical velocity (V_0; intercept of the L-V with the x-axis). However, to our knowledge, no study has explored the possibility of assessing HTV and V_0 using L-V relationship modelling following different RT types.

Therefore, our main aim was to assess the effectiveness of the two most commonly used RT programmes (FW and EB) on velocity variables (HTV and V_0) through the assessment of the L-V relationship. Our additional aims were: (1) to explore the effects of FW and EB training programmes on the strength variables (i.e., maximal isometric force [Fmax] and bench press 1-repetition maximum [BP 1RM]) since the L-V relationship modelling is not a reliable procedure for exploring maximal theoretical force and power characteristics of throwing activity (based on our unpublished laboratory data) (Marques, et al., 2007), (2) to explore the validity of the two-point method with respect to the multiple-point method for detecting changes in HTV and V_0. We hypothesized that (1) both training programmes will increase the velocity ability, while this increment will be more accentuated in the FW group, (2) both FW RT and EB RT will increase HTV and V_0, although it is not known which RT type will provoke higher increments, and (3) V_0 and HTV will not be systematically different when obtained using two- and multiple-point methods.

Methods

Participants

Nineteen male sports science students were randomly assigned to either the EB group (n= 10, age = 20.7 ± 1.1 years, body mass = 77.5 ± 5.2 kg, body height = 1.82 ± 0.39 m) or FW group (n= 9, age = 22.1± 1.5 years, body mass = 84.5 ± 12.7 kg, body height = 1.84 ± 0.87 m). All participants were healthy and physically active in a minimum of 10 hours of moderate physical activity per week. They have completed the mandatory curricular course in handball during which they acquired an advanced level of specific handball throwing technique. They completed the study experimental protocol without missing any session and were instructed not to perform additional upper-body strength training over the course of the study. None of them had any arm injury that could have compromised training and testing protocols, nor were they former or present handball players. Participants were informed about research purposes, procedures, and gave their written consent before the start of the study. The study protocol adhered to the Declaration of Helsinki and was approved by the University Review Board (Approval number: 02-1550/20-1).

Study design

This study aimed to compare the effects of two different RT programmes on the maximal velocity ability of the arm muscles involved in handball throws and to explore the validity of the two-point method with respect to the multiple-point method for assessing changes in HTV and V_0. For this purpose, participants were randomly assigned either to the FW training group or EB training group. Both training programmes lasted six weeks and were performed in the same faculty gym. All participants came to the laboratory for 18 training sessions (i.e., three sessions per week). The main difference between the training programmes was in the type of resistance (free weight *vs.* elastic bands), while the movement patterns of the exercises were similar for both groups (i.e., the FW group performed bench press and overarm dumbbell pull-over against free weight, while the EB group performed the same exercises using elastic bands). In order to evaluate the effects of the different training programmes, the pre-test was organised a week before the first training session, while the post-test was performed a week after the last training session. Testing protocols consisted of measuring maximal isometric overarm pull, recording throwing velocity against six medicine balls that weighted from 0.5 to 3 kg, and determining BP 1RM.

Procedures

Both pre-RT and post-RT testing sessions were performed in the university research laboratory. Upon the entrance to the laboratory, the participants' height and body mass were measured, which was followed by the general warm-up consisting of five minutes of cycling, three sets of 10 push-ups and 10 minutes of calisthenics and dynamic stretching (Cuevas-Aburto, et al., 2020; Markovic, Suzovic, Kasum, & Jaric, 2016). After the warm-up, participants had a 5-minute rest before the testing protocol, which was organised in the following order:

– *Maximal isometric overarm pull-over.* This test was used for assessing the maximal voluntary isometric force ability (Fmax) of the arm muscles involved in the handball throw. Participants performed this test lying on their back on a flat bench, while their feet were resting on the floor. They were holding a metal extension of the dynamometer having their arm abducted and flexed in the elbow joint at 90° (i.e., the typical position of the handball throw). The hand was positioned 5-cm below the horizontal edge of the bench. Participants were instructed to maintain their arm in the initial position and relaxed until the same experienced researcher gave an instruction to perform a maximal voluntary isometric contraction (i.e., the maximal force of the muscles involved in throwing activity against an immovable resistance). The given instruction was to perform the described action as strongly and as quickly as possible during a period of 3-5 seconds (Wilson & Murphy, 1996). Participants performed one probatory attempt and two experimental attempts. The rest between two consecutive attempts was two minutes (Suzovic, Nedeljkovic, Pazin, Planic, & Jaric, 2008), while the attempts performed using an incorrect technique (i.e., lifting the elbow, etc.) were repeated. The attempts with greater muscle force were selected for statistical analyses.
– *Handball throwing test.* This test was used for exploring the maximal velocity ability of the participants. The test consisted of performing a basic overhead handball throw against six Thera Band Balls (standard men circumference), that weighted 0.5, 1.0, 1.5, 2.0, 2.5, and 3 kg. The actual testing started with a specific warm-up that consisted of five submaximal handball throws of the standard weight handball (0.425-0.475 kg and circumference 56-58 cm). Later, in a randomised order, participants performed three maximal handball throws with each ball (18 throws in total). The first throw with each ball was considered a probatory trial, while the two other throws were considered as experimental trials. The handball throw test was performed in the seated position with the extended legs, while the back of the participants was leaning on the hard, immovable support (see Figure 1 for the experimental set-up). The ball was thrown always with the dominant arm. The technique of the handball throw was considered correct if the participants kept their body still and used only their arm to throw the ball as powerful as possible after hearing the instruction "Go!". The pause between two consecutive throws was 30 s. The velocity of the ball was recorded using three cameras for kinematic analysis of the movement. A single reflective marker was positioned on the participant's dominant hand (at the *styloid process of the ulna*). The velocity data recorded during the fastest throw for each ball were later used for the L-V modelling. The trials were repeated in case of an incorrect throwing technique (e.g., having the elbow of the throwing arm lower than the shoulder line, moving the non-throwing arm, throwing the ball to the wrong direction, etc.) or if the participants separated their back from the back

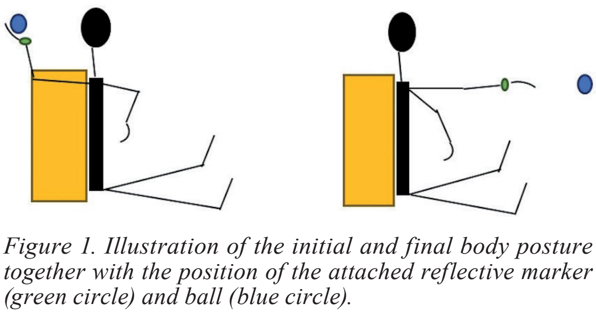

Figure 1. Illustration of the initial and final body posture together with the position of the attached reflective marker (green circle) and ball (blue circle).

support during the throw. The Doppler-radar gun (Sports Radar 3300, Sports Electronics) was used for providing velocity feedback since previous studies showed that it increased the motivation of the participants (Marques, et al., 2007; van den Tillaar & Marques, 2009).

– *Bench press 1-repetition maximum (BP 1RM).* BP 1RM was evaluated in a Smith machine following a standardized protocol (for more details see García-Ramos, et al. 2018d). The initial load was 35 kg for all participants, while the participants were encouraged to self-select the grip width. The load was increased by 10 kg until the mean concentric velocity did not reach 0.50 m·s^{-1} after which the load continued to be increased by 5-1 kg until the 1RM load was reached.

Training procedure

All the training sessions were completed in the faculty gym. Each training session started with the same warm-up (10 minutes of jogging at a self-selected pace, dynamic stretching, and three sets of 10 push-ups). The training programme consisted of 18 training sessions (three sessions per week), and it was supervised by the same experienced researcher. The specificities of the two resistance training programme are described below.

– *Free weight training group (FW group).* The participants from this group performed two exercises: bench press and dominant overarm dumbbell pull-over. The specific warm-up consisted of two sets of 10 repetitions at the intensity of 50% of individually determined BP 1RM (Sabido, Hernández-Davó, Botella, & Moya, 2016) and overarm pull-over. Participants were thereafter instructed to complete six sets of 10 repetitions of each exercise. The initial load for the BP was approximately 50% of the previously determined individual 1RM and was progressively increased each week, reaching approximately 60% in week two, 64% in week three, 68% in week four, 73% in week five, and 78% in week six. The initial load for the dominant overarm dumbbell pull-over was 4-kg for each participant, and was increased to approximately 5-kg week two, 5.6 kg in week three, 6.4 kg in week four, 7.1 kg in week five, and 7.8 kg in week six. The instruction given to the participants was to perform the concentric phase of the movement as rapidly as possible.

– *Elastic band training group (EB group).* Participants performed the overarm pull-over and BP exercises using resistive elastic bands. They were always using 1.2 m elastic bands that were attached to the wall with a free end. Both exercises were performed seated, with the elastic bands extended 15 cm at the initial position. The final position corresponded to the end of the movement (i.e., for overall pull-over the final position was the same as the final position of the arm during the handball throw [~90 cm], while the final position during BP was complete extension of both arms [~60 cm]. Resisting elastic force of the used elastic bands was increased from week to week. Initially, the elastic bands had resistive forces that corresponded to approximately 40% of the individual maximal force recorded during isometric overarm pull-over and isometric bench press. Then the resistance of the elastic bands was increased every week, corresponding to ~50% during week two, ~54% during week three, ~58% in week four, 62% in week five, and 66% in week six. They were performing exercises using the same elastic band until they could complete six series of 10 repetitions. At that moment, the elastic band was changed, and from the next training, they were performing exercises with the elastic band with a greater resistive force.

Data acquisition and analysis

Maximal isometric force during the overarm-pull was measured using the isokinetic dynamometer (Kin-Com Chatex Corp., Chattanooga, TN). The force-time curves were recorded at 500 Hz and low-pass filtered (10 Hz) applying the second-order (zero-phase lag) Butterworth filter (Sports Medical Solutions system Isometricus, SMS, All 4 Gym, Belgrade, Serbia). The force was directly recorded and the trial with the highest force value was used for statistical analyses. The velocity of the handball throw was recorded using the Qualisys Track Manager program package with 3D motion recording cameras (Qualisys Pro Reflex MCU120 Motion Capture System, Sweden). Later on, the obtained velocity and the actual weights of the balls thrown were used for L-V modelling (Garcia-Ramos, et al., 2018a).

Statistical analyses

Descriptive data are presented as means and standard deviations (SD). Shapiro-Wilk test confirmed the normal distribution of HTV, Fmax and 1RM BP (p>.05). Between-within ANOVA with training group (FW vs. EB) as between- and time (pre-RT intervention vs. post-RT intervention) as within-participant factors was applied on the HTV, V_0 parameter, Fmax, and 1RM BP. In case of significant differences, *post-hoc* paired t-tests with Bonferroni corrections were used, while the Cohen's *d* effect size (ES) was used to evaluate the magnitude of the differences. The standard error of the estimate (SEE) expressed in absolute and relative values (coefficient of variation; CV%) were used to explore the validity of the two-point method with respect to the multiple-point method and also the validity of the two-point and multiple-point method for estimating HTV. The level of validity was defined as high and acceptable when the CV% was ≤ 5% and ≤ 10%, respectively (James, Roberts, Haff, Kelly, & Beckman, 2017). The scale used to interpret the magnitude of the ES was specific to training research: negligible (< 0.20), small (0.20–0.49), moderate (0.50–0.79), and large (≥ 0.80) (Cohen, 1988). All statistical analyses were performed using SPSS software version 20.0 (SPSS Inc., Chicago, IL, USA) and statistical significance was set at an alpha level of 0.05.

Results

Velocity ability (V_0 and HTV)

Between-within ANOVA performed on V_0 revealed significant main effect of time (F = 7.167, p≤.001) and interaction time × group (F = 5.159, p=.036), while the main effect of the group did not reach statistical significance (F = 0.010, p=.923). The significant interaction time × group revealed that the increments in V_0 were greater for the FW group (Figure 2). The overall magnitude of the differences between pre- and post- RT intervention was larger in the FW (ES = 1.34) than in the EB group (ES = 1.01). Pairwise comparisons showed that a significant increment in velocity output was achieved for all the experimental conditions and both groups, except for the handball throw-like movement pattern with the two heaviest loads in the resistance band group (Table 1). Similar results were found for HTV. The main effect of time (F = 27.574, p≤.001) and interaction time × group (F = 4.649, p=.046) were significant, while the main effect of the group did not reach statistical significance (F = 0.007, p=.936). The increase in HTV was

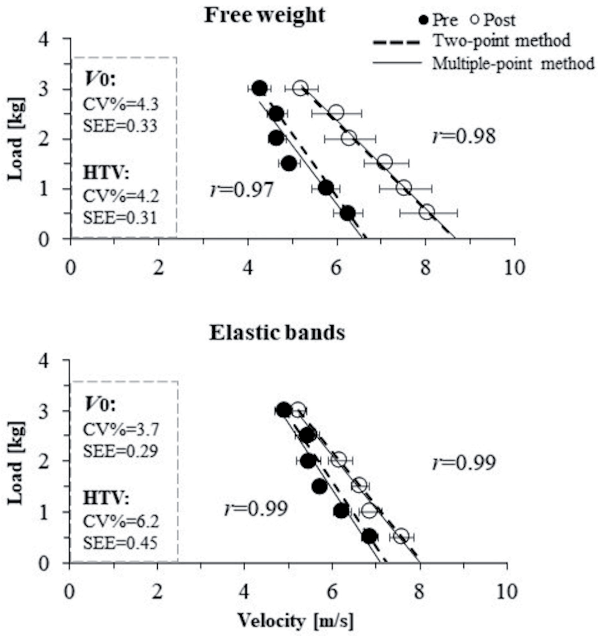

Figure 2. Load-velocity relationships of the handball throw pre (full circles) and post (empty circles) the free weight (upper panel) and elastic bands training (lower panel) modelled using multiple-point method (full line) and two-point method (dashed line). V_0, maximal theoretical velocity; HTV, handball throwing velocity; r, coefficient of correlation; CV%, coefficient of variation; SEE, standard error of estimate.

greater in the FW group (2.30 m·s^{-1}) than in the EB group (0.96 m·s^{-1}).

Strength ability (Fmax and 1RM BP)

Between-within ANOVA performed on Fmax revealed a significant main effect of time (F = 17.866, p≤.001), while the main effect of the group (F = 1.869, p=.189) and interaction time × group (F = 0.203, p=.658) did not reach statistical significance.

Table 1. Changes in peak throwing velocity outputs following the resistance training interventions

Training group	*Variable*	*Pre (ms^{-1})*	*Post (ms^{-1})*	*ES*	*p*
	V_0	6.81	9.00	1.33	**.004**
	$V_{0.5}$	6.25	8.06	1.25	**.005**
	V_1	5.76	7.55	1.30	**.003**
Free weight	$V_{1.5}$	4.97	7.11	1.96	**.000**
	V_2	4.66	6.29	1.38	**.009**
	$V_{2.5}$	4.66	6.00	1.15	**.023**
	V_3	4.26	5.21	1.00	**.029**
	V_0	7.52	8.40	1.00	**.007**
	$V_{0.5}$	6.85	7.59	0.98	**.014**
	V_1	6.23	6.88	0.86	**.011**
Elastic band	$V_{1.5}$	5.71	6.64	1.80	**.000**
	V_2	5.45	6.18	0.84	**.005**
	$V_{2.5}$	5.42	5.50	0.12	.798
	V_3	4.90	5.23	0.52	.193

Note. V_0, maximal theoretical velocity; $V_{0.5}$, velocity achieved against 0.5 kg; V_1, velocity achieved against 1 kg; $V_{1.5}$, velocity achieved against 1.5 kg; V_2, velocity achieved against 2 kg; V_2, velocity achieved against 2 kg; $V_{2.5}$, velocity achieved against 2.5 kg; V_3, velocity achieved against 3 kg; ES, effect size. Bolded numbers represent significant differences (p≤.05).

Table 2. Changes in strength outputs following the resistance training interventions

Training group	*Strength variable*	*Pre*	*Post*	*ES*	*p*
Free weight	Fmax	308 ± 182 N	360 ± 195 N	0.27	**.007**
	BP 1RM	84 ± 16 kg	93 ± 14 kg	0.58	**≤.001**
Elastic band	Fmax	215 ± 91 N	279 ± 61 N	0.84	**.019**
	BP 1RM	67 ± 19 kg	19 ± 17 kg	0.44	**.003**

Note. Fmax, maximal isometric velocity; BP 1RM, bench press 1-repetition maximum; ES, effect size. Numbers in bold represent significant differences (p≤.05).

Another between-within ANOVA performed on BP 1RM revealed a significant main effect of time (F = 46.560, p≤.001) and the group (F = 5.509, p=.031), while the interaction time × group (F = 0.119, p =.661) did not reached statistical significance. Pairwise comparisons are depicted in Table 2.

Validation of the two-point method

Very large correlations were observed between the magnitudes of the V_0 and HTV obtained between the two-point and multiple-point methods (V_0: r=0.96 and HTV: r=0.93). All CVs showed high validity for both V_0 and HTV (all CV ≤ 6.2%), while all SEE were always lower than 0.45 m·s^{-1}.

Discussion and conclusions

The aim of this study was to explore the effectiveness of the FW and EB RT programmes for the enhancement of the handball throw maximal velocity ability as well as the possibility to quickly estimate HTV and V_0 ability through the two-point method. The main findings showed the following: (1) both training methods improved maximal velocity ability, although, the magnitude of this increment was higher for the FW group, (2) the magnitude of HTV and V_0 did not differ when obtained by the two- and multiple-point methods, and (3) both training methods significantly increased strength ability of the participants, although the magnitude of the changes was small for Fmax in the FW group and 1RM BP in the EB group, moderate for 1RM BP in the FW group, and large for Fmax in the EB group. Summing up, FW is a more effective resistance type for increasing the maximal velocity ability of the arm muscles involved in the handball throw, while the L-V relationship can be confidently used for estimating HTV and V_0 through the two-point method.

Six weeks of the upper-body RT programmes significantly improved the maximal velocity ability of our participants, which is in line with previous studies applying RT programmes of similar duration (6-9 weeks) (Aloui, et al., 2019, 2021; Bauer, et al., 2021; Gorostiaga, et al., 1999; Mascarin, De Lira, et al., 2017a). However, many of the previous studies implemented RT programmes in addition to the main handball programme, and that is why Mascarin et al. (2017b) argued that it could be attributed to a generally greater training volume in groups that were involved in the additional RT programme. The main novelty of our study is that it directly compares the effectiveness of two commonly used RT programmes on HTV and V_0. What is also interesting is that we observed greater increments in HTV and V_0 following the FW RT compared to the EB RT, similarly as reported in the study by Dilshan Priyadarshana, Keerthirathne, and De Silva (2021). The possible explanation for this result may be the actual mechanics of the handball throwing movement. Specifically, when the participants performed exercises using EB, the actual loading went from lower to higher as the elastic band elongated, which is the mechanism opposite to an actual throw during which the muscles need to develop more force at the beginning of movement pattern execution compared to the end of the movement.

Both the FW and EB training modalities increased the magnitude of strength variables, although the participants belonging to the FW group incremented 1RM BP more, while the participants belonging to the EB group incremented Fmax more. These findings corroborate the hypothesis regarding the selective effect of strength training (Djuric, et al., 2016), meaning that the participants who were lifting free weights incremented their ability to lift free weights, while the participants that were experiencing isometric contractions at the end of each repetition (final part of the movement produced against EB) increased more their Fmax. Moreover, similar to previous studies (Marques, et al., 2007), increments in velocity ability in our study were not followed by the same increments in the strength ability, and vice versa. All these findings speak in favour of the necessity to explore the strength ability of the muscles involved in the throwing action separately from velocity assessment.

Confirming our third hypothesis, the two-point method showed a higher validity with respect to the multiple-point method. Previously, the two-point method has shown to be valid for exploring all theoretical maximal mechanical capacities during different multi-joint tasks (Garcia-Ramos, et al., 2018a; 2019; Janicijevic, García-Ramos, Knezevic, & Mirkov, 2019; Janicijevic, et al., 2020). However, to our knowledge, this is the first study that validated the two-point method for exploring HTV and V_0 during a unilateral throwing activity, which is very important from the testing perspective. The downside of the two-point method for throwing assessment is that it is unsuitable for assessing maximal force and power capacities since the maximal load that can be implemented during the unilateral handball throw is relatively small. This means that the maximal load applied during the testing is far from y-intercept jeopardising the reliability of maximal theoretical force and power estimation. Possible limitation of the present study is that we did not include handball players as participants, which was due to their dense schedule during the competitive season. Future studies should explore if the same methodology (i.e., two-point method) can reliably be applied for assessing HTV and V_0 of the amateur and professional handball players and whether the FW training will be a more effective strategy also in this population.

This study carries several important practical applications. Firstly, the FW RT type was found to be more effective than the EB type for increasing HTV and V_0. Secondly, the two-point method is a feasible solution for estimating HTV and V_0. In order to model the L-V relationship using two-point method, sports practitioners should record throwing velocity against two weights (i.e., a very light load [i.e., ball lighter than 0.5 kg] and the heaviest load that does not compromise the throwing technique [i.e., it will depend on the participants; 3 kg in our study]). In this manner, the two-point method will reveal both HTV and V_0, and, therefore, provide more comprehensive information about participants' velocity ability than it would be done by assessing only HTV. Thirdly, both the FW and EB interventions were more effective for increasing velocity ability against lighter loads, which can also be explored by implementing the two-point method (i.e., examining the slope of the L-V relationship; see Figure 2). Fourthly, implemented strength training programmes had selective effects on our variables—the FW training increased 1RM BP more, while the EB training increased Fmax more. Although improvements in the HTV were found also after implementing the EB RT programme, the FW training should be preferably used for incrementing the maximal velocity ability of the arm muscles involved in unilateral throws, while the two-point method should be used to systematically follow those changes.

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PROPOSAL OF A PREDICTIVE MODEL FOR THE ATTACK IN WOMEN'S FOOTBALL DEPENDING ON THE PART OF THE MATCH

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Abstract:

Women's football is currently a phenomenon in expansion, both in the number of practitioners and federative records. Scientific research must be at the forefront of this growth, proposing solutions with empirical support that help improve performance not only during training but also during competition. The objective of this study was to propose a multivariate model based on the decision tree technique, with the aim of classifying and predicting the criteria that modulated the attack depending on the part of the match (either the first or second part). To do this, 6063 attacks from the two most recent world championships have been collected and analysed. The available results indicate that, although more attacks occur during the first part, it is in the second part when the goals are scored. In addition, the presented model confirms that the most successful attacks (goal, shot or sending to the area) occur with the score winning or losing, and with a duration of less than 20 seconds. The results of this study can help female soccer coaches to improve the training process of offensive actions and attack.

Key words: *female soccer, performance analysis, decision tree, offensive phase*

Introduction

The analysis of sports performance is a subdiscipline of research in the field of sports sciences (Borms, 2008), which has experienced great interest in the scientific community for two decades now. The consolidation of new methodologies that allow a holistic approach to sports performance (Anguera, Camerino, Castañer, & Sánchez-Algarra, 2014; Castañer, Camerino, & Anguera, 2013), as well as the development of new technologies such as GPS devices, heart rate monitors or new observation-based data collection tools such as LINCE Plus (Soto, Camerino, Iglesias, Anguera, & Castañer, 2019), is leading to new paradigms within the analysis of sport.

Women's sport, and more specifically women's football, has experienced exponential growth in recent years. According to data from the FIFA Research Report, it is estimated that by 2026 more than 60 million girls and women will play football in the world, also enjoying great social and media interest among part of the population (Lago, Lago-Peñas & Lago-Peñas, 2022; Williams, Pope, & Cleland, 2021).

As far as scientific research is concerned, the available works are still not up to the sociological and sports data. Kirkendall (2007) points out that most of the studies on women's sports are focused on injury or physiological aspects, and very few on motor behaviour. In addition, only 20% of the works focus on the analysis of soccer and its variables (Kirkendall & Krustup, 2020). As Cho (2013, in Lago, et al., 2022) points out, women's football is not a by-product of men's football, but the empowerment of women promotes the success of women's football.

Some of the works that have focused on the technical-tactical profile have done so by addressing set pieces (Beare & Stone, 2019; Lee & Mills, 2021; Maneiro, Casal, Ardá, & Losada, 2019), or ball possession and its variables (Maneiro, Losada, Casal, & Ardá, 2020; Maneiro, Losada, Casal, &

Ardá, 2021; Scanlan, Harms, Cochrane, & Ma'ayah, 2020). Regarding the analysis of the offensive phase and the mechanisms for scoring goals, the literature is still scarce (de Jong, Gastin, Angelova, Bruce, & Dwyer, 2020; Iván-Baragaño, Maneiro, Losada, & Ardá, 2021; Iván-Baragaño, Maneiro, Losada, & Ardá, 2022a; Iván-Baragaño, Maneiro, Losada and Ardá, 2022b; Mara, Wheeler, & Lyons, 2012;).

Therefore, the objective of this study was to continue deepening the knowledge of women's football. It has been shown that in men's soccer the parts of the match (the first half or the second half) modify the behavior of players (Greve, Nesbø, Rudi, & Salikhov, 2020). Knowing what criteria or variables are modulating this behaviour in women's soccer can help optimize not only training, but also performance during competition and subsequent success during it. For this, the decision tree statistical technique has been used. This technique is based on a prediction model, based on the information gain presented by each criterion considered.

Methods

For the development of this work, the observational methodology (Anguera, 1979) has been used, a methodology that has been shown to be one of the most suitable for the study of spontaneous behaviour of interaction between athletes, also from its mixed methods aspect (Anguera, et al., 2014; Anguera & Hernández-Mendo, 2016; Castañer, et al., 2013)

The design of this research is punctual, intersessional, multidimensional and nomothetic (Anguera, Blanco-Villaseñor, Hernández-Mendo, & Losada, 2011). Please, note that the observation is governed by the criteria of scientificity, with a total perceptivity and non-participant observer.

Participants

For the selection of participants, an intentional or convenience observational sampling was carried out (Anguera, et al. 2011). The ball possessions executed during the final phase of the FIFA Women's World Cup, specifically the 2015 and 2019 editions, were collected and analysed. In total, 6,063 attacks were analysed. For this, the inclusion criteria proposed by Garganta (1997) were followed. In addition, extra times were not collected as they were considered special situations.

The data collection was carried out through public images broadcast on television, which were of general interest and sponsored by different private entities.

Observational instrument

To carry out this work, the observational instrument proposed by Maneiro et al. (2020) (Table 1) was used, given its good molar-molecular fit in the collection of this type of data, which was used in similar studies on women's football (Iván-Baragaño, 2021).

Table 1. Observational instrument. Source: Maneiro, et al. (2020)

Criteria	Categories
Classification phase	Groups
	Round of 16
	Quarterfinals
	Semifinals
	Final
Half time (match part)	First half
	Second half
Start form	Transition
	Set piece
Interaction context	AR: forward versus delayed line
	AM: forward versus middle line
	AA: forward versus forward line
	MM: middle versus middle line
	MR: middle versus delayed line
	MA: middle versus forward line
	RA: delayed versus forward line
	RM: delayed versus middle line
	PA: goalkeeper versus forward line

Criteria	Categories
Intention	Progress
	Keep
MD	Time the observed team keeps the ball in its defensive zone
MO	Time the observed team keeps the ball in its offensive zone
ZC	Zone in which the team maintained possession the most time
Time possession	Total possession duration
Passes	Number of total passes of the team possessing the ball
Move outcome	Goal scored
	Shot on goal
	Send to area
	No success
Match status	Winning
	Drawing
	Losing
Final score	Win
	Draw
	Lose

The observational instrument is a combination of field format and category systems (Anguera, Magnusson, & Jonsson, 2007), being nested in the different field formats.

Recording and coding

The registration of the data (Hernández-Mendo, et al., 2014) was carried out using the Lince Plus program (Soto, et al, 2019), reaching an inter-concordance value between the observers of 0.83 that was very good according to the scale of Fleiss, Levin, and Paik (2003). Four observers were selected for data collection, three of them Ph.D.s in sports sciences and national-level soccer coaches. In addition, to ensure the quality of the methodological process, a methodologist, an expert in observational methodology also participated in the study (Table 2).

Before the coding process, and to reduce the interobserver variability, eight training sessions were carried out, following Anguera, Blanco-Villaseñor, Losada, and Sánchez-Algarra (1999). The training sessions lasted 2-h each. The first three sessions were carried out in groups with the selected observers. The study was presented to them theoretically, the players' behaviours to be observed were defined, the observational instrument was presented to them, and the observers were trained in the use of the Lince Plus recording instrument. The fourth session consisted of the observation and recording by the observers of 20 offensive actions previously selected by the principal investigator, arranged from the least to the most complex. Once the actions were registered, the discrepancies found were discussed. The fifth and sixth sessions were carried out individually with each of the observers. The delimitation of the registered actions was previously carried out by the principal investigator, and those observed were instructed in the registration of actions. The last two training sessions were also carried out individually, and in them, Cohen's Kappa coefficient of agreement was verified between the principal investigator and each of the observers. Finally, two files were delivered to each of the observers with the offensive actions under analysis.

The data obtained are type IV, that is, concurrent and time-based (Bakeman, 1978). This responds to the fact that there are co-occurrences of players' behaviours.

Analysis of data

To carry out the analyses, the SPSS Statistics 25 program was used. The decision tree is a predictive classification technique that allows the organisation and classification of different predictive criteria based on the information gained from each criterion. In the data analysis, all variables were treated as nominal and each node contained a frequency table showing the number of cases (frequencies and percentages) for each category of the explained criterion. As a growth method, the *Chi-square automatic interaction detector* (CHAID) was used; it consists of a statistical and multidirectional tree algorithm that explores the data quickly and efficiently and creates segments and profiles with respect to the desired result. This growth method chooses at each moment the independent criterion or predictor that presents the strongest association with the dependent criterion at each moment. In the creation of the decision tree, 11 criteria were used without including the "half time" criterion, with a total of 6063 observations from both competitions.

The analysis of sports performance through decision trees has been implemented in different works of the same nature (Iván-Baragaño, et al., 2021; Pic, Lavega-Burgués, & March-Llanes, 2019).

Table 2. Results of Cohen's Kappa analysis for each criterion

Criteria	O1O2	O1O3	O1O4	O2O3	O2O4	O3O4	$\overline{X}$
Classification phase	0.961	0.958	0.953	0.972	0.921	0.949	0.939
Half time (match part)	0.919	0.813	0.906	0.853	0.860	0.847	0.883
Start form	0.985	0.971	0.981	0.942	0.960	0.963	0.967
Interaction context	0.915	0.921	0.941	0.896	0.846	0.871	0.989
Intention	0.839	0.943	0.916	0.864	0.828	0.943	0.888
MD	0.86	0.847	0.826	0.880	0.848	0.874	0.844
MO	0.882	0.827	0.876	0.926	0.888	0.926	0.887
ZC	0.818	0.823	0.813	0.951	0.779	0.723	0.817
Time Possession	0.795	0.791	0.789	0.870	0.91	0.818	0.828
Passes	0.807	0.907	0.829	0.657	0.713	0.763	0.779
Move Outcome	0.872	0.887	0.911	0.793	0.801	0.816	0.846
Match Status	0.829	0.850	0.839	0.718	0.670	0.632	0.756
Final Score	0.919	0.928	0.910	0.988	0.891	0.91	0.954
$\overline{X}^b$	0.860	0.851	0.849	0.841	0.839	0.852	0.831

Results

The CHAID classification tree shows a total of nine nodes, of which six are terminal. The tree has three levels (level 1: partial match result; level 2: time of possession; and level 3: move outcome). The general results of the decision tree model are presented in Table 3.

Next, the prediction criteria of the model are presented in Table 4 (Classification table) and Table 5 (Risk table). In this way, the evaluation of the goodness of the model's operation can be observed. The results in Table 3 indicate that the model correctly classified 63.8% of the cases in general. Specifically, for each category of the dependent criterion, it offered a higher success rate for the "first part" category, with 71.2%.

The optimized decision tree (Figure 1) is presented using the test set. It opens with the first node that corresponds to the "half time" criterion, which is the dependent criterion. In this node, a higher percentage of attacks was observed in the first part (52.4%) compared to the second part (47.6%). This criterion branches into two nodes, node 1 and node 2, belonging to the "match status of the match" criterion, indicating that this is the main predictor criterion (χ^2=295.27; p<.001). Node 1 was formed by the categories "winning" and "losing", presenting a greater occurrence in the second part of the matches (62.3%), compared to node 2, formed by the category "drawing", which occurred mostly in the first part (69.9%). The next criterion that the algorithm introduced from node 1 was MD (time in seconds of own field possession; χ^2=29.57; p<.001), which branches into nodes 3, 4 and 5 (two of them terminal). In these three nodes, the proba-

Table 3. Summary of the presented model

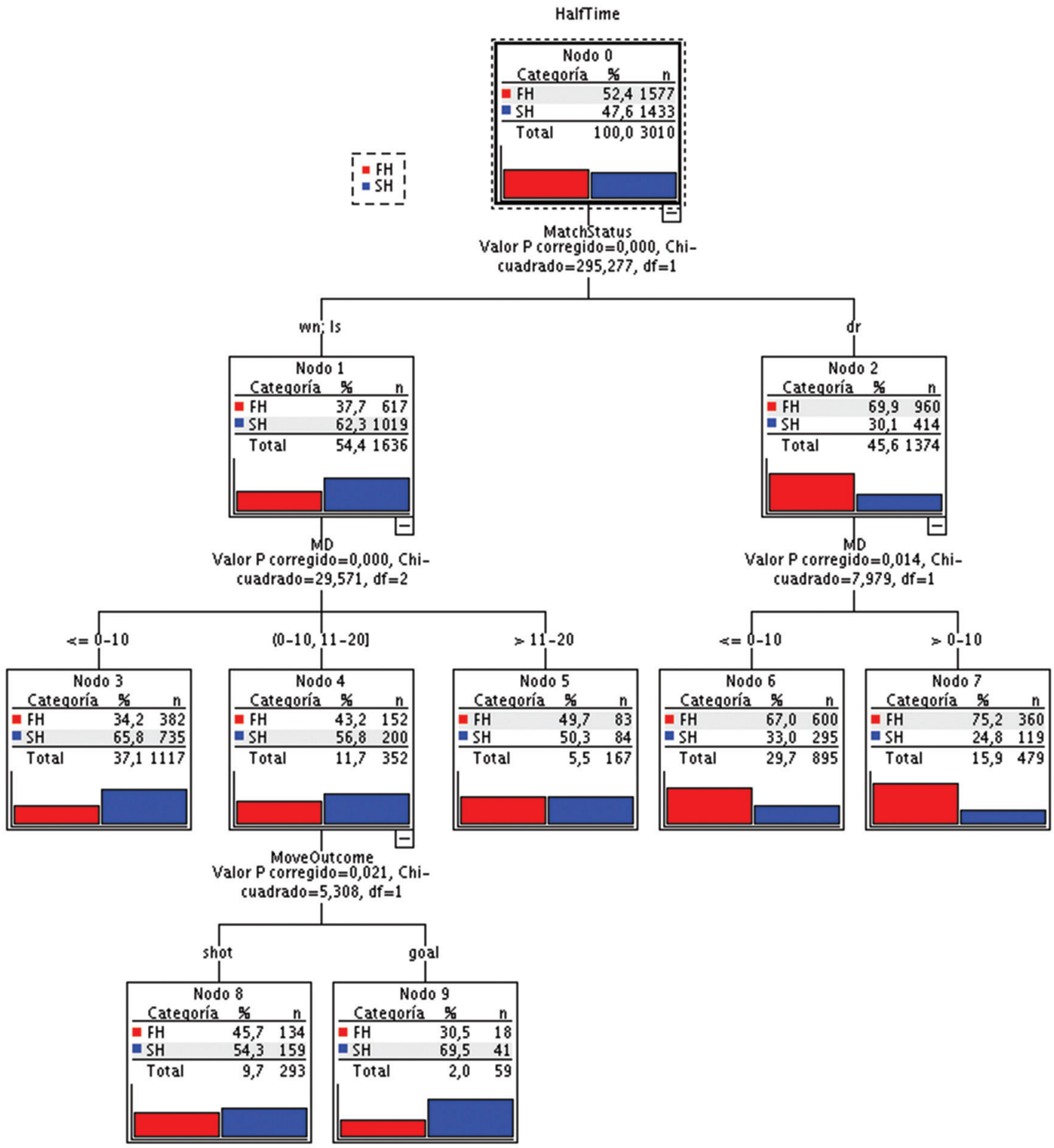
MODEL SUMMARY		
Specs	Growth method	CHAID
	Dependent criterion	Half time
	Independent criteria	*Clasification phase, start form, interaction context, intention, MD, MO, ZC, Time Posssession, Passess, Move Outcome, Match Status, Final Score*
	Validation	Sample division
	Maximum depth	3
	Minimum cases in parent node	100
	Minimum cases in child node	50
Results	Dependent criteria included	*Match Status, MD, Passess, Move Outcome, ZC, Intention*
	Number of nodes	9
	Number of terminal nodes	5
	Depth	3

Table 4. Classification of the model

Classification				
Sample	Observed	Predicted		
		FH	SH	Percent correct
Training	FH	1160	467	71.3%
	SH	561	875	60.9%
	Overall percentage	56.2%	43.8%	66.4%
Contrast	FH	1100	445	71.2%
	SH	641	814	55.9%
	Overall percentage	58.0%	42.0%	63.8%
Growing methods: CHAID Dependent criterion: HalfTime				

Table 5. Risk of the predictive model

Risk		
Sample	Estimate	Típ. Error
Training	.336	.009
Contrast	.362	.009
Growing methods: CHAID Dependent criterion: HalfTime		



Note. Nodo: node; Valor P corregido: corrected p-value; categoría: category; chi cuadrado: Chi squared.

Figure 1. Representation of the decision tree model for the attack in women's football.

bility of the attacks taking place in the second part decreased as the MD variable increased. On the other hand, node 2 also included the MD criterion as the one that presented the greatest information gain (χ^2=7.97; p=.014), and a greater probability was observed that the possessions carried out through a partial result of "drawing", took place in the first part. This node branches off into two terminal nodes (node 6 and node 7). In node 6 it was found that possessions lasting less than 10 seconds in their own half occurred mainly in the first half (67%), and in the same way, the probability that an attack lasting more than 10 seconds in their own field and developed in the partial result of "drawing" took place in the first part was 75.2% (node 7, n=479). Finally, the last criterion that presented the greatest information gain from node 4 was "final result" (χ^2=5.30; p=0.02), which branches into two terminal nodes (node 8 and node 9). For node 8, the data revealed that the attacks that ended by a shot on goal occurred predominantly in the second part (54.3%); in the same way as in node 9: those possessions that ended with a goal scored occurred mainly in the second half (69.5%), both nodes under the influence of the MD criterion (10-20 seconds) and the "partial result: winning or losing".

Discussion and conclusions

The main objective of this study was to find out which criteria may be modulating the effectiveness of the attack in women's football depending on the particular part of the match. For this, the statistical analysis focused on the search for a classification model based on the creation of a decision tree that provides validation tools for the exploratory and confirmatory classification analysis, assigning an adequate level of measurement to all the variables of analysis.

In general terms, it is possible to affirm that the available results corroborate the alternative of the teams that bet on an offensive style of play, as the best option to score a goal or to shoot on goal. In addition, it is possible to affirm that, despite the fact that there are more attacks or offensive phases during the first parts, the highest efficiency rates in terms of goals scored were found in the second parts. In applied terms, it is plausible to think that the teams attack more in the first parts, but with less success, being the second ones where there is an imbalance in the scoreboard. In addition, offensive success is not based on a gradual construction of the attack, but the available data advocates for a quick attack, of less than 20 seconds from the recovery of possession. Specifically, seven out of 10 goals were scored in the second half, with attacks that did not exceed 20 seconds and with the match score winning or losing for the executing team. One of the possible explanations for a higher rate of efficacy in the second half may be associated with the physical exhaustion of the players of the lower-level teams (Krustrup, Mohr, Ellingsgaard, & Bangsbo, 2005), the inability to maintain established tactical standards set previously by the coaches, or to the great differences in performance between the best and not so good teams, as has already been evidenced in recent works (Iván-Baragaño, et al., 2022b).

Broadly speaking, these results corroborate the results of previous studies on men's soccer (Fernández-Navarro, Fradua, Zubillaga, & McRobert, 2018; Sgrò, Aiello, Casella, & Lipoma, 2017; Tenga, Holme, Ronglan, & Bahr, 2010), as well as on women's football (Iván-Baragaño, et al, 2021, 2022b). The success of the attack in football, regardless of the gender of players, is based on brief actions, with a quick transition towards the rival goal and mainly carried out in the second parts of the matches.

In the absence of more research that makes it possible to have more scientific evidence, the success of the attack in women's football does not present great differences in terms of its male counterpart in its general construction. This opens a new path towards the tactical understanding of women's football in its offensive phase and complements other previous recommendations based on technical (Soroka & Bergier, 2010) and physical or physiological aspects (Casanova, Travassos, Ferreira, Garrido, & Costa, 2020; Krustrup, et al, 2005).

The present study was proposed with the objective of predicting and classifying which were the variables or criteria that may be modulating the attack in women's soccer from the perspective of a particular part of the match. The available results highlight the value of short-duration attacks preferably in the second parts of the matches. These tips could help teams increase their potential offensive success during matches.

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COMPARISON OF TWO 8-WEEK TRAINING INTERVENTIONS ON THE ATHLETIC PERFORMANCE OF PADEL PLAYERS

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Abstract:

Padel is an intermittent racket sport played in pairs (2 vs. 2) on a small-sized grass court (20 x 10 m), involving high physical fitness demands for the players. Therefore, this study aims to compare the effect of two 8-week in-season training programs on the athletic performance of male padel players. Participants (age, 22.1±0.8 yr; body height, 182.0±1.0 cm ; body mass, 74.7±0.7 kg) were randomly assigned to the integrated training group (IG, n=12) and non-integrated training group (NIG, n=12). The IG trained inside the padel court, integrating neuromuscular exercises with sport-specific (i.e., use of the racket) technical actions. The NIG trained outside the padel court, performing the same neuromuscular exercises and sport-specific technical actions as the IG, although not simultaneously. Before and after the intervention, athletes were assessed for their hand-grip strength, two legged and one-legged Abalakov jump, bench press performance, padel stroke velocity, cardiorespiratory endurance ($30\text{-}15_{IFT}$), 5-m and 10-m linear sprint time and change of direction ability at 90º and 180º using left and right leg. Both groups improved their scores on Abalakov jump tests, bench press performance, stroke velocity, cardiorespiratory endurance ($30\text{-}15_{IFT}$), and change of direction ability at 90º and 180º (all changes p<.05; effect size = 0.22-2.58). The IG improved stroke velocity compared to NIG (p<.05), and only the IG showed pre-post improvements (p<.05; effect size = 0.30-0.76) in change of direction ability at 90º and 180º involving the non-dominant leg (i.e., turn to the right). An 8-week in-season integrated training approach and a non-integrated training approach may induce similar improvements in athletic performance among highly trained male padel players. However, the neuromuscular training program involving an integration of padel-specific and non-specific training exercises may induce greater improvements in padel-specific performance (i.e., stroke velocity) and change of direction speed ability, particularly in movements involving the non-dominant leg.

Key words: *human physical conditioning, resistance training, plyometric exercise, muscle strength, musculoskeletal and neural physiological phenomena, team sports*

Introduction

Padel is an intermittent racket sport played in pairs (2 vs. 2) on a small-sized grass court (20 x 10 m) surrounded by glass and mesh walls. Rallies last ~9 seconds, involving 15-20 actions and strokes per player, a greater demand compared to racket sports like badminton, tennis, or squash (Courel-Ibáñez, Sánchez-Alcaraz Martínez, Benítez, & Echegaray, 2017a; Courel-Ibáñez, Sánchez-Alcaraz Martínez, & Munoz Marin, 2019; Courel-Ibáñez, Sánchez-Alcaraz, & Cañas, 2017b). Due to the exponential growth of the popularity of padel in the last few years, several studies have been published aiming to describe the activity profile of the sport, as well as its physical and physiological demands (Carrasco, Romero, Sañudo, & de Hoyo, 2011; Courel-Ibáñez, et al., 2017a, 2017b; Courel-Ibáñez, et al., 2019). Previous studies examining its game dynamics and match activity have defined padel as a high-intensity intermittent activity, which combines high-frequency (0.7–1.5 per second) of high-intensity and low-intensity actions, during rallies that are of a moderate duration (9–15 seconds), interspersed by 1,020 seconds of rest in between, leading to longer breaks of 90 seconds (Carrasco, et al., 2011; García-Benítez, Courel-Ibáñez, Pérez-Bilbao, & Felipe, 2018; Torres-Luque, Ramirez, Cabello, Nikolaidis, & Alvero Cruz, 2015). In addition, the average heart rate during a game was 148±13.7 beats per minute (73.9±4.6% of the maximal heart rate), with values up to 169±18.4 beats per minute (Carrasco Páez, de Hoyo, & Sanudo, 2007), with some variations depending on contextual factors (Roldán-Márquez, Onetti-Onetti, Alvero-Cruz, & Castillo-Rodríguez, 2022). Padel and tennis players demonstrate a similar VO_{2max} ((Ferrauti, Kinner, & Fernandez-Fernandez, 2011)).

Furthermore, physical fitness (including padel-specific markers) has high impact on determining padel players' performance at professional and non-professional levels, independent of sex or age (Courel-Ibáñez & Llorca-Miralles, 2021; Courel-Ibáñez, et al., 2019; Escudero-Tena, Sánchez-Alcaraz, García-Rubio, & Ibáñez, 2021; Müller & Del Vecchio, 2018; Pradas, Sánchez-Pay, Muñoz, & Sánchez-Alcaraz, 2021; Pradas, et al., 2022), and may help to reduce the risk of injury (Demeco, et al., 2022). In this sense, the increasing intensity of sport competitions make strength and conditioning training a priority for success (Gale-Watts & Nevill, 2016). However, the effects of strength and conditioning methodologies involving padel-specific (integrated model) and non-specific exercises, that target the optimization of a comprehensive number of key athletic performance markers (strength, power, endurance, sport-specific performance, acceleration, and change of direction [COD] ability), have not been explored in high-level male padel players. Therefore, and in line with recent recommendations for more research in this field (García-Giménez, Pradas de la Fuente, Castellar Otín, & Carrasco Páez, 2022), the purpose of this study was to examine the effect of two different combined neuromuscular training methods (i.e., a combination of plyometric, strength, COD, and power-oriented exercises) applied to two training intervention groups (integrated vs. non-integrated) on the athletic performance of high-level male padel players. It was hypothesized that such training methods would lead to increases in athletic performance gains of the two training intervention groups (integrated vs. non-integrated) but in different ways.

Methods

Study design

This study was designed to examine how integrated and non-integrated physical training interventions affected padel-specific performance parameters. This study was conducted during an 8-week (16 sessions) padel in-season training period with padel players. After initial measurements, participants were randomly assigned (A–B distribution, based on their sprint performance) to the following two training intervention groups: integrated training group (IG, n = 12), and non-integrated training group (NIG, n = 12). Physical performance was assessed before (Pre) and after (Post) the 8-week training period using a battery of tests as follows: (a) anthropometric measures, (b) hand-grip strength test in both hands (right [HGR] and left [HGL], (c) Abalakov jump test bipodal (ABK) and monopodal with the right leg (ABKR) and the left leg (ABKL), (d) 10 meter linear sprint time test (10-m), (e) stroke velocity test (SV), (f) bench press test (BP), (g) 30-15 Intermittent Fitness Test (30-15IFT), and (h) change of direction test at 90º with the right leg (COD90R) and left leg (COD90L) and at 180º with the right leg (COD180R) and left leg (COD180L). All tests were conducted on an indoor synthetic court. Participants were instructed to avoid any additional strenuous physical activity not related to the training interventions and to maintain their usual dietary habits and their normal padel training sessions for the duration of the study.

Participants

A total of 24 licensed male padel players (participants' characteristics provided in Table 1) volunteered to participate in the present study.

Participants belonged to the same club that competed both at the national (First Spanish padel division) and international level. The players were ranked between 1 and 100 in their respective national singles ranking; they trained 16 ± 3 $h.wk^{-1}$ and had a training background of 4 ± 2.4

Table 1. Participants characteristics

	Age (years)	Height (cm)	Body mass (kg)	Playing experience* (years)
IG = 12	22.6 ± 1.4	182.7 ± 6.7	75.2 ± 10.2	4.1 ± 2.6
NIG = 12	21.5 ± 1.8	181.3 ± 8.1	74.2 ± 11.8	4.3 ± 1.9

Note. Values are reported as mean ± standard deviation. *: in the first Spanish padel division.
IG: integrated training group; NIT: non-integrated training group.

years, which focused on padel-specific training (i.e., technical, and tactical skills), aerobic and anaerobic training (i.e., on and off-court exercises) and strength training. All the participants were familiarized with the testing exercises. A detailed description of the typical training week included the following: specific padel training (five sessions with technical exercises: hits from the back of the court, forehand and backhand, volley at the net, lobs, defensive and offensive movements, and tactical exercises); physical conditioning (four sessions, out of which two strength training sessions and two focused on speed and agility development); and competitive play (one game per week), totaling ~16 hours per week on average. Data collection took place during the two months (i.e., the in-season training period) of the season. Before participating in this project, which was approved by the institutional ethics review committee, participants were fully informed about the protocol and were required to give their written consent in accordance with the Declaration of Helsinki II. Also, participants completed a questionnaire regarding their medical history, age, body height, body mass, training characteristics, injury history, padel experience, and performance level. In addition, before their participation in this study, the players had a medical examination to determine whether there were any orthopedic or other conditions that would preclude them from high-intensity training.

Testing procedures

All the participants were familiarized with the test procedures two weeks before the pre-testing sessions. The tests were conducted over a 2-day period. To account for diurnal effects, all testing sessions were performed at the same time of the day (±1 h) for each athlete. On day 1, the tests were completed in the following order: anthropometric measures, vertical ABK jump, and muscular strength in hand grip and BP exercises. On day 2, SV, 10-m sprint time, COD in 90º and 180º and 30-15IFT tests were completed. Before testing, participants carried out a standardized warm-up consisting of 10-minute submaximal running at 9 $km.h^{-1}$ followed by joint mobilization exercises, 10 full-squats with their own body mass (no external loads), and a specific warm-up consisting of several submaximal trials before each test. Verbal encouragement was provided to each participant during the testing sessions.

Hand-grip strength. Hand-grip strength was measured using a hand dynamometer (T.K.K. 5401 Grip D®, Takei Scientific Instruments, Japan). Participants were standing with their arms flexed. They were asked to perform a maximal voluntary contraction standing with the dynamometer at one side (i.e., the dominant hand) and squeezing the dynamometer as hard as they could for three seconds. This was repeated for each hand (i.e., the dominant and non-dominant hand). The maximum voluntary handgrip strength was obtained from two trials for each hand.

Abalakov jump. The ABK jump height was calculated from flight time values determined using an infrared timing system (Optojump®, Microgate France, 38330 St. Ismier). The ABK jump was assessed bipodal (ABK) as well as monopodal with both legs (ABK-R and ABK-L). Three trials were completed with 2-minute rests between each trial. The mean of the three trials was then used for subsequent statistical analyses.

10-meter sprint time*.* Sprint times were recorded for a 10-meter distance (with 5-meter split time) indoors on the synthetic surface. The participants started the test using a crouch start and commenced sprinting upon a random sonorous sound. Infrared beams were positioned at the sprint distance to be measured with photoelectric cell (Microgate®, Bolzano, Italy). After a warm-up (5-minute jogging, stretching exercises, squats, and two 20-m and 10-m sprints), the participants were given two practice trials performed at half speed to familiarize them with the timing device. Then two test trials were completed, and the best trial performance was used for the subsequent statistical analysis. Three minutes of rest was permitted between the 10-meter trials.

Stroke velocity. A radar gun (Stalker Professional Sports Radar®, Radar Sales, Plymouth, MN, USA) was used to measure SV (smash velocity; $km.h^{-1}$). On the padel court, the radar gun was placed 2-m behind each participant (Ramos Veliz, et al., 2015). Valid trials involved the ball that hit the synthetic-glass background panel (after one bounce off the court). With this aim, cones were placed at one meter from the dividing line (central service line) and from the side-line (Figure 1). Players received the balls from another player sending lobs. The set of balls was placed at two meters, in crossed direction with the position of the participants, from the dividing net and they stood at two meters from this net. Once a warming up of the stroke-involved joints was done and five soft strokes were made, the speed was measured for five consecutive strokes made. The same ball conditions were used to carry out the post-tests (Head CS, Amsterdam, NL). For later statistical analysis, the highest and lowest values were eliminated and the average was calculated from the three remaining values.

Muscle strength in BP. Participants performed the BP by lowering the bar from a fully extended arm position until the bar was at the chest height, but did not touch it, and then immediately they extended their arms as fast as possible to return the bar to the starting position (Martin, Pareja Blanco, & Sáez de Villarreal, 2021). All BP tests were performed in a Smith machine (Adan Sport®, Granada,

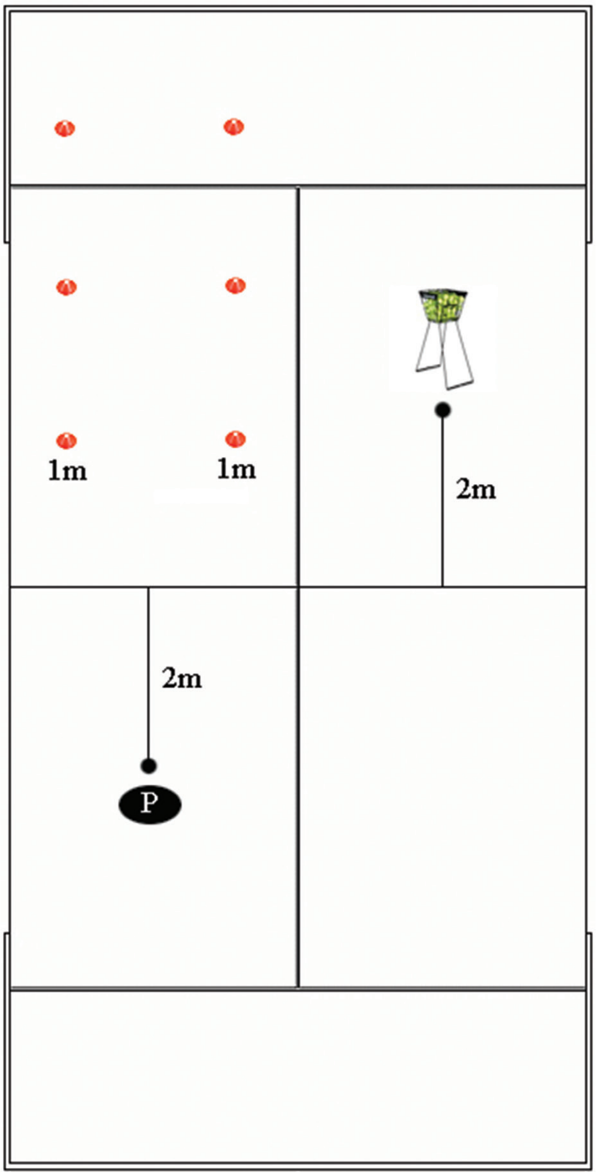

Figure 1. Schematic representation of the power shot test for velocity. "P" denotes the position of the player on the court.

Spain). The Smith machine was instrumented with a linear encoder, which was attached to one end of the bar to determine bar velocity (in meters per second) at 1000 Hz (T-Force System®; Ergotech, Murcia, Spain). The reliability of this device has been reported elsewhere (Sánchez-Medina & González-Badillo, 2011). Two sets of eight and four repetitions with 20 and 40 kg, respectively, were performed before testing as a warm-up protocol. Three maximal repetitions were performed against 50 kg. The fastest velocity values attained with 50 kg in BP (BP-50 kg) were recorded for further analysis. The rest period between trials was maintained at two minutes. All velocities reported in this study refer to mean propulsive velocity, which is defined as the fraction of the concentric phase during which barbell acceleration is greater than the acceleration due to gravity (Sanchez-Medina, Perez, & Gonzalez-Badillo, 2010).

30-15 intermittent fitness test. Supra maximal intermittent performance with changes of direction was assessed using the 30-15IFT (Buchheit, 2008), which consisted of 30-second shuttle runs interspersed with 15-s passive recovery periods. The athletes had to run back and forth between two lines set 40 meters apart at a pace dictated by an auditory signal. The speed was set at 8 km.h^{-1} for the first 30-second run and was increased by 0.5 km.h^{-1} every 45-second stage thereafter. The speed during the last completed stage was noted as the velocity obtained in the intermittent fitness test (VIFT).

90º and 180º change of direction. The athlete's ability to perform a single, rapid 90° and 180° COD using the right or left leg was measured, with a modified version of the 505-agility test, as previously described (Gabbett, Kelly, & Sheppard, 2008). Briefly, players assumed a preferred foot behind the starting position line and accelerated voluntarily, sprinting with maximal effort without a racquet over 5-meter distance, and then performed a 90° or 180° COD with the left or right leg (COD90L, COD90R, COD180L, and COD180R, respectively) for a final 5-meter sprint. The time was recorded to the nearest 0.01 second using electronic timing gates (Microgate®, Bolzano, Italy). Three trials were completed for COD90L, COD90R, COD180L, and COD180R. The best of the three trials was used for subsequent statistical analysis. Two minutes of rest were allowed between trials.

Training procedures

The descriptive characteristics of the integrated and non-integrated training program are presented in Table 2. The two groups trained twice a week (training sessions being 48–72 hours apart) for eight weeks, before usual padel training. Each session lasted 60 minutes, consisting of 10 minutes of standard warm-up (5-minute submaximal running at 9 km.h^{-1}, mobilization exercises for 5-min, and two submaximal jump exercises [20 vertical jumps and 10 long jumps]), 45 minutes of combined neuromuscular training (a combination of plyometric, strength, COD, and power-oriented exercises) for each group, and five minutes of cool down including stretching exercises. Integrated group (IG) trained inside padel court and finished all the combined neuromuscular exercises proposed with a specific technical execution of game actions (i.e., forehand ground stroke, backhand ground stroke, forehand volley, backhand volley, overhead, smash, lob). Non-integrated group (NIG) realized neuromuscular training outside the court, but on the same surface, without technical execution of game actions and without the racket. The training load was quantified by analyzing the rating of perceived exertion (RPE) of each session. Each participant's session RPE was collected 30 minutes after each training session using Borg scale-10 (Borg, Hassmén, &

Lagerström, 1987), with which they were previously familiarized. Then, RPE value was multiplied by the total duration of training (minutes) to represent in a single number the magnitude of internal training load in arbitrary units (AU) (Foster, et al., 2001). The total duration of specific training for all the groups was controlled and was similar (45 minutes) for each group. All training sessions for both groups were fully supervised, and training diaries were maintained for each participant. All the players completed all the training sessions.

Statistical analysis

Descriptive statistics (mean ± standard deviation) for different variables were calculated. The intraclass correlation coefficient (ICC) was used to determine the reliability of the measurements. Homogeneity of variance across the groups was verified using the Levene's test, whereas the normality of distribution of the data was examined with the Shapiro-Wilk's test. Data were analyzed using a 2x2 factorial analysis of variance with the contrast F of Snedecor one between-group factor (IG vs NIG) and one within-group factor (pre-training vs. post-training). The effect size (ES) values were calculated using Hedges's *g*, as a ratio of the difference between two means divided by the combined estimate of the standard deviation (Rosnow & Rosenthal, 2003). Statistical significance was accepted at an alpha level of $p \leq .05$. The SPSS statistical package, version 24.0 was used (SPSS, Inc., Chicago, IL, USA).

Results

All measurements were considered reliable based on the ICC values for the tests, as follows: HG: 0.94 (95% confidence interval [CI], 0.92 to 0.96); ABK: 0.91 (95% CI, 0.89 to 0.93); BP: 0.92 (95% CI, 0.90 to 0.94); SV: 0.90 (95% CI, 0.88 to 0.92); 30-15 IFT: 0.89 (95% CI, 0.87 to 0.91); SP: 0.87 (95% CI, 0.85 to 0.89); COD: 0.87 (95% CI, 0.84 to 0.90).

No significant differences (p>.05) were observed after training in the session RPE between the groups: IG = 315.5 ± 15.8 AU (95% CI, 308.8–318.8), and NIG = 302.6 ± 12.6 AU (95% CI, 295.4–3010.4).

At baseline, no significant differences (p>.05) were observed between the groups in any of the performance variables tested (Table 3).

Table 2. Description of the different training programs performed by each experimental group

Exercises	W1 S1-S2	W2 S3-S4	W3 S5-S6	W4 S7-S8	W5 S9-10	W6 S11-S12	W7 S13-14	W8 S15-S16
INTEGRATED GROUP (IG)								
CMJ + smash	3x15	3x15	3x15	3x15	3x20	3x20	3x20	3x20
Burpee + forehand volley	3x5	3x6	3x7	3x8	3x9	3x10	3x10	3x10
Burpee + backhand volley	3x5	3x6	3x7	3x8	3x9	3x10	3x10	3x10
Jump lunge + smash	3x5	3x6	3x7	3x8	3x9	3x10	3x10	3x10
5+5 m 90° left + volley	3x10	3x10	3x12	3x12	3x12	3x15	3x15	3x15
5+5 m 90° right + volley	3x10	3x10	3x12	3x12	3x12	3x15	3x15	3x15
5+5 m 180° + lob	3x10	3x10	3x12	3x12	3x12	3x15	3x15	3x15
NON-INTEGRATED GROUP (NIG)								
CMJ	3x15	3x15	3x15	3x15	3x20	3x20	3x20	3x20
Burpee	3x5	3x6	3x7	3x8	3x9	3x10	3x10	3x10
Burpee	3x5	3x6	3x7	3x8	3x9	3x10	3x10	3x10
Jump lunge	3x5	3x6	3x7	3x8	3x9	3x10	3x10	3x10
5+5 m 90° left	3x10	3x10	3x12	3x12	3x12	3x15	3x15	3x15
5+5 m 90° right	3x10	3x10	3x12	3x12	3x12	3x15	3x15	3x15
5+5 m 180°	3x10	3x10	3x12	3x12	3x12	3x15	3x15	3x15
COMMON EXERCISES FOR BOTH GROUPS								
MB throw (kg)	3x10x1	3x10x1	3x10x1	3x10x2	3x10x2	3x10x2	3x10x3	3x10x3
MB chest throw (kg)	3x10x5	3x10x5	3x10x5	3x10x7	3x10x7	3x10x7	3x10x10	3x10x10
Bird-dog	3x10	3x10	3x12	3x12	3x12	3x15	3x15	3x15
Front bridge (s)	3x30	3x30	3x30	3x45	3x45	3x45	3x60	3x60
Side bridge (s)	3x30	3x30	3x30	3x45	3x45	3x45	3x60	3x60

Note. CMJ: countermovement jumps; MB: medicine ball (one-handed overhead throwing technique involving MB of 1, 2 or 3 kg. The MB chest throw involving up to 10 kg MB); S: session; W: week; 5+5 m 90°: 5 m front sprint, turn, and 5 m sprint to the left or right side; 5+5 m 180°: 5 m front sprint and 5 m back sprint. A rest period between sets of 90 seconds was used for all exercises.

Table 3. Performance variables of pre-test and post-tests for experimental groups

	Integrated group (n = 12)				Non-integrated group (n = 12)			
	Pre-test	Post-test	Δ%	ES	Pre-test	Post-test	Δ%	ES
HGR (kg)	51.39 ± 6.45	53.17 ± 6.24	3.46	0.27	54.86 ± 5.68	55.13 ± 4.66	0.49	0.04
HGL (kg)	48.06 ± 6.24	48.81 ± 6.09	1.56	0.12	46.94 ± 4.36	47.52 ± 4.18	1.23	0.13
ABK (cm)	37.77 ± 7.59	40 ± 6.24 *	5.90	0.29	41.21 ± 5.07	43.60 ± 3.98*	5.79	0.47
ABKR (cm)	20.17 ± 4.42	21.16 ± 3.95 *	4.90	0.22	22.64 ± 4.07	24.80 ± 2.99 *	9.54	0.53
ABKL (cm)	19.77 ± 5.30	21.64 ± 4.18 *	9.45	0.35	20.72 ± 3.91	23.04 ± 3.87 *	11.19	0.59
BP (m/s)	1.24 ± 0.14	1.43 ± 0.13 *	15.32	1.35	1.27 ± 0.18	1.44 ± 0.08 *	13.38	0.94
PS ($km.h^{-1}$)	132.95 ± 8.95	156.05 ±6.53 * $	17.41	2.58	133.43 ± 12.37	145.10 ± 11.30*	8.74	0.94
30-15 ($km.h^{-1}$)	20.43 ± 1.62	21.93 ± 1.37 *	7.34	0.92	21.57 ± 1.51	22.86 ± 0.90 *	5.98	0.85
SP5 (s)	1.12 ± 0.13	1.09 ± 0.06	2.67	0.23	1.05 ± 0.06	1.04 ± 0.09	0.95	0.17
SP10 (s)	1.97 ± 0.19	1.96 ± 0.16	0.50	0.05	1.95 ± 0.09	1.93 ± 0.12	1.02	0.22
COD90R (s)	2.37 ± 0.20	2.31 ± 0.21*	2.53	0.30	2.26 ± 0.13	2.22 ± 0.18	1.76	0.31
COD90L (s)	2.34 ± 0.10	2.28 ± 0.11*	2.56	0.60	2.27 ± 0.11	2.19 ± 0.12 *	3.52	0.72
COD180R (s)	3.14 ± 0.21	2.98 ± 0.17 *	4.93	0.76	3.05 ± 0.20	2.99 ± 0.16	1.96	0.30
COD180L (s)	3.19 ± 0.21	3.06 ± 0.17*	4.07	0.61	3.15 ± 0.17	3.04 ± 0.12 *	3.49	0.64

Note. Values are reported as mean ± standard deviation. ABK = Abalakov jump bipodal; ABKL and ABKR = Abalakov jump with left and right leg, respectively; BP = bench press; COD90L, COD90R, COD180L, and COD180R = change of direction 90° and 180° to the left and right, respectively; ES = effect size; HGL and HGR = hand grip left and right hand, respectively; PS = power shot; SP5 and SP10 = sprint 5 and 10 meters, respectively; 30-15 = 30-15 intermittent fitness test. * = denotes significant differences between pre-training and post-training (p<0.05); $ = denotes significant differences between groups after training (p<.05).

There were no significant pre-post intervention improvements (within-group changes) in any group for HGR, HGL, SP5, and SP10 (Table 3). However, both training groups exhibited significant improvements (p<.05; ES = 0.22 – 2.58; Table 3) in ABK, ABKR, ABKL, BP, PS, 30-15 IFT, COD 90L, and COD 180L.

Only the IG improved COD 90R and COD 180R (p<.05; ES = 0.30 – 0.76; Table 3). Further, compared to the NIG, a greater (p<.05) improvement in PS was noted in the IG (Table 3).

Discussion and conclusion

Both NIG and IG training groups experienced similar improvements in athletic performance after eight weeks of intervention. However, compared to the NIG training approach, the IG training approach induced greater improvements in padel-specific performance (i.e., PS). Further, CODs performance improved in the IG, particularly in actions involving the non-dominant leg (i.e., left). A discussion of these findings is provided in the paragraphs that follow.

Vertical jump performance (ABK bipodal and monopodal) has been the focus of attention in previous literature and in several individual and team sports, using a myriad of training methods (Arabatzi, Kellis, & Sáez de Villarreal, 2010; Saéz de Villarreal, Suarez-Arrones, Requena, Haff, & Ramos-Veliz, 2014; Sáez de Villarreal, Suarez-Arrones, Requena, Haff, & Ramos Veliz, 2015). In the present study, both training methods induced a positive stimulus in ABK performance. In agreement with our findings, a previous study (Fernandez-Fernandez, Saez de Villarreal, Sanz-Rivas, & Moya, 2016) reported that plyometric training, specific tennis training or combined training meaningfully increased vertical jump ability. It is conceivable that specific neuromuscular training, which involves specific technical execution of game actions (forehand and backhand volleys, smash strokes, lobs) used in padel skills, allows players to improve their jumping ability. However, our findings suggest that isolated and analytic neuromuscular training without technical actions may provide enough stimulus to improve jump performance (ABK bipodal and monopodal) in young male padel players.

In agreement with the previous literature (Salonikidis & Zafeiridis, 2008) our findings indicated that combined neuromuscular training significantly increased strength performance (BP) in padel players. However, there were no improvements in HGR or HGL in both groups. This finding may be explained by the fact that hand grip strength gain is an action that needs strength development in a specific zone (forearm musculature) rather than a technical skill. Hence, the addition of power-oriented exercises (burpees) with an emphasis on high velocity execution during the exercises seems to provide a positive stimulus for improving BP in young male padel players.

Hitting power of the ball is an important skill in padel, and high accuracy and control in the overhead stroke is an essential component of smashing and volleying for the purpose of scoring points. The faster and more accurately the ball can be struck, the less time opponents have in returning the ball. Several studies on overarm hitting have identified that several factors, including upper and lower limb and trunk strength, stroking technique and vertical jumping ability affect SV (Fernandez-Fernandez, Kinner, & Ferrauti, 2010; Fett, Ulbricht, & Ferrauti, 2020; Palmer, Jones, Morgan, & Zeppieri, 2018). Previous studies have reported that general resistance and ballistic training, including upper and lower body exercises, induces positive adaptations in SV ((Baiget, Corbi, Fuentes, & Fernández-Fernández, 2016; Fett, et al., 2020; Palmer, et al., 2018). Our results concur with those studies showing that a combined strength and power-oriented training program can significantly increase overhead SV performance (8-17%, $p<.05$). The high relationship between force and SV (Colomar, Baiget, & Corbi, 2020; Ramos Veliz, Requena, Suarez-Arrones, Newton, & Sáez de Villarreal, 2014) lends support to the theory that SV is also influenced by lower body force enhancing the capacity to improve hitting power. However, power alone is unlikely to be sufficient in less-skilled players whose lower limb strength is not as proficient (Courel-Ibáñez & Llorca-Miralles, 2021; Courel-Ibáñez, et al., 2019; Escudero-Tena, et al., 2021; Müller & Del Vecchio, 2018; Pradas, et al., 2021, 2022). Knowledge of the game also suggests that ability to prepare the technical gesture (i.e., volley, smash, drop, and lob) would increase strategic options for players during competition.

From a physiological point of view, the importance of the aerobic capacity in padel, as a basis for the correct use of different anaerobic energy channels and for a better inter-effort recovery, is highly proven (Castillo-Rodríguez, Alvero-Cruz, Hernández-Mendo, & Fernández-García, 2014). For example, an average heart rate of 148±13.6 beats per minute and demands of 43.7% of VO2max during games was reported in young male players from national category (Carrasco Páez, et al., 2007). These average heart rate values are similar, although a bit lower, to those studied in tennis (Fernandez-Fernandez, et al., 2010), possibly because padel is, compared to individual tennis, played in pairs and the points are longer with more strokes per point but at a lower intensity (Sánchez-Alcaraz Martínez, Pérez González, & Pérez Llamazares, 2013). However, the average heart rate as an intensity indicator does not reflect the interval character of a padel match (Courel-Ibáñez, et al., 2019). Therefore, due to the aerobic-anaerobic requirements considering in the padel time structure, a specific high-intensity interval exercise was introduced in our research to improve the aerobic capacity of the player. Our results showed improvements ($p<.05$) in 30-15IFT in both experimental groups. However, the training methodology that achieved the greatest improvements in 30-15IFT was IG (7.3%, $p<.05$). Therefore, this type of specific neuromuscular training (plyometric, COD and power-oriented exercises), either IG or NIG, could improve oxidative capacity, recovery between efforts, the reserve anaerobic capacity and the neuromuscular fatigue of the young padel players.

Padel players frequently perform repeated actions of maximal acceleration and rapid COD, most of which are very short-duration efforts over 5-10 meters (Castillo-Rodríguez, et al., 2014). Additionally, positive results in sprint ability have been obtained when strength training was combined with plyometric training (Delecluse, et al., 1995; Kotzamanidis, Chatzopoulos, Michailidis, Papaiakovou, & Patikas, 2005) or when plyometric training was applied alone (Meylan & Malatesta, 2009). However, even though padel players significantly increased jumping, strength and endurance ability, the results of the current investigation did not show that a combined neuromuscular program (plyometric, strength, COD, and power-oriented exercises) significantly improved sprint time performance (0.5-2.6%, $p>.05$). Acceleration and sprint performance are related to factors such as stride rate, stride length, technical skills, anthropometric characteristics, genetic factors, maximal strength, rate of force development, and power (Mero, Komi, & Gregor, 1992). Complex interaction of these factors makes it difficult to identify a potential cause for the lack of sprint improvements in both study groups. Although speculative, a potential factor related to the lack of improved sprint performance may be the reduced specificity of speed exercises during intervention, in addition to reduced technical skills or lack of proper sprint conditioning in their padel training program. Other reason could be that jumping exercises were non-specific to sprint performance and did not cause any effect on running speed (Fry, et al., 1991). When exercises were specific (e.g., speed bounding) to running performance, the training program had a positive effect on running velocity (Ford, et al., 1983). It is possible that a training program that incorporates greater horizontal acceleration (i.e., skipping, jumps with horizontal displacement) would result in the most beneficial effects (Sáez de Villarreal, et al., 2015).

Previous studies examined the influence of different types of training methods, including resistance training, plyometric and combined plyometric and resistance training on the development of COD performance (Asadi, 2013; Asadi, Arazi, Young, & Saez de Villarreal, 2016; Thomas, French, & Hayes, 2009; Váczi, Tollár, Meszler, Juhász, & Karsai, 2013). It has been previously reported that the combination of different neuromuscular exercises can influence the rate of adaptation and consequently greater improvements in COD performance (Arazi, Coetzee, & Asadi, 2012; Asadi, 2013; Váczi, et al., 2013), in line with our findings, showing COD improvements (2.5–4.9%, p<.05). Neuromuscular training may enhance athletes' ability to use the elastic and neuromuscular benefits of the stretch-shortening cycle (Aagaard, Simonsen, Andersen, Magnusson, & Dyhre-Poulsen, 2002; Asadi, et al., 2016), in line with improved motor unit recruitment, thus COD (Aagaard, et al., 2002). Improvement in COD requires rapid force development and high-power output, and it seems that combined neuromuscular training can improve these requirements (Miller, Herniman, Ricard, Cheatham, & Michael, 2006; Sheppard & Young, 2006). In addition, the combined neuromuscular training may have improved the eccentric strength of the thigh muscles, a prevalent component in COD during the deceleration phase, decreasing ground reaction times through the increase in force output and movement efficiency, therefore positively affecting COD performance (Asadi, et al., 2016). Of note, the experimental group improved COD90R and COD180R. Handball players usually perform a high number of COD movements during regular handball-specific training and competition (Ortega-Becerra, Belloso-Vergara, & Pareja-Blanco, 2020), potentially decreasing the space for further improvement in COD ability. Therefore, the experimental training approach may have maximized this space in the non-dominant leg (i.e., the one with the "greater room" for improvement). If physiological changes (associated to COD performance) occurred to a greater level in the experimental group, particularly in the non-dominant leg (i.e., the left leg) including lower-limb power, rate of force development, maximal strength, speed, and reactive force (Brughelli, Cronin, Levin, & Chaouachi, 2008; Young & Farrow, 2006), these should be explored in future studies.

Some potentially relevant limitations of the study should be acknowledged. Firstly, although we included high-level padel players, the relatively reduced number of participants precluded generalization of the results. Secondly, in line with the first limitation, our findings may not be translated to other groups of padel players (e.g., females; youth; older athletes; low-level or recreative athletes). Thirdly, the lack of physiological and biomechanical measures precluded a comprehensive understanding of the changes observed during training. Future studies should aim to solve these potential limitations, particularly during longer-term interventions.

In conclusion, elite male padel players improved strength and specific padel skills such as jumping, SV and COD by undertaking an 8-week in-season combined neuromuscular training, consisting of strength, COD, and power-oriented exercises for both the upper and lower body.

Practical applications

We found that both training approaches were effective to improve padel players athletic performance. However, the integrated training approach induced greater improvements in padel-specific performance and was particularly effective to improve change of direction speed performance in actions involving the non-dominant leg (i.e., turns to the left). The performance improvements shown in this study are of great interest for padel coaches and are directly applicable to padel players. It is recommended that padel coaches implement during competitive season resistance and power-oriented training to enhance the performance of their players. The outcomes may help coaches and sport scientists formulate better guidelines and recommendations for athletes' assessment and selection, training prescription and monitoring as well as preparation for competition.

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Competing interests

None of the authors declares competing financial interests.

SURVEY ON COACHING PHILOSOPHIES AND TRAINING METHODOLOGIES OF WATER POLO HEAD COACHES FROM THREE DIFFERENT EUROPEAN NATIONAL SCHOOLS

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Abstract:

The ability to change swimming styles and body positions, involving continuous shifting from horizontal to vertical posture and performing jumps, as well as technical skills play a fundamental role in water polo performance. To face with these demands, the coaching staff of elite and sub-elite water polo clubs might adopt a variety of training methods, also based on their specific coaching philosophies. This point has led to an enlargement of the staff, with higher head coaches' responsibilities, who may interpret their professional activity according to their own coaching philosophy, education, and their respective national water polo schools. In fact, based on their international sports achievements, some countries can be identified as recognised water polo national schools. For this reason, the purpose of this study was to survey 40 head coaches of three important national water polo schools (Italy, Greece, and Serbia) to identify and compare their coaching philosophies and training methodologies. The survey was based on five sections (Technical staff composition, Team roster, Weekly periodization, Testing and monitoring, Tactics and strategies). Furthermore, using a detailed descriptive statistic, the current study gives interesting information on how 40 high-ranking elite and sub-elite teams of different national championships organize their training during a typical week of the competitive season. A further improvement of this research line could include more national schools, expanding the sample to more countries from all over the world.

Key words: *team sports, team management, coach education, typical training week, competitive season*

Introduction

Water polo is a very stressful body-contact aquatic team sport played all over the world. It combines high-intensity short-duration efforts and low-duration actions (Ruano, Serna, Lupo, & Sampaio, 2016). The latest worldwide survey, published in 2019 by the Fédération Internationale de Natation (FINA) and based on data supplied by the national federations, shows a number of 24,482 coaches and 22,690 referees, out of which 8,155 and 19,113 are involved in European competitions at all levels, respectively (FINA, 2019). These data pose Europe as the most important geographic area for this sport in terms of the relevance of elite national (e.g., the Italian 'Serie A1', Serbian 'Prva A liga', Hungarian 'OB I', Spanish 'División de Honor', Croatian 'Prva hrvatska liga', Montenegrin 'Prva liga Crne Gore', and Greek 'A1 Ethniki') and elite continental (e.g., Champions League, LEN Euro Cup, and Adriatic Water Polo League) water polo championships. All these championships include the best European water polo players and clubs, showing a variety of water polo cultures belonging to different parts of Europe. In the last years, the Italian national team won the 2019 World Championship held in Gwangju and the Serbian national team won the last two Olympic Games (Rio de Janeiro in 2016 and Tokyo in 2020). As well, in the history of European tournaments, the Italian clubs won twenty-four and the Serbian eleven editions in both the Champions League and the LEN Euro Cup. At the same time, Greece has currently reached a very high level of water polo development, achieving noticeable results with both the senior national team (silver medal at Tokyo in 2020) and youth national team (gold medal in 2019 at the U20

World championships). Also, Greek clubs usually compete in the final eight of European cups. For this reason, in our study, we surveyed head coaches from these three countries. However, Europe is also the home of other water polo prestigious countries that are very important for this sport, based on the history of their international trophies (i.e., Hungary, Croatia, Spain, Montenegro), and that have highly contributed to the development of water polo in Europe along the years, as we are going to explain in the next paragraph.

Regarding the evolution of the game, two studies have identified five historical stages of its development, characterized by changes in the rules of play, the need for higher levels of physical condition and technical skills, imposed by increased matches' demands, and the coaching philosophies employed by the technical staffs (Donev, & Aleksandrović, 2008; Hraste, Bebić, & Rudić, 2013). The first stage of water polo evolution (from 1869 to 1907) has been marked as the search for identity and unified rules of the game, which was characterized as a sort of an 'unattractive' game played exclusively in conjunction with swimming or rowing competitions. The second evolution stage (from 1908 to 1949) can be considered as the period of restructuring and internationalization of the game, distinguished by a relevant improvement of players' individual technical skills. The third stage (from 1950 to 1969) saw a faster development of both defensive and offensive play phases determined by new game rules. In particular, the defensive phase was characterized by the first forms of man-to-man defence, while the role of the centre forward was significantly changed who became the organizer of the attacking phase. The fourth stage (from 1970 to 1986) transformed the water polo performance by introducing a new attack limit of 35 seconds, thus making it a more dynamic, fluid, and high-tempo game. The fifth and final stage (from 1987 to 2012) can be considered as the period of evolution of the high-intensity game. The new rules allowed the goalkeeper to score, and the team ball possession phase was limited to 30 seconds. Consequently, the total volume of swimming activities increased considerably in both training and matches. Furthermore, due to the rise of the number of contacts and tougher struggling in the duels between players, training with weights and exercise equipment gained much relevance. Nowadays, with the latest changes in the rules of play, established by FINA in 2019 (FINA, 2020), which have had a relevant impact on the core elements of play, we can affirm that water polo is experiencing the sixth phase of its history.

To face the new requirements of game play, in addition to the traditional figure of coach, such continuous game evolution also requires the contribution of other professional figures within the coaching staff, such as strength and conditioning coaches, technical collaborators, goalkeeper coaches, and match analysts. Consequently, the enlargement of the coaching staff has carried out a new culture of management of training and competitions, which is also influenced by the coaches' personal coaching philosophy and the knowledge and traditions of different national water polo schools. The training methodologies are largely influenced by the coaching philosophy of the head coach, which consists of his/her major objectives and values, beliefs and principles he/she wants to achieve during the coaching career (Martens, 2012). The coaches' national schools reflect the cultural diffusion of the sporting environment, which exerts a large influence over coaches in social and sporting terms, through their attitudes to coaching moulded by a national background of common values and experiences. In this regard, specific coaching programmes provided by sports federations are an essential part of the coaches' education. A study commissioned by the Australian Institute of Sport and involving coaches of several sports disciplines, showed how scientific findings provided through appropriate forums, using simple and accessible language, were likely to be useful for coaches' professional development (Williams & Kendall, 2007). However, in water polo, to the best of our knowledge, except for a survey on physical trainers of male and female Spanish First League teams (Reverter-Masía, Jove-Deltell, Legaz-Arrese, & Munguía-Izquierdo, 2012), there are no studies investigating the characteristics of coaching philosophies from national water polo schools of different countries. Indeed, such a kind of study, exploring the real identity of national water polo schools and the coaches' profiles belonging to them, would bring valuable information to professionals by defining what kind of methodologies and educational programmes are used in different areas of the world, how players are selected and sustained, as well as the composition of roasters and coaching-staffs.

Therefore, the purpose of this study was to survey the coaches of three main national water polo schools to identify and compare their coaching philosophies.

Methods

Study design

In reporting this survey study, a Consensus-Based Checklist for Reporting of Survey Studies (CROSS) was followed with the aim of strengthening the quality (Sharma, et al., 2021). All the participants surveyed in this study were head coaches, during the season 2019-2020, of their respective teams playing in the first and/or second divisions of the national championships of the three worldwide recognised water polo national schools of Italy, Serbia and Greece. After the authors elaborated on the survey's first draft, it was sent to one elite water polo coach from each of the three countries (Italy, Serbia and Greece) to gather information about the questionnaire's clarity and format, as well as to receive any other feedback. These coaches were chosen due to their qualifications and experience and because they closely resembled the actual study participants' profiles; however, they were not included in the actual study.

The final version of the survey was composed of 38 close-ended questions, divided into five sections of inquiry: 1) Technical staff composition (15 items); 2) Team roster (5 items); 3) Weekly periodization (8 items); 4) Testing and monitoring (4 items), and 5) Tactics and strategies (6 items) (see Appendix A).

Participants

Forty male head coaches from the Greek (n=12), Serbian (n=14) and Italian (n=14) national first (n=22) and second division (n=18) teams were recruited for this study.

The study was approved by the Ethical Committee of the University of Rome 'Foro Italico' (number CAR 27/202).

Procedure

The questionnaire was built in digital format through the Google Docs platform and translated into the Italian, Serbian and English language. After receiving their agreement to participate in the study, the link was sent to the head coaches by email.

Statistical analysis

Descriptive statistics of all the parameters, including means, standard deviations and frequencies for all the participants and pooled data were calculated. Because nominal data were gathered in this survey study, a non-parametric Kruskal-Wallis' test was conducted to examine the differences in the answers according to the water polo national schools of the coaches. Descriptive data of the three groups is provided in the report that clearly showed the difference between each pair of groups. The statistical analyses were conducted using the statistical package SPSS (version 26.00; Institute, Inc., Cary, NC), and the criterion for significance was set at a 0.05 alpha level.

Results

Section 1. Technical staff composition

Even 92% of the surveyed head coaches reported being a former water polo player and no significant differences were found regarding their competitive level as former players. The pooled data showed that 52.5% of head coaches (n=21) played in the second division of their respective national water polo leagues.

Regarding their experience as head coaches, the pooled data showed an average of 12.3 ± 9.7 years of coaching experience. In particular, 50% of respondents indicated being in charge as a head coach for up to 10 years [<5 years (n=8): 20% and 5-9 years (n=12): 30%, respectively], while the rest 50% of them showed over 10 years of experience [10-14 years (n=6): 15%; 15-20 years (n=8): 20% and > 20 years (n=6): 15%, respectively].

No differences were found between the groups (national water polo schools) regarding their highest level of education. Specifically, 32.5% of respondents (n=13) declared to have a high school degree, 25% (n=10) a bachelor's degree, 35% (n=14) a master's degree and two head coaches earned the Ph.D. Out of the 67.5% of coaches with higher education, only four of them (all from the Serbian school) answered to have a degree in sports science.

When the head coaches were asked '*Which of the following aspects have most influenced your current coaching philosophy?*' (multiple choice answers), their answers showed 'had other coaches as mentors' (n= 29 head coaches), 'my own experience as a player' (n= 21), 'years of continuous practice as a water polo coach' (n=18), 'education from my water polo federation' (n= 15), 'the club's philosophy' (n=13), 'having a degree in sport science' (n=4) and 'education from other sports federations (different disciplines)' (n=2). The most frequent head coaches' answers describing the ways of their continuing learning were the following: 'sharing ideas with other coaches' (n=15); 'refresher training courses' (n=14); 'research and courses on the internet' (n=11). Regarding the investigation of whether sports disciplines different from water polo might have influenced their training methodologies (Figure 1), data showed team sport of basketball was their answer with the highest score (n= 22).

Furthermore, 62.5% of head coaches (n=25) stated that water polo was their main professional activity, compared to 37.5% of coaches to whom it was a hobby or a secondary profession. In particular, the Kruskal-Wallis' test showed a significant difference between the three groups (Figure 2).

In the item '*Does your team have a full job technical collaborator (helping the head coach)*?', most of the respondents (n=31) indicated to have at least one technical assistant in their professional staff. Also, in this case, there was a significant difference between the three national water polo schools (Italian school: yes=9, no=5; Greek school: yes=8, no=4; Serbian school: yes=14). Figure 3 shows the item investigating whether their own coaching staff included three specific figures of professional collaborators: a goalkeeper coach, strength and conditioning coach, and match analyst.

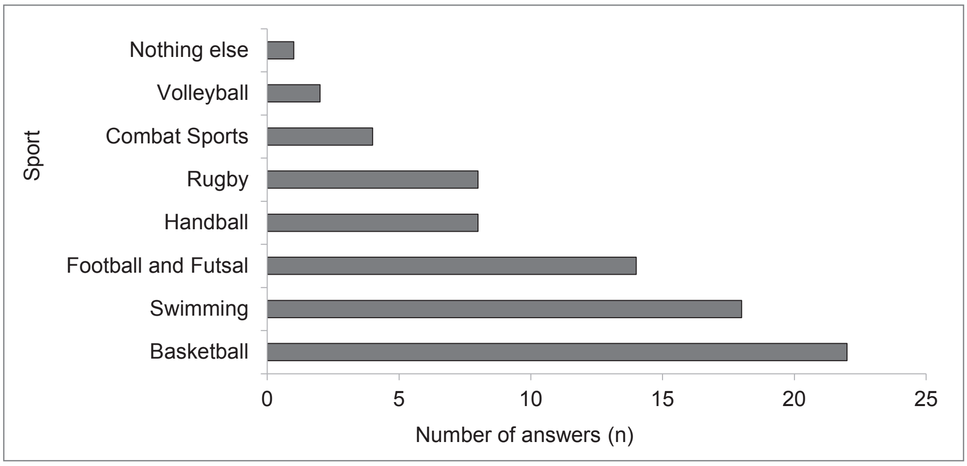

Figure 1. 'In addition to water polo, which of the following sports has influenced your training methodology?'

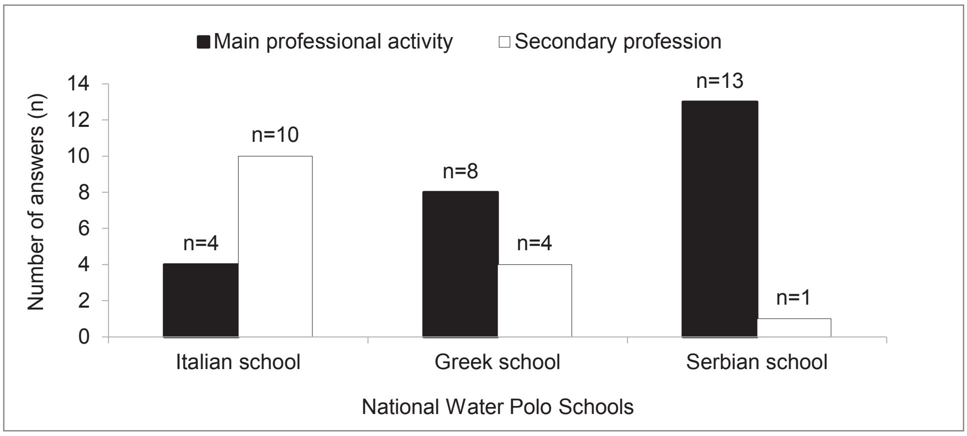

Figure 2. Number of coaches for whom coaching is their main profession.

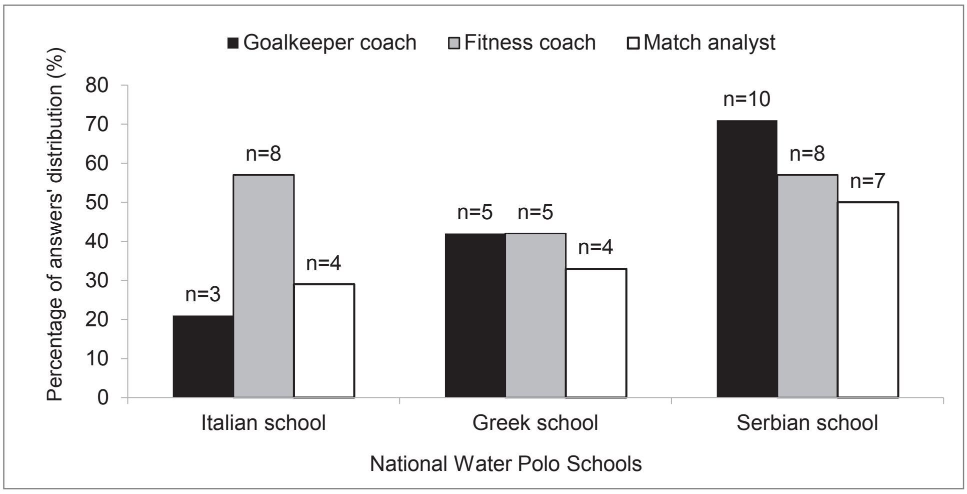

Figure 3. Percentage of professional collaborators for each water polo national school.

Two items investigated the selection of youth players for the first team. The Kruskal-Wallis' test showed no differences between the three national water polo schools, so the results are shown as pooled data. The answers to item '*Who should reach the decision of selecting a player from the youth team to be employed with the first team*' showed that 50% of respondents (n=20) indicated that the decision was reached '*as a collaborative choice of the entire technical staff*, 23% (n=9) answered the decision was made by the head coach, 25% (n=10) by '*coaches and clubs*', while only one answered '*by the club*'. When head coaches were asked what kind of skills related to a tactical phase (defensive or offensive) of the game was preferred when determining to select a youth player for their senior team, most of them answered that they considered more the defensive skills (62.5%) than the offensive (5%)

ones, while 32.5% of respondents answered that their choice was equally influenced by both types of skill. Finally, 30 head coaches indicated an average age of 16 years (16.1±0.9 yr) to be considered as the right age for directing a player from the youth team to train and compete in a senior team.

Section 2. Team roster

The survey's second section inquiries about the roster's composition in terms of the total number of players in it, the number of players in the roster coming from the youth team, employment of foreign players, age (range of years) and the number of professional players in the roster (Table 1). The Kruskal-Wallis' test showed a significant difference between the three national schools only in the number of youth players included in the roster of the senior team.

Section 3. Weekly periodization

The third section investigated the weekly periodization. The pooled data showed an average of 6±2 sessions and 14±4 hours of training per week. No significant differences between the groups were found for the number of two daily training sessions (average of 1±1.5 per week) and for the days of rest (average of 1±0.5 per week). Most of the head coaches declared to play the official match on Saturday (n=33; 82.5%) and to have a day of rest on Sunday (n=32; 80%). Figure 4 shows the main activities performed during a typical week (microcycle) according to their answers.

All the head coaches (n=40) declared to perform at least one session of strength training in the gym. The Kruskal-Wallis' analysis showed a significant difference between the groups regarding the number of sessions conducted in a gym and the number of injury prevention sessions during a typical microcycle (Table 2).

Regarding the meeting with players to prepare for an upcoming match, no significant differences among the head coaches of the three national schools were observed. Based on their coaching philosophy, head coaches declared to schedule their pre-match preparation meeting as follows: 40% on the day of the match (n=16), 40% on the day before the match (n=16), 10% on any previous day (n=4), while 7.5% answered that they did not fix the day but decided according to the difficulty of the game (n=3). Furthermore, regarding the pre-match meeting preferrable duration, seven head coaches considered effective meetings to last up to 10 minutes, 19 head coaches said between 10 and 20 minutes, nine head coaches between 20 and 30

Table 1. Characteristics of teams' rosters

Items	Number of players	National water polo schools		
	(n)	ITA	GRE	SRB
		Number of teams (n)		
Number of players in the roster	< 13	1	0	1
	13-15	6	5	4
	16-18	5	2	5
	>18	2	5	4
Number of players in the youth squads team's roster	<6	2	1	0
	6-10	7	5	4
	11-15	5	6	4
	> 15	0	0	6
Number of professional players employed (players that can live on the club's salary)	Not at all	8	7	8
	1	2	1	5
	2-4	1	4	0
	5-7	1	0	0
	> 7	2	0	1
Players' age distribution	Age (years and range of years)	ITA	GRE	SRB
	< 21	4	4	3
	21-25	8	5	10
	26-30	2	3	1
	> 30	0	0	0
Presence of foreign players in the roster	Yes/No	ITA	GRE	SRB
	Yes	5	3	6
	No	9	9	8

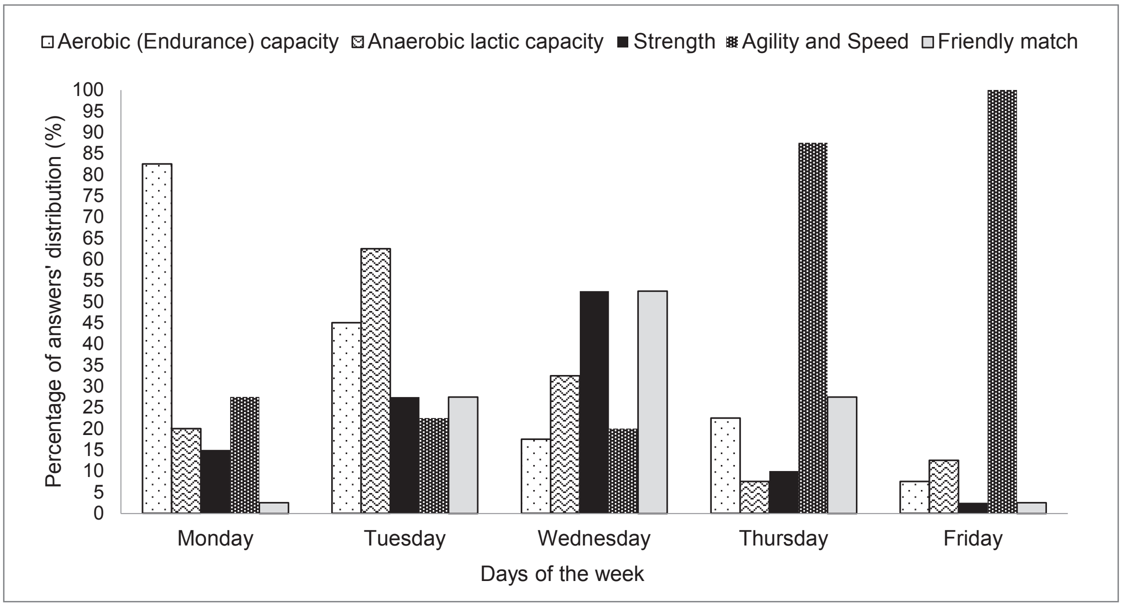

Figure 4. Typical training contents being components of every working day in a week.

Table 2. Planning of strength and injury prevention training sessions during a typical week

Questions	Answers	ITA	GRE	SRB
	Number of sessions	Number of teams (n)		
Strength training sessions	Only body weight load	0	2	2
	1	2	2	0
	2	11	6	2
	3	0	2	10
Injury prevention sessions before training sessions	Never	1	0	0
	1	3	0	0
	2	3	2	0
	3	4	3	0
	4	0	0	0
	5	0	2	1
	Every session	3	5	13

minutes, and only four head coaches believed that the meeting should last more than 30 minutes.

Section 4. Testing and monitoring

The fourth section of the survey focused on the use of physical fitness tests and monitoring of training. The pooled data showed 55% of the head coaches (n=22) used only one tool for monitoring, 27.5% two tools, only one head coach used three monitoring tools, and six head coaches were not monitoring training effects at all. Regarding the specific system of monitoring, a common tool used by 85% of the head coaches was a manual pulse check (n=34), while only three head coaches also used heart rate (HR) monitors. Surprisingly, only four head coaches (10%) pointed out the use of the session-RPE method (and then the use of a modified RPE Borg scale), six head coaches the use of a sort of questionnaire of self-evaluation and only one head coach used a time motion analysis evaluation. Regarding the use of field tests, 31 head coaches (77.5%) declared to test players during the competitive season; however, only six of them did it regularly each month, whereas the others indicated a range from one to four testing sessions per year.

Turning to match analysis, Figure 5 shows which kind of analysis was carried out in their respective teams.

Section 5. Tactics and strategies

The last survey's section focused on teams' tactics and strategies. In this regard, head coaches indicated carrying out 2±1 tactical training sessions per week. Specifically, 27.5% of the head coaches (n=11) declared to give more importance to the defensive phase, while 72.5% of them (n=29) considered both (defensive and offensive) phases of play equally relevant.

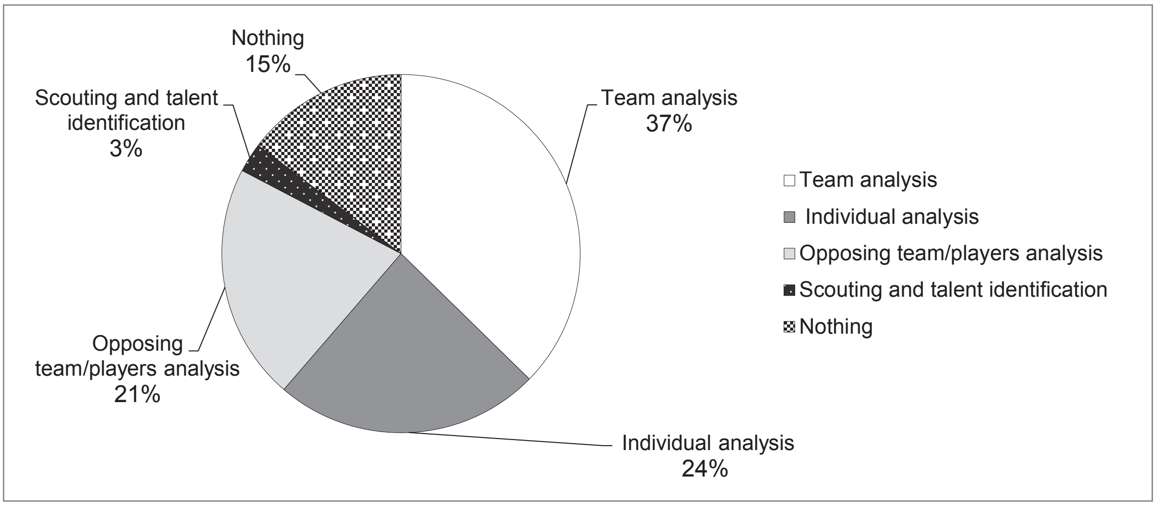

Figure 5. Type of match analysis carried out by the teams.

Table 3. Tactical and strategical schemes

Situation	Number of schemes	ITA	GRE	SRB
			Number of teams (n)	
Even offensive phase	No scheme	1	1	0
	1-2	1	3	2
	3-4	7	8	9
	5-6	3	0	1
	>6	2	0	2
Even defensive phase	No scheme	0	0	0
	1	0	2	0
	2	6	7	2
	3	4	3	10
	4	3	0	1
	>4	1	0	1
Extra-player	No scheme	2	1	0
	1-2	2	6	2
	3-4	6	5	9
	5-6	2	0	2
	>6	2	0	1
Player-down	No scheme	1	5	0
	1	6	4	1
	2	5	2	6
	3	2	1	7
	4	0	0	0
	>4	0	0	0

In relation to the weekly periodization, Friday (which is the day before the match for most teams) was the day most used by coaches for their tactical sessions. In particular, Table 3 shows the numbers of schemes of play (pre-configured strategies) organized for the three water polo schools in consideration with different game situations: even in offensive phase (6vs6); even in defensive phase (6vs6); extra-player (6vs5), and player-down (5vs6). A significant difference between the three national schools was found in the schemes for the even defensive situation and extra-player (Table 3).

Discussion and conclusions

Using a 38 close-ended questions survey, this study aimed to survey the head coaches of the three national water polo schools (Serbia, Italy, and Greece) to identify and compare their coaching philosophies. The survey was based on five sections: 1) Technical staff composition (15 items); 2) Team roster (5 items); 3) Weekly periodization (8 items); 4) Testing and monitoring (4 items), and 5) Tactics and strategies (6 items). The main differences between the three national water polo schools investigated reflect various cultural and environmental aspects of coaching philosophies.

Regarding the section investigating the technical staff, the Kruskal-Wallis' test showed a significant difference between the three schools in terms of the professional and employment status of head coaches. For the majority of Serbian (93%) and Greek (67%) head coaches the profession of water polo head coach was their main job, while in Italy this percentage drops to a threshold below 30%. Another significant difference between the national schools in terms of staff composition is that in Serbia, all the teams' staff investigated employed at least one assistant coach. Based on this result it can be speculated that this country is more prone to value the water polo coach profession.

Regarding the different figures (specializations) of technical collaborators, 52.5% of the pooled sample indicated having a strength and conditioning coach. Such a percentage is still lower compared to the presence of strength and conditioning specialists revealed in surveys from studies covering the period of 25 years in other team sports (Sutherland & Wiley, 1997; Weldon, Duncan, Turner, Lockie, & Loturco, 2021). The full-time employment of strength and conditioning coaches helps head coaches to better understand some physical aspects and plan weekly training strategies, as well as to better interpret data provided using time-motion analysis (Dopsaj & Matković, 1994; Melchiorri, et al., 2021; Platanou, 2004). Furthermore, the percentage (45%) of respondents indicating the presence of goalkeeper coaches in their teams was even lower than the percentage of the strength and conditioning ones. In this case also Serbia showed to be the national water polo school with the highest number of employed goalkeeper coaches. Only 37.5% of total respondents declared to have a match analyst in their teams, which is an emergent professional figure that helps to produce and interpret technical and tactical indices for both their own and opponent teams (Casanova, et al., 2020; Ordóñez, Pérez, & González, 2016; Perazzetti & Tessitore, 2021; Takagi, Nishijima, Enomoto, & Stewart, 2005).

In terms of water polo coaches' education, the latest FINA general survey (FINA, 2019) shows that only 38% of the 209 national federations affiliated with the international federation provide specific water polo educational programmes. All the head coaches surveyed in our study declared to have a water polo specific certification delivered by their national federations (Greece, Serbia and Italy), whilst 37.5% of the pooled sample also stated that having attended these courses has been fundamental to driving and expanding their coaching skills. Indeed, considering the fundamental role of learning as a lifelong process, it is also very important to promote education initiatives for coach developers, to focus on proper planning of coach developer courses, which are in turn responsible for conceptualizing formal coach education courses (Ciampolini, Tozetto, Milan, Camiré, & Milistetd, 2020), to face new challenges posed by the coach profession that emerge from dealing with new generations of athletes.

Another important aspect of the profession of coaching is to develop its own coaching philosophy, which provides a set of principles to guide its decision-making to overcome practical problems and to favour consistency in coaching (Cassidy, Jones, & Potrac, 2009; Lyle, 2002). A coaching philosophy changes over time as coaches' life experiences impact their practice. To inquire about this aspect, we asked the head coaches in our study how relevant, to build their own coaching philosophy, it had been '*to have other coaches as mentors*' (72.5%), '*to rely on their own experience as a player*' (53%), as well as what was the influence of '*years of continuous practice as a water polo coach*' (45%), in terms of positive influence, respectively. Moreover, we also investigated whether other sports disciplines different from water polo might have influenced our head coaches' training methodologies. Surprisingly, with respect to the well-known habits of water polo coaches that included frequent use of methodologies based on swimming distances (Reed, 2019; Smith, 1998), the head coaches of our survey indicated to be more influenced by methodologies driven by other team sports.

The section of our study that investigated the teams' composition, showed a significant difference between the groups in terms of the number of players in the first team coming from the youth teams of the same club. In particular, six head coaches from Serbian teams indicated having more than 15 players from the youth teams in their current rosters, which is a relevant number. For youth players, the opportunity to debut in the first team of their club could bind the players in a very strong way to the club, the head coach's philosophy, and teammates, tremendously improving their sense of belonging. In turn, the clubs that employ many players from their youth teams might receive advantages in terms of economic sustainability by reducing the budget for expensive players from other clubs or foreign players. In this regard, we also asked our head coaches the following question '*Based on your coaching philosophy, at which age a young talent is ready to play and train with the first team?*'. The answers to this question showed that most head coaches from Serbia and Greece suggested a specific age as opposed to most Italian head coaches (n=8) who argued (in a generic way) on the necessity to wait until the youth player 'is ready'. Such generic decisions could slow down the young athletes' process of growth and lead to a situation in which the club is forced to buy and find other players. Generally, grouping by players' chronological age is a common strategy in sports competitions for organizing and managing young talents of the same categories and January the 1st is often used as the cut-off date for each selection year (Boccia, Rainoldi, & Brustio, 2017). This aspect, also named the relative age effect (RAE), has been investigated in different fields, including academic and sports performance. The results of previous studies conducted in other team sports by Lupo et al. (2019), suggested that relatively older players had more chances to join senior teams, especially at the beginning of their adult careers. However, in water polo, the RAE has not been revealed either in male or in female elite water polo players, probably due to the lower popularity of this sport (Barrenetxea-Garcia, Torres-Unda, Esain, & Gil, 2019).

In terms of training periodization, despite planning proper training contents that combine loads and recovery might enhance athletes' preparedness (Mujika, Halson, Burke, Balagué, & Farrow, 2018), information related to the strategies used to plan training in water polo is still limited compared to other team sports (e.g., soccer, basketball, rugby) (Botonis, Toubekis, & Platanou, 2019a). For this reason, in our study, we investigated the organization of the 'standard' in-season weekly microcycle. All the three national schools indicated to adopt a microcycle periodization characterized by an undulation design of training workloads to reduce loads and prevent the accumulation of fatigue in the days close to the competition (Issurin, 2010). In particular, our head coaches showed training strategies based on endurance activities and aerobic capacity development implemented mainly in training programmes at the beginning of the week; further, anaerobic lactic activities were mainly scheduled on Tuesdays and Wednesdays (away from the match), while alactic activities mainly characterized training programmes scheduled for Thursdays and Fridays, the days close to the competition.

Regarding strength training, all head coaches answered that they plan specific training sessions, most of which are performed using an equipped gym to this scope. In particular, most Serbian head coaches usually planned three training sessions in the gym per week, while most of the Italian and Greek teams planned two sessions. However, it can also be speculated that the number of training sessions scheduled with exercises performed outside the water (as for example some strength training) is also determined by the characteristics of the training facilities, which are frequently available only for limited hours to the water polo clubs (as it is the main case in Italy).

The limited sports science background in coaches' profiles (for instance, only 10% of our entire sample of head coaches, all from Serbia, had a degree in sport science) could also explain a low use of monitoring of training strategies, including physiological, psychological, and tactical parameters (Clemente, 2016; Sansone, et al., 2020). Indeed, in our study, most of the respondents declared to use only the manual pulse measurement method, while only a few teams provided regular monitoring using tools and methods indicated by the relevant literature (Botonis, Toubekis, & Platanou, 2019b; Lupo, Capranica, & Tessitore, 2014). Furthermore, most of our respondents showed a lack of regular and calendarized use of physical and swimming tests. This aspect is in contrast with previous literature that suggested choosing different protocols to apply water polo specific tests (Chirico, Tessitore, & Demarie, 2021).

To understand how water polo is played at different competitive levels and to investigate the relationship between game demands and players' individual skills, it is useful to use notational analysis (Hughes, 1995), a tool that provides coaches with accurate and comprehensive information on technical and tactical aspects of play demonstrated by own team and the opponents (Lupo, Condello, & Tessitore, 2012; Lupo, Tessitore, Minganti, & Capranica, 2010). However, despite the usefulness of these feedback, the results of our survey showed that 11 out of 40 head coaches were not using match analyses at all.

In the end, in terms of training tactics and strategies, we asked our head coaches which one of game phases, offence or defence (Lupo, et al., 2011) received more attention or did they consider them of same relevance. Most of the respondents answered that both phases were of same relevance to them, only 11 highlighted defence as more important. None of the head coaches answered that they paid more attention to offence. In support of this choice, most of the head coaches declared that they relied more on the players' defensive skills when selecting young players for their debut in the first team.

Talking about team strategic schemes, significant differences were found in the player-up situation and even defensive phase. In this regard, the Greek school seems to be the one with fewer schemes of play than the other two schools, probably due to the creativity that usually characterizes Greek players, as could be seen in play that Greek young categories demonstrated during the last youth international competitions.

Based on the survey's results, our research can offer an objective indication of differences and similarities in training methodologies and competition management derived from the coaching philosophies of the interviewed head coaches as well as from the different water polo national schools. Indeed, how a sport discipline develops in a country can be seen in a complex interaction of social relevance, sports achievements, media coverage, financial resources, and so on, in addition to the country's historical link to that specific sport. In the latter respect, for instance, water polo has expanded in Serbia starting from a single Central School in Belgrade and in the main cities of the former Yugoslavia (Bratuša, 2021); in Greece, it has developed from the main clubs in the Greater Piraeus area, while in Italy, it could be speculated that the Italian school has been developed in parallel with different and original features between the various Italian regions (mainly Liguria, Lazio, Campania and Sicily). To further improve this line of research, the sample must be expanded involving more head coaches from water polo clubs all over the world and including the head coaches of the U18 and U20 teams. In fact, in our opinion, the same questions posed to a wider audience of head coaches from different countries and from different national water polo schools would expand the scientific data available to researchers and favour the transferability of knowledge to the coaches of this discipline.

Appendix A

Section 1: Technical staff composition

1. Is water polo coaching your main job?
2. Does the team you train have technical collaborators to help the head coach?
3. Does the team you train have a goalkeeper coach?
4. Does the team you train have a fitness coach?
5. Does the team you train have a match analyst?
6. Based on your coaching philosophy: who should reach the decision of selecting a player from the youth team to be employed with the first team?
7. Based on your coaching philosophy: considering a player from the youth team, which one of the following game phases could determine his/her higher employment in the first team?
8. Based on your coaching philosophy: at which age is a young talented player considered "ready" to play and train with the first team?
9. Have you been a water polo player?
10. If your answer is "Yes": which one of the following has been your highest competitive level?
11. How many years have you been coaching in water polo?
12. Which is your highest educational level?
13. Which one of the following aspects has mostly influenced your coaching philosophy?
14. In addition to water polo, which one of the following sports has influenced your coaching philosophy in regard to training methodologies?
15. Based on your personal experience: indicate the most used way for continuing learning.

Section 2: Team roster

1. Indicate how many players are in the roster of your first team.
2. Indicate how many players of the roster of your first team were in the youth teams of your club the year before.
3. Indicate the range of players' age of your first team.
4. How many foreign players has the roster of your first team?
5. For how many players in the roster of your first team is water polo the main job?

Section 3: Weekly periodization

1. Indicate the weekly hours of training of your first team (including also the workouts performed in the gym).
2. Indicate how many times per week your team has two training sessions a day.
3. Indicate how many times per week your team has a full day rest (without training).

4. Considering the typical training week of your team: indicate how many resistance training sessions per week are performed in the gym.
5. Considering the typical week of your team: indicate how many times per week injury prevention or pre-activation activities are performed.
6. Considering the typical week of your team: indicate which is the main workload of each daily training session.
7. Based on your coaching philosophy: indicate on which day of the week the pre-match meeting with players is scheduled.
8. Based on your coaching philosophy: indicate how long should the pre-match meeting last.

Section 4: Testing and monitoring

1. Which ones of the following methods are used to monitor training loads?
2. Does your team use tests to assess players' fitness?
3. Considering the entire water polo season: indicate the period in which tests are usually executed.
4. Indicate what kind of match analysis is carried out in your team.

Section 5: Tactics and strategies

1. Which phase of play (defensive or offensive) receives more attention in your training periodization?
2. Based on your coaching philosophy: indicate how many strategies and tactics (pre-configured) has your team to attack in a player-up situation.
3. Based on your coaching philosophy: indicate how many strategies and tactics (pre-configured) has your team to attack in a common situation with equal number of players.
4. Based on your coaching philosophy: indicate how many types of defence (pre-configured) has your team to defend in a player-down situation.
5. Based on your coaching philosophy: indicate how many types of defence (pre-configured) has your team to defend in a common situation with equal number of players.
6. Considering the typical week of your team: indicate on which days the focus of a training session is mainly on game strategies and tactics.

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EFFECTS OF PROBIOTICS ON STRENGTH AND POWER PERFORMANCE IN A TRAINED POPULATION: A SYSTEMATIC REVIEW AND META-ANALYSIS

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Review
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Abstract:

The main purpose of this systematic review and meta-analysis was to evaluate the effects of probiotics intake on strength and power performance in a trained population. This study was designed following Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement guidelines. The review was registered in PROSPERO with the following registration number: CRD42021248173. PubMed/MEDLINE, Web of Science, and Scopus databases were searched from their inception to the 18th March 2022 to find original research studies evaluating the effects of probiotic supplementation on strength and power performance tests in a trained population. The following inclusion criteria were applied to select studies: probiotics supplementation; trained population; strength and power performance measurements; human experimental trial; controlled with a placebo group; peer-reviewed and original articles written in English language. Random effects model and standardized mean differences (SMD) were used following Hedges' G for the meta-analysis. Seven studies were finally included after the inclusion/exclusion criteria were applied (n=142 participants). Results of the meta-analysis identified a significant benefit of probiotics compared to placebo treatments (p=.04), with a small pooled effect size (SMD=0.36 [0.02-0.70]; I^2=43%), and no funnel plot asymmetry was present. In summary, this systematic review and meta-analysis demonstrated that probiotic supplementation could effectively enhance strength and power performance in a trained population.

Key words: *recovery, physiology, nutrition, exercise, athlete*

Introduction

An active lifestyle, involving regular physical activity, is associated with good health and a reduction in risk factors that could lead to chronic diseases later on (Warburton, Nicol, & Brendin, 2006). However, athletes often intensify their training to improve exercise induced adaptations (D'Andrea, et al., 2013). During exercise, blood flow is redirected mainly to skeletal muscles, lungs, and heart, causing splanchnic hypoperfusion and hypoxia (Chantler, et al., 2021). This reduction in intestinal perfusion, in addition to the increase in body temperature, induces epithelial cell injury (Pires, et al., 2017; van Wijck et al., 2012). The gut cell damage is commonly measured by the rise in serum of intestinal fatty acid binding protein (I-FABP) concentration (Chantler, et al., 2021).

As a result of enterocyte damage, gut permeability is increased, promoting nutrient malabsorption (Dokladny, Zuhl, & Moseley, 2016). Gut permeability is even more elevated in athletes due to their lifestyle, involving excessive training load, sleep disturbances, psychological stress, foreign travels, and environmental extremes (Jäger, et al., 2019).

Thereby, it is essential for athletes to keep a proper gut permeability in order to guarantee an adequate absorption of ingested nutrients. Specifically, probiotics have been shown to enhance gut health and thus they may help athletes to maintain a proper fitness status (Jäger, Purpura, et al., 2016). Probiotics are defined as "live microorganisms, which administrated in adequate amounts, confer benefits to the health of the host" (Hill, et al., 2014). Intestinal microorganisms are capable of producing short chain fatty acid (SCFA), mainly acetate, propionate, and butyrate, mostly due to the fermentation of undigested carbohydrates in the intestine (Markowiak-Kopeć & Śliżewska, 2020). Butyrate is the primary energy source of the enterocytes and has been estimated to be 60-70% of colonocytes' energy needs (Kiela & Ghishan, 2016; Roefiger, 1980). Thus, this compound could reduce intestinal cell injury and gut permeability, and the subsequent inflammatory response by feeding enterocytes (Clark & Mach, 2016; Mach & Fuster-Botella, 2017). Thereby, the intake of probiotics could reduce gut damage (Jäger, et al., 2019), improve essential nutrients absorption for recovery, and therefore sports performance (Jäger, Mohr, & Pugh, 2020; Pugh, et al., 2020).

A previous meta-analysis found significant positive effects after probiotic supplementation on aerobic performance tests in a trained population (Santibañez-Gutierrez, Fernández-Landa, Calleja-González, Delextrat, & Mielgo-Ayuso, 2022). However, to the best of the authors' knowledge, there is still no evidence of probiotics' effects on strength and power exercise, characterized by short duration, high intensity, and high energy demands (Baker, McCormick, & Robergs, 2010). These activities could increase gut damage as demonstrated in the study by Wijck et al. (2013), in which after 30 minutes of resistance training, serum I-FABP concentration was significantly raised, impairing protein absorption after exercise (van Wijck, et al., 2013). Thus, proper intestine health may enhance the recovery process improving nutrient absorption after strength training. Additionally, it was recently hypothesized that greater gut health due to probiotic intake could improve anaerobic performance (Przewłócka, Folwarski, Kaźmierczak-Siedlecka, Skonieczna-żydecka, & Kaczor, 2020).

Therefore, the main objective of this systematic review and meta-analysis (SRMA) was to examine whether probiotic supplementation could improve strength and power performance in a trained population (trained/developmental, highly trained/national level, and/or elite/international level [McKay, et al., 2022]).

Methods

This SRMA was designed following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement guidelines (Liberati, et al., 2009) to evaluate the effects of probiotics supplementation on strength and power performance in a trained population. The study protocol was registered in the Prospective Register of Systematic Review (PROSPERO) with the following registration number: CRD42021248173.

Search strategy

Records were identified by searching in PubMed/MEDLINE, Scopus and Web of Science (WOS) from their inception to 18th of March of 2022. For that aim, the following Boolean search equation was used for the PubMed/MEDLINE database: ("probiotics"[MeSH Terms] OR "probiotics"[All Fields] OR "probiotic"[All Fields]) AND (("exercise"[MeSH Terms] OR "exercise"[All Fields]) OR ("sports"[MeSH Terms] OR "sports"[All Fields] OR "sport"[All Fields]) OR performance[All Fields] OR strength[All Fields] OR anaerobic[All Fields] OR ("power"[MeSH Terms] OR "power"[All Fields])) AND (("athletes"[MeSH Terms] OR "athletes"[All Fields] OR "athlete"[All Fields]) OR trained[All Fields] OR elite[All Fields]). For the Scopus and WOS databases, the following Boolean search was used: (Probiotic AND (exercise OR sport OR performance OR strength OR anaerobic OR power) AND (athlete OR trained OR elite)).

In addition, the snowball strategy was used in order to identify possible missing studies in the search (Greenhalgh & Peacock, 2005). Two authors (JFL and ASG) conducted the search independently, and disagreements were resolved by discussion or using the third-party adjudication (NT).

Inclusion and exclusion criteria

For the articles obtained in the search, the following inclusion criteria were applied to select studies: (1) probiotics supplementation; (2) trained population (trained/developmental, highly trained/national level, and/or elite/international level [McKay, et al., 2022]); (3) strength and power performance measurements involving the following tests: vertical jump, 100-m freestyle swim, simulated casualty drags, 100m-shuttle run, 60-s pull ups, Wingate test, maximal voluntary isometric peak, 40-m dash, T-test, handgrip, squat (1RM), deadlift (1RM), bench press (1RM), pro-agility, 10-yard sprint, and standing long jump; (4) human experimental trial; (5) controlled with a placebo group; and (6) peer-reviewed and original articles written in the English language.

On the other hand, the articles were excluded when: (1) combined probiotics with other supplements (except studies in which orange drink or recovery drinks were used in placebo and experimental group from the baseline level); (2) participants were not trained population; (3) lack of placebo condition for comparison; (4) articles that did not report pre- and post-exercise information; and (5) the studies were review articles, unpublished abstracts, thesis, and dissertations.

Text screening

Two investigators (JFL and ASG) independently screened titles and abstracts of the initial search based upon *a priori* determined inclusion and exclusion criteria. Subsequently, the same investigators independently screened full texts to further assess congruence with the inclusion and exclusion criteria and to determine which studies deserved inclusion in the study. Discrepancies between the authors were discussed until a consensus decision was reached.

Data extraction and study coding

Studies were closely reviewed to extract group means (pre and post data), standard deviations (pre and post data), and sample sizes in probiotic and placebo groups. When the data were not expressed in figures, and numerical data was lacking, values were estimated through Image J software® (National Institutes of Health, Bethesda, MD, USA). Mean values were calculated by measuring the pixel length of each plotted value in the figure and standard deviation with its associated error bar.

All studies satisfying inclusion criteria were carefully reviewed and relevant study characteristics were added in a spreadsheet (Microsoft Excel, Microsoft Corporation, Washington, DC, USA). Extracted information involved study authors and publication year, study design, participants' sex, participants' age, probiotic strain, form and dose of supplementation, duration of supplementation protocol, pre-test protocols, side effects, and performance tests outcomes. The majority of studies showed more than one outcome that met study inclusion criteria. For that reason, "MAd" package in R software was used to obtain a unique effect size estimate for each investigation (Cooper, Hedges, & Valentine, 2009). This package assumes within-study correlation to give an accurate effect size to each study. The within-study correlation used for this SRMA was the same as used by Trexler et al. (2019), that carried out a meta-analysis evaluating the effects of an ergogenic aid in strength and power performance using 0.70 as within-study correlation (Trexler, et al., 2019).

Study quality assessment

The methodological quality of included studies was assessed by the Physiotherapy Evidence Database (PEDro) scale (Morton, 2009). This tool consists of 11 different items. Items 2 to 11 can be rated with 0 or 1, and consequently, the highest possible rate in the PEDro scale is 10 (low risk of bias), and the lowest 0 (high risk of bias). The PEDro scale score was evaluated as poor quality (when the score was ≤3 points), fair quality (when the score ranged between 4 and 5 points), good quality (when the score was 6 to 8 points), and excellent quality (when the score was 9 to 10 points) (Cashin & McAuley, 2020). This process was performed by two independent researchers (JFL and ASG).

Statistical analysis

The analyses were performed with the "metafor" package in R software (R Foundation for Statistical Computing, Vienna, Austria). For all extracted outcomes that met inclusion criteria, standardized effect sizes were calculated as Hedges' *G*, giving an individual effect size and variance for each study result (Borenstein, Hedges, Higgins, & Rothstein, 2021). In order to obtain the variance, the correlation coefficient used was 0.70 ($r = 0.70$) following Rosenthal's recommendation (Rosenthal, 1991). The meta-analysis was carried out using the inverse variance random effects model by DerSimonian and Laird method (DerSimonian & Laird, 1986). The calculation of the effects of probiotic supplementation vs placebo on strength and power performance was measured using the standardized mean differences (SMD) with a 95% of confidence interval (95% CIs; [lower bound–upper bound]), and significance was set at $p<.05$. In order to calculate the SMD of probiotic and placebo groups, Hedges' *G* was used (Hedges, 1981). The SMD was classified as trivial (<0.2); small (0.2-0.3); moderate (0.4-0.8); and large (>0.8), following the Cohen criteria (Cohen, 1992).

Heterogeneity across the included studies was assessed by I^2 statistic and it was evaluated as low ($I^2<25\%$), moderate ($I^2=25\text{-}75\%$), and considerable ($I^2>75\%$) risk of heterogeneity (Higgins, Thompson, Deeks, & Altman, 2003).

For the included studies, standard errors were plotted against Hedges' *G* values for visual assessment of potential funnel plot asymmetry to determine publication bias. Funnel plot asymmetry was as well evaluated through Egger's regression test (Egger, Davey Smith, Schneider, & Minder, 1997) and Duval and Tweedie's Trim and Fill method (Duval & Tweedie, 2000).

Results

Literature search

Total records of 910 were identified through database searching. After duplicates removal (n=246), 664 unique records were included in this SRMA. Title and abstract screening eliminated 634 irrelevant studies, resulting in 30 eligible studies for full-text screening. After the full-text screening, 7 articles were included in this SRMA, with a total number of 142 participants. The PRISMA flow diagram is presented in Figure 1.

Studies meeting the inclusion criteria are summarized in Table 1. The average age of the participants was between 19.5 and 25 years, with an exception that did not report that information (Carbuhn, et al., 2018). Probiotic supplementa-

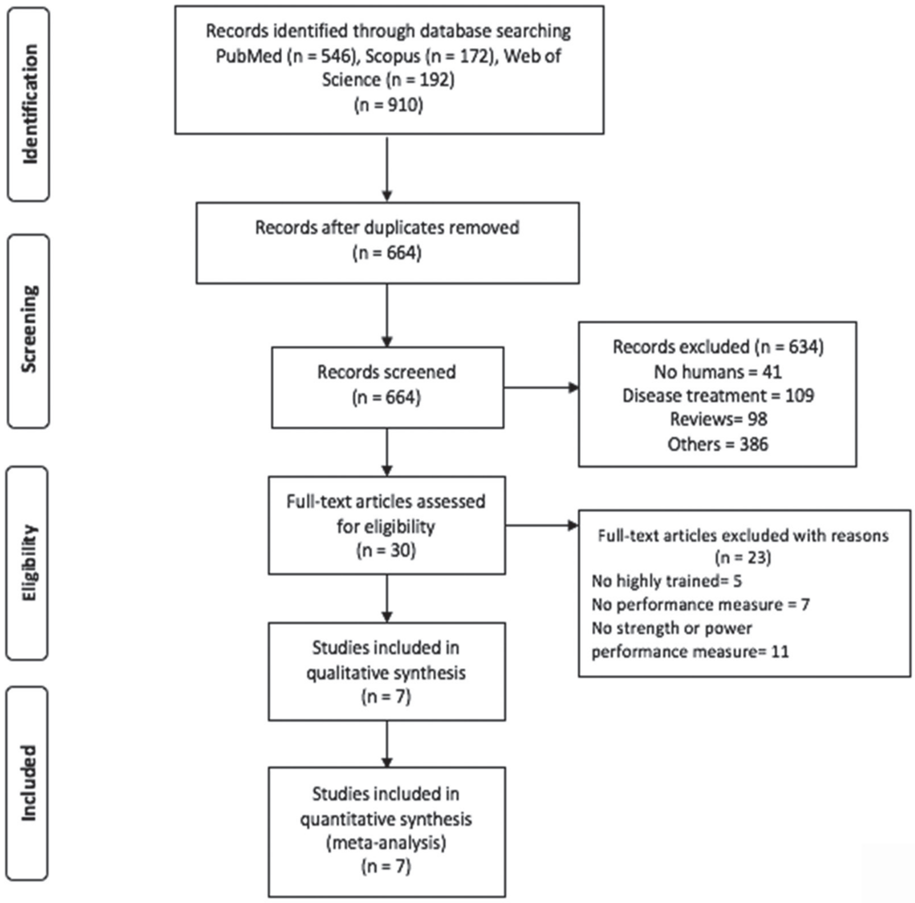

Figure 1. PRISMA flow diagram with information about search and screening process.

tion strains were different among studies, and the following strains had been used: *Bidifobacterium longum, Bifidobacterium breve, Bacillus coagulans, Bacillus subtilis, Lactobacillus plantarum*, *Lactobacillus casei,* and *Streptococcus thermophilus*. Regarding probiotics administration, four studies used capsules (Carbuhn, et al., 2018; Huang, Wei, Huang, Chen, & Huang, 2019; Jäger, Purpura, et al., 2016; Townsend, et al., 2018), one study used powder sachet (Hoffman, et al., 2019), another study provided a bottle containing the supplement (Salleh, et al., 2021), and finally, one study did not mention the form of administration (Toohey, et al., 2020). The ingested dosage ranged from 1 x 10^9 CFU (Carbuhn, et al., 2018; Hoffman, et al., 2019) to 3 x 10^{10} CFU (Huang, Wei, Huang, Chen, & Huang, 2019; Salleh, et al., 2021). There was a large variation in the supplementation duration period, going from 14 days (Hoffman, et al., 2019) to 84 days (Townsend, et al., 2018). In two studies, a pre-test protocol was performed 48 and 72 (Huang, Wei, Huang, Chen, & Huang, 2019; Jäger, Purpura, et al., 2016) hours before carrying the performance test.

In order to evaluate strength and power performance the following tests were carried out: vertical jump (Carbuhn, et al., 2018; Hoffman, et al., 2019; Salleh, et al., 2021; Toohey, et al., 2020); 100-m free style swim (Carbuhn, et al., 2018); simulated casualty drags (Hoffman, et al., 2019); 100m-shutle run (Hoffman, et al., 2019); 60-s pull ups (Hoffman, et al., 2019); Wingate (Huang, Wei, Huang, Chen, & Huang, 2019); maximal voluntary isometric peak (Jäger, Purpura, et al., 2016); 40-m dash (Salleh, et al., 2021); T-test (Salleh, et al., 2021); handgrip (Salleh, et al., 2021); squat (1RM) (Toohey, et al., 2020; Townsend, et al., 2018); deadlift (1RM) (Toohey, et al., 2020; Townsend, et al., 2018); bench press (1RM) (Toohey, et al., 2020); pro-agility (Toohey, et al., 2020; Townsend, et al., 2018); 10-yard sprint (Townsend, et al., 2018); and standing long jump (Townsend, et al., 2018). In all studies supplementation was tolerated with no side effects reported.

Level of the quality of the studies

The mean score of the PEDro scale was 9.14, with an average score of excellent quality. One study obtained a value of 8 (good quality) (Jäger, Purpura, et al., 2016), 4 studies achieved a value of 9 points (excellent quality) (Carbuhn, et al., 2018; Hoffman, et al., 2019; Huang, Wei, Huang, Chen, & Huang, 2019; Toohey, et al., 2020), and the remaining two studies (Salleh, et al., 2021; Townsend, et al., 2018) obtained 10 points, the maximum possible score (excellent quality). All the information is detailed in Table 2.

Table 1. Summary of the studies included in the systematic review that investigated the effect of probiotics on strength and power performance

Author/s	Population	Supplementation protocol	Duration	Training protocol	Pre-test protocol	Test	Outcomes	Effect
Carbuhn et al., (2018)	17 female swimmers from Division I	1 x 10^9 CFU of *Bifidobacterium longum* 35624 daily (1 capsule/day)	42 days	5 workouts/ week, 8-20 h/ week	None	Vertical jump force plate test	Rate of eccentric force production (N/s)	↔
							Concentric force production (N/kg)	↔
							Overall vertical jump height (m)	↔
						100-m freestyle anaerobic swim test	Time trial (s)	↔
Hoffman et al., (2019)	16 male soldiers (EG: 20.0±0.6 years; PLA: 20.2±0.6 years)	1.0 × 10^9 CFU of Inactivated *Bacillus coagulans* daily (1 powder serving/ day)	14 days	5 workouts/week	None	Simulated casualty drags	Time (s)	↔
						100-m shuttle run	Time (s)	↔
						Vertical jump power	Mean power (W)	↔
						60-s pull ups	Repetitions (#)	↔
Huang et al., (2019)	16 triathletes (EG: 22.3±1.2 years; PLA: 20.1±0.3 years)	3 × 10^{10} CFU of *Lactobacillus plantarum* PS128 daily (2 capsules/ day)	21 days	Specialized training	Triathlon championship (72 h before)	Wingate	Peak anaerobic power (W)	↑
							Mean power (W)	↑
Jäger et al., (2016)	15 resistance-trained men (25±4 years)	5 x 10^9 CFU of *Streptococcus thermophilus* FP4 (DSMZ 18616) and 5 x 10^9 CFU of *Bifidobacterium breve* BR03 (DSMZ 16604) (1 capsule/ day)	21 days	Usual training	Bout of eccentric exercise (48 h before)	Maximal voluntary isometric peak	Peak torque (NM)	↔
Salleh et al., (2021)	30 badminton players (EG: 19.5±1.0 years; PLA: 19.9±1.3 years)	3 x 10^{10} CFU of *Lactobacillus casei Shirota* (1 bottle/ day)	42 days	5 workouts/ week, 10h/week	None	40-m dash	Time (s)	↔
						T-test	Time (s)	↔
						Handgrip test	Weight (kg)	↔
						Vertical jump	Height (cm)	↔
Toohey et al., (2020)	23 Division I female volleyball and soccer players (19.6±1 years)	5 × 10^9 CFU CFU of *Bacillus subtilis* (DE111) (undefined)	70 days	3–4 workouts/ week	None	Squat (1RM)	Weight (kg)	↔
						Deadlift (1RM)	Weight (kg)	↔
						Bench press (1RM)	Weight (kg)	↔
						Vertical jump	Time (s)	↔
						Pro-agility test	Time (s)	↔
Townsend et al., (2018)	25 Division I male baseball athletes (20.1±1.5 years)	1.2 × 10^9 CFU of *Bacillus subtilis* (DE111) (1 capsule/ day)	84 days	2–3 workouts/ week	None	Squat (1RM)	Weight (kg)	↔
						Deadlift (1RM)	Weight (kg)	↔
						10 yard-sprint	Time (s)	↔
						Pro-agility test	Time (s)	↔
						Standing long jump	Time (s)	↔

Note. ↑ the effect of probiotic supplementation was statistically higher from placebo; ↓ the effect of probiotic supplementation was statistically lower from placebo; ↔ The effect of probiotic supplementation was not statistically different from placebo; #, number; 1RM, one-repetition maximum; CFU, colony-forming units; EG, experimental group; kg, kilograms; N/s, Newtons/seconds; N/kg, Newton/kilograms; NM, Newton meters; m, meters; PLA, placebo group; s, seconds; W, watts.

Pooled effect estimate

The I^2 test showed no significant heterogeneity among studies (p=.10). However, the I^2 statistic indicated a moderate risk of heterogeneity (I^2=43%). Visual assessment of the funnel plot (Figure 2), revealed no substantial asymmetry, and Egger´s regression test for funnel plot asymmetry showed a non-significant result (df=5; p=.46). Duval and Tweedie Trim and Fill´s method did not identify missing studies on either side of the plot.

Table 2. Table PEDro ratings of the included studies

Study	1	2	3	4	5	6	7	8	9	10	11	TOTAL
Carbuhn et al., (2018)	Yes	1	1	0	1	1	1	1	1	1	1	9
Hoffman et al., (2019)	Yes	1	1	0	1	1	1	1	1	1	1	9
Huang et al., (2019)	Yes	1	0	1	1	1	1	1	1	1	1	9
Jager et al., (2016)	Yes	1	0	0	1	1	1	1	1	1	1	8
Salleh et al., (2021)	Yes	1	1	1	1	1	1	1	1	1	1	10
Toohey et al., (2020)	Yes	1	0	1	1	1	1	1	1	1	1	9
Townsend et al., (2018)	Yes	1	1	1	1	1	1	1	1	1	1	10

Note. Items in the PEDro scale: 1 = eligibility criteria were specified; 2 = participants were randomly allocated to groups; 3 = allocation was concealed; 4 = the groups were similar at baseline regarding the most important prognostic indicators; 5 = blinding of all participants; 6 = blinding of all therapists who administered the therapy; 7 = blinding of all assessors who measured at least one key outcome; 8 = measures of one key outcome were obtained from 85% of participants initially allocated to groups; 9 = all participants for whom outcome measures were available received the treatment or control condition as allocated or, where this was not the case, data for at least one key outcome was analysed by "intention to treat"; 10 = the results of between-group statistical comparisons are reported for at least one key outcome; 11 = the study provides both point measures and measures of variability for at least one key outcome.

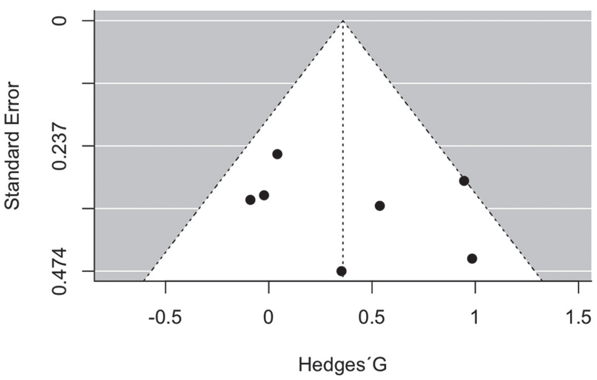

Figure 2. Funnel plot of the included studies.

The pooled meta-analysis results identified a significant benefit of probiotics in comparison to placebo for measures of strength and power performance in a trained population (p=.04), with a small effects size (pooled SMD=0.36 [0.02-0.70]; Figure 3). Concerning the effect sizes of individual studies, two studies (Huang, Wei, Huang, Chen, & Huang, 2019; Jäger, Purpura, et al., 2016) showed a large effect size of the intervention (SMD>0.8), one study (Townsend, et al., 2018) showed a moderate effect size (SMD between 0.4 and 0.8), another one (Hoffman, et al., 2019) noticed small effects size (SMD between 0.2 and 0.3), and the remaining three

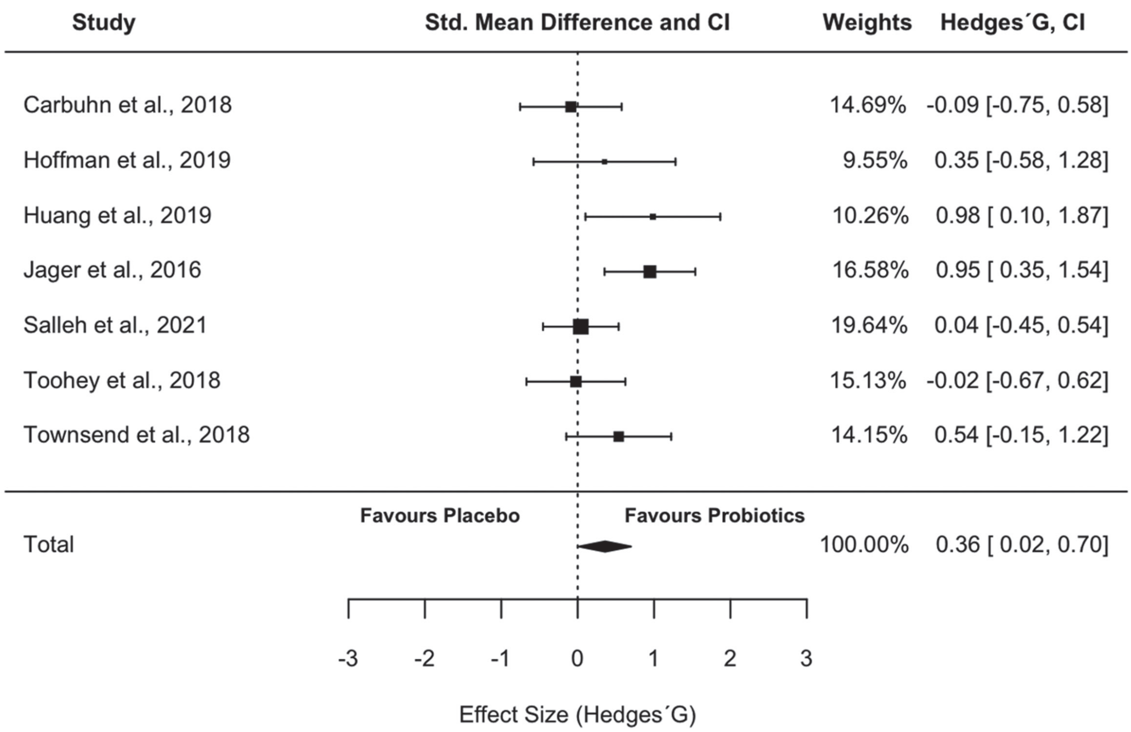

Figure 3. Pooled meta-analysis of the included studies.

articles (Carbuhn, et al., 2018; Salleh, et al., 2021; Toohey, et al., 2020) obtained trivial results.

Discussion and conclusions

In this current SRMA, the main aim was to summarize and analyze the existing scientific literature concerning the effects of probiotic supplementation on strength and power performance in a trained population. Seven independent articles met inclusion criteria, with a total pooled sample size of n=142. The meta-analysis results revealed that probiotic intake exerted significant positive effects on strength and power performance compared to placebo, with a pooled standardized mean difference (Hedges' *G*) of 0.36.

The SMD found probiotics effects are comparable to other popular ergogenic aids in terms of measuring strength and power performance. For example, caffeine showed a small effect when strength and power performance were measured (SMD=0.20 and SMD=0.17, respectively) (Grgic, Trexler, Lazinica, & Pedisic, 2018). Additionally, in a previous meta-analysis, creatine displayed small effects on lower body exercise (SMD=0.21) and moderate effects on upper body exercise (SMD=0.42) (Branch, 2003). Therefore, the utility of probiotics for athletes should be considered to enhance strength and power performance.

Despite the promising results found in the pooled meta-analysis results, it is essential to note that only one included study in this systematic review found significant differences after probiotic supplementation (Huang, Wei, Huang, Chen, & Huang, 2019), while the remaining studies showed no significant differences in strength and power performance after probiotic intake (Carbuhn, et al., 2018; Hoffman, et al., 2019; Jäger, Purpura, et al., 2016; Salleh, et al., 2021; Toohey, et al., 2020; Townsend, et al., 2018). The trend to improve performance on tests of original studies could have influenced this result.

Concretely, the study carried out by Hoffman et al. (2019), in which inactivated *Bacillus coagulans* strain was ingested, showed a trend to enhance vertical jump power (Hoffman, et al., 2019). Moreover, Jager, Purpura et al. (2016) did not discover significant differences among groups when they measured maximal isometric peak torque after an eccentric exercise protocol in triathletes (Jäger, Purpura, et al., 2016). Nevertheless, they did find significant differences when using the probiotic-placebo difference score adjusted for the value at baseline to measure maximal isometric peak torque. In addition, Townsend et al. (2018) did not identify any positive effect on the measurements of strength or physical performance among groups after ingestion of 1.2×10^9 CFU of *Bacillus subtilis* (DE111) during 84 days (Townsend, et al., 2018). Nonetheless, the authors explained that the test results could have been influenced by baseline differences in strength measures (i.e., squat and deadlift) and lack of training volume control during the intervention.

On the other hand, it is also necessary to mention that the investigations with a smaller effect size in the meta-analysis were Carbuhn et al. (2018), Salleh et al. (2021), and Toohey et al. (2020). Two of these studies did not perform a warm-up before conducting the tests (Carbuhn, et al., 2018; Salleh, et al., 2021). Therefore, that could be considered as methodology bias, which therefore influenced studies results. Otherwise, the results on strength performance tests in Toohey's study on football players could have been influenced by changes in body mass among studied groups (Toohey, et al., 2020). The body mass of the experimental group decreased more than that of the placebo group during the study, and these changes could have directly influenced the results of strength tests. The greater body mass in the placebo group could be associated with greater muscle mass and thus influencing the results in lifting higher weights in 1RM bench press, deadlift, and squat tests.

Despite the possible methodological bias influencing the results of the SRMA, the average quality of studies was established as excellent, and the sum of all the included articles discussed above revealed significant results favouring probiotic ingestion. Moreover, it is important to mention that the highest effect sizes were found in the studies when the tests were carried out after strenuous exercise (48 and 72 hours before testing) (Huang, Wei, Huang, Chen, & Huang, 2019; Jäger, Purpura, et al., 2016). These results highlight even more the importance of probiotics for the recovery process and hence their usefulness for athletes.

Probiotic intake could boost the recovery process attenuating exercise-induced undesirable effects in the gut. In addition, this ergogenic aid could promote intestinal health by improving the intestinal barrier function of epithelial cells through increased production of SCFA (Lamprecht, et al., 2012). In fact, most of the strains consumed during the studies included in this SRMA (*Bidifobacterium longum* [Huang, Hsu, Huang, Liu, & Lee, 2020], *Bifidobacterium breve* [Tian, et al., 2020], *Bacillus coagulans* [Nyangale, Farmer, Keller, Chernoff, & Gibson, 2014], *Bacillus subtilis* [Xu, et al., 2021], *Lactobacillus plantarum* [Huang, Pan, Wei, & Huang, 2020], and *Lactobacillus casei* [Matsumoto et al., 2010]) have been demonstrated to increase acetate, propionate, and butyrate production. On the other hand, *Streptococcus thermophilus* (Shen, et al., 2021) has so far only been shown to be capable of increasing acetate production.

Concretely butyrate, the main enterocyte fuel, could play a key role in maintaining intestinal integrity during exercise, attenuating the cell injury caused by exercise induced gut hypoperfusion and body temperature increase. Probiotic (e.g., *Bacillus subtilis)* intake could attenuate the increment of enterocyte damage (measured by I-FABP) during exercise, as shown in a study conducted on rats (Ducray, et al., 2020). This attenuation of intestinal damage could improve nutrient absorption, thereby enhancing the recovery process. Previous studies showed a better absorption of proteins (e.g., casein [Jäger, Shields, et al., 2016] and whey protein [Tarik, et al., 2022]) and carbohydrates (Pugh, et al., 2020) when they were combined with probiotics. Thus, the main reason for the probiotic ingestion is to improve nutrients absorption so as to enhance strength and power performance.

In addition, propionate and acetate could also impact strength and power performance via different physiological pathways. Propionate may be able to produce glucose in the liver and gut through gluconeogenesis, increasing glucose availability (Holscher, 2017). Moreover, acetate could increase gamma-aminobutyric acid (GABA) neurotransmitter (Frost, et al., 2014). GABA, the main central nervous system inhibitor, could elevate resting serum growth hormone improving resistance training-induced muscular adaptations (Power, Yarrow, McCoy, & Borst, 2008).

In summary, improving gut health and nutrient absorption could be the primary pathway for probiotics to enhance the recovery process. Besides, enhancing hepatic and intestinal gluconeogenesis and increasing GABA release could also play a role in boosting recovery. All of the previously mentioned mechanisms of action may be capable of improving strength and power performance in a trained population.

The results of the SRMA must be cautiously interpreted within the context of its limitations. The articles included in this SRMA (n=7) involved different independent variables (probiotic strains, dosages, duration, and performance tests), thus possibly influencing the final results of the pooled meta-analysis. In order to mitigate limitations, this SRMA followed a rigorous methodology to analyze and quantify the outcomes. The quality of the included articles ranged from good to excellent, with an average score of excellent quality, and no publication bias was found. Besides, as a novelty statement, this is the first SRMA to assess probiotics' effects on strength and power performance in a highly trained population.

With the aim of enhancing the validity and precision of probiotics usage in sports context, future double-blind, randomized, placebo-controlled studies with similar supplementation protocols and measurement methodologies are needed to get a deeper insight into the effect of each strain on strength and power performance.

In summary, this SRMA demonstrated that probiotic supplementation could effectively enhance strength and power performance in a trained population. However, research is at an early stage, and the precise conditions (probiotic strain, dose, and duration) in which probiotics may be ergogenic have yet to be firmly established.

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PHYSICAL, PHYSIOLOGICAL DEMANDS AND MOVEMENT PROFILES OF PROFESSIONAL MEN'S FIELD HOCKEY GAMES

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Abstract:

The aim of this study was to investigate physical demands, physiological demands, and movement profiles of different positions across four quarters in professional men's field hockey games. Eighteen professional male field hockey players participated in the study, and data were collected in eleven official matches. Players wore global positioning system units and heart rate monitors to collect physical, physiological, and movement profile data. Defenders had significantly higher absolute total distance covered, player load, acceleration and deceleration count, and forward-backward initial movement analysis (IMA) count, but lower high speed running distance, compared with midfielders and forwards (p<.05). However, when using relative metrics (normalised by playing time), defenders had the lowest physical and physiological outputs, and forwards had the highest (p<.05). Total distance covered per minute, high-speed running distance per minute, player load per minute, acceleration and deceleration count per minute, and repeated high-intensity efforts per minute were all significantly higher in quarter 1 than in other three quarters (p<.05). The percentages of linear running and non-linear dynamic movement duration decreased quarter by quarter. Modified training impulse per minute reached its peak in quarter 2 (p<.05). It was concluded that defenders had the highest volume in terms of the game demands due to their high playing minutes; however, they had the lowest relative volume compared with the other two positions. Forwards had the highest linear running intensity, while midfielders were required to perform more multi-directional, non-linear movements. Quarter 1 was the most active quarter and players became fatigued in quarter 2. IMA counts were not sensitive to fatigue compared to movement profile and modified training impulse variables.

Key words: *GPS, activity profile, heart rate, team sports*

Introduction

Using athlete tracking technologies to monitor performance in team sports has become increasingly common in order to gain insights into game demands, mitigate risks of injury, and quantify training load (Torres-Ronda, Beanland, Whitehead, Sweeting, & Clubb, 2022). Positioning information such as distance covered and speed can be reported by using the Global Positioning System (GPS), and GPS units for performance tracking purposes are usually embedded with other sensors such as accelerometer, magnetometer, and gyroscope to quantify explosive movements such as change of directions (COD), jumps, and movement patterns (Chambers, Gabbett, Cole, & Beard, 2015; Lutz, Memmert, Raabe, Dornberger, & Donath, 2019; Szigeti, Schuth, Kovacs, Pavlik, & Barnes, 2021).

In recent studies on physical demands of field hockey games, the commonly used variables are total distance covered and distance in each speed zone. There are also a number of studies that investigated the numbers of accelerations and decelerations, heart rate variables (Lim, Sim, & Kong, 2021), and player load (McMahon & Kennedy, 2019a; White & MacFarlane, 2013). The comparisons were made among different playing positions (Dewar & Clarke, 2021; Harry & Booysen, 2020; Ihsan, et al., 2021; James, Gibson, Dhawan, Stewart, & Willmott, 2021; Kapteijns, Caen, Lievens, Bourgois, & Boone, 2021; McGuinness, Malone, Petrakos, & Collins, 2019; McGuinness, Passmore, Malone, & Collins, 2020; Morencos, Romero-Moraleda, Castagna, & Casamichana, 2018; Vescovi, 2016), different playing rules (McMahon & Kennedy, 2019a), and different competition levels (Vinson, Gerrett, & James, 2018). After the 2015 change of rules of field hockey games, there were only a few studies on the physiological demands using heart rate data. Currently, the elite game heart rate data were only reported in women's games (McGuinness, Kenna, Grainger, & Collins, 2021; McGuinness, Malone, Hughes, Collins, & Passmore, 2019; Sell & Ledesma, 2016; Vescovi, 2016). There was only one study that investigated the heart rate data for men's team, however, the participants in the study were student athletes, not professional athletes. Meanwhile, the game format was different from the standard Federation of International Hockey (FIH) rules (Lam, et al., 2021). Field hockey is a fast-paced and intermittent team sport that allows unlimited substitutions during the game. Due to its nature with repeated high-intensity bouts, there has been an increased focus on monitoring not only locomotive running load, but also the count of accelerations and decelerations (Harry & Booysen, 2020; Morencos, et al., 2018). Traditionally, these metrics are quantified by GPS which has its limitations when it comes to accurately measuring short, sharp changes in actions (i.e., explosive change of directions) (Malone, Lovell, Varley, & Coutts, 2017; Szigeti, et al., 2023). Therefore, only looking at GPS-derived data (i.e., linear running distance) will be underestimating the physical demands of field hockey games. Movement profile is quantified by inertial sensors which have been shown to have good reliability and validity and it could differentiate between linear running and dynamic movements (Szigeti, et al., 2021, 2023). Understanding the movement profiles of different positions provides additional insight into the multi-directional component of the field hockey game, which could further inform practitioners when it comes to load management.

The objectives of the current study are: 1) to investigate the physical demands, physiological demands, and movement profiles across different position groups in professional men's field hockey games; 2) to investigate the changes in physical performance, physiological performance, and movement profiles across quarters in professional men's field hockey games and identify fatigue indicators.

Methods

Participants

Eighteen professional male field hockey players (age 25.6 ± 2.5 years, body height 171.8 ± 5.2 cm, body mass 70.1 ± 7.5 kg) participated in the study, including seven forwards, six midfielders, and five defenders. Participants worked full-time as professional athletes and trained at least five days per week, two sessions per day throughout the year. The team won the National Games championship and represented the highest competition level of the country. Prior to the data collection, all athletes were verbally informed of the purpose, procedures, risks, and benefits of the research, and written informed consent forms were signed. The research was approved by the Ethics Committee of Guangdong Institute of Sport Science.

Measures

The physical data and movement profile data were collected using GPS technology integrated with inertial sensors (Vector S7, Catapult Sports, Melbourne, Australia, Firmware Version 8.1). The GPS sampling frequency was 10 Hz, and the inertial sensor sampling frequency was 100 Hz. The physiological data were collected using heart rate monitors (Polar H1 chest strap, Polar Electro Oy, Kempele, Finland). The validity and reliability of both devices have been reported acceptable (Clavel, et al., 2022; Crang, et al., 2022; Schaffarczyk, Rogers, Reer, & Gronwald, 2022). Both physical, physiological, and movement profile data were processed in OpenField (Catapult Sports, Melbourne, Australia, Version 3.3.1).

The physical demand metrics reported were:

- Total distance (m) and distance per minute (m$\cdot$min^{-1});
- High-speed running distance (m, HSRD) and HSRD per minute (m$\cdot$min^{-1}), threshold set as > 15 km$\cdot$h^{-1};
- Inertial movement analysis count (n, IMA) and IMA count per minute (n$\cdot$min^{-1}) in each direction at medium and high intensity. IMA uses inertial sensors to detect instant one-step movement efforts (e.g., sudden change of direction). The direction of an IMA event is calculated relative to the device's orientation at the time of the step and is measured in degrees. IMA counts were categorised into medium (2.5 to 3.5 m·s^{-1}) and high (>3.5 m·s^{-1}) intensities, and were also categorised into four directions, which include forward (-45 to 45 degrees), backward (-135 to 135 degrees), left (-135 to -45 degrees) and right (45 to 135 degrees). Luteberget, Holme, and Spencer's (2018) study showed that IMA count is a reliable variable in reporting the physical demands in team sports. In the current study, four categories of IMA counts were reported: total high intensity IMA count (total high IMA count), total medium and high IMA count (total MedHigh IMA count), medium and high intensity forward and backward IMA count (MedHigh FB IMA count), medium and high intensity left and right IMA count (MedHigh LR IMA count);
- Repeated high-intensity efforts (RHIE, n) and RHIE per minute (m$\cdot$min^{-1}). One RHIE was registered when there were three consecutive

high-speed runs, and the recovery interval between each two high-speed runs were less than 21 seconds;

- Player load (au) and player load per minute (au). Player load was derived from the accelerometer in the GPS unit, sampling at 100 Hz, being the sum of the accelerations across all axes of the internal tri-axial accelerometer during movement. It takes into account the instantaneous rate of change of acceleration and divides it by a scaling factor (divided by 100). Player load reports the total external mechanical stress accumulated and was reported as a valid and reliable metric (Barrett, 2017; Lutz, et al., 2019);
- Accelerations and decelerations count (n, AccDec count) and AccDec count per minute ($nmin^{-1}$), threshold set as > 2 ms^{-2};

The movement profile metrics reported were:

- Duration percentage in each movement type (%). Movement profiles were categorised into four types:
  1) Static: when the athlete is static, standing still, or of minimal movement;
  2) Walking: when the athlete is walking, or of low intensity movement;
  3) Linear running: when the athlete is running in linear line;
  4) Non-linear dynamic movements: when the athlete is moving multi-directionally.

The movement profile categories were based on player load values, which had previously been shown to be a valid and reliable metric (Barrett, 2017).

The physiological demand metrics reported were:
Average heart rate (beat per minute, Avg. HR);

- Relative average heart rate (%, Avg. HR%), the individualised average heart rate calculated from each individual's maximal heart rate;
- Duration percentage in each heart rate zone (%), the percentage of the time spent in each heart rate zone compared to the total field time. Zone 1: 65-71% HR_{max}, Zone 2: 72-78% HR_{max}, Zone 3: 79-85% HR_{max}, Zone 4: 86-92% HR_{max}, Zone 5: 93-100% HR_{max};
- Modified training impulse (au, $TRIMP_{mod}$) and $TRIMP_{mod}$ per minute (au). $TRIMP_{mod}$ is a method adopted from previous research to quantify the internal load of intermittent team sports. $TRIMP_{mod}$ was calculated by multiplying the weighting factors by the time spent in the respective heart rate zones, and summing them up (Stagno, Thatcher, & van Someren, 2007). Heart rate zones, weighting factors, and training descriptors are shown in Table 1.

The individual maximal heart rate was collected from all the YOYO IR2 tests, training and games in the 12-month period prior to the tournament. Research shows that the maximal heart rate collected from the YOYO IR2 tests has no difference from the maximal heart rate collected from conventional laboratory treadmill incremental tests to exhaustion (Bradley, et al., 2011).

Design and procedures

The data were collected from 18 professional male field hockey players in 11 official games in the National Games Series. The players were categorised into three positions: forward, midfielder, and defender. Overall, there were 169 observations included in the dataset (64 for forwards, 62 for midfielders, and 43 for defenders).

Every player wore his own GPS unit, GPS vest, and heart rate straps throughout the tournament to ensure consistency. Prior to each game, the GPS units were turned on at least fifteen minutes before warming up and the heart rate sensors were moisturised per the manufacturers' instructions to ensure optimal data quality. The average number of satellites connected was 14.99±1.66, and the average horizontal dilution of precision (HDOP) was 0.73±0.08, which was considered good satellite signal quality (Malone, et al., 2017). The data were processed and trimmed according to the actual playing time of the players: the between-quarter breaks, off-pitch time, and video review time were excluded from the analysis.

Statistical analysis

Data are expressed as mean ± standard deviation. The repeated measures ANOVA was used to determine the differences across positions and quarters. In the event of a significant difference, the Bonferroni *post-hoc* test was used. Statistical

Table 1. The heart rate zones, weighting factors, and training descriptors of modified training impulse calculation

Zone	% maximal heart rate	Weighting factor	Training type
1	65-71	1.25	Moderate activity
2	72-78	1.71	Lactate threshold training
3	79-85	2.54	Steady-state training
4	86-92	3.61	OBLA training
5	93-100	5.16	Maximal training

Note. Adopted from Stagno et al., 2007

significance was set at p<.05. All statistical analyses were conducted using IBM SPSS Statistics (IBM Corp., Armonk, USA, Version 27).

Results

Full-game positional differences

The game average physical demands in absolute values of different positions are presented in Table 2. The field time of defenders was significantly higher than the time of midfielders and forwards. In terms of the physical demands in absolute values, total distance, player load, AccDec count, and MedHigh FB IMA count of defenders were significantly higher than those of forwards and midfielders (p<.05); however, high-speed running distance of defenders was significantly lower than the one of forwards and midfielders (p<.05). Total high IMA count, total MedHigh IMA count, and MedHigh LR IMA count of defenders were significantly higher than those of forwards (p<.05).

The game average physical demands in relative values of different positions are presented in Table 3. For distance per minute, HSRD per minute, player load per minute, and RHIE per minute, the data were significantly different across all the positional groups, where forwards had the highest numbers and defenders had the lowest values (p<.05). AccDec count per minute of defenders was significantly lower than that of forwards and midfielders (p<.05), and the MedHigh LR IMA count per minute of defenders was significantly lower than that of forwards (p<.05).

The game average movement profiles of different positions are presented in Table 4 and Figure 1. There were significant differences across all the positions for static duration% and non-linear dynamic movement duration% (p<.05). Walking duration% of defenders was significantly higher than it was in midfielders and forwards, while linear running duration% of defenders was significantly lower than that of midfielders and forwards (p<.05).

Table 2. Game average physical demands in absolute values for different playing positions

	Midfielders	Forwards	Defenders
Field time (min)	38.7±3.3	36.2±1.4	63.4±8.2[a]
Total distance (m)	4788±237	4700±262	6252±908[a]
High-speed running distance (m)	1142±128	1213±155	947±242[a]
Player load (au)	471±34	503±27	605±90[a]
AccDec count (n)	217±24	206±17	266±43[a]
RHIE count (n)	25.4±1.3	26.3±2.1	29±8.4
Total high IMA count (n)	18.6±7	15.3±2.6	24±8[b]
Total MedHigh IMA count (n)	70.6±25.5	59.1±8.1	87.8±23.4[b]
MedHigh BF IMA count (n)	23.2±9.1	22.1±2.3	33.6±9[a]
MedHigh LR IMA count (n)	47.3±16.7	36.9±5.9	54.2±14.9[b]

Note. Au – arbitrary units; AccDec count – accelerations and decelerations count; RHIE – repeated high-intensity efforts; IMA – inertial movement analysis; MedHigh – medium and high intensity; BF – backward and forward; LR – left and right; a indicates defenders were significantly different from midfielders and forwards (p<.05); b indicates forwards were significantly different from defenders (p<.05).

Table 3. Game average physical demands in relative values for different positions

	Midfielders	Forwards	Defenders
Distance per minute ($mmin^{-1}$)	124±6	130±5	98±4[a]
HSRD per minute ($mmin^{-1}$)	29.8±4.7	33.5±3.9	14.8±2.5[a]
Player load per minute (au)	12.2±0.7	13.9±0.6	9.5±0.6[a]
AccDec count per minute ($nmin^{-1}$)	5.63±0.5	5.68±0.51	4.2±0.41[b]
RHIE count per minute ($nmin^{-1}$)	0.66±0.06	0.72±0.05	0.45±0.09[a]
Total high IMA count per minute ($nmin^{-1}$)	0.48±0.18	0.42±0.08	0.38±0.11
Total MedHigh IMA count per minute ($nmin^{-1}$)	1.81±0.64	1.64±0.25	1.39±0.33
MedHigh FB IMA count per minute ($nmin^{-1}$)	0.59±0.22	0.61±0.07	0.53±0.13
MedHigh LR IMA count per minute ($nmin^{-1}$)	1.21±0.42	1.02±0.17	0.86±0.21[c]

Note. Au – arbitrary units; HSRD – high-speed running distance; AccDec count – accelerations and decelerations count; RHIE – repeated high-intensity efforts; IMA – inertial movement analysis; MedHigh – medium and high intensity; BF – backward and forward; LR – left and right; a indicates the data were significantly different amongst midfielders, forwards, and defenders (p<.05); b indicates defenders were significantly different from midfielders and forwards (p<.05); c indicates forwards were significantly different from defenders (p<.05).

Table 4. Game average movement profiles of different positions

	Midfielders	Forwards	Defenders
Static duration%	10.1±1.8	11±2.3	19.5±3.5 [a]
Walking duration%	38.4±1.4	34.5±1.4	41±1.3 [b]
Linear running duration%	15.7±1.6	19.7±1.7	11.6±1.2 [b]
Non-linear dynamic movement duration%	35.9±2.7	34.8±2.7	27.9±2.9 [a]

Note. a indicates the data were significantly different amongst midfielders, forwards, and defenders ($p<.05$); b indicates defenders were significantly different from midfielders and forwards ($p<.05$).

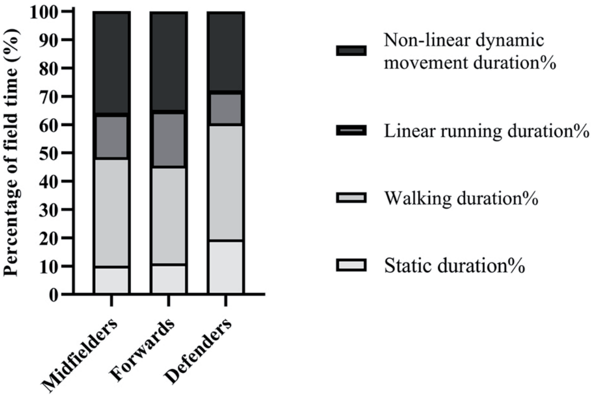

Figure 1. Movement profiles of each position.

The game average physiological demands of different positions are presented in Table 5. Average heart rate and $TRIMP_{mod}$ of defenders were significantly higher than it were in midfielders and forwards ($p<.05$), while their 72-78% HR_{max} duration%, 86-92% HR_{max} duration%, and $TRIMP_{mod}$ per minute were significantly lower than in midfielders and forwards ($p<.05$). Avg. HR% of forwards was significantly lower than that of midfielders and defenders, and their 65-71% HR_{max} duration% was significantly higher than in defenders ($p<0.05$).

Differences across quarters

Physical demands in relative values of four quarters are presented in Table 6. Distance per minute, HSRD per minute, player load per minute, AccDec count per minute, and RHIE per minute were all higher in quarter 1 compared with the other quarters ($p<.05$). There was no significant difference in all IMA variables. Distance per minute and player load per minute of quarter 2 were significantly higher than in quarter 4 ($p<.05$).

Movement profiles of four quarters are presented in Table 7 and Figure 2. Walking duration% in quarter 1 was significantly lower than in the other three quarters ($p<.05$), while linear running duration% and non-linear dynamic movement duration% were significantly higher than in the other three quarters ($p<.05$). Static duration% in quarter 2 was significantly higher than in quarter 4, while linear running duration% was significantly lower than in quarter 4 ($p<.05$).

Physiological demands of four quarters are presented in Table 8. 65-71% HR_{max} duration% and 72-78% HR_{max} duration% in quarter 1 were significantly higher than in quarters 3 and 4, and 86-92% HR_{max} duration% was significantly higher than in quarter 4 ($p<.05$). Average heart rate, 65-71% HR_{max} duration%, Avg. HR%, 72-78% HR_{max} duration%, 93-100% HR_{max} duration%, and $TRIMP_{mod}$ per minute were significantly higher in quarter 2 compared to quarters 3 and 4 ($p<.05$). 86-92% HR_{max} duration% in quarter 4 was significantly higher compared to quarters 1 and 2 ($p<.05$).

Table 5. Game average physiological demands of different positions

	Midfielders	Forwards	Defenders
Average heart rate (beat per minute)	161±3	162±3	166±4 [a]
Average heart rate%	88.9±2.7	81.6±2.4 [b]	86.8±2.3
65-71% HR_{max} Duration%	4.8±1.1	5.6±1	3.9±2.2 [c]
72-78% HR_{max} Duration%	9.3±1.7	9.6±1.3	7.3±2.7 [a]
79-85% HR_{max} Duration%	19.3±5.1	20.7±3.3	16.9±6.1
86-92% HR_{max} Duration%	42.4±6.6	41.8±3.4	34.5±6.4 [a]
93-100% HR_{max} Duration%	15.5±8.2	17.2±4.8	17.2±9.2
$TRIMP_{mod}$ (au)	118±9	115±7	175±41 [a]
$TRIMP_{mod}$ per minute (au)	3.04±0.28	3.16±0.18	2.74±0.47 [a]

Note. Au – arbitrary units; HR_{max} – maximal heart rate; $TRIMP_{mod}$ – modified training impulse; a indicates defenders were significantly different from midfielders and forwards ($p<.05$); b indicates forwards were significantly different from midfielders and defenders ($p<.05$); c indicates forwards were significantly different from defenders ($p<.05$).

Table 6. Physical demands in relative values of four quarters

	Quarter 1	Quarter 2	Quarter 3	Quarter 4
Distance per minute (mmin-1)	126±4 a	118±8 b	115±7	111±7
HSRD per minute (mmin-1)	28.3±2.9 a	25±3.3	25±3.9	24.6±3.6
Player load per minute (au)	13±0.7 a	11.9±1.1 b	11.5±0.9	11±0.9
AccDec count per minute (nmin-1)	5.77±0.6 a	5.08±0.65	5.01±0.56	4.79±0.56
RHIE count per minute (nmin-1)	0.67±0.06 a	0.6±0.1	0.6±0.06	0.58±0.05
Total high IMA count per minute (nmin-1)	0.46±0.12	0.43±0.14	0.43±0.11	0.39±0.11
Total MedHigh IMA count per minute (nmin-1)	1.8±0.41	1.6±0.39	1.57±0.38	1.5±0.36
MedHigh FB IMA count per minute (nmin-1)	0.65±0.15	0.58±0.14	0.57±0.14	0.54±0.13
MedHigh LR IMA count per minute (nmin-1)	1.15±0.27	1.03±0.27	1±0.25	0.96±0.25

Note. Au – arbitrary units; HSRD – high-speed running distance; AccDec count – accelerations and decelerations count; RHIE – repeated high-intensity efforts; IMA – inertial movement analysis; MedHigh – medium and high intensity; BF – backward and forward; LR – left and right; a indicates that quarter 1 was significantly different from quarter 2, quarter 3, and quarter 4 (p<.05); b indicates that quarter 2 was significantly different from quarter 4 (p<.05).

Table 7. Movement profiles of four quarters

	Quarter 1	Quarter 2	Quarter 3	Quarter 4
Static duration%	9.8±2.2 c	12.2±4.6 b	14.8±3.5	17.2±4.5
Walking duration%	36±1.4 a	39.2±2.1	38.1±2	38.8±2.1
Linear running duration%	17.7±1.7 a	15.7±1.6 b	15±2.1	13.6±1.5
Non-linear dynamic movement duration%	36.5±2.8 a	32.9±3.8	32±3.2	30.3±3.6

Note. a indicates that quarter 1 was significantly different from quarter 2, quarter 3, and quarter 4 (p<.05); b indicates that quarter 2 was significantly different from quarter 4 (p<.05); c indicates that quarter 1 was significantly different from quarter 3 and quarter 4 (p<.05).

Table 8. Physiological demands of four quarters

	Quarter 1	Quarter 2	Quarter 3	Quarter 4
Average heart rate (beat per minute)	164±3	166±3 b	161±3	163±3
Average heart rate%	84.3±2.8	85.6±2.2	83.6±3.4	83.6±2.9
65-71% HR_{max} Duration%	3.6±1 a	3.8±1.8 b	5.3±1.7	5.3±1.8
72-78% HR_{max} Duration%	7.3±1.9 a	7.1±1.6 b	9.6±2.4	9.8±2.7
79-85% HR_{max} Duration%	20±4.4	16.4±5.7	19.9±3.5	17.9±3.6
86-92% HR_{max} Duration%	41.7±3.2	40.9±4.5	39.5±7.7	35.7±4 c
93-100% HR_{max} Duration%	16.6±8.4	22.5±8.2 b	13.2±6.1	16±5.5
$TRIMP_{mod}$ (au)	3.04±0.31	3.23±0.31 b	2.85±0.34	2.81±0.25

Note. Au – arbitrary units; HR_{max} – maximal heart rate; $TRIMP_{mod}$ – modified training impulse; a indicates that quarter 1 was significantly different from quarter 3 and quarter 4 (p<.05); b indicates that quarter 2 was significantly different from quarter 3 and quarter 4 (p<.05); c indicates that quarter 4 was significantly different from quarter 1 and quarter 2 (p<.05).

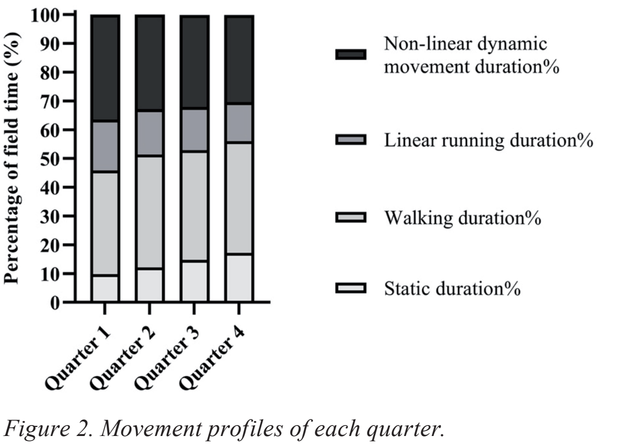

Figure 2. Movement profiles of each quarter.

Discussion and conclusions

The current study analysed the differences and changes in the physical demands, physiological demands, and movement profiles of professional men's field hockey players in different positions and quarters of the game. It is the first study that investigated the physiological demands and movement profiles in professional men's field hockey games under the standard FIH new rules. A detailed understanding of the differences between the load characteristics of different positions and different quarters of the game will help coaches to make informed decisions in squad selection and rotation strategies during the games, as well as drill prescription and load periodisation during the training, so to prepare the players for the game demands.

Positional differences

The results of the current study showed that defenders achieved 63.4 ± 8.2 min of field time, which was significantly higher than forwards and midfielders (36.2 ± 1.4 min and 38.7 ± 3.3 min, respectively). Similar results have been reported for longer playing time for defenders at international level (James, et al., 2021; McMahon & Kennedy, 2019b), due to the fact that coaches are usually less likely to rotate defenders during games. Defenders in the current study had the highest average total distance of 6252 ± 908 m, significantly higher than forwards and midfielders (4700 ± 262 m and 4788 ± 237 m, respectively). Ihsan et al. (2021) have reported that in the four-quarter format following the FIH new rule changes in 2015, forwards had the highest total distance (8922 ± 818 m), followed by midfielders (8613 ± 406 m), then defenders (7631 ± 753 m), which conflicts with the findings of the current study because the data in that study were not measured by the actual playing time, but rather based on the data divided by field time and then multiplied by 60 minutes to predict what players would run to if they played a full game. This prediction method ignored the effect of different playing times on the intensity of the game and may overestimate the game demands. Other studies that reported actual running values had produced results that match the current study, with defenders having the highest total distance covered and player load (James, et al., 2021; McMahon & Kennedy, 2019), due to the fact that defenders had the longest playing time. However, defenders had significantly lower HSRD (947 ± 242 m) than forwards and midfielders (1213 ± 155 m and 1142 ±128 m, respectively). These findings imply the need to use relative variables to describe load and game demands in field hockey studies, i.e., the total values divided by the actual playing time on the field, as there is no limit to the number of substitutions that can be made at any time during a field hockey game, and players may have different playing time and accumulate different amounts of load for the game. In the following analyses, the physical demands of the game are described in terms of relative values (normalised by actual playing time on the field).

In the running load category (total distance per minute, HSRD per minute, RHIE per minute), there were significant differences across all the positions and forwards achieved the highest values, while defenders had the lowest values. This indicates that the game places the highest demand on forwards to run, followed by the midfielders and the lowest demand on defenders, which is consistent with findings in other studies (Ihsan, et al., 2021; James, et al., 2021). In the mechanical load category (i.e., movements such as acceleration and deceleration, change of direction), AccDec count per minute was lower for defenders than for forwards and midfielders, while there was no significant difference between forwards and midfielders, but MedHigh LR IMA count per minute was significantly higher for midfielders. Movement profile analysis relies on inertial sensors in wearable devices to identify the types of movement (static, walking, linear running, non-linear dynamic movements) performed by players, and is an intuitive variable to indicate the proportion of time spent while executing each type of movement on the field (Szigeti, et al., 2021, 2023). In terms of the distribution of movement profiles across the game, defenders had the highest percentage of time spent static (19.5±3.5%), followed by forwards (11±2.3%), and the lowest percentage of time spent static had midfielders (10.1±1.8%). Defenders also had the highest percentage of time spent in walking (41±1.3%), significantly higher than forwards (34.5±1.4%) and midfielders (38.4±1.4%). Forwards had the highest percentage of time spent in linear (19.7±1.7%), while the midfielders had the highest percentage of time spent in non-linear dynamic movements (35.9±2.7%). These findings corroborate the above results for running load and mechanical load demands. This indicates that, in terms of the full game, defenders have lower demands than forwards and midfielders both in terms of running load and in terms of short, explosive mechanical load such as acceleration and deceleration, and change of direction. Forwards are more required to run lineary, including intensive high-speed running, while midfielders are more demanded in short, explosive mechanical load, especially lateral movements that require left and right changes of direction. Overall, judged by the comprehensive intensity indicator player load per minute, which takes into account all movements, forwards had the highest physical demands (13.9±0.6), followed by midfielders (12.2±0.7), and the lowest had defenders (9.5±0.6).

In the current study, individualised heart rate data were used to reflect the physiological demands in the games, where the individual maximal heart rate was derived from training, competition and YOYO IR2 tests over 12 months prior to data collection. The modified training impulse ($TRIMP_{mod}$) introduced by Stagno et al. (2007) was reported to be more appropriate to reflect the physiological load of intermittent team sports such as field hockey. The intensity of the physiological load was expressed in terms of $TRIMP_{mod}$ per minute based on the actual playing time of the players. Heart rate data processed in this way showed that defenders had a significantly lower $TRIMP_{mod}$ per minute than forwards and midfielders (2.74 ± 0.47, 3.16 ± 0.18, 3.04 ± 0.28, respectively). A breakdown of the time spent in each heart rate zone showed that 72-78% HR_{max} duration% and 86-92% HR_{max} duration% were significantly higher for forwards and midfielders than for defenders, suggesting that forwards and midfielders should focus more on lactate threshold and anaerobic threshold training compared to defenders. There was no significant difference in 93-100% HR_{max} duration% across the three positions, suggesting that none of the three positions, especially defenders, should neglect the maximal intensity training. Combining the above analysis of external physical demands and internal physiological demands, it can be concluded that forwards have the highest game demands in both external physical load and internal physiological load, while defenders have relatively lower physical demands.

There could be several contributing factors causing the positional differences. McMahon et al. (2019) and James et al. (2021) both found significant differences in the playing time between forwards, midfielders and defenders, with the basic pattern being that defenders had the longest playing time and forwards the shortest, which is consistent with the findings of the current study. James et al. (2021) also found a strong negative relationship between total playing time and average speed of play in their study. The fewer the rotations, the longer playing time during the game, which would result in decreased intensity, both in terms of objective fitness level and subjective pacing strategy. Therefore, in both the previous study and the present study, it was defenders who played the longest time on the field who had the lowest physical demands. Positional differences may also be related to the tactical roles and responsibilities of each position, and specific game scenarios. Forwards are supposed to create opportunities and score goals in the game, which requires of them to create space and quickly break the opponent's defensive line. Meanwhile for the midfielders, they are not only responsible for offensive actions but also for defensive ones, more specifically, responsibilities during offense to defense or defense to offense transitions. Hence, the midfielders are required to have more multi-directional movements for choosing the appropriate positions and directions. For defenders, their main responsibilities are marking the opponents and passively responding to the opponent players' actions and the changes of ball directions, which would happen in smaller area, hence, not much space for free running (Delves, Bahnisch, Ball, & Duthie, 2021; Polglaze, Dawson, Hiscock, & Peeling, 2015), and this might also be the reason why the majority of the short, explosive movements (IMA counts) of defenders in the current study were not significantly lower than those of the forwards and midfielders. These assumptions need to be confirmed by contextualised performance data (i.e., analysing the physical outputs and movement profile for each specific tactical scenario).

When comparing running intensity recorded in this study with other studies, the distance per minute for forwards was 130±5 m, which was lower than the 134±15 m of the Malaysian national team forwards (James, et al., 2021) and higher than the 123±17 m of the Olympic team forwards (McMahon & Kennedy, 2019). It is challenging to compare the HSRD data across studies because there is no standardised HSRD threshold. The commonly used HSRD thresholds in men's hockey were 15 kmh^{-1}, 15.5 kmh^{-1}, and 19 kmh^{-1} (Casamichana, Morencos, Romero-Moraleda, & Gabbett, 2018; Ihsan, et al., 2021; Lam, et al., 2021; McMahon & Kennedy, 2019; Morencos, et al., 2018; Sunderland & Edwards, 2017; White & MacFarlane, 2013). In the current study, 15 kmh^{-1} was chosen as the threshold for HSRD in order to facilitate comparison with recent studies that had similar methodologies. In comparison with a men's team competing in the Olympic Games reported by McMahon and Kennedy (2019), HSRD per minute in our study was lower for defenders (14.8±2.5 $mmin^{-1}$) than the 22.8±8.9 $mmin^{-1}$ for defenders on that team, and lower for midfielders (29.8±4.7 $mmin^{-1}$) than 36.1±6.1 $mmin^{-1}$ for midfielders on that team. HSRD per minute for forwards in the present study and previous study were slightly lower (33.5±3.9 $mmin^{-1}$ and 34.6±8.9 $mmin^{-1}$, respectively). The main reason why the high-speed running performance of the subjects in the present study was lower than that of the teams competing in the Olympic Games may be due to the level of competition and team ranking, as reported in previous research (Paul, Bradley, & Nassis, 2015). AccDec count per minute for each position in our study was much higher than the average of 71 matches over a two-year period reported by James et al. (2021); however, the high IMA count per minute findings were similar. This indicates that the acceleration and deceleration data derived from GPS technology (>2 ms^{-2}) and the high-intensity IMA data obtained from inertial sensor technology (>3.5 ms^{-1}) are essentially describing different types of physical demands, with the former being the ability to start and brake, and the latter being the ability to make explosive movements over small distances.

Differences among quarters

The results show that all running variables (total distance per minute, HSRD per minute, and RHIE per minute), as well as AccDec per minute, and player load per minute were significantly higher in quarter 1 than in the other three quarters. Total distance per minute and player load per minute were significantly higher in quarter 2 than in quarter 4. This suggests that under the current

FIH four-quarter format, the intensity of play for the teams in this study was highest in quarter 1, followed by a significant drop in quarter 2 and after an intermission, there was no further significant drop in quarter 3, but a further drop in overall running performance occurred in quarter 4 relative to quarter 2. The change in total distance per minute was consistent with previous reports, but not with the findings of previous studies in terms of HSRD per minute. The previous study by James et al. (2021) found that HSRD per minute reached its peak in quarters 1 and 4, which could be due to specific game scenarios such as the scoring situation in each quarter, substitution strategies, tactical strategies, etc. The study by Ihsan et al. (2021) suggested that players may intentionally conserve their effort during the game and run at high speed only when it matters most. It is therefore important to understand and consider the context on the field when interpreting the patterns of change in the variables over time, in addition to the natural effects of physiological fatigue. There were no significant differences between the four quarters in all IMA category variables, suggesting that the IMA counts are not sensitive to fatigue. In future studies, these can be further clarified if the game data is further segmented into smaller time intervals (i.e., 1-min intervals) and if the trend of IMA counts is analysed after each rotation or quarter break.

When looking at the movement profiles, results show that static duration% increased quarter by quarter (from 9.8±2.2% in quarter 1 to 17.2±4.5% in quarter 4). Linear running duration% dropped significantly from 17.7±1.7% in quarter 1 to 15.7±1.6% in quarter 2, recovered in quarter 3 after the halftime break (15±2.1%), and again dropped in quarter 4 to 13.6±1.5%. The pattern for non-linear dynamic movement duration% was similar to linear running duration%, dropping from 36.5±2.8% in quarter 1 to 30.3±3.6% in quarter 4. This suggests that the players were most active in quarter 1, with 54.2% of the time (linear running and non-linear dynamic movement combined) being spent doing meaningful running, acceleration and deceleration, while by quarter 4, only 43.9% of the time was spent doing active movements. This result suggests that movement profile analysis can also be used to flag fatigue status during a game and provide supporting information for substitution strategies. The current study revealed for the first time the movement profiles during a field hockey game. In a previous study on football, Szigeti et al. (2021) collected data from 34 international matches of a national team and reported 15.6% for static duration% during official games, 35.8% for walking, 20.8% for linear running, and 27.8% for non-linear dynamic movements. Comparing the results of the present study with football, it can be seen that field hockey game is similar to the football game in terms of the percentage of active, but within the active time, football games are having more time spent on linear running, while in field hockey games players spend more time on non-linear movements such as acceleration and deceleration, change of direction and other movements.

After the 2015 FIH rule change, only one study included heart rate data for the four-quarter format of men's field hockey games. However, each quarter of that study was 17.5 minutes in length rather than the FIH standard of 15 minutes used in the current study, and the study was conducted with college athletes, not professional athletes (Lam, et al., 2021). In that study, the relative mean heart rate values in the first to fourth quarters were 84.5±5.2%, 84.5±5.1%, 82.3±5.9%, and 82.4±6.0%, respectively, similar to the results of the present study (84.3±2.8%, 85.6±2.2%, 83.6±3.4%, and 83.6±2.9%, respectively), all being slightly higher in the first two quarters and slightly lower in the last two quarters. However, there was no significant difference. The previous study also reported the percentage of time with a heart rate >85% of the individual's maximal heart rate, which was 60.8%, 60.8%, 51.1%, and 51.0% from quarter 1 to quarter 4, respectively. The present study used >86% HR_{max} as a threshold and reported similar results (58.3%, 63.4%, 52.7%, and 52.2 from quarter 1 to quarter 4, respectively). In another previous study that was under the old 2-half rule, Lythe and Kilding (2011) reported similar results—the Avg. HR% in the 1st half was higher than the Avg. HR% in the 2nd half, but the difference was not significant.

As can be seen in the current study, >86% HR_{max} duration% was highest in quarter 2. Also, approximately 50-60% of the time in professional level men's field hockey game players are working at anaerobic threshold intensity under the current four-quarter rule. The $TRIMP_{mod}$ per minute also shows that the physiological demand was highest and statistically significant in the second quarter. The external physical load data from quarter 2 decreased in intensity, while an increase was observed in internal load (physiological response) compared to quarter 1; this suggests that players reach a state of fatigue in the second quarter and are unable to maintain a higher intensity of external physical load output, indicating that the coaches should focus more on quarter 2 in terms of the substitution strategies and make more frequent substitutions in the second quarter to ensure that players are fresh and can maintain external physical output at a high level.

The current study is not without limitations. When interpreting the data of the current study, there are several contexts to be considered. The participants were all from only one team and competed in one championship. Hence, some findings might not be representative for other teams with different playing philosophies, and at different competitive levels. Additionally, the team in the current study was the champion of the tournament and beat most of the opponents, therefore, the physical outputs might be impacted. Furthermore, there was no context of tactical considerations (i.e., rotations, ball possessions, etc.). It is recommended for the future studies to investigate further with multiple teams and embed the tactical contexts into the physical and physiological data to gain more specific demands for specific scenarios.

To conclude, defenders had the highest volume in terms of the absolute game demands due to their high playing minutes; however, they had the lowest game intensity compared with the other positions. This includes both physical outputs and physiological responses. Forwards had the highest linear running intensity, while midfielders were required to execute more multi-directional, non-linear movements. Defenders had lower demands in linear running intensity, but not lower in explosive, multi-directional movements. Heart rate data suggested that forwards and midfielders should focus more on lactate threshold and anaerobic threshold training compared to defenders. Nevertheless, none of the three positions, especially defenders, should neglect the maximal intensity training. Practitioners should take positional requirements into considerations when prescribing training loads. Quarter 1 was the most active quarter and players became fatigued in quarter 2. Movement profile variables and $TRIMP_{mod}$ per minute can be used in game to inform coaches of real-time physical condition of the players and assist with the decision-making in terms of substitutions.

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UNSTABLE COMPARED TO STABLE CORE EXERCISES IMPROVE MUSCULAR ENDURANCE IN PREADOLESCENTS AND ADOLESCENTS: AN EIGHT-MONTH RANDOMIZED TRIAL

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Abstract:

Although previous studies have indicated the importance of a core strength and muscular endurance training in preadolescents and adolescents, there is a lack of evidence regarding effects of a long-term core training in unstable conditions. The purpose of this study was to compare the effects of core training in stable versus unstable body positions on core and upper body strength and muscular endurance in non-trained children aged 11-14 years. Participants were randomly assigned to either stable (SC, N=569) or unstable (UC, N=633) core-exercise group and assessed at baseline, after four, and eight months for sit-ups, dynamic trunk extension, static trunk extension, and push-ups. Repeated measures ANOVA, with time as a within factor, and exercise group, age, and gender as between factors, was employed for data analysis. *Post-hoc* comparisons showed greater absolute improvements after the eight-month training in UC compared to SC for all measures, age groups, and both genders ($p \leq .01$), and greater relative improvements (differences in Cohen's *d* between UC and SC ranged from 0.08 to 1.58), except for static trunk extension in 11- and 12-year-old participants. However, the differences between SC and UC in four-month effects were inconsistent. These results point out that core exercises in unstable compared to stable conditions have a greater capacity for long-term improvement of core and upper body strength and muscular endurance in non-trained preadolescents and adolescents.

Key words: *children, resistance training, abdominal strength, lower back strength*

Introduction

Muscular strength and endurance are recognized as important elements of health-related fitness (Caspersen, Powell, & Christenson, 1985). There is a growing body of research trying to elicit resistance training programmes that can be efficient for optimal improvement of muscular strength, muscular endurance, and physical performance in different populations (Allen, Hannon, Burns, & Williams, 2014; Behm, et al., 2017; Coratella & Schena, 2016; Faigenbaum, et al., 2001; Sekendiz, Cug, & Korkusuz, 2010). Some of the widely used programmes for enhancing body strength and functionality are oriented towards the body core.

The core is described as a muscular corset surrounding the lumbar spine that serves as an engine of all limb movements (Akuthota & Nadler, 2004). A stable, strong, and enduring core is important for musculoskeletal injuries prevention (Hibbs, Thompson, French, Wrigley, & Spears, 2008; McGill, 2010; Mendiguchia, Ford, Quatman, Alentorn-Geli, & Hewett, 2011), in rehabilitation (Akuthota & Nadler, 2004), as well as for improving physical performance in everyday functioning (Granacher, Gollhofer, Hortobágyi, Kressig, & Muehlbauer, 2013) and specific sports activities (Kibler, Press, & Sciascia, 2006; Myer, Ford, Palumbo, & Hewett, 2005; Reed, Ford, Myer, & Hewett, 2012). Core training mostly refers to a variety of exercises that involve both global, dynamic core muscles (e.g., *m. rectus abdominis*) and local, postural core muscles (e.g., *mm. multifidi*), and focuses on their proper inter-activation in order to improve core stability and strength. Furthermore, a body of evidence suggests that neural coordination in core muscle recruitment is more important for the core and whole-body functionality than the core muscle hypertrophy (Akuthota & Nadler, 2004; Hibbs, et al., 2008). In line with this, unstable and asymmetric core exercises could provide additional stimulation to the neuromuscular system for improving parameters of core stability, strength, and muscular endurance (Behm, Leonard, Young, Bonsey, & MacKinnon, 2005; Vera-Garcia, Grenier, & McGill, 2000).

Neuromuscular stimulations could be especially important in preadolescents' core training, bearing in mind that their strength improvements during resistance training can be obtained rather due to neural adaptations (i.e., motor unit activation, coordination, recruitment, and firing) than to muscle hypertrophy related to a hormonal spurt (Behringer, vom Heede, Yue, & Mester, 2010; Faigenbaum, 2000; Ozmun, Mikesky, & Surburg, 1994). On the contrary, adolescents have greater strength improvement as a result of their hormonal status (e.g., increased levels of circulating androgens in males and growth hormone and insulin-like growth factor in females) (Kraemer, 1987) and it is not clear whether additional neuromuscular stimulation (e.g., engaging, unstable exercises) would be beneficial or detrimental for strength during adolescents' resistance training. Bearing in mind the different physiological mechanisms of strength gains in preadolescents and adolescents, establishing a core resistance training that would be beneficial for core strength and muscular endurance in both preadolescents and adolescents is quite challenging.

Oliver, Adams-Blair, and Dougherty (2010) proposed feasible core-strength training for preadolescents, which consisted of four isometric core exercises (the fifth exercise was a modified form in case of failing to perform one of the exercises) in one set for 30 seconds. Although this training increased muscular endurance of trunk flexors in the first two months, the achieved plateau was maintained throughout the rest of the ten-month training period. The authors concluded that there was a need for additional neuromuscular stimulation in order to prolong positive training effects. This issue was partially addressed in another study by designing training that consisted of ten engaging dynamic core conditioning exercises performed during 30 seconds each, one after another (Allen, et al., 2014). This one-per-week training routine lasted six weeks and showed significant gains in trunk muscular endurance in both preadolescents and adolescents. However, due to the short training period, it could not be concluded whether this training would have prolonged positive effects on trunk muscular endurance. Both of the previously mentioned studies did not include a control group, and therefore trunk muscular endurance gains could not be attributed solely to the training. In another study (Granacher, et al., 2014), resistance training in stable and unstable conditions was organized two times a week for a total of six weeks as a randomized control trial for adolescents. Increasing the training load every two weeks (i.e., the number of repetitions in the dynamic exercises and contraction time in the isometric exercises) improved core muscular endurance but did not show greater effects in either of the two condition groups. The reason for such findings might be the short training period (six weeks), with insufficient time for neuromuscular adaptation as an answer to the complexity of the unstable exercises.

To address the mentioned shortcomings in previous research, we designed a feasible eight-month core resistance training that consisted of engaging exercises in unstable body positions. Moreover, to address the issue of the lacking control group in previous research, in this study we included resistance training with similar exercises, but in stable body positions. This study aimed to compare the efficacy of core training in unstable versus stable conditions (UC vs SC) in improving core strength and muscular endurance in 11-14 years old children of both sexes. Also, we aimed to reveal whether functional core training can improve upper body muscular endurance, if we have in mind that engaging core exercises could be beneficial for multiple parts of the kinetic chain (Kibler, et al., 2006; Reed, et al., 2012). Bearing in mind the importance of neuromuscular stimulation for strength gains (Behm, et al., 2005; Vera-Garcia, et al., 2000), especially in preadolescents (Behringer, et al., 2010; Faigenbaum, 2000), we hypothesized that younger children (i.e., 11-year-olds) would show greater improvements in core muscle strength and endurance as well as in upper body muscular endurance when trained using UC compared to SC exercises. We could not hypothesize which of the two types of training would be more efficient in adolescents, when considering their greater hormonal response to strength and muscular endurance training, compared to preadolescents (Behringer, et al., 2010; Tsolakis, Vagenas, & Dessypris, 2004).

Methods

Study design

This randomized trial involved 1202 non-trained participants randomly assigned to SC or UC. After familiarization with the testing protocol, the participants undergone a baseline testing of muscular strength and endurance, body weight and body height. The intervention programme lasted for two four-month periods with a 3-week pause apart and mid-intervention testing in between. The programme consisted of 12 exercises in SC vs UC with volume monthly increased. At the end of the programme, the final testing was applied.

Participants

In the first phase of the participant recruitment 1348 students aged 11-14 (not younger than 10.5 years and not older than 14.5 years at the pretest; mean age ≈ 12.5 years), without neurological or physical impairment, from five public schools who had not trained any sports for at least six months (i.e., non-athletes), volunteered to participate in this study. The Local Ethics Committee approval was obtained, and the children's parents or legal guardians provided all the required information and gave their written informed consent. Participants were informed about the benefits and risks of the study and gave verbal assent. They were randomly assigned either to SC or UC. During the eight-month study, 146 participants dropped out due to being absent for 15 or more classes (N=80), being involved in some sport within the study period (N=9), lacking one or more testing sessions (N=47) or residential relocation (N=10). At the end of the experiment, 1202 participants (569 in SC; 596 females) completed the study.

Testing procedures

Prior to baseline testing, participants were given a 45 min instruction-session in order to become familiar with the techniques of the four testing exercises (sit-ups, dynamic trunk extension, push-ups, and static trunk extension). All the participants completed a standardized dynamic warm-up and as many practice-attempts as needed to learn the proper exercise technique. After a five-day pause, they attended two testing sessions separated by three days. Prior to both sessions, participants completed a ten-minute standardized warm-up consisting of dynamic bodyweight exercises, gradually increased in intensity. During the first session, the participants' body height and body weight were measured, and they performed sit-ups and dynamic trunk extensions, with at least 5-minute rest between the exercises. During the second session, participants performed static trunk extensions and push-ups, with the same pause in between. The testing protocol was identical for the middle effect testing (after four months) and postintervention testing (after eight months) and performed at the same time of a day. The same experimenters within each school obtained the measures at each of the three time points, and they were not aware of the core exercise group (SC or UC) to which the participants were assigned.

Anthropometric assessment

Body height was measured using stadiometers (Seca Instruments Ltd., Hamburg, Germany) to the nearest 0.1 cm, and body weight was measured with portable weighing scales (Tanita Europe GmbH., Sindelfingen, Germany) to the nearest 0.1 kg. Body mass index (BMI) was calculated using the standard formula and expressed in $kg{\cdot}m^{-2}$.

Strength and muscular endurance assessment

Sit-ups in 30 seconds was used as an exercise for assessing the muscular endurance of trunk flexors (Adam, Klissouras, & Ravazzolo, 1988). The participant lay supine on the floor with 90° flexion in the knee joints, hands at the side of his/her head, with elbows pointing straight forward and the feet securely held by a partner. In a correct sit-up, the elbows should touch the knees and, when going back, the shoulders should touch the floor. The number of correctly completed repetitions in 30 s was used for data analysis.

Dynamic trunk extension test was used for assessing muscular endurance of trunk extensors because it requires proper activation of the *m. erector spinae* (Kearns, Brechue, Bauer, Pollock, & Fulton, 1997). The participants performed the test on a Roman chair with their legs fixed by one experimenter. They started at a 180º angle between the back and legs while keeping their arms folded across the chest (neutral position). The participants flexed their trunk in a controlled manner until they reached a 90º angle between the trunk and legs and then extended back to the neutral position. An indicator of a well flexed position was the paperclip (at a free end of a chain attached to the participants' shirt), which would barely touch the floor at the 90º trunk flexion angle. The participants performed the trunk extensions at a pace of one repetition every three seconds. The test stopped when the participant was unable to keep up with a required pace of 20 extensions per minute or voluntarily stopped. The total number of repetitions was used for data analysis.

Static trunk extension test was used for assessing trunk extension strength (Cooper Institute for Aerobics Research, 1999). Participants lay in the prone position on a mat with their hands under the thighs and performed trunk extension as high as possible in a slow and controlled manner, keeping the feet in contact with the floor and the head in the Frankfurt plane. The contraction lasted until the tester measured the distance from the floor to the participants' chin (up to 5 s). Two trials were performed, and the better score was recorded.

Push-ups test, which assesses upper body muscular endurance, was modified by placing the hands on a higher surface (a 55 cm high gymnastics bench). We used this exercise despite the fact that it is not a core exercise, in order to investigate if the core strengthening would improve strength and muscular endurance parameters in a task that is indirectly dependent on core stability and strength (McGill, McDermott, & Fenwick, 2009; Santana, Vera-Garcia, & McGill, 2007). The other validated versions of the push-up test were not chosen for this study because the 90° push-up (Cooper Institute for Aerobics Research, 1999) was too challenging for a great proportion of the participants, and the knee push-up test was not challenging enough for the body core engagement. Except for the modified placement, the hands were under the shoulders and wider than a vertical shoulder projection

(10 cm each), arms straight, and legs together and straight with the toes tucked downward. The participants lowered the body by bending their elbows outwardly to a 90° angle and continued the movement in reverse until the arms were straight again (the back and legs were in a straight line throughout the movement). The participant needed to repeat this movement as many times as possible. The test ended when the participant voluntarily stopped, did not maintain the correct body position, or did not achieve a 90° bend at the elbow on two consecutive trials (after the first mistake the participant was warned to correct his/her technique).

Training procedure

Prior to initiating training programmes, all participants completed three familiarization sessions, separated by 24h, during which they mastered the performance of 12 exercises implemented during the core training programme (Table 1). At the end of the instruction week, they were tested without a strict testing procedure in each exercise for the maximal number of repetitions (except for the exercises which were the same as the test, i.e., sit-ups and push-ups in SC), or maintaining the proper body position for as long as possible (i.e., plank with hands on a medicine ball). This information was used in defining the conservatively progressed training volume and intensity (not at the expense of technical properness) for each exercise (Table 1). Three different exercises were performed in one training session, three times a week (total of 12 exercises in a four-week-cycle). Each exercise was performed in four sets: 60, 70, 80, and 90% of the MNR (maximal number of repetitions performed at baseline), with a 1-minute pause between the sets. Training volume was increased monthly: in sets 1-3 for 5% MNR, in the 4th set 3 to 1 repetition in reserve (10 to 5 s, for plank on a medicine ball). In the UC group, one-leg-standing exercises were counted as a whole set, and the next set began with the support on the opposite leg (e.g., left-right-left-right, in four sets, respectively). In the next month-cycle, the first set of the same exercise was performed on the leg opposite to the one at the beginning of the previous month. The tenseness of the resistance band was adjusted individually, according to MNR ≈ 15. The training programmes were incorporated into the mandatory physical education programme, in the form of an introductory and preparatory phase of a class. In the main phase of a class, all participants (SC and UC) were involved in their regular physical education programme for 20 min, which consisted of athletics (running, jumping) in each grade (age group), and technique-oriented exercises related to handball, basketball, volleyball, and soccer (for 11-, 12-, 13-, and 14-year-old participants, respectively). A physical education teacher supervised the training process and corrected the exercise technique if needed. Due to perturbation during exercises in UC, participants were instructed to continue the exercise after a mistake (e.g., losing balance in one-leg-standing exercises). After the four-month training period, participants had a three-week rest (school holidays), and when they were back in school, the last training month-cycle, in terms of the training volume and intensity, was repeated. The following month-cycles were executed with a gradual increase in training volume as prior to the three-week rest.

Statistical analysis

Descriptive statistics (mean, SD, skewness, and kurtosis) was used to inspect participants' characteristics and measures' distribution prior to the intervention. A repeated-measures ANOVAs with time as within- and exercise group (SC vs. UC), age (11 vs. 12 vs. 13 vs. 14 years), and sex (male

Table 1. Stable core exercises and unstable core exercises in a one-month training cycle

Week	SC	UC
1st	Glute bridge	One leg glute bridge
	Seated oblique twists with 624 gr ball (LS)	Seated oblique twists with 624 gr ball (LR)
	Knee push-ups	T knee push-ups
2nd	Dynamic trunk extension	Back scale
	Push-ups (hands on a 55 cm high surface)	One-leg-standing chest press with RB
	Sit-ups	Standing-on-heel crunches
3rd	Squat to overhead press with MB	One leg half squat to overhead press with MB
	Horizontal chopping with RB	One-leg-standing horizontal chopping with RB
	Reverse push-ups	One leg reversed push-ups
4th	Crossed-leg single-leg glute bridge	Single leg glute bridge on MB
	Down-to-upward facing dog	Plank with hands on MB
	Split squat	Sliding split squat

Note. SC = stable core exercises group; UC = unstable core exercises group; LR = legs raise; LS = legs sustained; RB = resistance band; MB = medicine ball.

Table 2. Descriptive statistics for the pretest measures in the stable conditions and unstable conditions

	SC			UC		
	M (SD)	Skew (SE)	Kurt (SE)	M (SD)	Skew (SE)	Kurt (SE)
BMI (kg·m^{-2})	19.84 (2.85)	0.07 (0.10)	-0.53 (0.20)	19.51 (2.95)	0.58 (0.10)	0.61 (0.19)
Sit-ups (n)	21.13 (3.80)	-0.17 (0.10)	0.49 (0.20)	20.79 (5.16)	0.13 (0.10)	0.17 (0.19)
Dynamic trunk extension (n)	36.53 (7.13)	-0.29 (0.10)	-0.06 (0.20)	33.20 (8.58)	-0.21 (0.10)	0.03 (0.19)
Push-ups (n)	13.56 (3.63)	-0.12 (0.10)	0.41 (0.20)	12.76 (4.73)	0.28 (0.10)	-0.05 (0.19)
Static trunk extension (cm)	21.27 (4.24)	0.18 (0.10)	2.08 (0.20)	19.32 (5.38)	0.63 (0.10)	0.45 (0.19)

Note. SC = stable core exercises group; UC = unstable core exercises group; M = mean; SD = standard deviation; Skew = skewness; Kurt = kurtosis; SE = standard error; n = number of repetitions.

Table 3. Results of the repeated measures ANOVA[a]

		T	T × E	T × E × A	T × E × G	T × E × A × G
Sit-ups	F	2881.47**	403.30**	7.05**	3.43	1.69
	Partial η^2	.71	.25	.02	.003	.004
	df (Error)	1.54 (1832)	1.54 (1832)	4.63 (1832)	1.54 (1832)	4.63 (1832)
Dynamic trunk extension	F	1916.40**	375.64**	4.30**	0.75	3.70**
	Partial η^2	.62	.24	.01	.00	.01
	df (Error)	1.61 (1904)	1.61 (1904)	4.82 (1904)	1.61 (1904)	4.82 (1904)
Push-ups	F	4238.84**	907.12**	4.92**	3.19	4.25**
	Partial η^2	.78	.43	.01	.003	.01
	df (Error)	1.59 (1889)	1.59 (1889)	4.78 (1889)	1.59 (1889)	4.78 (1889)
Static trunk extension	F	1070.87**	166.55**	3.02*	.57	.86
	Partial η^2	.47	.12	.01	.00	.002
	df (Error)	1.37 (1627)	1.37 (1627)	4.12 (1627)	1.37 (1627)	4.12 (1627)

Note. T = time (baseline, four-month, eight-month); E = exercise group (stable core exercises, unstable core exercises); A = age (11, 12, 13, 14 years); G = gender (females, males); [a]degrees of freedom with Greenhouse-Geisser's correction; ** p<.01; * p<.05.

vs. female) as between-participants factors were performed on each dependent variable. Accompanied *post-hoc* tests (*t*-test) were used for detecting the absolute mean difference between pre- and mid-test as well as pre- and post-test in each group, and Cohen's *d* was calculated as a measure of their relative improvement (Rhea, 2004). In order to reduce Type I error possibility, Bonferroni–Holm correction was applied (Cramer, et al., 2016). Greenhouse-Geisser's correction was used due to a violated assumption of sphericity. Alpha level of significance was set at p≤.05. Bearing in mind that sample size was not an issue, *post-hoc* power analysis indicated statistical power of 1.00 for these data.

Results

Descriptive statistics for BMI, strength and muscular endurance measures at the baseline showed relatively normal distribution in both the SC and UC (Table 2). The highest significant interactions for each measure, yet with small effect sizes, were time × exercise group × age × gender for dynamic trunk extension and push-ups, and time × exercise group × age for sit-ups and static trunk extension (Table 3). *Post-hoc* analysis (Bonferroni–Holm correction) showed statistically significant (p<.01) four- and eight-month improvements for all measures in both groups (SC and UC), all age groups (11-14), and both genders (males and females), except there was no gain in dynamic trunk extension in 11-year-old males in SC after four months (mean difference 0.131, p=1.00). Compared to SC, after the eight-month training UC showed greater absolute improvements in all measures (independent samples *t*-tests, p≤.01) and greater relative improvements (Cohen's *d*) in all measures, except in the strength of trunk extensors (static trunk extension) in 11- and 12-year-old participants (Table 4, Figure 1). Differences between the groups (SC vs. UC) in four-month training-effects were not consistent.

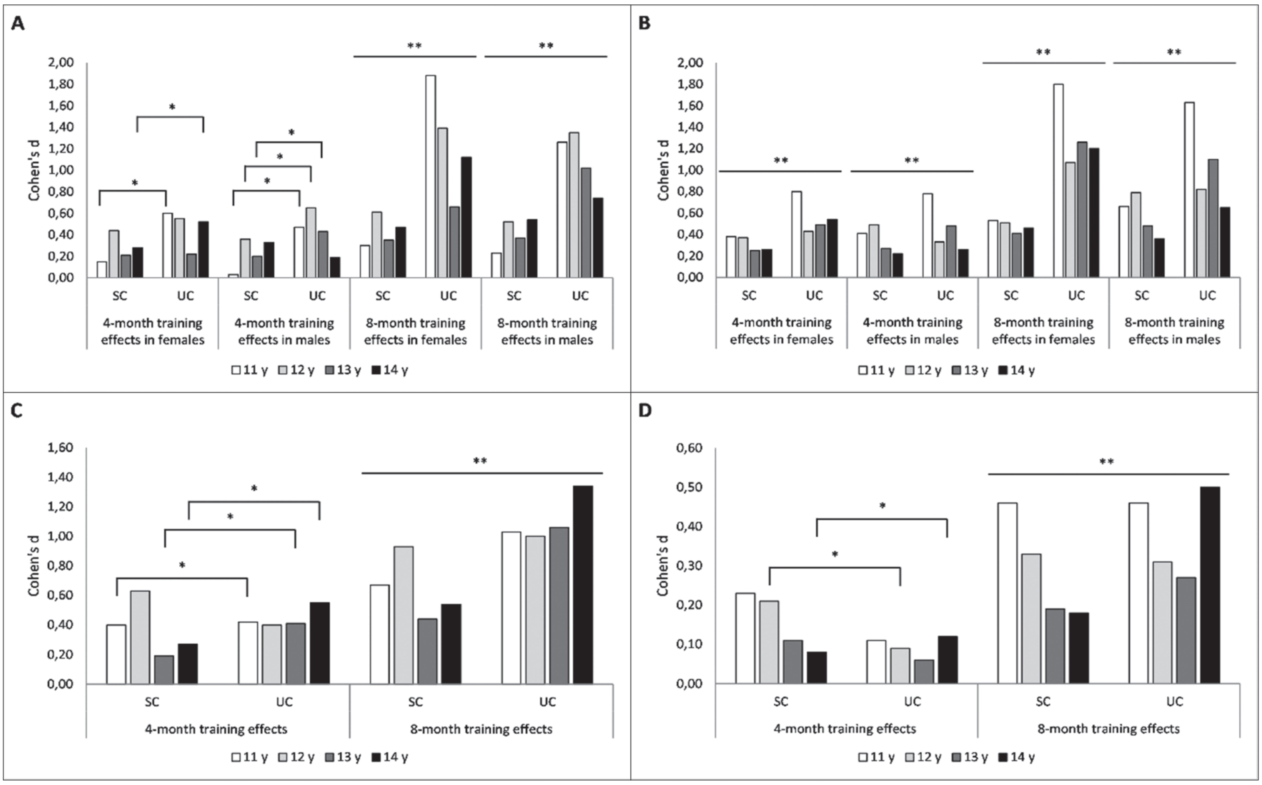
Discussion and conclusions

In this study we aimed to create a feasible core training in SC and UC in order to improve core strength and endurance. In spite of the different modalities of instability in the previous studies, we assumed that unstable body positions while performing resistance exercises would be appropriate for activating core muscles in order to ensure lumbar stabilization and maintain the body's center

Table 4. Effect size (Cohen's d) for strength and muscular endurance gains in the stable conditions and unstable conditions

			By age and gender[a]								Overall[b]
			11		12		13		14		
			F	M	F	M	F	M	F	M	
Sit-ups	4-month	SC	0.40		**0.63**		0.19		0.27		0.36
		UC	**0.42**		0.40		**0.41**		**0.55**		**0.38**
	8-month	SC	0.67		0.93		0.44		0.54		0.63
		UC	**1.03**		**1.00**		**1.06**		**1.34**		**0.96**
Dynamic trunk extension	4-month	SC	0.15	0.03	0.44	0.36	0.21	0.20	0.28	**0.33**	0.21
		UC	**0.60**	**0.47**	**0.55**	**0.65**	**0.22**	**0.43**	**0.52**	0.19	**0.28**
	8-month	SC	0.30	0.23	0.61	0.52	0.35	0.37	0.47	0.54	0.35
		UC	**1.88**	**1.26**	**1.39**	**1.35**	**0.66**	**1.02**	**1.12**	**0.74**	**0.71**
Push-ups	4-month	SC	0.38	0.41	0.37	**0.49**	0.25	0.27	0.26	0.22	0.31
		UC	**0.80**	**0.78**	**0.43**	0.33	**0.49**	**0.48**	**0.54**	**0.26**	**0.40**
	8-month	SC	0.53	0.66	0.51	0.79	0.41	0.48	0.46	0.36	0.48
		UC	**1.80**	**1.63**	**1.07**	**0.82**	**1.26**	**1.10**	**1.20**	**0.65**	**0.95**
Static trunk extension	4-month	SC	**0.23**		**0.21**		**0.11**		0.08		**0.12**
		UC	0.11		0.09		0.06		**0.12**		0.08
	8-month	SC	0.46		**0.33**		0.19		0.18		0.20
		UC	0.46		0.31		**0.27**		**0.50**		**0.31**

Note. **Bold** font indicates exercise group (SC or UC) which has higher Cohen's *d* for each age/gender category;
SC = stable core exercises group; UC = unstable core exercises group; F = females; M = males.
[a]For the measures (dynamic trunk extension and push-ups) where the highest order interaction was T × E × A × G, the exercise group effect throughout time is displayed by age and gender, and for the measures (sit-ups and static trunk extension) where the highest order interaction was T × E × A, the exercise group effect throughout time is displayed only by age.
[b]Effect size of exercise group after four- and eight-month training, when data are collapsed over age and gender.



Note. **Significantly greater absolute improvement in the unstable conditions (UC) compared to the stable conditions SC (p≤.01) for all age groups (11, 12, 13, 14 years), and both genders (males and females).
*Significantly different absolute improvement between UC and SC (p≤.01) for specific gender and/or age group.

Figure 1. Participants' relative improvement (Cohen's d) and absolute improvement (independent samples t-test) after 4- and 8-month training in dynamic trunk extension (a) and push-ups (b) as a function of age (11, 12, 13, and 14 years) and gender (males and females), and in sit-ups (c) and static trunk extension (d) as a function of age.

of gravity within its base and thus to retain the balance. Along with this, an eight-month training duration can be long enough for continuous neuromuscular adaptations and therefore a continuous improvement in core strength and endurance measures. In line with our hypothesis, both the absolute and relative improvement in this study (Figure 1, Table 4) indicated that resistance core training in UC was more beneficial than the one in SC, when observing the sample as a whole, especially for muscular endurance of trunk flexors (sit-ups), trunk extensors (dynamic trunk extension), and upper body (push-ups). The lower efficacy in improving the strength of trunk extensors (static trunk extension) in both groups (SC and UC) could be because both interventions were mainly focused on increasing the number of repetitions, rather than on increasing load.

Further, smaller trunk extensors' strength gains in UC compared to SC after four months may be in line with the findings of previous research (Anderson & Behm, 2004; Behm, Anderson, & Curnew, 2002), which indicated that maximal isometric force was decreased when performing movements under UC. Although those studies refer to an unstable testing position in which force cannot be produced fully (which was not an issue in our stable-position static trunk extension test), resistance training in UC could indeed result in smaller strength gains compared to resistance training in SC. However, after eight months, UC showed greater improvement in trunk extensors' strength than SC. Moreover, in all muscular endurance measures, UC demonstrated more substantial gains in the second four-month training-cycle (i.e., from the fourth to the eighth month of the intervention) compared to the first four-month cycle, while in SC, a pattern of strength and muscular endurance gains was rather opposite (Figure 1). The reason for such a positive acceleration curve of core strength and endurance in UC could be assigned to prolonged neuromuscular adaptation to unstable conditions, hence a prolonged period of improvements in strength and muscular endurance throughout time. In line with this, Oliver et al. (2010) pointed out the importance of additional neuromuscular stimulation in resistance training of preadolescents in order to overcome a plateau in core strength and endurance improvement.

When the training effects are presented as the function of gender, there was a similar pattern of the training effects in males and females throughout the 11-14 age span within each training group (SC, UC) and each measure of muscular endurance and strength (Figure 1). This is in line with the results of Allen et al. (2014), who did not find any differences between male and female youth in trunk muscular endurance after resistance core training. When data were described additionally by age, the greatest efficacy in SC was revealed in 12-year old participants for all the measures except the muscular endurance of trunk extensors (dynamic trunk extension), which improved fairly equally in 12- and 14-year old males. Contrary to that, the pattern of improvement in UC showed decreased gains after the age of 11 year (except for sit-ups, due to a large standard deviation in 11-year-old participants), especially in 12-13 years old participants (Figure 1). According to our hypothesis, we argue that the relatively largest effect of unstable core exercises on core strength and muscular endurance in 11-year-old participants compared to other age groups could be one of the benefits of the prepubescent or early pubescent period (Nielsen, Nielsen, Behrendt-Hansen, & Asmussen, 1980; Pfeiffer & Francis, 1986). Proper sensory integration, neurocognitive processing and neuromuscular control that could be jeopardized by puberty onset are important prerequisites of controlling body stature and movements by timely activating specific core muscles and may be a valuable basis for strength and muscular endurance gains in preadolescents exercising in UC (Behringer, et al., 2010; Faigenbaum, 2000; Ozmun, et al., 1994). In addition, when analyzing gains in SC in order to conclude the reasons for the largest strength and muscular endurance gains in 12-year-old participants, we cannot attribute this improvement to a hormonal spurt related to puberty onset, due to the lack of maturation measures. Although it is quite certain that female participants were in puberty after the 12th year, such information for males cannot be inferred.

Our study presented novel conclusions based on previous research results on core training in preadolescents and adolescents (Allen, et al., 2014; Granacher, et al., 2014; Oliver, Adams-Blair, & Dougherty, 2010). Taking the conclusion on the rapid-achieved plateau in the muscular endurance of trunk flexors after 10-month isometric core training in preadolescents as a starting point (Oliver, et al., 2010), we designed core training in engaging, dynamic, unstable conditions, with gradually increased volume and therefore showed prolonged effects on core/upper body muscular endurance and core strength. In addition, if a core training is too short (i.e., six weeks), the differences in efficacy of exercises in SC and UC on core strength and muscular endurance might not be detected (Granacher, et al., 2014), or could be trivial to small (Allen, et al., 2014), according to the standards of treatment effects in strength training research (Rhea, 2004). Addressing this shortcoming, after our eight-month intervention, the conservatively interpreted Cohen's d for all measures in almost all age groups and both genders indicated trivial to small effects in SC (Cohen's $d < 0.50$, and 0.50-1.25, respectively), and small to moderate effects in UC (Cohen's d for moderate effects range 1.25-

1.90), except for strength of trunk extensors (static trunk extension), for which the effect in UC was trivial to small, too.

As a possible limitation of our research, it should be stressed that both SC and UC performed exercises that were not focused only on the body core but also on other parts of kinetic chains (e.g., the upper body's activity in push-ups and one-leg-standing chest press with resistance band). For the push-ups test, in which core muscles have only a stabilizing role, muscular endurance improvement was probably greatly due to the mobilizers' endurance gains (upper body muscular endurance), but this does not diminish the benefits of the functional training in UC. Further, in this study, we did not control the variables that could potentially impact the efficacy of the exercise programmes, such as sleep, nutrition, hydration, body composition, maturation and hormonal status, nor the menstrual cycle in female students. Nevertheless, in our large sample in which students were randomly assigned to training conditions, those variables were probably randomly distributed across the whole sample and did not produce a difference between the conditions. As it was not in the scope of this research, future studies need to include an additional control group in order to account for the effects of maturation on overall gains in core strength and muscular endurance, as well as to expand the age range of the sample in order to obtain more reliable results for depicting the patterns of strength and muscular endurance improvement in females and males throughout preadolescence and adolescence.

Our results revealed that an eight-month functional core training in UC was more efficient in improving core and upper body muscular endurance than training in SC, in a sample of preadolescents and adolescents who were involved only in regular physical education classes and not in systematically guided physical activity (i.e., sports). Bearing in mind the hypothesis on a prolonged period of neuromuscular adaptation when children are trained using unstable functional core exercise, training that lasts eight months or even more might result in considerable gains in core and upper body muscular endurance. This training is especially efficient in 11-year-old males and females. Alternatively, traditional core training could be a fairly good option for core strengthening in 12-year-old children, especially when having less time for the training-cycle (i.e., four months). The proposed 20-min exercises for both training groups are low cost, children-appropriate, and easy to administer in class, as a part of the regular physical education programme. Further, those exercises are feasible not only in school settings but in every other indoor and outdoor space that can be used for core strength and muscular endurance improvement.

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INTEGRATING COGNITIVE CONTENTS IN PHYSICAL EDUCATION CLASSES: EFFECTS ON COGNITIVE VARIABLES AND EMOTIONAL INTELLIGENCE

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Abstract:

The aim was to analyse the effect of a 4-week programme integrating cognitive contents in Physical Education (CogniPE) on cognitive performance (CP) and emotional intelligence (EI) of adolescents. A randomised controlled trial was conducted with a control group (CG, n=58), which performed physical exercises at low intensity (i.e., stretching or pilates), an experimental group 1, which performed small-sided games of team sports (EG1, n=62), and experimental group 2, which performed CogniPE (EG2, n=60). Intensity of exercises and scores were registered after each station to classify and motivate the teams. Selective attention and concentration increased by 11.9% and 9.2% in EG1, and by 18.2% and 14.4% in EG2, respectively, compared to CG. Mathematical calculation improved by 15.9% and 18.7% in EG1 and EG2, compared to CG. In EI, well-being improved by 10.9% in EG1, sociability improved by 12.8% in EG1 and 15.9% in EG2 compared to CG. It is concluded to use CogniPE in school context.

Key words: *cognitive performance, mathematical calculation, physical exercise, secondary education, sociability*

Introduction

Beyond traditional teaching methodologies, emergent innovative pedagogical models based on physical activity (PA) are appearing in educational systems in an attempt to enhance cognitive and emotional aspects in young people (Beck, et al., 2016; Benzing, Heinks, Eggenberger & Schmidt, 2016; Ruiz-Ariza, Suárez-Manzano, López-Serrano & Martínez-López, 2019; Schmidt, Jäger, Egger, Roebers & Conzelmann, 2015; Schmidt, et al., 2019). Among other benefits, the literature has shown the effects of integrating PA in academic lessons, based on the embodied learning theory, to improve executive functions, mathematical, linguistic, or scientific contents (Donnelly & Lambourne, 2011; Mullender-Wijnsma, et al., 2016; Schmidt, et al., 2019). However, these research studies were usually focused on young children and inside classrooms. Nevertheless, the inverse analysis from the physical education (PE) point of view has scarcely been analysed. In this sense, it is well known that the PE class is one of the most important contexts where young people practice PA in a controlled way (Ruiz-Ariza, et al., 2019), and several programmes between eight and 30 minutes have shown that PE classes could promote integral health benefits and better cognitive performance (CP) and emotional intelligence (EI) (Costigan, Eather, Plotnikoff, Hillman & Lubans, 2016; Kubesch, et al., 2009; Ruiz-Ariza, et al., 2019). However, PE is usually mostly based on physical stimulus, and the effects of integrating intentionally specific cognitive content within PE classes are unknown.

Furthermore, the cognitive demand inherent to games or physical exercises in PE is already known to enhance cognitive variables (Best, 2010; Schmidt, et al., 2015). This cognitive demand is defined as the degree to which the allocation of attentional resources and mental effort are needed to perform difficult skills in contexts such as sport games (Schmidt, Benzing, & Kamer, 2016). According to Budde et al. (2008), cognitive demand is supposed to lead to better attention by preactivating the same cognitive processes during the physical exercise as those used in a subsequent cognitive task. For example, playing a team sport requires the ability to discriminate between different visual stimuli and to make appropriate motor decisions. To enhance the cognitive result, participants in team sports can perform physical–cognitive exercises involving exactly the same mechanisms (Schmidt et al., 2016). Results from basic research seem to support this theory, in which particularly complex motor tasks should be used to develop the relationship between physical action and cognition (Schmidt, et al., 2016).

Regarding the integration of cognitive aspects in PA, some experimental research studies have already altered the cognitive demands of PA in young people showing controversial results. Depending on the kind of cognitively engaging PA, several studies have examined these effects. For example, one study, conducted by Schmidt et al. (2015), investigated the effects of two qualitatively different chronic PA interventions of a 6-week PE programme with high cognitive engagement based on team games, a low cognitive engagement (aerobic exercise) and a CG with low physical exertion and low cognitive demand, on executive functions in 10-12-year-old children. One year later, Schmidt et al. (2016) examined four groups of children between 11 and 12 years: 1) PA with high cognitive demands (HR = 154 bpm); 2) sedentary condition with high cognitive demands (HR = 102 bpm); 3) PA with low cognitive demands (HR = 144 bpm); and 4) sedentary CG with low cognitive demands. Other researchers have studied the effects of a less cognitively engaging PA (Budde, et al., 2008); a less cognitively engaging PA and a passive control group (Gallotta, et al., 2012); or a less cognitively engaging PA, a cognitively engaging sedentary condition and a passive control group (Jäger, Schmidt, Conzelmann & Roebers, 2015). Some of them have found positive benefits on CP in the cognitively engaging group (Budde, et al., 2008), while others have shown no difference regarding the control sample (Jäger, et al., 2015), or even unfavourable effects compared to PA without cognitive demand (Gallotta, et al., 2012). In accordance with the above, different PE interventions should be cognitively demanding, integrating and combining cognitive content within PE classes in a single study design, to challenge higher-order cognitive processes and to continue analysing the effects on important CP and EI variables.

On the other hand, the use of group dynamic in PE (non-static groups, modified inter–intra sessions to facilitate the cooperation among participants) is more favourable for social contact and the inter–intra relationship among young people (Ruiz-Ariza, et al., 2019). Physical activity controlled with group heart rate monitoring and performed in groups (i.e., team sports), has been shown to provide increases in motivation, promotion of continued play and playful entertainment, group decision-making and increases in self-efficacy and pro-social behaviours, with direct impact on CP and EI (Martínez-López, De la Torre-Cruz, Suárez-Manzano & Ruiz-Ariza, 2018; Ruiz-Ariza, et al., 2019). Thus, to know whether a 4-week programme integrating cognitive contents in PE (CogniPE) affects important variables of CP and EI, could be important in promoting novel educational strategies to enhance specific integral benefits from PE classes.

Based on the above reasoning, the aim of this study was to analyse the effect of two PE programmes (team sports and CogniPE) on the CP and EI of Spanish adolescents, independently of age, body mass index (BMI), maternal education, daily study time, or extracurricular PA at moderate to vigorous intensity (MVPA). These variates have been previously associated with the dependent variables of this study, and recent studies have used them as covariates (Dohrn, Kwak, Oja, Sjöström & Hagströmer, 2018; Ruiz-Ariza, Casuso, Suarez-Manzano & Martínez-López, 2018, Ruiz-Ariza, Suárez-Manzano, Mezcua-Hidalgo & Martínez-López, 2022). We hypothesised that young people performing CogniPE would show higher cognitive and emotional levels than their peers performing traditional programmes of PE (individual low-intensity activities or team sports).

Methods

Design

The study used a quantitative randomised controlled and blind trial with a control group (CG, n=58), which performed individual PA at low intensity (i.e., stretching or Pilates), an experimental group 1, which performed small-sided games of team sports (EG1, n=62), and another experimental group 2, which performed CogniPE (EG2, n=60).

Participants

A total sample of 180 adolescents from three Andalusian schools (Spain) took part in this study. The adolescents (49.4% girls) were 14.61±1.14 years of age (range=13–16), and had a BMI of 20.58±3.55 kg/m^2 (range=15.95–32.48) (see Table 1). Adolescents with some physical pathology or medical contraindication to performing PA were excluded from this study. Those diagnosed with learning disabilities (e.g., ADHD) were not included among the eligible students. Despite this, they performed the PA corresponding to their group, but these data were not included in the analysis. The final sample was formed of students who completed the cognitive or EI data and carried out the total intervention period correctly. Thirty-five participants did not complete the cognitive or EI data and 11 left the study during the intervention. The structure used for group formation and intervention characteristics are shown in Figure 1.

Table 1. Anthropometric, sociodemographic, cognitive, and emotional characteristics at the beginning of the study. Values are presented as mean and standard deviation or percentage. EG1 = small-sided games, EG2 = CogniPE

Variable		All (n=180)	CG (n =58)	EG1 (n=62)	EG2 (n =60)	p-value
Age (years)		14.61 ± 1.14	14.41 ± 1.20	14.55 ± 1.16	14.87 ± 1.03	0.086
Sex (%)	Girls Boys	89 (49.4) 91 (50.6)	25 (43.1) 33 (56.9)	28 (45.2) 34 (54.8)	36 (60.0) 24 (40.0)	0.131
Body weight (kg)		57.25 ± 11.87	57.33 ± 9.94	56.89 ± 11.13	57.55 ± 14.29	0.953
Body height (m)		1.68 ± 0.07	1.67 ±0 .08	1.67 ± 0.06	1.64 ± 0.05	0.144
BMI (kg/m²)		20.58 ± 3.55	20.39 ± 2.69	20.30 ± 3.36	21.04 ± 4.39	0.463
Computer at home (n)		2.61±1.47	2.53±1.17	2.77 ± 1.92	2.47±1.03	0.226
Maternal education (%)	No studies Primary school Secondary school University	35 (19.4) 28 (15.6) 56 (31.1) 61 (33.9)	13 (22.4) 14 (24.1) 16 (27.6) 15 (25.9)	8 (12.9) 4 (6.5) 24 (38.7) 26 (41.9)	14 (23.3) 10 (16.7) 16 (26.7) 20 (33.3)	0.057
Daily study time (min/day)		65.45 ± 41.22	58.89 ± 44.74	73.27 ± 40.19	63.71 ± 37.96	0.149
MVPA (days/week, range: 0-7)		3.23 ± 1.67	2.91 ± 1.86	3.37 ± 1.66	3.38 ± 1.46	0.224
Memory (range 0–15)		3.98 ± 2.32	3.83 ± 0.70	3.97 ± 0.73	4.2 ± 1.10	0.377
Selective attention [number of processed elements – (omissions + mistakes)]		135.85 ± 37.09	131.33 ± 46.34	142.00 ± 35.20	140.33 ± 35.71	0.422
Concentration (number of hits – number of mistakes)		125.99 ± 36.55	121.09 ± 45.03	128.84 ± 36.03	127.80 ± 33.25	0.459
Mathematical calculation (n operations/min)		6.71 ± 2.42	6.34 ± 1.72	6.97 ± 2.20	6.78 ± 2.23	0.358
Linguistic reasoning (n words/min)		20.12 ± 5.21	20.88 ± 4.19	20.68 ± 4.88	21.40 ± 5.21	0.653
Emotional intelligence (1-7)	Wellbeing	4.18 ± 0.74	4.07 ±0.71	4.28 ± 0.84	4.17 ± 0 .64	0.311
	Self-control	3.92 ± 0.70	3.74 ± 0.59	4.04 ± 0 .70	3.87 ± 0 .53	0.019
	Emotionality	3.75 ± 0.61	3.70 ± 0.57	3.64 ± 0 .48	3.86 ± 0 .54	0.237
	Sociability	4.07 ± 0.73	4.07 ± 0.69	4.05 ± 0.78	4.10 ± 0 .74	0.928

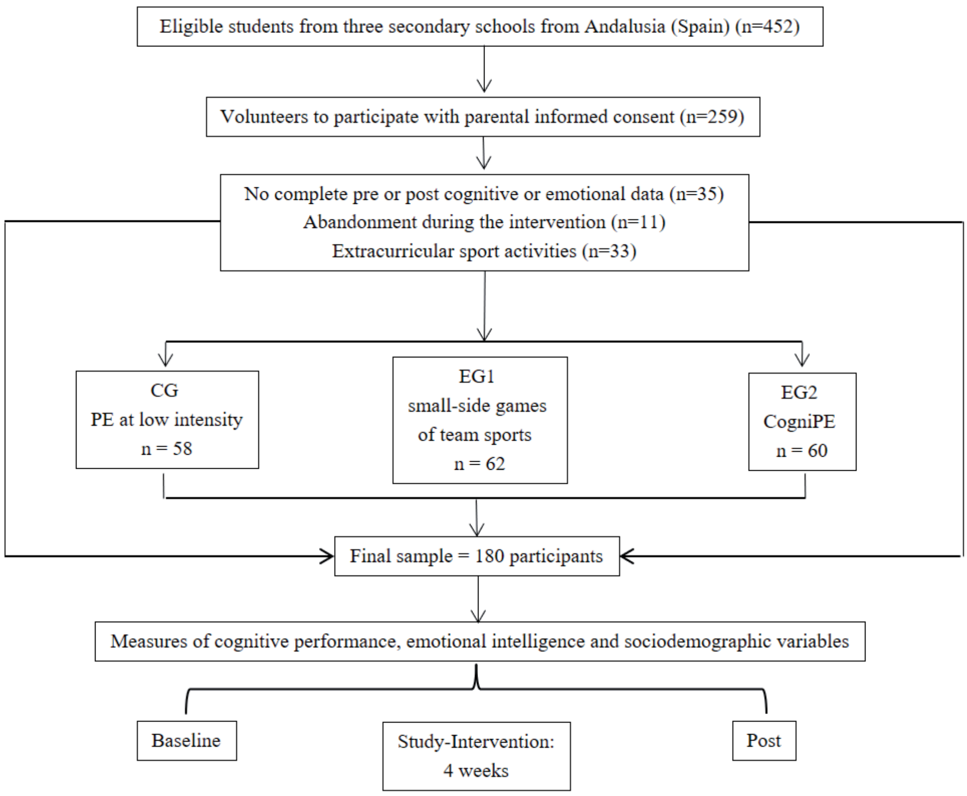

Figure 1. Study flow. CG = control group; EG = experimental group.

Measures

Cognitive performance

Memory

To assess memory, an 1-minute *ad hoc* test was used, from the original ideas of Wechsler (1945) and Tombaugh (1996), and from the memory test included in the Spanish adaptation of the RIAS test (Santamaría-Fernández & Fernández-Pinto, 2013). A poster of 15 Spanish playing cards, randomly selected, was projected for 20 seconds on a 3x2 metre screen. Immediately afterwards, the participants had 40 seconds to record, on a standardized sheet of paper, the largest number of remembered cards. The total number of correct answers (range 0–15) was counted. Before the test, it was verified that all the participants knew the structure and content of the 40 cards of the Spanish deck. This memory test has been previously used by Ruiz-Ariza et al. (2018). The reliability test–retest (48 h, n = 19) was 0.892.

Selective attention and concentration

Selective attention and concentration capacity were assessed under stress induced by a completion time using the Spanish version of Brickenkamp's d2 Test (Seisdedos, 2012). The d2 Test assesses performance in terms of visual perceptual speed and concentration capacities by assessing the individual's ability to selectively, quickly and accurately focus on certain relevant aspects in a task while ignoring other irrelevant aspects. The complete duration of the test is four minutes and 40 seconds. Selective attention capacity was calculated using the following formula:

[number of processed elements – (omissions + mistakes)].

In addition, the concentration was calculated with:

(number of hits – number of mistakes).

The reliability test–retest (48 h, n = 19) was 0.800.

Mathematical calculation

To analyse mathematical calculation an *ad hoc* test was used. This test was based on previous studies, such as the test by Passolunghi and Siegel (2004), who checked the processing capacity, speed and resolution of mathematical operations. This test included two groups of additions and subtractions with six digits (i.e., 8 – 6 + 5 + 8 – 6 = 9). Participants had one minute to perform as many operations as possible, and the total number of hits was counted. This test has been previously used by Ruiz-Ariza et al. (2018). Test–retest reliability (48 h, n = 19) was 0.851.

Linguistic reasoning

To evaluate the reading speed and semantic comprehension of participants (linguistic reasoning), an *ad hoc* test was developed based on Lervåg and Aukrust (2010), and the Neale Analysis of Reading Ability [NARA test]. The test showed 30 rows of four words each. In each row of words, three belonged to the same semantic field, whereas the fourth had no relation to the others (e.g., car, dog, motorbike, lorry). The order of these was randomly established. For a minute, the students had to cross out the highest number of words that had no relation to the others (intruder words). The total number of correctly crossed out words was counted. This test has been previously used by Ruiz-Ariza et al. (2018). The reliability test–retest (48 h, n = 19) was 0.865.

Emotional intelligence

To assess EI, this study used the Trait and Emotional Intelligence Questionnaire Short Form (TEIQue-SF) designed by Petrides (2009). This version has been used in the Spanish context with an internal consistency of alpha = 0.82 (Cejudo, Díaz, Losada & Pérez-González, 2016). The TEIQue-SF is composed of 30 items with seven possible responses to each statement, ranging from *completely disagree* = 1 to *completely agree* = 7. This test assesses four factors: 1) well-being: 5, 20, 9, 24, 12, and 27, e.g., *On the whole, I'm pleased with my life*; 2) self-control: 4, 19, 7, 22, 15, and 30, e.g., *I'm usually able to find ways to control my emotions when I want to*; 3) emotionality: 1, 16, 2, 17, 8, 23, 13, and 28, e.g. *I often find it difficult to show my affection to those close to me*; and 4) sociability: 6, 21, 10, 25, 11 and 26, e.g., *I would describe myself as a good negotiator*. Items 3, 18, 14 and 29 contribute only to the global average trait EI score (data not shown). The results obtained in this questionnaire rendered Cronbach's alpha coefficients of 0.89, 0.82, 0.78, and 0.74, respectively. The total alpha was 0.83. The reliability test–retest (48 h, n = 21) in items showed high results (Rho = 0.791 and Rho = 0.888 for the lowest and highest respectively, all $p<.001$).

Intervention

The duration of sessions was 50 minutes (5 min of warm-up + 40 min of main part + 5 min of final part), two sessions a week during PE classes, over four weeks (eight sessions in total). The CG carried out individual physical exercises at low intensity (40%: ≤ 90 bpm), i.e., stretching, sensory games and Pilates (Jago, Jonker, Missaghian & Baranowski, 2006; Ruiz-Ariza et al., 2019). The EG1 performed small-sided games of team sports, i.e., indoor football, handball, basketball or hockey (Cooper, et al., 2018; Kubesch, et al., 2009). The class was split into four groups of 6−8 students, each group was in a station carrying out a reduced version of a team sport, i.e., usual small-sided basketball match 3 vs 3 or 4 vs 4. Each group had to rotate towards their right after 10 minutes of playing the respective sports game. The EG2 performed CogniPE based on group physical tasks enriched with specific cognitive demand, e.g., players holding hands must find all the right resolutions of arithmetic tasks among different numeric cards on the floor. The tasks were offered by the teacher in several boxes with different colours and numbers. Before the resolution, players had to jump several obstacles and first travel a distance of 10 metres. An example of a CogniPE session can be observed in Table 2. In addition, each team was scored according to their intensity (%HR max) and their scores in each exercise. Participants wore heart rate monitors (Seego Realtracksystems® [Spain]) to motivate the exercise intensity. Each participant from the EGs had a prize for the intensity during the exercise, e.g., for the intensity of between 60% (≈120 bpm) and 80% (≈160 bpm) of HRmax, during at least the 80% of total session, three points were awarded (Ardoy, et al., 2014; Martínez-López, et al., 2018; Ruiz-Ariza, et al., 2019). These points and the points achieved after the CogniPE sessions were summed in a final classification. The CogniPE sessions were delivered by PE teachers specialised in this research method. Data from 33 students were not included due to the fact that they practised extracurricular sport activities.

Confounders

Age and BMI were controlled. This last measure was calculated as weight/height (kg/m^2). An ASIMED® B-type-class III (Spain) and a portable height measure SECA® 214 (Germany) were used, respectively. Both measurements were performed on barefoot individuals dressed in light clothing. Maternal educational level was classified into one of four categories (1 = No studies, 2 = Primary school, 3 = Secondary school, 4 = University). The daily study time was recorded by an item that requested the number of minutes of study during the extracurricular period on each day of the week. For the final measure, the average of seven days of the week was obtained. Finally, the Adolescent Physical Activity Measure questionnaire was used to know the weekly MVPA (Prochaska, Sallis, & Long, 2001). Two items were used to assess MVPA: at least 1-h a day in the previous week and a typical week. The response scale was the same for both items: 1 = no days, 2 = one day, 3 = two days, 4 = three days, 5 = four days, 6 = five days, 7 = six days, and 8 = seven days. A mean of the responses to both items was used. Similar to previous studies (Martínez-López, et al., 2015), internal consistency of PA items was high (Cronbach's alpha = .828).

Procedure

The participants' CP and EI were measured at two time points during the first school hour in the morning in the groups: at baseline and after four weeks. Previously, at the beginning of the data collection, a signed written consent was obtained from the participants' parents. Pre- and post-tests were performed in the usual classroom with individual desks. During the pretest, a sociodemographic sheet was also completed. All tests were paper-and-pencil tests and were group-administered. During testing, one specialised researcher gave instructions and kept track of time, while two research assistants each observed the possible

Table 2. Description of an example session of CogniPE. Work at each station has a duration of 10 minutes

	CogniPE session
Station 1	Players holding hands must find all the right resolutions of arithmetic tasks among different numeric cards on the floor. The tasks are offered by the teacher in several boxes with different colours and numbers. Before the resolution, players must jump over several obstacles and run a distance of 10 metres. The winner will be the team with more correct resolutions at the end of the game.
Station 2	With shuttle-run displacements, players must solve cognitive tasks (puzzles, tangrams, guess-the-hidden image). Each team can choose the task and the winner would be the team with the most completed tasks at the end of the game. They have the pieces in a side and take them to the resolution zone, 10 metres away. Just one piece for displacement. They need to place the pieces as fast as possible.
Station 3	Each team has a t-shirt with a different number (1, 2, or 3). They must pass the ball between them. Passes between t-shirt number 1 and 2, will be summed. Passes with '3', are multiplied by this number. When a team achieves 50 points, they will gain a point. The winner will be the team with the most points at the end of the game.
Station 4	Rows of four words each on the floor, covered with a cone. In each row of words, three belong to the same semantic field while the fourth has no relation to the others (e.g. red, green, orange, knife). For the game, the players have to run towards the rows (10 metres), pick up one cone, and look for the word that has no relation with the others (intruder word). In each displacement, players can only discover one cone. They must memorise the words and communicate it to their colleagues. When they discover all the words, they must agree on the intruder word, and write it on a sheet of paper. The total number of correctly answered rows will be counted at the end of the game. The winner will be the team with the most points at the end of the game.

doubts and any possible disturbances (e.g., noise outside the classroom, confused students, mistakes in some sheet copies, or students having an empty pen). To ensure the adequate PE teachers' behaviour and students' engagement in learning, it is very important to carry out the specific instruction targeted at the teacher involved (Derri, Vasiliadou, & Kioumourtzoglou, 2015). Following the above, to perform the programme in PE classes, each PE teacher was instructed about the CogniPE programme two times per week, for four weeks. A one-day training programme was provided before the start of the intervention by the researchers who developed the programme. This study was approved by the Bioethics Committee of the University of Jaén (Spain), reference CEIH211015. The design complies with the Spanish regulations for clinical research in humans (*Law 14/2007, July 3rd, Biomedical Research*), with the regulations for private data protection (*Organic Law 15/1999*), and with the principles of the *Declaration of Helsinki* (2013 version, Brasil).

Data analysis

The comparison of the continuous and categorical variables according to participation in programmes was carried out through one-factor analysis of variance (ANOVA) and Chi^2, respectively. Homoscedasticity and normality of the distribution of variables was tested by the Levenne and Kolmogorov-Smirnov tests, respectively (all cases p>.05). To study the relationship between variables, Spearman's correlation was used. The repeated measures analysis of covariance (ANCOVA) 3 Group (CG, EG1, EG2) x 2 Time (pre, post) was used to analyse the effects of this intervention. All CP and EI measures were used as dependent variables, the group was used as the fixed factor, and age, BMI, maternal education, daily study time and MVPA as confounders. *Post-hoc* analysis was adjusted according to Bonferroni. Analyses were carried out separately for each dependent variable. When there were differences between the groups at the beginning of the study, the pre-measure was included as a covariate. The effect size was computed and reported as a partial η^2 value for the ANOVA evaluations. To quantify the magnitude of changes between and within the groups in the dependent variables, we calculated the effect sizes Cohen's d. A Cohen's d value ≥ 0.8 indicates a large effect size, a Cohen's d value ≥ 0.5 < 0.8 indicates a medium effect size, and a Cohen's d value ≥ 0.2 < 0.5 indicates a small effect size (Cohen, 1998). For all the analyses, a 95% confidence level was used (p<.05). The percentage of change between the groups after the intervention was calculated as:

[(corresponding EG post-measurement – CG post-measurement) / CG post-measurement] x 100.

The analyses were completed using the statistical software package SPSS (v.22 for Windows).

Results

Descriptive analysis of variables and intensity of the programmes during the application

Table 1 shows the sociometric, cognitive and emotional values of participants. Participants spent 2.61 ± 1.47 hours in front of a computer at home, carried out a mean of 3.23 ± 1.67 days/week of MVPA and studied daily 65 ± 41 min. The participants memorised 3.98 ± 2.32 words/min, carried out 6.71 ± 2.42 mathematical operations/min and associated 20.12 ± 5.21 words/min. Only 34% of their mothers had undergone university studies. Within EI, the well-being factor got the highest score (4.18 ± 0.74, range: 1−7). Only the self-control factor showed differences between the groups (p=.019) at the beginning of the study. No initial differences were found between the CG and experimental groups in other socio-anthropometric, cognitive or emotional measures (all p>.05). On the other hand, the average intensity during the application of the programmes was different in each group (heart rate = 101.9 bmp, 147.4 bmp and 137.8 bmp for CG, EG1 and EG2, respectively).

Bivariate analysis between anthropometric, sociodemographic and cognitive−emotional measures

Table 3 shows the results of Spearman's correlation between variables. Age was positively related to BMI (Rho = 0.250, p<.05) and attention (Rho = 0.236, p<.05). Girls demonstrated higher attention (Rho = 0.213, p<.05) and daily studying time (Rho = 0.334, p<.05). Mothers with a higher educational level were related to children with higher concentration, mathematical calculation and linguistic reasoning (Rho = 0.329 for the highest, p<.01). Attention and concentration were highly correlated (Rho = 0.969, p<.001) and, at the same time, both were associated with mathematical calculation and linguistic reasoning (Rho = 0.509, p<.05 for the highest). Well-being was positively associated with linguistic reasoning (Rho = 0.2012, p<.05), and negatively with BMI (Rho = 0.283, p<.01), whereas emotionality was negatively associated with memory (Rho = -0.249, p<.05). Finally, sociability was positively related to self-control and emotionality (Rho = 0.350, p<.01 for the highest).

ANCOVA analysis of the effect of the intervention on cognitive performance and emotional intelligence variables

Figures 2, 3 and 4 show the results of ANCOVA analysis when each cognitive and EI measure was used as the dependent variable, the group (CG, EG1,

Table 3. Bivariate correlation of Spearman between the studied variables (n = 180)

	1	2	3	4	5	6	7	8	9	10	11	12	13
1. Age	1												
2. BMI	.250*	1											
3. Maternal education	-.098	.109	1										
4. Daily study time	-.127	.334**	.039	1									
5. MVPA	-.096	-051	.150	-.052	1								
6. Memory	.016	-.165	-.060	.004	-.102	1							
7. Atenttion	.236*	.213*	.037	.128	.099	.184	1						
8. Concentration	.193	.198	.019	.163	.121	.169	.969**	1					
9. Math calculation	.043	.117	.014	.329**	.183	.243*	.361**	.345**	1				
10. Linguistic reasoning	.164	.118	-.156	.236*	.163	.260*	.458**	.467**	.509**	1			
11. Well-being	.140	.083	-.283**	.009	.220*	-.015	.181	.191	.028	.212*	1		
12. Self-control	.080	-.107	.007	.006	.097	-.091	-.193	-.162	-.194	-.074	-.026	1	
13. Emotionality	-.085	-.072	-.084	.058	-.058	-.249*	-.058	-.017	.083	.005	.108	.385**	1
14. Sociability	-.032	-.021	-.012	.263*	.278*	-.148	-.195	-.207	.092	-.072	.158	.307**	.350**

Note. **Correlation is significant at level 0.01 (bilateral). *Correlation is significant at level <0.05 (bilateral). BMI = body mass index. MVPA = moderate to vigorous physical activity.

EG2) as fixed, and age, BMI, maternal education level, daily study time and MVPA as confounders. The interest analysis in memory (Figure 4A) showed a main time effect (p=.012) but not main group effect nor interaction between time and study groups (all p>.05). Results in selective attention (Figure 4B) showed a main time effect (p<.001), a main group effect F(1,177) = 5.024, p=.008, *partial* η^2 = 0.054, *1-β* = 0.810 and an interaction group x time effect near to significance F(2,177) = 2.752, p=0.066, *partial* η^2 = 0.030, *1-β* = 0.538. After 8 sessions, GE1 and GE2 increased selective attention (Pre: 142.0 ± 35.25 vs Post: 159.47 ± 33.62, p=.012; and Pre: 140.33 ± 35.71 vs Post: 168.48 ± 41.64, p<.001, respectively). Additionally, selective attention improved by 11.9% in EG1 and by 18.2% in EG2 compared to CG (EG1: 159.47 ± 33.62 vs CG: 142.52 ± 39.16, p=.023, *Cohen's d* = 0.464 and EG2: 168.48 ± 41.64 vs. CG: 142.52 ± 39.16, p<.001, *Cohen's d* = 0.644, respectively). Finally, concentration (Figure 4C) showed a main time effect (p<.001) and a main group effect F(1,177) = 4.391, p=.014, *partial* η^2 = 0.047, *1-β* = 0.75. After 8 sessions, concentration improved by 9.2% in EG1 and by 14.4% in EG2 compared to CG (EG1: 147.01 ± 36.03 vs CG: 134.57 ± 45.03, p=.036, *Cohen's d* = 0.305 and EG2: 154.38 ± 39.36 vs. CG: 134.57 ± 45.03, p<.007, *Cohen's d* = 0.468, respectively).

Data on mathematical calculation (Figure 3A) showed a main group effect F(1,177) = 4.149, p=.017, *partial* η^2 = 0.045, *1-β* =0.727 and an interaction group x time effect near to significance F(1,177) = 2.764, p=.066, *partial* η^2 = 0.030, *1-β* = 0.540. After 8 sessions, EG1 and EG2 increased mathematical calculation (Pre: 6.97 ± 2.20 vs Post: 7.72 ± 2.51, p=.011; and Pre: 6.78 ± 2.23 vs. Post: 7.91

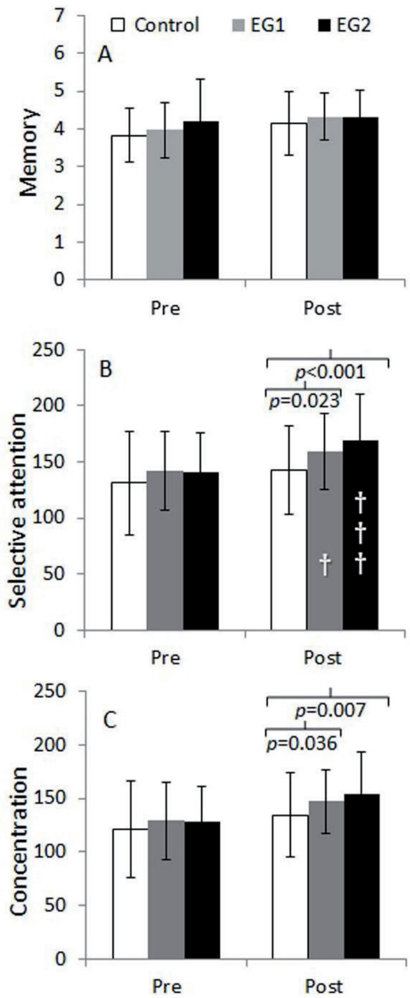

Figure 2. ANCOVA analysis in memory, selective attention, and concentration after 8-session physical activity programmes in adolescents. Data expressed as mean and SD. EG1 = small-sided games of team sports; EG2 = CogniPE programme. † and ††† denote p<.05 and p<.001, respectively, compared to pre-measure in the same group.

± 2.15, p<.001, respectively). Additionally, mathematical calculation improved by 15.9% in EG1 and by 18.7% in EG2 regarding to CG (EG1: 7.72 ± 2.51 vs. CG: 6.66 ± 2.10, p=.009, *Cohen's d* = 0.458; and EG2: 7.91 ± 2.15 vs. CG: 6.66 ± 2.10, p<.001, *Cohen's d* = 0.588, respectively). Results in linguistic reasoning did not show any main or interaction effect (all p>.05, Figure 3B).

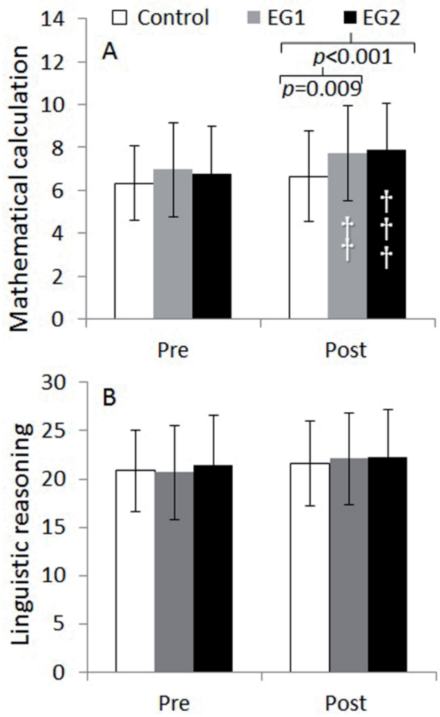

Figure 3. ANCOVA analysis in mathematical calculation and linguistic reasoning after 8-session physical activity programmes in adolescents. Data expressed as mean and SD. EG1 = small-sided games of team sports; EG2 = CogniPE programme. †† and ††† denote p<.01 and p<.001, respectively, compared to pre-measure in the same group.

Results in EI are shown in Figure 4. Well-being showed a main time effect (p=.022), and main group effect F(1,177) = 4.826, p=.009, *partial* η^2 = 0.052, *1-β* = 0.794. After 8 sessions, EG1 increased in well-being by 10.9% compared to CG (EG1: 4.55 ± 0.60 vs CG: 4.10 ± 0.61, p<.001, *Cohen's d* = 0.743). Data about sociability showed a main time effect (p=.001), main group effect F(1,177) = 4.414, p=.013, *partial* η^2 = 0.048, *1-β* = 0.755, and a group x time interaction F(1,177) = 7.898, p=.001, *partial* η^2 = 0.082, *1-β* = 0.951. After 8 sessions, sociability improved in EG1 (Post: 4.40 ± 0.80 vs. Pre; 4.05 ± 0.78, p=.005) and in EG2 (Post: 4.52 ± 0.94 vs. Pre: 4.05 ± 0.78, p<.001). Additionally, the EG1 improved by 12.8% and the EG2 by 15.9% in sociability regarding to CG (EG1: 4.40 ± 0.80 vs. CG: 3.90 ± 0.62, p=.005, *Cohen's d* = 0.741; and EG2: 4.52 ± 0.94 vs. CG: 3.90 ± 0.62, p<.001, *Cohen's d* = 0.778, respectively). Results in self-control (Figure 4B) and emotionality (Figure 4C) did not show any main nor interaction effect (all p>.05).

Discussion and conclusions

This study analysed the effect of four weeks of two programmes of PE (team sports and CogniPE) on the CP and EI of Spanish adolescents aged between 13 and 16 years. Main results have shown that the selective attention, concentration and math-

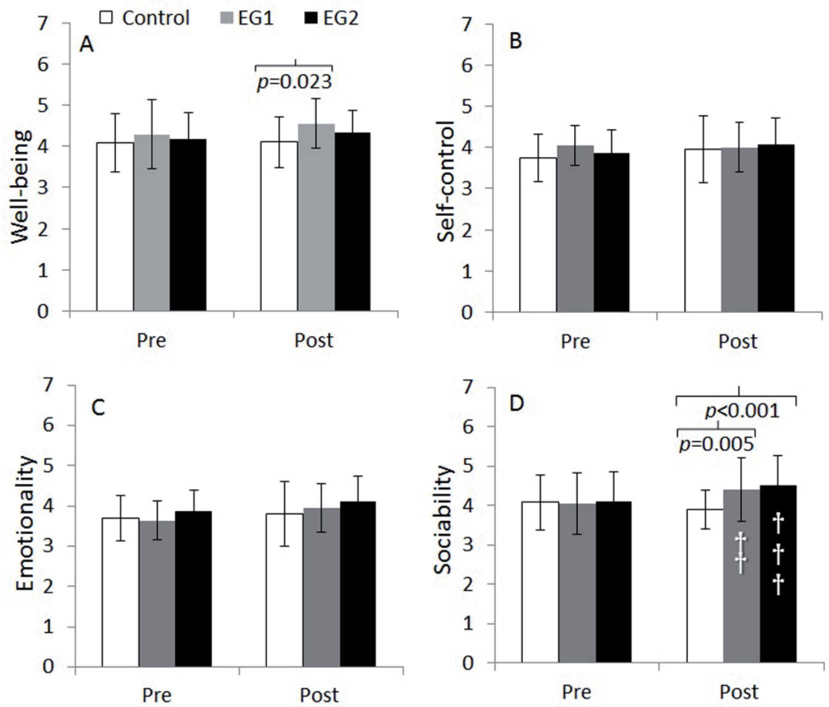

Figure 4. ANCOVA analysis in emotional intelligence after 8-session physical activity programmes in adolescents. Data expressed as mean and SD. EG1 = small-sided games of team sports; EG2 = CogniPE programme. †† and ††† denote p<.01 and p<.001, respectively, compared to pre-measure in the same group.

ematical calculation improved after eight sessions of small-sided games of team sports. Furthermore, when the programme was based on CogniPE, the percentage of improvement was larger. With regard to IE, it has been proven that well-being expresses significant improvements after small-sided games of team sports. Sociability shows improvement after both interventions, being higher in the CogniPE group. No negative effects have been observed and no injury occurred during the programmes.

The results of this study show that selective attention and concentration increased by 11.9% and 9.2%, respectively, in small-sided games of team sports, and 18.2% and 14.4% in CogniPE, relative to CG. These findings confirm, in part, the authors' previous hypothesis and are similar to the study by Martínez-López et al. (2018), in which a monitored intervention of 16 minutes of C-HIIT during 12 weeks at the beginning of PE classes showed positive effects on attention or concentration. It has also been found that the maintenance of on-task attention in the face of distraction was improved by an aerobic endurance exercise-based 30 min PE programme, but not by a short aerobic movement break of 5-min in 13-14-year-old German students (Kubesch, et al., 2009). This suggests that a duration of between 16 and 30 minutes is decisive for improving students' attention. Moreover, more specifically, some authors have confirmed that interventions mixing PA and cognitive contents improve sustained attention (Donnelly & Lambourne, 2011). In line with our results, the studies conducted by Schmidt (2015 and 2016), found that cognitive variables of attention and speed processing improved to a greater extent in the cognitive demand group after just three weeks of intervention. Pesce et al. (2013) and Crova et al. (2014) also support the above hypothesis and showed that the receptive attention and inhibition improved in the long term way after both 6-month interventions with cognitively enriched PA versus non-cognitively enriched PA, in 5-10-year-old children and in 9-10-year-old overweight children, respectively. In adolescents, Benzing et al. (2016) showed a positive relationship between PA with higher cognitive demand and executive functions after 15 minutes of intervention. In this regard, we found that the CogniPE group showed better improvements in attention than the small-sided games group compared to the CG (+6.3%) and concentration (+5.2%). These results show that PA with cognitive engagement could be the most interesting approach in benefiting CP in children. However, contrary to the above conclusions, Gallotta et al. (2012) reported that children's attention was lower in the condition that mixed cognitive and physical exertion. Furthermore, Egger, Conzelmann & Schmidt (2018) found deteriorative effects on children's executive functions after applying 20 min of physically and cognitively challenging PA. Even Jäger et al. (2015) found no main effect for PA nor for cognitive engagement conditions. Despite our positive results, the controversy in the literature questions whether physical exertion, cognitive engagement or both in combination are most beneficial for children's attention-concentration, and more interventional studies with an exhaustive control of variables are necessary.

On the other hand, the mathematical calculation improved by 15.9% in small-sided games of team sports and 18.7% in CogniPE compared to CG after four weeks of intervention. Other studies, such as the one carried out by Martínez-López et al. (2018), showed that the C-HIIT applied in PE classes produced improvement in mathematical calculation, above all in inactive adolescents (Martínez-López, et al., 2018). This could show that the simple PA stimuli could be enough to positively affect maths variables. More specifically, when the programme is mixed with physically active lessons of 20-30 min/day x 2-3 days/week x 21-22 weeks, it increased mathematical scores (Mullender-Wijnsma, et al., 2016). This is similar to our results, which showed that both PA through small-sided games of team sports and CogniPE programmes can develop maths aspects in young people, although to a greater extent in the latter one (+2.8%). Similar to the above, Beck et al. (2016), investigated whether an intervention of 60 min/day x 3 days/week x 6 weeks of fine or gross motor activity integrated into maths lessons could improve mathematical performance. Three groups were included: a CG, which received non-motor enriched conventional mathematical teaching, and two EGs, which received mathematical teaching enriched with fine and gross motor activity, respectively. All groups improved their mathematical performance, but in line with our findings, the improvement was significantly greater in the gross motor maths group compared to the fine one. The gross motor group performed inter-limb movements, and static-dynamic movements involving a large range of movement (e.g., skipping, throwing, crawling, one-legged balance). In a similar way to our CogniPE proposal, the gross motor movements were performed while solving maths problems during the lessons (Beck, et al., 2016). Therefore, based on all these evidence, combining PA and maths content during PE classes could improve the mathematical performance of young people.

As regards the EI, the well-being factor improved by 10.9% compared to CG after eight sessions of small-sided games of team sports. In addition, sociability improved after both interventions, with small-sided games of team sports improved by 12.8% and with CogniPE by 15.9% compared to CG. Compared with other studies, for example 16 minutes of C-HIIT in PE classes also improved well-being and sociability in adolescents (Ruiz-Ariza, et al., 2019). These authors attribute justifiably these results to enjoyment and social contact during the games. Our findings are also similar to those obtained by Costigan et al. (2016), who showed a positive chronic effect on psychological well-being among adolescents after a programme of 8-10 minutes of high intensity (>85%), with a work-to-rest ratio of 30:30 seconds, 3 sessions/week, during two months. Other studies have also found a specific association between moderate intensity PA and well-being (Ruiz-Ariza, de la Torre-Cruz, Redecillas-Peiró, & Martínez-López, 2015) or sociability (Ruiz-Ariza, et al., 2018) in adolescents. And Azevedo, Burges-Watson, Haighton & Adams (2014) found a positive significant effect of a dynamic 12-month follow-up dance intervention on psychological well-being, which increased positive emotions and socio-emotional balance. Thus, playing small-sided games could have an intrinsic positive motivation that improves well-being. For its part, thinking while playing could decrease the enjoyment during the practice, with worse results in well-being, however the social contact in solving some of the cognitive tasks during the exercise could have the most effects on sociability.

Some of the mentioned effects could be explained through several mechanisms. The assumption of cognitive stimulation hypothesis is that coordinative demanding and non-automated sport-related activities activate the same brain regions that are used to control higher-order cognitive processes (Best, 2010; Schmidt, et al., 2015). Based on the theoretical assumption of shared information processes in both motor and cognitive control, this hypothesis explains intervention effects in terms of the specific activation of these processes during PA, which promotes cognitive benefits (Schmidt, et al., 2015). In addition, connecting information deriving from two different sources might have resulted in a greater cognitive load in the PA enriched with cognitive demand than in the team sport condition, for example, thinking in solving maths tasks is probably more cognitively challenging than simply playing team sports (Schmidt, et al., 2019). Also, doing an activity of running towards different numbers according to a mathematical problem result requires the ability to discriminate between different responses, reaction to visual stimuli, and appropriate motor decisions making. In this sense, physical and cognitive tasks involve exactly the same cognitive processes in a single exercise (Schmidt, et al., 2015). As another explanation, children's level of cognitive exertion can be linked to mental effort (Chen, Castro-Alonso, Paas & Sweller, 2017). Hence, the multimodal information arising from the external learning environment of movement requires greater attention and concentration, resulting in a substantial depletion of children's attentional resources, even if they are not aware of the additional mental effort they are investing (Schmidt, et al., 2019). The great effect found for cognitive intervention could also be related to the embodied cognition and the cognitive load theory. The use of learning processes during body movements can transform abstract information into concrete and tangible concepts (Mavilidi, et al., 2018). The sensorimotor experiences in the embodied learning condition allow incoming information to be processed simultaneously through different systems (Schmidt, et al., 2019). From the perspective of cognitive load theory, this way of information processing is associated with a relative expansion of the available processing capacity, enrichment of the resulting cognitive schema, and consequently better learning performance (Mavilidi, et al., 2018). In this sense, it is argued that embodying knowledge through motor actions contributes to the construction of higher-quality mental representations, facilitating recall, and enhancing memory and learning (Madan & Singhal, 2012).

Although the results of the present study did not find an effect of CogniPE intervention on memory, linguistic reasoning, self-control and emotionability, the majority of studies show that memory increases after exercise (Budde, et al., 2008). For example, a current chronic study shows that six weeks of a PA programme resulted in improvements in working memory (Moreau, Kirk, & Waldie, 2017). Sjöwall, Hertz, and Klingberg (2017) found in a 2-year school-based intervention in preadolescent children (ages 6-13) that the increase in the number of weekly PE classes (aimed at increasing cardiorespiratory fitness) from 2 to 5 days per week did not affect working memory. With regard to linguistic reasoning, in agreement with the present study's data, Ardoy et al. (2014) did not find any effect on the verbal reasoning factor. However, a current systematic review showed that 60% of studies found beneficial effects on linguistic skills (Carson, et al. 2016). More specifically, a long-term programme based on 20-30 min/day x 2-3 days/week x 21-22 weeks, did not increase language performance (Mullender-Wijnsma, et al., 2016). However, Barnard, Van Deventer, and Oswald (2014) analysed the role of active teaching programmes in linguistic skills over eight weeks using two conditions: 1) an integrated academic skills and physical development programme; and 2) a moderately intensive PA programme. The results indicated that both programmes showed progress in language. Therefore, the above disagreement shows the need to continue studying the effects of other specific programmes on these variables.

Furthemore, during CogniPE we noticed that it was rather difficult for some participants to continuously play and think at a recommended intensity. In fact, the average intensity during the application of the programmes was different in each group. The heart rate for CG was 101.9 bmp, 147.4 bmp for EG1 and 137.8 bmp for EG2. This difference between EGs could be due to the stimuli in EG2 requiring participants to think during the exercise, and maybe they paused their PA for some seconds during the execution of cognitive tasks. The intensity level and duration of stimuli vary widely across the studies, with heart rates ranging from 120 (Budde, et al., 2008) to 160 bpm (Best, 2010) and activity durations ranging from 10 (Budde, et al., 2008) to 50 min (Gallotta, et al., 2012). For example, Cooper et al. (2018) showed in their intervention of 60 min games-based activity (basketball) that participants' heart rate was 158±11 bpm. This intensity was higher than in our EG2, maybe for the same continued stimuli during 60 min without changes or breaks. Also, although it was indicated that none of the participants carried out extracurricular PA during the weeks of the study, this was measured with a self-report measurement (MVPA questionnaire). Finally, positively influencing a participant's enjoyment could be relevant for CP‒EI, since changes in positive affect have been previously found to mediate the relationship between cognitive-engaging activities and children's attention (Schmidt, et al., 2016), interpreted as being additional support for mood being a facilitator for cognitive processing.

It is concluded that a 4-week programme of CogniPE improves attention, concentration and mathematical calculation, besides increasing variables of emotional intelligence, such as sociability in young people. It is suggested that PE teaching units integrating CogniPE promote cognitive and emotional aspects in children. Additional intervention studies are required to learn more details of the acute effects of including cognitive content in PE, as well as influencing other important variables of physical and academic performance.

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COMPETITIVE ANXIETY IN ATHLETES: EMOTION REGULATION AND PERSONALITY MATTER

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Abstract:

Competitive anxiety is an important issue in sport psychology since it is capable of influencing athletes' performance. This study aims to examine the role of emotion regulation and personality in explaining individual differences in competitive anxiety of athletes, considering their sex and sport modality. A total of 101 athletes (50.5% males), aged between 18 and 69 years (M = 26.22; SD = 0.99), were included in this cross-sectional study. They filled out self-report scales on emotion regulation, personality, and competitive anxiety. Multiple regressions were used to analyze the data. Results partially supported our hypotheses. While sex differences were found in competitive anxiety, with women experiencing higher cognitive and somatic anxiety and lower self-confidence in comparison to men, no differences were found according to sport modality. Additionally, cognitive reappraisal was significantly associated with self-confidence, whereas neuroticism and extroversion were significantly associated with competitive anxiety dimensions.

Key words: *emotion regulation, personality, competitive anxiety*

Introduction

Competitive anxiety (CA) can be defined as "a tendency to perceive competitive situations as threatening and to respond to these situations with feelings of apprehension and tension" (Martens, Vealey, & Burton, 1990, p. 23). CA is an important issue in sport because it has been linked to athletic performance (e.g., disrupted attention, sleep patterns and appetite disorders, and increased fatigue) (e.g., Khan, Khan, Khan, & Khan, 2017; Neil, Wilson, Mellalieu, Hanton, & Taylor, 2012). Indeed, CA can affect not only the athletes' physiological functioning by impacting body functions (e.g., muscles shaking, fast heartbeat), but also their psychological functioning by impacting their feelings and perceptions, something that can negatively influence their performance (Khan, et al., 2017). CA has been linked not only to performance but also to other important outcomes such as reduced enjoyment, discontinuation of sport participation, and injury vulnerability (Grossbard, Smith, Smoll, & Cumming, 2009).

For this reason, it is important to examine what factors are responsible for individual differences in CA in athletes. Three dimensions of CA have been widely studied in the field of sports psychology, and researchers have developed various measures to assess each dimension separately or in combination. One of the most used measures is the Competitive State Anxiety Inventory-2 (CSAI-2), which includes three dimensions: cognitive anxiety, somatic anxiety, and self-confidence (Cox, Martens, & Russell, 2003; Martens, et al., 1990; Woodman & Hardy, 2003). Cognitive anxiety "refers to negative self-evaluations and self-doubts about an athlete's ability to perform", being characterized by worry and negative thoughts related to one's performance; somatic anxiety "refers to athlete's perception of physiological elements of anxiety, such as muscle tension and increased heart rate", being characterized by physical symptoms of anxiety (Lundqvist & Hassmén, 2005, p. 727), and self-confidence that refers to athlete's belief in his/her ability to be successful, being characterized by positive thoughts and feelings related to one's performance.

Several variables have been identified as potential explanations for individual differences in CA levels. These variables encompass a range of factors, including demographic characteristics and psychological factors. In terms of sociodemographic variables, in a recent review (Rocha & Osório, 2018), it was found that sex and sport modality contributed to the explanation of individual differences in CA among athletes. More specifically, women tended to experience higher levels of anxiety in comparison to men; the same pattern was found for athletes who practiced individual sports and tended to experience higher levels of anxiety in comparison to athletes who practiced team sports (Rocha & Osório, 2018). However, in some studies no differences have been found or differences in the opposite direction have been reported (e.g., Fernandes, Nunes, Vasconcelos-Raposo, & Fernandes, 2013; Modronno & Guillen, 2011). Thus, it is important to continue to explore sex and sport modality differences in CA levels. Moreover, previous studies found gender and type of sport were important factors affecting personality and CA (Kemarat, Theanthong, Yeemin, & Suwankan, 2022; Patsiaouras, Chatzidimitriou, Charitonidis, Giota, & Kokaridas, 2017) as well as emotion regulation and CA (Bardeen & Stevens, 2015). Thus, it is important to understand how these factors interact when explaining individual differences in CA levels.

In terms of psychosocial variables, emotion regulation and personality emerge as important dimensions, among others (e.g., cognitive bias, self-confidence, hardiness, coping, motivation) (Mellalieu, Hanton, & Fletcher, 2009). Indeed, competitive sports create a wide range of emotions, both positive and negative (Martinent, Ledos, Ferrand, Campo, & Nicolas, 2015; McCarthy, 2011). However, researchers have focused their attention on negative emotions because they can have a detrimental effect on athletes' performance and engagement (e.g., Hanin, 2007; Martinent, et al., 2015). For this reason, emotion regulation (ER) plays a central role within the sport context. ER refers to individuals' attempts to control the type of emotions they experience, their timing, and expression (Gross, 2015; McRae & Gross, 2020). While ER is often deliberate, it can also occur outside of conscious awareness and it can target one's own emotions (i.e., intrinsic regulation) or someone else's emotions (i.e., extrinsic regulation) (McRae & Gross, 2020).

According to the process model of emotion regulation proposed by Gross (2015), individuals may regulate their emotions at five temporal points of the emotion generative process: situation selection, situation modification, attentional deployment, cognitive change, and response modulation. The first four points involve antecedent-focused strategies aiming at changing the way individuals think about the stimuli/event to change its emotional impact (e.g., cognitive reappraisal) and the last one involves response-focused strategies (e.g., expressive suppression) aiming at changing the behavioral expression of emotions (Gross, 2015). Indeed, these two strategies, cognitive reappraisal and expressive suppression, have been the most studied strategies of ER. While cognitive reappraisal has been linked to positive outcomes, expressive suppression has been linked to more negative outcomes (e.g., Butler, et al., 2003; Dryman & Heimberg, 2018; Moore, Zoellner, & Mollenholt, 2008). Yet, it is now recognized that the consequences linked to these ER strategies can varied if used in a flexible way or according to different contexts (e.g, Bonanno & Burton, 2013).

In the context of sport, ER has been linked to sport enjoyment (Tamminen, Gaudreau, McEwen, & Crocker, 2016), athletes' mental health – with cognitive reappraisal being positively and suppression negatively linked to mental health (Bird, Quinton, & Cumming, 2021), and greater experience of pleasant emotions (Uphill, Lane, & Jones, 2012). In a recent study, Kim and Tamminen (2022) found that when athletes used more cognitive reappraisal and less expressive suppression to regulate their emotions, they experienced more favorable sports outcomes such as pleasant emotions, confidence, satisfaction, lower emotional loneliness, and higher social connection. Molina, Oriol, & Mendoza (2018) also found that cognitive reappraisal was positively associated with positive affect, self-efficacy, and physical recovery, while expressive suppression was negatively linked to these sport-related outcomes. However, no studies have focused their attention on how ER contribute to the explanation of individual differences in CA among athletes, and on how ER interacts with sex and sport modality in this context. In fact, studies that examine sex differences in ER show that women are likely to experience higher levels of anxiety due to poor ER clarity, while men are likely to experience lower levels of anxiety due to higher perceived ER clarity (e.g., Bardeen & Stevens, 2015). Also, according to Nolen-Hoeksema (2012), cultural norms encourage males to suppress their emotions, while females are generally perceived as being more emotional (Barrett & Bliss-Moreau, 2009). Furthermore, women are typically considered to be superior in recognizing emotions and utilizing emotion-related information.

Another important psychological factor is personality. It can be defined as "the enduring configuration of characteristics and behavior that comprises an individual's unique adjustment to life, including major traits, interests, drives, values, self-concept, abilities, and emotional patterns" (VandenBos, 2015, p. 782). One of the most acceptable models of personality is the Big-Five model proposed by Costa and McCrae (1992) due to its empirical support (has consistently demonstrated its validity and reliability across cultures and demographics), comprehensiveness (covers a broad range of personality traits and dimensions), and predictive power (has been shown to predict a range of outcomes, as detailed below) (Bainbridge, Ludeke, & Smillie, 2022; Soto & John, 2017). According to this model, personality can be described using five dimensions: extroversion, agreeableness, conscientiousness, emotional stability (or neuroticism), and openness. Extroversion is characterized by higher levels of sociability, energy, and assertiveness; agreeableness is characterized by cooperation and kindness, warmth, sympathy and honesty; conscientiousness is characterized by orderliness, responsibility, reliability, hard work, and discipline; neuroticism (the opposite of emotional stability) is characterized by insecurity, susceptibility to suggestion, lack of persistence against obstacles, feeling of inferiority or nervousness; and, finally, openness is characterized by openness to experiences, creativity, curiosity, and ingenuity (John, Naumann, & Soto, 2008; Larsen & Buss, 2009).

These personality traits have been associated with a wide range of psychological outcomes. For instance, low extroversion, high neuroticism, and low conscientiousness were associated with an increased risk of depressive symptoms (Hakulinen, et al., 2015). High neuroticism, low conscientiousness, and low agreeableness were found to be risk factors for parental burnout (Le Vigouroux, Scola, Raes, Mikolajczak, & Roskam, 2017). Other studies showed that personality was linked to relationship satisfaction, emotion regulation, quality of life, among others (e.g., Pocnet, Dupuis, Congard, & Jopp, 2017; Vater & Schroder-Abé, 2015).

Also, personality seems to influence several sport-related outcomes. For example, in a previous study with university athletes, it was found that high agreeableness, high conscientiousness, and high openness were significant predictors of athletes' performance (Habib, Waris, & Afzal, 2020). Also, Zhang et al. (2019) found that low neuroticism and high agreeableness, conscientiousness, and extraversion were associated with more self-control and self-efficacy among male and female boxers. Other studies showed the influence of personality traits in preparation strategies, coping strategies during competitions, relationship with teammates and coaches (see Allen & Laborde, 2014, and Roberts & Woodmann, 2017, for more details).

In terms of personality influence on CA, the research is scarce. A recent study (Kemarat, et al., 2022) found that among the five personality dimensions, neuroticism was the only one to have a significant effect on CA, being associated with higher levels of CA. When the subsamples were analyzed separately, it was found that agreeableness had also a positive effect on CA among athletes of team sports (only). In one study conducted only with males, it was found that high neuroticism was associated with higher levels of competitive anxiety and physiological arousal. However, this association was only significant in the experimental group, in which anxiety was manipulated by means of an incentive (Balyan, Tok, Tatar, Binboga, & Balyan, 2016). Indeed, some studies found that gender and type of sport were important dimensions in shaping personality and competitive anxiety (Kemarat, et al., 2022; Patsiaouras, et al., 2017), thus they deserve more attention.

The present study

The aims of this study were twofold: to examine differences in competitive anxiety according to sex and sport modality, and to examine the role of emotion regulation and personality in explaining individual differences in competitive anxiety, considering the sex and sport modality.

We hypothesized that (H1) women would present higher cognitive and somatic anxiety and less self-confidence in comparison to men; (H2) athletes from individual sports would experience higher cognitive and somatic anxiety and less self-confidence in comparison to athletes from team sport (Rocha & Osório, 2018). Additionally, we hypothesized (H3) that cognitive reappraisal would be associated with less cognitive and somatic anxiety and with more self-confidence, while expressive suppression would be associated with more cognitive and somatic anxiety and less self-confidence (e.g., Bird, et al., 2021; Kim & Tamminen, 2022; Tamminen, et al., 2016). Also, (H4) athletes with higher levels of neuroticism would present more cognitive and somatic anxiety and less self-confidence (e.g., Balyan, et al., 2016; Kemarat, et al., 2022).

Methods

Recruitment

An online calculator was used to estimate the sample size needed (https://www.danielsoper.com/statcalc/default.aspx). Given the number of predictors in each regression model (from four to seven), to achieve 80% of power (with a significance level of $\alpha = .05$) and a medium effect size (d = .015; Cohen, 1988), the minimum required sample size ranged between 74 and 93.

Inclusion criteria were the following: (1) being an athlete – this means that the participant must engage in some form of sports activity; (2) have more than 18 years – this means that the participant must be 18 years old or older; (3) involved in practicing a team or individual sport – this means that the participant must be involved in either a team sport or an individual sport that involves competition with other individuals. The selection of participants was based on the personal contacts of the first author, who is also an athlete, and for that reason had personal connections within the athletic community.

Measures and instruments

Sociodemographic questionnaire – used to collect data regarding sex, age, sport modality (individual or team sport), type of sport, number of hours per week of practicing sport.

Competitive anxiety was measured with the Competitive State Anxiety Inventory – 2 (CSAI-2), developed by Martens et al. (1990) and validated to the Portuguese population by Cruz et al. (2006). The CSAI-2 has 27 items divided by three dimensions: cognitive anxiety (9 items; item example: "*I'm concerned that others will be disappointed with my performance*"), somatic anxiety (9 items; item example: "*I feel tense in my stomach*"), and self-confidence (9 items; item example: "*I'm confident I can meet the challenge*"). Items were rated on a four-point scale ranging from 1 (not at all) to 4 (very much so). Cronbach's alpha (values above 0.6 were considered reliable and acceptable index; Nunnally & Bernstein, 1994) in this study was .90 for cognitive anxiety, .89 for somatic anxiety, and .77 for self-confidence.

Personality was measured using the Ten-Item Personality Inventory (TIPI) developed by Gosling, Rentfrow, and Swann (2003) and validated to the Portuguese population by Nunes, Limpo, Lima, and Castro (2018). The TIPI has 10 items with two items measuring each of the Big-Five personality dimensions. Items were rated on a seven-point scale ranging from 1 (strongly disagree) to 7 (strongly agree). Cronbach's alphas obtained in this study were similar to the original English version (range .48 - .68) and to the Portuguese translated version (range .39 - .72), ranging from .35 to .71. Despite the low-to-moderate Cronbach's alphas (something usually found in shorter scales), the TIPI is considered a reliable measure due to their temporal stability and convergence with longer measures (Nunes, et al., 2018).

Emotion regulation was measured using the Emotion Regulation Questionnaire (ERQ), developed by John and Gross (2003) and validated to the Portuguese population by Vaz (2009). The ERQ has 10 items and contains two dimensions: expressive suppression (4 items; item example "*I keep my emotions to myself*"), and cognitive reappraisal (6 items; item example "*When I want to feel less negative emotion (such as sadness or anger), I change what I'm thinking about*"). Items were rated on a seven-point scale ranging from 1 (strongly disagree) to 7 (strongly agree). Cronbach's alpha in this study was .71 for expressive suppression and .66 for cognitive reappraisal.

Procedure

This study was approved by the Ethics Committee from CIP – Universidade Autónoma de Lisboa Luís de Camões (Reference number: 12-2021). Data were collected via an online platform (i.e., Google Forms). Data collection for the study began during the COVID-19 pandemic when competitions were suspended. As a result, an initial pool of participants (n = 34; 33.7%) were asked to recall a specific and noteworthy competition they had participated in within the preceding weeks/ months. Once competitions resumed, the remaining participants completed the questionnaire after a competition had taken place.

The study was shared in social networks of sports clubs that were contacted for the purpose of this study. Informed consent was presented on the first page and was obtained from all participants. Confidentiality and voluntariness were ensured.

Data analysis

The data were organized in the following order: descriptive results of participants, differential analysis, correlations, and, finally, linear regressions. Descriptive statistics (mean, standard deviations – SD, and frequencies) were used to summarize the participants' characteristics, including mean age, sex distribution, and sport modality. Differential analyses were performed by multivariate analysis of variance (MANOVA). A MANOVA was used due to significant correlations found between the three dimensions of competitive anxiety scale – cognitive anxiety, somatic anxiety, and self-confidence (that ranged between $r = -.54$ and $r = .68$). Wilks' Lambda (Λ) was used to test whether there were differences between the variable means according to sex or sport modality. The partial eta-squared η^2 was used as the effect size. This effect size was interpreted following these guidelines: $\eta^2 = 0.01$ indicated a small effect; $\eta^2 = 0.06$ indicated a medium effect; $\eta^2 = 0.14$ indicated a large effect (Cohen, 1973).

Pearson correlations were used to assess the strength and direction of the linear relationships between the variables in the study. Finally, a multiple regression was conducted to assess the predictive relationship between the variables. Two hierarchical regressions (following a two-block strategy with enter method) were used to examine the role of personality and emotion regulation (block one included sex and modality; block two included emotion regulation dimensions/ personality dimensions). Sex and modality were turned into dummy variables to be included in correlations and regression analyzes.

Assumption checking was conducted to ensure that the regression analysis was appropriate. First, in terms of linearity, scatter plots revealed linear relationships between the dependent variables and each independent variable. Second, in terms of normality, the Q-Q plots and histograms of the residuals showed a relatively normal distribution. Additionally, skewness and kurtosis z-values were below 3.29 suggesting data normality (for medium-sized samples [50 < n < 300]; Kim, 2013) (except one dimension of personality – agreeableness that presented a skewness z-value of 4.53). Third, in terms of multicollinearity, the correlation matrix showed no correlation coefficients between the independent variables, suggesting that the assumption of no multicollinearity was met. Additionally, the VIF values were below 2, further confirming that multicollinearity was not a major concern in the analyses.

To assess regression quality, we used the coefficient of determination R-squared (together with the other variables in a statistical model). It measures how well a statistical model predicts an outcome since it represents the proportion of variance in the dependent variables that is explained by the independent variables. It ranges from 0 to 100%, with a higher value indicating a stronger relationship between the independent and dependent variables. For all analyses, the significance level was set as a p-value less than 0.05. Data were analyzed using SPSS (version 28).

Results

Participants

A total of 101 Portuguese athletes (50.5% males) participated in this study. In terms of age, 69.3% (*n* = 70) were between 18 and 25 years old, 22%. (*n* = 22) between 26 and 40 years, and 8.7% (*n* = 9) were between 41 and 69 years (*M* age = 26.22; *SD* = .99).

Sixty of the participants practiced team sports and 41 practiced individual sports. Their sport experience was, on average, ±9.96 years (SD = .58) and they practiced, on average, 8.6 hours per week (*SD* = .49). Most had a national competitive experience (Tier 3: Highly Trained/National Level) with five athletes having experience in international competitions (Tier 4: Elite/International Level; according to the classification proposed by McKay, et al., 2022).

The main individual sports included: swimming (n = 7; 6.9%), athletics (n = 6; 5.9%), and combat sports (n = 5; 5%); and the main team sports were: volleyball (n = 21; 20.8%), handball (n = 13; 12.9%), rugby (n = 8; 7.9%), football (n = 7; 6.9%) and roller hockey (n = 7; 6.9%).

Descriptive analyses

Descriptive statistics for the whole sample and according to sex and sport modality are presented in Table 1.

Table 1. Descriptive statistics for the whole sample and according to sex and sport modality

Sex	Modality		ES	CR	CA	SA	SC	Ext	Amability	Cons	Emo S	Open
Men	Individual	M	3.73	4.99	2.03	1.92	2.83	5.48	5.91	5.61	4.43	5.65
		N	23	23	23	23	23	23	23	23	23	23
		SD	1.22	.89	.67	.48	.53	1.43	.98	1.16	1.44	1.21
	Team	M	4.35	5.07	2.27	1.79	2.95	4.54	5.96	5.63	3.96	5.16
		N	28	28	28	28	28	28	28	28	28	28
		SD	1.16	.94	.75	.34	.44	1.50	.84	1.02	.94	.81
	Total	M	4.07	5.03	2.16	1.85	2.90	4.96	5.94	5.62	4.18	5.38
		N	51	51	51	51	51	51	51	51	51	51
		SD	1.21	.91	.72	.41	.48	1.53	.90	1.08	1.20	1.03
Women	Individual	M	3.94	4.88	2.50	2.36	2.47	4.92	5.83	5.75	3.78	5.44
		N	18	18	18	18	18	18	18	18	18	18
		SD	1.15	.86	.65	.54	.51	1.68	.92	1.23	1.09	1.03
	Team	M	3.95	4.63	2.73	2.07	2.57	4.97	6.09	5.50	3.97	5.48
		N	32	32	32	32	32	32	32	32	32	32
		SD	1.32	.80	.65	.56	.42	1.51	.92	1.19	1.16	1.30
	Total	M	3.95	4.72	2.65	2.18	2.53	4.95	6.00	5.59	3.90	5.47
		N	50	50	50	50	50	50	50	50	50	50
		SD	1.25	.82	.654	.56	.45	1.56	.92	1.20	1.12	1.20
Total	Individual	M	3.82	4.94	2.24	2.11	2.67	5.23	5.88	5.67	4.15	5.56
		N	41	41	41	41	41	41	41	41	41	41
		SD	1.18	.87	.70	.54	.54	1.55	.95	1.18	1.32	1.12
	Team	M	4.13	4.83	2.52	1.94	2.74	4.77	6.03	5.56	3.97	5.33
		N	60	60	60	60	60	60	60	60	60	60
		SD	1.25	.89	.73	.49	.46	1.51	.88	1.11	1.05	1.103
	Total	M	4.01	4.89	2.40	2.01	2.71	4.96	5.97	5.60	4.04	5.43
		N	101	101	101	101	101	101	101	101	101	101
		SD	1.23	.88	.73	.52	.50	1.53	.91	1.13	1.17	1.11

Note. M = mean; N = number of participants; SD = standard deviation; ES = expressive suppression; CR = cognitive reappraisal; CA = cognitive anxiety; AS = somatic anxiety; SC = self-confidence; Ext = extroversion; Consc = consciousness; Emo S = emotional stability; Open = openness.

Differential analyses

For sex, multivariate tests indicated significant differences (Λ [3,97] = 6.64, p<.001, η^2 = *.17*). Tests of between-subjects effects showed significant medium-large differences for the three dimensions, specifically for cognitive anxiety (*F* [1,99] = 12.66, p<.001, η^2 = .11), for somatic anxiety (*F* [1,99] = 11.43, p=.001; η^2 = .10) and for self-confidence (*F* [1,99] = 15.71, p<.001, η^2 = .14). Women presented more cognitive (*M* = 2.65; *SD* = .65) and more somatic anxiety (*M* = 2.18; *SD* = .56) than men (*M* = 2.16; *SD* = .72; *M* = 1.85; *SD* = .41), respectively. On the contrary, men (*M* = 2.90; *SD* = .48) presented more self-confidence than women (*M* = 2.53; *SD* = .45).

For sport modality, multivariate tests indicated significant differences (Λ [3,97] = 8.50, p<.001, η^2 *= .21)* but tests of between-subjects effects showed small effects with no significant differences in any of the three dimensions (cognitive anxiety: *F* [1,99] = 3.76, p=.055, η^2 = .04; somatic anxiety; *F* [1,99] = 2.76, p=.100, η^2 = .03; self-confidence: *F* [1,99] = .48, p =.489, η^2 = .01).

For ER multivariate tests indicated no differences nor according to sex (Λ [2,98] = 1.66, p=.195, η^2 *= .03)* neither according to sport modality (Λ [2,98] = 1.09, p=.339, η^2 = .02). Also, for personality multivariate tests indicated no differences nor according to sex (Λ [5,95] = .36, p=.877, η^2 = .02) neither according to sport modality (Λ [5,95] = .67, p=.646, η^2 = .03).

Correlations analyses

Correlations among the study variables are presented in Table 2. We found that sex was positively associated with cognitive (*r* = .34, p<.01) and somatic anxiety (*r* = .32, p<.01) and negatively associated with self-confidence (*r* = -.39, p<.01) (positive = being women; negative = being men). Modality was not significantly associated with any study variable. Cognitive reappraisal was positively associated with self-confidence (*r* = .24, p<.05) and consciousness (*r* = .20, p<.01), and expressive suppression was negatively associated with extroversion (*r* = -.37, p<.01), consciousness (*r* = -.28, p<.01), and openness (*r* = -.20, p<.01).

Extroversion was negatively associated with somatic anxiety (*r* = -.26, p<.01) and positively associated with self-confidence (*r* = .32, p<.01). Consciousness was positively associated with self-confidence (*r* = .21, p<.05). Emotional stability was negatively associated with cognitive (*r* = -.54, p<.01) and somatic anxiety (*r* = -.48, p<.01) and positively associated with self-confidence (*r* = .44, p<.01).

Regression analyses

Regression results are presented in Table 3 (for emotion regulation variables) and Table 4 (for personality variables). Regression models explained a significant portion of the variance in competitive anxiety subscales. The entry of emotion regulation subscales in step 2 of the regression model (Table 3) did not show a relevant contribution, since emotion regulation only explained the 15% of the cognitive anxiety variance, the 15% of the somatic anxiety variance and the 21% of the self-confidence variance. Only cognitive reappraisal was associated with higher levels of self-confidence, controlling for sex and sport modality.

The entry of personality dimensions in step 2 (Table 4) explained 39% of the cognitive anxiety variance, 40% of the somatic anxiety variance, and 39% of the self-confidence variance. Those with higher levels of emotional stability tended to experience higher levels of cognitive and somatic anxiety and lower levels of self-confidence. And those with higher levels of extroversion tended to experience lower levels of somatic anxiety, controlling for sex and sport modality.

Table 2. Correlations among the study variables (N = 101)

	Sex	Mod	CR	ES	Cog_A	Som_A	SC	Extr	Agree	Cons	ES
Mod	.093	-									
CR	-.179	-.062	-								
ES	-.051	.125	.135	-							
Cog_A	.343**	.180	-.097	.105	-						
Som_A	.322**	-.165	-.077	.044	.681**	-					
SC	-.385**	.059	.237*	-.101	-.621**	-.538**	-				
Extr	-.004	-.150	.015	-.374**	-.195	-.256**	.315**	-			
Agree	.033	.085	.173	.063	.056	-.020	-.032	-.021	-		
Cons	-.012	-.049	.197*	-.281**	-.021	.024	.241*	.367**	.106	-	
ES	-.119	-.076	.098	-.107	-.541**	-.478**	.441**	.284**	-.079	.061	-
Open	.040	-.101	.141	-.196*	-.055	-.044	.129	.388**	.199*	.242*	.147

Note. **p<.01; * p<.05; Mod = modality; Cog_A = cognitive anxiety; Som_A = somatic anxiety; SC = self-confidence. Extr = extroversion; Agree = agreeableness; Cons = conscientiousness; ES = emotional stability; Open = openness.

Table 3. Hierarchical multiple regression analyses for emotion regulation variables predicting competitive anxiety levels

		Cognitive Anxiety		**Somatic Anxiety**		**Self-confidence**	
	Variables	B	B	B	B	B	B
Step 1	Sex	**.32****		**.34****		**-.38*****	
	Modality	.16		**-.20***		.11	
Step 2	Sex		**.32****		**.34****		**-.35*****
	Modality		.14		-.21*		.14
	Cognitive reappraisal		-.05		-.04		.21*
	Expressive suppression		.11		.09		-.17
	Adj R^2	.14	.15	.14	.15	.15	.21
F for change in R^2		7.92 .001	.76 .472	8.09 .001	.52 .599	8.50 .000	3.75 .027
Effect size (f^2)			0.01		0.01		0.08

Note. *p<.05; **p<.01; ***p<.001.

Table 4. Hierarchical multiple regression analyses for personality variables predicting competitive anxiety levels

		Cognitive Anxiety		**Somatic Anxiety**		**Self-confidence**	
	Variables	B	B	B	B	B	B
Step 1	Sex	**.33****		**.34****		**-.39*****	
	Modality	.15		**-.20***		.10	
Step 2	Sex		**.27****		**.30****		**-.36*****
	Modality		.11		**-.24****		.16
	Extroversion		-.06		**-.24***		.18
	Agreeableness		-.01		-.07		-.02
	Conscientiousness		.03		.12		.16
	Emotional stability		**-.49*****		**-.41*****		**.35*****
	Openness		-.04		.06		.00
	Adj R^2	.14	.39	.14	.40	.16	.39
F for change in R^2		7.96 .001	7.55 .000	8.09 .001	7.88 .000	9.13 .000	7.28 .000
Effect size (f^2)			0.41		0.43		0.38

Note. *p<.05; **p<.01; ***p<.001.

Discussion and conclusions

The purpose of this study was to investigate how emotion regulation and personality traits influence individual variations in CA among athletes, while considering their sex and sport modality. Given that CA can significantly impact athletes' performance (e.g., in terms of passing decision-making or attack/post defense attack; Costa, Fernandes, Silva, & Batista, 2019; Fortes, et al., 2018), gaining a better understanding of its underlying factors is crucial. Overall, our results showed that women tended to present more cognitive and somatic anxiety, while men tended to present more self-confidence. Additionally, cognitive reappraisal contributed to explain levels of self-confidence and personality dimensions contributed to the explanation of somatic anxiety and self-confidence, considering the sex and the sport modality of athletes.

The first aim of this study was to explore the differences in CA according to sex and sport modality. While H1 (i.e., women would present higher cognitive and somatic anxiety and less self-confidence in comparison to men) was confirmed with women presenting higher cognitive and somatic anxiety and men presenting higher self-confidence. However, H2 (i.e., athletes from individual sports would experience higher cognitive and somatic anxiety and less self-confidence in comparison to athletes from team sport) was not confirmed since no differences were found on competitive dimensions according to sport modality. As expected, women experienced higher levels of cognitive and somatic anxiety, while men experienced higher levels of self-confidence (Criticos, Layne, Simonton, & Irwin, 2020; Kemarat, et al., 2022; Rocha & Osório, 2018). However, it is important to note that men may underestimate their levels of anxiety and overestimate their self-confidence due to sex-related stereotypes that consider anxiety as a weakness and thus men should not experience it (e.g., Dias, Cruz, & Fonseca, 2020). Also, some authors (Rocha & Osório, 2018) highlight the role of neurology when explaining sex differences in anxiety since women tend to experience more oscillations in gonadal hormones levels, which may increase their vulnerability to stress and anxiety, in comparison to men (e.g., Kundakovic & Rocks, 2022). Other factors, however, may contribute to the explanation of these differences. Women, in comparison to men, tend to focus more on the risk of failure rather than on achieving success; they are more susceptible to pressures from sport environments and are more susceptible to external stimuli (Morris & Kavussanu, 2009; Rocha & Osório, 2018; Souza, Teixeira, & Lobato, 2012; Stefanello, 1990). Additionally, women are more likely to have poor ER clarity in comparison to men, which can contribute to increasing their levels of anxiety (e.g., Bardeen & Stevens, 2015).

In terms of differences according to sport modality, our results were not in accordance with the literature (H2 not confirmed). While most of the studies showed that athletes from individual modalities tended to experience higher levels of CA (Correia & Rosado, 2019; Kemarat, et al., 2022; Patel, Omar, & Terry, 2010; Ramis, Viladrich, Sousa, & Jannes, 2015; Rocha & Osório, 2018), we did not find that in our study since no differences were found according to sport modality in athletes' CA. We would expect that athletes from individual sport modalities would experience higher CA because their performance and responsibility for achieving the desired results depend only on them, and athletes from team sports would experience lower anxiety since the responsibility for achieving the desired results is shared with the other team members (e.g., Dias, et al., 2020; Rocha & Osório, 2018). However, we did not find differences.

In one study (Fernandes, et al., 2013), it was found that athletes from individual modalities experienced less cognitive anxiety (because they would have more control in what they were doing during the competition) and no differences were found for somatic anxiety and self-confidence. As emphasized by some authors (Fernandes, et al., 2013; Pluhar, et al., 2019), it is possible that other variables, such as relationship with the trainer or good trainer/athlete communication, may play a major role in explaining individual differences in CA.

Our results partially confirmed our H3 saying that cognitive reappraisal would be associated with less cognitive and somatic anxiety and with more self-confidence, while expressive suppression would be associated with more cognitive and somatic anxiety and less self-confidence. Only cognitive reappraisal had a positive effect on self-confidence, a result that was found in a previous study (Molina, et al. 2018). Because cognitive reappraisal is a strategy that allows changing the meaning of an event or situation, it would be expected that it would contribute to increase athletes' self-confidence during competitions (Lane, Beedie, Jones, Uphill, & Devonport, 2012; Oriol, Molina, DaCosta, & Páez, 2015). Also, it is possible to hypothesize that cognitive reappraisal is not linked to cognitive and somatic anxiety because cognitive reappraisal is usually linked to more positive emotions within sport contexts (e.g., Uphill, et al., 2012).

Expressive suppression, however, was not linked to CA. While previous studies have found that expressive suppression contributes to reducing athletes' capacities for reducing emotional intensity triggering symptoms of cognitive or somatic anxiety (Molina, et al., 2018) and even resulting in physical costs (e.g., blocks and muscular tension, difficulties in physical recovery and injuries; Mankad & Gordon 2010; Wagstaff, 2014), we did not find this pattern of association in this study. Expressive suppression was not linked to CA. More studies are needed to better understand the role of expressive suppression, since some studies have shown that expressive suppression is not always linked to adaptational costs (especially when used in a flexible way; Bonanno & Burton, 2013) and can even be associated with better performance in some contexts.

Finally, our H4 saying athletes with higher levels of neuroticism would present more cognitive and somatic anxiety and less self-confidence, was also partially confirmed. As found in a previous study (Balyan, et al., 2016), neuroticism (the opposite of emotional stability) was associated with higher levels of cognitive and somatic anxiety and lower levels of self-confidence. According to personality theories, it possibly hypothesizes that athletes with elevated levels of neuroticism would be more emotionally reactive being more vulnerable to experiencing anxiety symptoms and, in this specific case, CA. Also, they tend to present excessive worry and ordinary situations as threatening (Widiger & Oltmanns, 2017), something that can contribute to increased CA.

Limitations and future research

Some limitations of this study must be noted. First, this is a cross-sectional study that relies only on self-report measures. Thus, causality cannot be inferred, and results are susceptible to biases. Future studies should collect data over time and should use other type of information (e.g., physiological measures). Additionally, a portion of the participants were requested to recall a significant competition they had participated in within the preceding weeks/months. Consequently, retrospective data have the potential to be influenced by memory failures and can pose certain limitations. However, it should be noted that evaluating CA retrospectively is a method utilized in previous studies (e.g., Harger & Raglin, 1994; Lundqvist & Hassmén, 2005). Additionally, the CA scale was used online which can also add some bias to our results.

Also, this study is limited by the wide age range of our participants, spanning from 18 to 69 years old. Due to the heterogeneity of the age groups, we were unable to investigate potential age-related differences in CA. However, age may be a relevant variable in explaining such differences, and future research should aim to explore this aspect in greater detail.

Finally, the internal consistency of the TIPI is small to moderate. While authors recognized that this is a characteristic of shorter scales, it is important to consider that results may be influenced by this issue.

Practical implications

Findings from this study can have several practical implications. Firstly, it can help psychologists, coaches, and trainers to develop tailored interventions and techniques to enhance athletes' emotion regulation skills to facilitate the management of their anxiety levels, namely by promoting the use of cognitive reappraisal to enhance self-confidence, especially in female athletes that are likely to present less self-confidence. This can ultimately improve their performance and increase their chances of success in competitive sports.

Secondly, understanding the personality traits that contribute to CA can assist in identifying athletes who may be more prone to experiencing anxiety in competitive situations. Such knowledge can help coaches and trainers in providing targeted support and interventions to help these athletes to better cope with anxiety, thus minimizing its negative impact on their performance (especially for athletes with elevated levels of neuroticism).

Finally, by considering the role of sex and sport discipline, this research can highlight potential sex or sport-specific strategies for managing CA in athletes. While no differences were found according to sport modality, women may be at greater risk for presenting higher CA. Thus, they may benefit more from this type of intervention.

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RELATIVE AGE EFFECT IN YOUNG COMPETITIVE TENNIS PLAYERS

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Abstract:

The purpose of this study was to examine the presence of the relative age effect (RAE) in young tennis players. Data from a sample of all ranked (n= 3463) and licensed (n= 29150) players in consecutive age groups (10- to 17-year-old) were collected from the official web page of the national federation. They were assigned to four quartiles according to the month of birth: a) Quartile 1 = January-February-March, b) Quartile 2 = April-May-June, c) Quartile 3 = July-August-September, d) Quartile 4 = October-November-December. The players aged between 10 and 17 years affiliated with the national federation were assigned as theoretically expected distribution. The results revealed that 70%, 60.1%, and 56.6% of the top 10, 50, and all ranked players were born in the first half of the year, respectively. However, the results from the chi-square test of goodness-of-fit showed significant RAEs only in the distributions of all ranked and top 50 players at the age of 10 and 11 correspondingly. These results may suggest that RAE exists among young tennis players who are in their early adolescence years.

Key words: *racket sports, talent identification, biological age, physical growth, maturation*

Introduction

Players born within the same calendar year are grouped together in tennis and the majority of the other sports (Ulbricht, Fernandez-Fernandez, Mendez-Villanueva, & Ferrauti, 2015). The term "relative age effects" (RAE) describes the physical and psychological differences among athletes of the same selection year that result from variations in their birthdates (Andronikos, Elumaro, Westbury, & Martindale, 2016). Studies in different sports have shown that, within the same selection year, young athletes born earlier in the year have a higher chance of being selected for elite teams and talent development programs compared to those born later in the year (Augste & Lames, 2011; Cobley, Baker, Wattie, & McKenna, 2009; Delorme & Raspaud, 2009; Fumarco, Gibbs, Jarvis, & Rossi, 2017; Gómez-López, Granero-Gallegos, Molina, & Ríos, 2017; Helsen, et al., 2012; Helsen, Van Winckel & Williams, 2005; Mujika, et al., 2009). This situation results from the inhomogeneous distribution of athletes' birthdates. It is a well-known phenomenon that athletes born at the beginning of the competition year are disproportionately represented, while the athletes born towards the end of the competition year are typically underrepresented (Gerdin, Hedberg, & Hageskog, 2018; Loffing, Schorer, & Cobley, 2010). A child that benefits from an edge in relative age is likely to be viewed as talented in his/her age group; therefore, it is possible for truly talented athletes to be overlooked, which may create discrimination against players who were born later (Delorme, Boiché, & Raspaud, 2010; Koloničný, Agricola, Bozděch, & Zháněl, 2021; Musch & Grondin, 2001). However, studies have also revealed that comparatively younger athletes do better in rotational sports or gymnastics (Maffulli, King, & Helms, 1994). This is known as a "reverse relative age effect," which means an advantage for late-maturing players compared to early and on-time maturers (Andronikos, et al., 2016).

Research has shown that being relatively older or younger in one's age group can have both physical and psychological effects on young athletes

(Edgar & O'Donoghue, 2005). There is a strong link, supported by numerous studies, between birthdate and the selection for teams or competitions in physically demanding sports (Augste & Lames, 2011; Delorme & Raspaud, 2009; Gerdin, et al., 2018; Helsen, et al., 2012; Mujika, et al., 2009). However, the phenomenon known as RAE is also present in sports that require less physical exertion, such as chess (Breznik & Law, 2016), indicating that RAE may be influenced more by experience, psychology, and social factors than previously thought. In sports such as tennis, where factors such as height, strength, speed, and power are key to success (Fernandez-Fernandez, Sanz-Rivas, & Mendez-Villanueva, 2009), older children tend to have an advantage and are often considered more talented, leading to their selection for elite teams (Baxter-Jones, 1995; Edgar & O'Donoghue, 2005). The phenomenon referred to as the Pygmalion effect, where individuals who lack exceptional skills are perceived as talented by coaches, selectors, and even themselves is frequently observed in the world of sports (Rejeski, Darracott, & Hutslar, 1979). This can lead to better opportunities for development and growth, but not necessarily due to actual talent (Edgar & O'Donoghue, 2005). As a result, relatively younger players may have to match the physical capabilities of older players to stay competitive and be selected for higher levels of talent development (Ulbricht, et al., 2015). It is important to note that this phenomenon can lead to discrimination against players who were born later and may be overlooked for development opportunities.

There has been a heightened focus on RAE in the last two decades, especially in youth sports (Cobley, et al., 2009; Helsen, et al., 2005; Musch & Grondin, 2001). In their bibliometric analysis conducted in 2020, Bilgiç and Işın (2022) showed that RAE was a popular topic to be studied in sports sciences, and more than 85% of the studies on RAE were published in the last ten years, whereas more than half of the studies were published in the last five years. Despite the growing interest in RAE, several studies investigated RAE in youth tennis. For example, in their research on Swedish junior tennis players, Gerdin et al. (2018) compared the birthdates of the Swedish population to ranked tennis players. They revealed that the higher a player's rank was, the greater RAE occurred. The top 10 players showed the greatest proportion (64.1%) of being born in the first two quarters of the year when compared to the top 50 and all ranked players. They also presented some gender differences. Compared to the boys, RAEs for girls born in the first half of the year were more prevalent in all comparisons (ranked, top 50, and top 10). In another study, Ulbricht et al. (2015) analyzed young German male tennis players in terms of RAE and physical fitness characteristics. In line with Gerdin et al. (2018), their results showed inhomogeneous birth distributions in young competitive tennis players and greater prevalence of RAE with the progression of competition levels. However, more research is still needed to analyze the RAE in tennis players. Thus, the purpose of the study was to investigate the presence of RAE in young male and female competitive tennis players.

In studies investigating RAEs, the most commonly used methods are the equal distribution of birth quartiles and overall population percentages since they are relatively straightforward and do not require specialized data or knowledge about the specific population being studied. This study is original in the sense that it used the percentages of licensed players as the theoretical expected distribution, which is more accurate and relevant. Additionally, using this method can help to control for external factors that may influence RAEs, such as social and cultural factors, as well as other variables such as training opportunities, access to resources, and coaching quality.

Methods

Data collection

The data of all Turkish tennis players (*N* = 73.369), including their birth date and rankings, were collected through the public website of the Turkish Tennis Federation (www.ttf.org.tr). The inclusion criteria for the subjects were being licensed players and being born between 1 January 2004 and 31 December 2011. Subsequently, a total of 29.150 (14.680 males, 14.470 females) licensed players were included as reference categories to conduct the study. Then, the ranked players (*N* = 3.463) were classified based on their 2021 year-end ranking according to each age group from 10- to 17-years-old. After allocation, the subjects were divided into two groups, boys and girls, and each gender group was assigned to one of the four quartiles according to the month of birth: a) Quartile 1 (Q1) = January-February-March, b) Quartile 2 (Q2) = April-May-June, c) Quartile 3 (Q3) = July-August-September, d) Quartile 4 (Q4) = October-November-December (Zháněl, Válek, Bozděch, & Agricola, 2022). The birth data of the general population was collected from the General Directorate of Civil Registration and Citizenship Affairs. The ethical approval was obtained from the Human Subjects Ethics Committee of the Middle East Technical University (0056-ODTUİAEK-2023).

Data analyses

A chi-square test of goodness-of-fit was performed to test the presence of RAE in Turkish tennis players for each gender separately. The players aged between 10-17 years, affiliated with the Turkish Tennis Federation, were assigned as theoretically expected distribution as previously suggested (Delorme & Raspaud, 2009). Following, the observed frequency of the top 10, top 50, and all ranked players of each age group and gender were evaluated accordingly to determine whether the observed and expected frequency were significantly different. All statistical analyses were performed using SPSS 28.0 (IBM, Chicago, Illinois, USA) and Microsoft Excel (Microsoft, Seattle, Washington, USA) and the level of alpha was set at .05.

Results

The results revealed that nearly 70%, 60%, and 57% of the top 10, 50, and all ranked players, respectively, were born in the first half of the year. The results from the chi-square test of goodness-of-fit when both the boys and girls were pooled are presented in Table 1. The distribution of the observed and expected frequency significantly differed in 10-year-old (all ranked) tennis players

Table 1. All gender

Age group	Rank	Q1 (%)	Q2 (%)	Q3 (%)	Q4 (%)	N	χ2	w	Group comparison
	Top 10	12 (60%)	4 (20%)	2 (10%)	2 (10%)	20			
	Top 50	38 (38%)	23 (23%)	24 (24%)	15 (15%)	100	7.32		
10	Ranked	122 (31.20%)	110 (28.13%)	93 (23.79%)	66 (16.88%)	391	**9.08***	0.15	Q1>Q2>Q3>Q4
	Licensed	653 (26.5%)	628 (25.49%)	662 (26.87%)	521 (21.14%)	2464			
	Population	312023 (24.91%)	293565 (23.43%)	348501 (27.82%)	298723 (23.84%)	1252812			
	Top 10	11 (55%)	7 (35%)	2 (10%)	0 (0%)	20			
	Top 50	41 (41%)	29 (29%)	17 (17%)	13 (13%)	100	**9.26***	0.30	Q1>Q2>Q3>Q4
11	Ranked	195 (32.23%)	168 (27.77%)	128 (21.16%)	114 (18.84%)	605	5.39		
	Licensed	929 (29.67%)	816 (26.06%)	777 (24.82%)	609 (19.45%)	3131			
	Population	318050 (25.22%)	312594 (24.79%)	337045 (26.72%)	293480 (23.27%)	1261169			
	Top 10	8 (40%)	6 (30%)	3 (15%)	3 (15%)	20			
	Top 50	36 (36%)	27 (27%)	22 (22%)	15 (15%)	100	3.80		
12	Ranked	187 (28.86%)	181 (27.93%)	154 (23.77%)	126 (19.44%)	648	0.42		
	Licensed	1031 (28.07%)	1011 (27.53%)	888 (24.18%)	743 (20.23%)	3673			
	Population	314240 (24.81%)	315062 (24.87%)	349213 (27.57%)	288236 (22.75) %	1266751			
	Top 10	4 (20%)	5 (25%)	10 (50%)	1 (5%)	20			
	Top 50	33 (33%)	23 (23%)	26 (26%)	18 (18%)	100	1.04		
13	Ranked	132 (26.61%)	125 (25.20%)	131 (26.41%)	108 (21.77%)	496	2.33		
	Licensed	1107 (28.51%)	985 (25.37%)	1044 (26.89%)	747 (19.24%)	3883			
	Population	331485 (25.59%)	319969 (24.70%)	354495 (27.36%)	289562 (22.35%)	1295511			
	Top 10	8 (40%)	9 (45%)	3 (15%)	0	20			
	Top 50	40 (40%)	24 (24%)	22 (22%)	14 (14%)	100	7.56		
14	Ranked	115 (29.64%)	101 (26.03%)	101 (26.03%)	71 (18.30%)	388	1.05		
	Licensed	1152 (28.19%)	1053 (25.76%)	1054 (25.79%)	828 (20.26%)	4087			
	Population	328010 (25.43%)	318637 (24.70%)	351548 (27.25%)	291797 (22.62%)	1289992			
	Top 10	4 (20%)	10 (50%)	3 (15%)	3 (15%)	20			
	Top 50	31 (31%)	29 (29%)	19 (19%)	21 (21%)	100	3.01		
15	Ranked	110 (30.73%)	95 (26.54%)	73 (20.39%)	80 (22.35%)	358	7.57		
	Licensed	1147 (28.20%)	1042 (25.61%)	1083 (26.62%)	796 (19.57%)	4068			
	Population	327594 (26.09%)	313543 (24.97%)	339553 (27.05%)	274742 (21.88%)	1255432			
	Top 10	3 (15%)	6 (30%)	6 (30%)	5 (25%)	20			
	Top 50	28 (28%)	24 (24%)	21 (21%)	27 (27%)	100	4.11		
16	Ranked	95 (29.32%)	83 (25.62%)	77 (23.77%)	69 (21.30%)	324	2.41		
	Licensed	1072 (26.59%)	1086 (26.93%)	1072 (26.59%)	802 (19.89%)	4032			
	Population	337074 827.10%)	312810 (25.14%)	325769 (26.19%)	268388 (21.57%)	1244041			
	Top 10	10 (50%)	5 (25%)	0	5 (25%)	20			
	Top 50	32 (32%)	23 (23%)	20 (20%)	25 (25%)	100	3.42		
17	Ranked	74 (29.25%)	66 (26.09%)	59 (23.32%)	54 (21.34%)	253	1.30		
	Licensed	1091 (28.62%)	956 (25.08%)	1006 (26.39%)	759 (19.91%)	3812			
	Population	336830 (27.55%)	308743 (25.26%)	320019 (26.18%)	256892 (21.01%)	1222484			

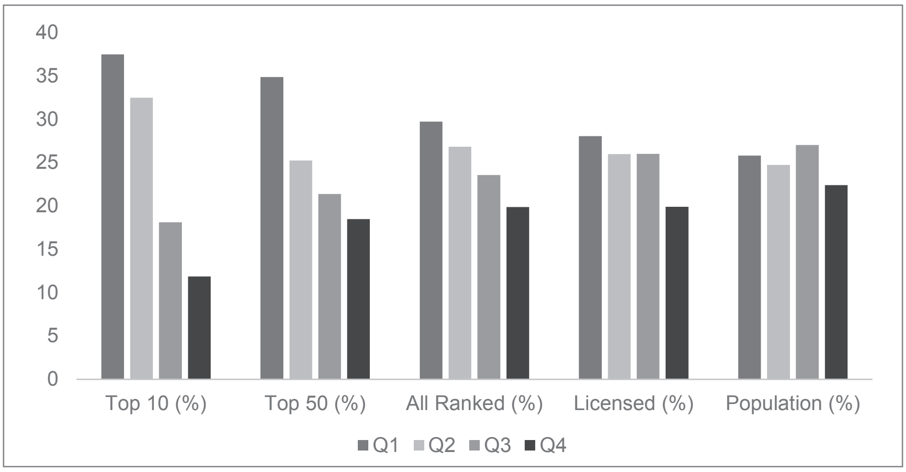

Figure 1. Birth distribution of all players.

Table 2. Comparison of the seasons of birth distribution in girls

Age group	Rank	Q1 (%)	Q2 (%)	Q3 (%)	Q4 (%)	N	χ2	w	Group comparison
10	Top 10	6 (60%)	2 (20%)	0	2 (20%)	10			
	Top 50	18 (36%)	10 (20%)	13 (26%)	9 (18%)	50	2.56		
	Ranked	47 (28.83%)	40 (24.54%)	48 (29.45%)	28 (17.18%)	163	1.08		
	Licensed	303 (26.19%)	287 (24.81%)	336 (29.04%)	231 (19.97%)	1157			
11	Top 10	6 (60%)	3 (30%)	1 (10%)	0	10			
	Top 50	24 (48%)	12 (24%)	10 (20%)	4 (8%)	50	**8.72***	0.4	Q1>Q2>Q3>Q4
	Ranked	100 (35.84%)	71 (25.45%)	63 (22.58%)	45 (16.13%)	279	4.4		
	Licensed	486 (30.62%)	405 (25.52%)	389 (24.51%)	307 (19.34%)	1587			
12	Top 10	6 (60%)	3 (30%)	0	1 (10%)	10			
	Top 50	16 (32%)	17 (34%)	8 (16%)	9 (18%)	50	2.69		
	Ranked	93 (30%)	92 (29.68%)	63 (20.32%)	62 (20%)	310	3.04		
	Licensed	496 (27.79%)	486 (27.23%)	426 (23.87%)	377 (21.12%)	1785			
13	Top 10	1 (10%)	3 (30%)	6 (60%)	0	10 (10%)			
	Top 50	17 (34%)	11 (22%)	15 (30%)	7 (14%)	50	1.96		
	Ranked	62 (29.95%)	50 (24.15%)	52 (25.12%)	43 (20.77%)	207	0.7		
	Licensed	555 (28.19%)	509 (25.85%)	518 (26.31%)	387 (19.65%)	1969			
14	Top 10	5 (50%)	4 (40%)	1 (10%)	0	10			
	Top 50	25 (50%)	12 (24%)	9 (18%)	4 (8%)	50	**12.58***	0.5	Q1>Q2>Q3>Q4
	Ranked	64 (36.57%)	41 (23.43%)	48 (27.43%)	22 (12.57%)	175	**8.33***	0.2	Q1>Q3>Q2>Q4
	Licensed	583 (28.72%)	520 (25.62%)	534 (26.31%)	393 (19.36%)	2030			
15	Top 10	2 (20%)	4 (40%)	3 (30%)	1 (10%)	10			
	Top 50	13 (26%)	12 (24%)	12 (24%)	13 (26%)	50	1.83		
	Ranked	50 (33.11%)	37 (24.50%)	31 (20.53%)	33 (21.85%)	151	4.1		
	Licensed	590 (28.82%)	531 (25.94%)	546 (26.67%)	380 (18.56%)	2047			
16	Top 10	1 (10%)	3 (30%)	5 (50%)	1 (10%)	10			
	Top 50	12 (24%)	14 (28%)	9 (18%)	15 (30%)	50	5.06		
	Ranked	42 (32.06%)	32 (24.43%)	30 (22.90%)	27 (20.61%)	131	2.95		
	Licensed	533 (26.68%)	519 (25.98%)	562 (28.13%)	384 (19.22%)	1998			
17	Top 10	6 (60%)	1 (10%)	0	3 (30%)	10			
	Top 50	19 (38%)	10 (20%)	10 (20%)	11 (22%)	50	2.2		
	Ranked	35 (35.71%)	22 (22.45%)	24 (24.49%)	17 (17.35%)	98	1.59		
	Licensed	571 (30.10%)	437 (23.04%)	509 (26.83%)	380 (20.03%)	1897			

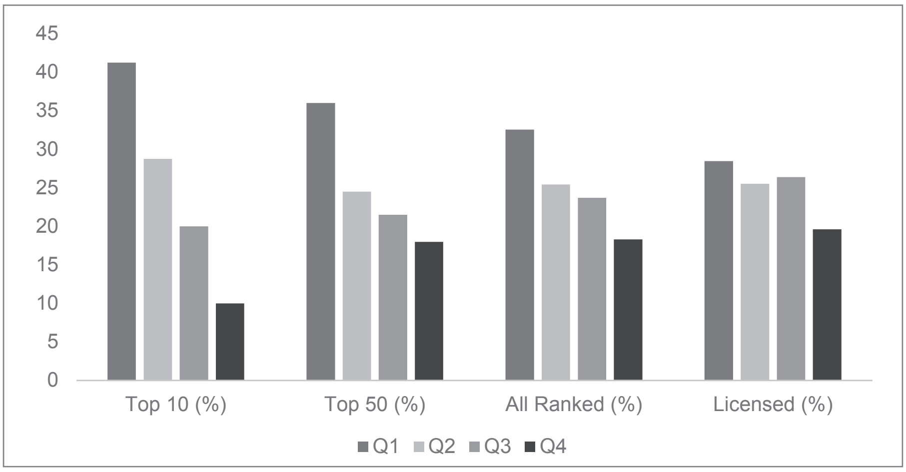

Figure 2. Birth distribution of girls.

Table 3. Comparison of the seasons of birth distribution in boys

Age group	Rank	Q1 (%)	Q2 (%)	Q3 (%)	Q4 (%)	N	χ2	w	Group comparison
10	Top 10	6 (60%)	2 (20%)	2 (20%)	0	10			
	Top 50	20 (40%)	13 (26%)	11 (22%)	6 (12%)	50	5.78		
	Ranked	75 (32.89%)	70 (30.70%)	45 (19.74%)	38 (16.67%)	228	**10.65***	0.22	Q1>Q2>Q3>Q4
	Licensed	350 (26.78%)	341 (26.09%)	326 (24.94%)	290 (22.19%)	1307			
11	Top 10	5 (50%)	4 (40%)	1 (10%)	0	10			
	Top 50	17 (34%)	17 (34%)	7 (14%)	9 (18%)	50	4.04		
	Ranked	95 (29.14%)	97 (29.75%)	65 (19.94%)	69 (21.17%)	326	5.15		
	Licensed	443 (28.69%)	411 (26.62%)	388 (25.13%)	302 (19.56%)	1544			
12	Top 10	2 (20%)	3 (30%)	3 (30%)	2 (20%)	10			
	Top 50	20 (40%)	10 (20%)	14 (28%)	6 (12%)	50	5.16		
	Ranked	94 (27.81%)	89 (26.33%)	91 (26.92%)	64 (18.93%)	338	1.16		
	Licensed	535 (28.34%)	525 (27.81%)	462 (24.47%)	366 (19.39%)	1888			
13	Top 10	3 (30%)	2 (20%)	4 (40%)	1 (10%)	10			
	Top 50	16 (32%)	12 (24%)	11 (22%)	11 (22%)	50	1.01		
	Ranked	70 (24.22%)	75 (25.95%)	79 (27.34%)	65 (22.49%)	289	4.36		
	Licensed	552 (28.84%)	476 (24.87%)	526 (27.48%)	360 (18.81%)	1914			
14	Top 10	3 (30%)	5 (50%)	2 (20%)	0	10			
	Top 50	15 (30%)	12 (24%)	13 (26%)	10 (20%)	50	0.21		
	Ranked	51 (23.94%)	60 (28.17%)	53 (24.88%)	49 (23.01%)	213	1.84		
	Licensed	569 (27.66%)	533 (25.91%)	520 (25.28%)	435 (21.15%)	2057			
15	Top 10	2 (20%)	6 (60%)	0	2 (20%)	10			
	Top 50	18 (36%)	17 (34%)	7 (14%)	8 (16%)	50	6.28		
	Ranked	60 (28.99%)	58 (28.02%)	42 (20.29%)	47 (22.71%)	207	4.29		
	Licensed	557 (27.56%)	511 (25.28%)	537 (26.57%)	416 (20.58%)	2021			
16	Top 10	2 (20%)	3 (30%)	1 (10%)	4 (40%)	10			
	Top 50	16 (32%)	10 (20%)	12 (24%)	12 (24%)	50	2.00		
	Ranked	53 (27.46%)	51 (26.42%)	47 (24.35%)	42 (21.76%)	193	0.39		
	Licensed	539 (26.50%)	567 (27.88%)	510 (25.07%)	418 (20.55%)	2034			
17	Top 10	4 (40%)	4 (40%)	0	2 (20%)	10			
	Top 50	13 (26%)	13 (26%)	10 (20%)	14 (28%)	50	2.43		
	Ranked	39 (25.16%)	44 (28.39%)	35 (22.58%)	37 (23.87%)	155	2.30		
	Licensed	520 (27.15%)	519 (27.10%)	497 (25.95%)	379 (19.79%)	1915			

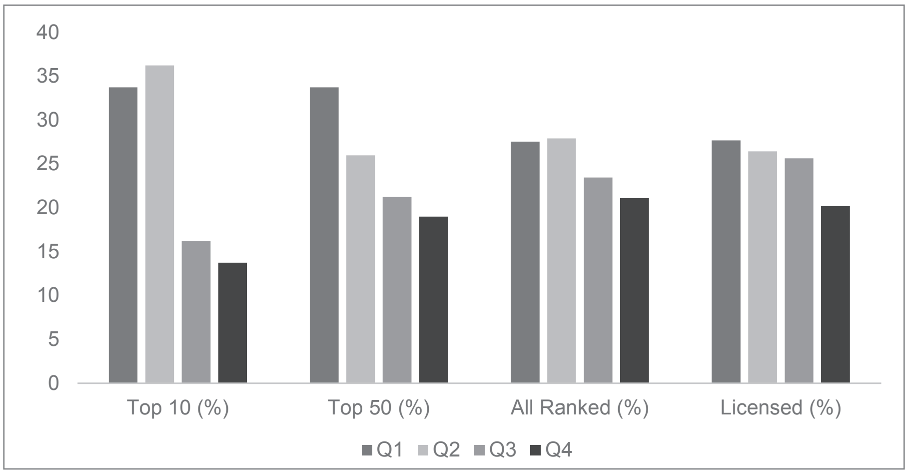

Figure 3. Birth distribution of boys.

(χ2 (3, 391) = 9.08, *p* < .05, *w* = .15). The percentage of the players were 31.2%, 28.1%, 23.8%, and 16.9% for Q1, Q2, Q3, and Q4, respectively. Concerning the 11-year-old age group, the players ranked in the top 50 showed a significant difference according to their birth quartile (χ2 (3, 100) = 9.26, *p* < .05, *w* = .30). The distribution percentage according to the birth quartile was 41%, 29%, 17%, 13% for Q1, Q2, Q3, and Q4, respectively. In terms of all other age groups, the distribution of the observed and expected frequency was constant. Figure 1 illustrates the distribution of all ranked and aged players compared to the distribution of licensed players and the general population.

The results also revealed that the expected and observed frequency significantly varied for 11-year-old girls, ranked in the top 50, (χ2 (3, 50) = 8.72, *p* < .05, *w* = .42). The birth quartiles of these players were clustered in Q1, Q2, Q3, and Q4 with the percentage of 48%, 24%, 20%, and 8%, respectively. Another significant difference was observed among 14-year-old girls ranked in the top 50 and all-ranked (χ2 (3, 175) = 8.33, *p* < .05, *w* = .22). Half (50%) of the top 50 ranked players were born in Q1, while 24% of those were born in Q2, 18% in Q3 and 9% Q4. RAE was not observed in the remaining age groups among girls (Table 2). The observed and expected distribution of girls regardless of their age and rank are shown in Figure 2.

For the boys, the results indicated that all ranked 10-year-old players showed the presence of RAE (χ2 (3, 228) = 10.65, *p* < .05, *w* = .22). Of these players, 32.9% were born in Q1, and 30.7%, 19.7%, and 16.7% were born in Q2, Q3, and Q4, respectively. The remaining age groups showed no significant difference among boys (Table 3). An illustration of all age and ranked boys compared with all licensed boys can be seen in Figure 3.

Discussion and conclusions

The purpose of the study was to evaluate the effect of relative age on young Turkish competitive tennis players. The assessment of RAEs in a population often involves comparing birth quartiles. There are three commonly used methods for this comparison. The first method assumes equal distribution of birth quartiles, where each quartile consists of 25% of the population. Comparisons are then made based on this equal distribution. The second method involves comparing the RAEs of the sample to the overall population percentages if the data is available. The third method involves comparing the RAEs of the sample to the percentages of licensed players if the data is accessible. In the present study, the third method was chosen for RAEs assessment since the sample consisted of competitive tennis players, and comparing the sample to licensed players with similar characteristics and backgrounds could provide more reliable results. The main findings from the present study can be summarized as RAE was limited to two age groups (11- and 14-year-olds) for girls, one age group (10-year olds) for boys, and two age groups (10- and 11-year olds) for genders pooled together. RAE was observed to be more pronounced higher up in the rankings. From all ranked to top 10, the prevalence of RAE was more pronounced in both boys and girls (see Figure 1, Figure 2, and Figure3).

The study revealed that a greater proportion of top-ranked tennis players were born in the first half of the year, particularly among the 10- and 11-year-old age groups, where the gap was most noticeable. It is consistent with prior research that has identified significant RAE in youth sports. The study conducted by Edgar and O'Donoghue (2005) on elite senior junior tennis players discovered that nearly 60% of the senior and junior players participating in the initial rounds of Grand Slam tournaments were born in the first six months of the year. The findings of a study conducted by Baxter-Jones (1995) showed that a high proportion, up to 85%, of elite British junior players were born in the first half of the year, and Dudink (1994) revealed that almost half (50%) of 60 12-16-year-old elite Dutch junior tennis players were born in the first birth quartile.

RAE in tennis has been well documented within a broad age and ranking range (Agricola, Zháněl, & Hubáček, 2013; Giacomini, 1999; Koloničný, Agricola, & Jiri, 2021b). The present study found varying results based on age group and gender, with the RAE being more pronounced in girls. There were significant differences for 11-year-old top 50 ranked girls, 14-year-old top 50 ranked girls, and all-ranked girls, as well as for 10-year-old top 50 ranked boys between the expected and observed frequency of birth quartiles. The findings indicated differences in the mean values between the expected and observed frequencies in favor of Q1 in the majority of all subcategories and age groups; however, it failed to show any significant difference (see Table 1, Table 2, and Table 3). Several studies (Gerdin, et al., 2018; O'Donoghue, 2009; Zhaněl, et al., 2022) have indicated that the RAE has an impact on both male and female tennis players, with some research (Gerdin, et al., 2018) suggesting that it is stronger for female players. However, Edgar and O'Donoghue (2005) found no significant difference between the genders. They revealed that the RAE was found to be more prevalent among players born in the first and fourth quarters of the year. A study by Koloničný et al. (2021a) found that the RAE was present in all male and female sub-categories, including "Ranked", "Top 100," and "Top 10". However, the effect was only statistically significant among the top 10 male players. The authors also identified earlier physical, psychological, and mental maturity as contributing factors to the RAE. Additionally, Zháněl et al. (2022) found that the effect was statistically significant for the top 100 senior female tennis players.

In conclusion, the results of this study indicate the trend of players being born mostly in the first half of the year, potentially giving them an advantage in physical and mental development. Yet, the distribution based on birth quartiles did not significantly differ among the majority of age groups in both genders. Thus, it can be concluded that several factors such as physical development, psychological and physiological differences might play a key role in the success of players other than the relative age factor. These findings shed light on the issue of RAE in youth sports and its impact on the development and selection of young athletes. This study highlights the importance of conducting further research to fully understand the mechanisms behind RAEs and to promote fairness in the selection process. These insights provide valuable information for coaches, trainers, and sports organizations to consider how to develop and when to select young athletes.

This study has several limitations. Firstly, it only focused on competitive tennis players aged between 10 and 17 years, and there is limited research on players older than 17 years. Future studies should consider including adult tennis players. Secondly, the RAEs were only assessed in tennis players, and future studies should examine this issue in other sports as well. Lastly, two important biological factors, the growth and maturity status of the players, were not considered.

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RELATIONSHIP BETWEEN WEIGHT STATUS AND BASAL METABOLISM IN SCHOOLCHILDREN: THE MODERATING ROLE OF DIET QUALITY AND PHYSICAL ACTIVITY

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Abstract:

There is currently a scientific trend to study the association between energy balance and its impact on health from the earliest stages of life. The aim of this study was to examine whether diet quality and physical activity moderate the association between weight status and basal metabolism in a sample of Murcian primary schoolchildren aged 8-12 years. Basal metabolism was calculated according to height, sex, and weight, with fixed coefficients following validated formulae. Physical activity was measured with the Krece-Plus test; the KIDMED questionnaire was used to quantify diet quality and nutritional status was assessed by body mass index (BMI; kg/m^2) adjusted for sex and age. The results obtained indicate that overweight schoolchildren had a higher basal metabolism than their normal-weight peers considering their diet quality and physical activity level ($p<.001$, for both). Also, the effects of weight status on basal metabolism may be moderated by diet quality ($p<.05$) but not by physical activity ($p>.05$). These results may be of particular interest to educational and health personnel since generating strategies to improve schoolchildren's eating habits, especially towards higher diet quality, could be vital as a method to increase basal metabolic energy expenditure and their overall health.

Key words: *Mediterranean diet, obesity, physical activity, health, schoolchildren*

Introduction

The energy required for the regulation of physiological functions depends on the balance between energy intake and expenditure. An imbalance between these conditions, where consumption is favoured over expenditure, leads to an increase in the reserve, which, in turn, favours hypertrophy and hyperplasia of adipose tissue; in chronic conditions, this energy reserve leads to obesity (Sánchez, Polanco, & Rosero, 2020). This study points out that childhood obesity is a pressing challenge and a public health priority in the 21st century, with more than one third of schoolchildren worldwide experiencing overweight or obesity by the end of primary school. In this regard, teachers should be aware of the importance of the main factors influencing an increase in obesity, as paediatric obesity is associated with increased disease risk, including impaired glycaemic and lipid control that can lead to the development of chronic and potentially disabling pathologies, such as type 2 diabetes mellitus and adverse cardiovascular events in adulthood (Martínez-González, Sánchez-Villegas, Toledo-Atucha, & Faulín-Fajardo, 2022; Sánchez, Llussà, & Bautista, 2021).

Basal metabolic rate (BMR) represents the major component of energy expenditure in humans and is therefore of great relevance in obesity treatment. BMR is defined as the minimum energy requirement to maintain vital functions such as cardiovascular and respiratory system function, organ synthesis, cell membrane ion pumps and body temperature programmes (Hulbert & Else, 2004). It is influenced by factors such as age, sex, body composition, physiological state (Mussoi & Rech, 2019), and genetics (Lee, Lee, Kang, Shin, & Sorn, 2021). BMR comprises 50-80 % of daily energy expenditure and is highly variable between subjects, even after adjusting for sex, body weight and body composition (Bi, Forde, Goh, & Henry, 2019; Ravussin, 1995). Determined by indirect calorimetry or with predictive equations, BMR can be a useful predictor of cancer risk independently of body fat (Kliemann, et al., 2020).

At the environmental level, the therapeutic strategy against obesity initially starts with interventions that aim to change lifestyle; increased physical activity (PA) (caloric expenditure) as it can influence the modification of certain structural and functional patterns related to energy metabolism and weight status (Rosa-Guillamón, 2015) and feeding behaviour (caloric intake) as an influence of the gut-brain axis on obesity and BMR has been reported (Ravussin, 1995; Zawada, et al., 2021). Both constructs are key to prevent, manage and potentially reverse metabolic disorders and weight status (calorie balance) (Bai, Goudie, Børsheim, & Weber, 2021; Calcaterra, et al., 2021).

Following a review of the literature (St-Onge & Gallagher, 2010), it has been proposed that reduced BMR and fat oxidation may lead to changes in body composition and that lower BMR at age of 10 years predicts greater change in the BMI z-score of schoolchildren. These aspects indicate that the effects of a relatively low metabolic rate on future weight gain in this population may begin in late childhood (Hohenadel, et al., 2021). In this sense, this study has identified evidence that schoolchildren at risk of obesity are generally not predisposed to higher body weight due to higher metabolic efficiency. Therefore, it is necessary to put more emphasis on defining different subgroups of overweight and normal-weight subjects in studies investigating BMR (Wurmser, et al., 1998) and to observe the influence of weight status on BMR at paediatric age in order to carry out appropriate nutritional approaches. In other words, obesity can modify BMR by several mechanisms with consequent implications for medical, educational and nutritional decisions; it can act in opposite directions (Doros, Delcea, Mardare, & Petcu, 2015; Itagi, Kalaskar, Dukpa, Chandi, & Yunus, 2022).

Based on these precedents, the aim of this study was to examine whether diet quality and physical activity moderate the association between weight status and basal metabolism in a sample of primary school children aged 8-12 years. The alternative hypothesis (H_1) was that normal-weight schoolchildren had a lower metabolism than their overweight peers and that diet quality and physical activity would moderate this association.

Method

Type of study and participants

Prior to conducting this research, the sample size was calculated in order to ensure robust results (Quispe, Pinto, Huamán, Bueno, & Valle-Campos, 2020). After jointly estimating the u (in reference to the number of variables) and f^2 (effect size in linear regression models) statistics, it was obtained that the minimum sample had to be of a total of 211 subjects to be able to carry out the linear regression technique, something that is fulfilled since we had a total sample of 281 students.

In this regard, a total of 281 schoolchildren (43.6% boys and 53.7% girls) from Murcia (Spain), aged between 8 and 12 years (M ± SD: 9.63 ± 1.81 years), participated in this descriptive and cross-sectional *ex post facto* study. The sampling was non-probabilistic, chosen non-randomly and by convenience (access to the sample). Four public schools were selected from rural (97 schoolchildren) and urban (184 schoolchildren) environments. These schools had a medium socio-economic level according to the annual general programme of each school. In previous meetings held with the school principals and legal guardians of the schoolchildren, they were informed of the study protocol and informed consent was requested so that the schoolchildren could participate. Inclusion criteria were: children must be between 8-12 years of age (since this is where healthy lifestyle habits begin to be created in the early stages of life) and must not suffer from previous pathologies. The exclusion criterion was the failure to present informed consent to participate in the research.

Procedure and instruments

The work was carried out during the months of March and April of the 2019/2020 academic year, and each headmaster of the school and the representatives of the parents' associations were informed of the purpose and protocol of the research at a meeting. The working team consisted of a principal researcher and four collaborating colleagues—teachers specialising in primary education and physical education (PE). A theoretical session was held prior to the completion of the *KIDMED* and *Krece-Plus* questionnaire with each study group in order to ensure that all participants understood the items of the questionnaires in this study. The research team administered the test in the natural groups of PE classes. All questionnaires were administered during the first session of the day in order to avoid possible fatigue induced by the school day and to interrupt the school dynamics as little as possible.

The research was carried out in accordance with the ethical standards recognised by the Declaration of Helsinki (2013 revision), following the recommendations of Good Clinical Practice of the EEC (document 111/3976/88 of July 1990) and the current Spanish legal regulations governing clinical research on humans (Royal Decree 561/1993 on clinical trials).

The independent variables were:

I) Diet quality determined using the *KIDMED* questionnaire (Serra, et al., 2004). This instrument is composed of 16 items representing standards of the traditional Mediterranean diet. Four of them are assessed with a negative score (-1 point) if answered positively (items 6, 12, 14 and 16), while the remaining twelve items are assessed with a positive score (+ 1) if answered positively. After summation, an overall score between 4 and 12 is obtained, which describes a better or worse quality of the diet. The value of the *KIDMED* index is: score ≤ 3 indicating a very low quality diet; score between 4 and 7 indicating the need to improve the dietary pattern to conform to the Mediterranean model; and, finally, score ≥ 8 showing an optimal Mediterranean diet. Participants were categorised into two groups: DQ improvable (≤ 7) and optimal DQ (≥ 8).

II) Participants' body weight and height were determined using an electronic scale (TANITA TBF 300A, USA) and measuring rod (SECAA800, USA) with an accuracy of 100 g and 1 mm, respectively, following the protocol of the International Society for the Advancement of Kynanthropometry (ISAK) with level I certified personnel. From these anthropometric variables, the body mass index (BMI; kg/m^2) was calculated. From this index, age- and sex-adjusted nutritional status was classified (Cole & Lobstein, 2012). Participants were categorised into two groups: normal weight and overweight (*overweight + obesity*).

III) Physical activity was measured with the short *Krece-Plus test*, part of the enKid study (Román-Viñas, Serra-Majem, Ribas-Barba, Pérez-Rodrigo, & Aranceta-Bartrina, 2003). This test measures the level of habitual PA (0-10) of schoolchildren based on the average daily hours spent watching television or playing video games, and the hours of out-of-school PA per week. Schoolchildren were categorised into two groups according to PA level: insufficient, X < P70 and adequate, X ≥ P70. Cronbach's alpha for this study was 0.70, which is considered adequate and valid.

The dependent variables

Basal metabolism wass considered as a dependent variable in this study:

Basal metabolism (calories), defined as the caloric quota necessary to maintain the organism and its physiological functions alive, in a state of absolute rest, fasting and at constant temperature (Neri & Bargosi, 2000), was calculated according to height, sex and weight, with fixed coefficients following these formulae:

Basal metabolism (male):
655 + (9.6 x weight) + (1.8 x height) - (4.7 x age).

Basal metabolism (female):
66 + (13.7 x weight) + (5 x height) - (6.8 x age).

Statistical analysis

Normality and homogeneity of variances were obtained using the Kolmogorov-Smirnov and Levene statistics, respectively. As a normal distribution of the values recorded was observed, a parametric analysis was chosen. A differential analysis was then carried out. To indicate the characteristics of this sample, frequency distribution was used for categorical variables and descriptive analyses using the mean ± standard deviation for continuous variables. Student's t-test was used to test for significant differences between the groups (sex [*males vs. females*]; weight status [*normal weight vs. overweight*]; diet quality [*improvable vs. optimal*], and level of physical activity [*improvable vs. optimal*]) and the chi-squared test for categorical variables.

Subsequently, the PROCESS macro tool (version 3.5) of the SPSS software (IBM Corp, Armonk, New York, USA) was applied (version 23). This tool allows for moderation analysis (Hayes, 2017). The initial analysis indicated no significant differences between sexes; consequently, all analyses were conducted with males and females together to achieve greater statistical power. Moderation analysis was used to analyse whether weight status (independent variable) was linked to basal metabolism (dependent variable) by looking at the moderating effect of diet quality and physical activity (moderator variable). Before interpreting the coefficients, goodness-of-fit and model assumptions were assessed. To analyse the goodness-of-fit, the F-test was used, which indicates whether the linear relationship being analysed is statistically significant. It should be noted that this statistic was significant, thus confirming the relevance of the regression technique (Martínez-González, Sánchez-Villegas, Toledo-Atucha, & Faulín-Fajardo, 2020). With respect to the assumptions, as indicated by Pardo and San Martín (2010), the assumption of non-collinearity, linearity, independence of the errors and the Breusch-Pagan test to check the homogeneity of the residuals were checked as indicated by Pardo and San Martín (2010). These assumptions were met in all models. The influence of outliers was also tested using Cook's distance. As the value obtained was less than one (1), it was concluded that there was no influential case. Ordinary least squares (OLS) regression analysis was performed to predict the continuous variables (*basal metabolism* and *KIDMED*). To visualise the effect of the moderator, a simple slope plot was used. Johnson Neyman's method was used to test the point at which diet quality moderated the relationship between weight status and basal metabolism. In turn, since determining the contribution of the predictor is critical when conducting a regression model, the R^2 statistic was used (Raschka & Mirjalili, 2019). For the calculation of the sample size, the programme R, version 4.1.2 (pwr package)

(Champely et al., 2018) was used with the significance level set at 5% (p≤.05).

Results

Table 1 shows that there were 130 males and 151 females in the study. Age and anthropometric markers defined the main characteristics of the sample analysed, where no statistically significant differences were observed (p>.05). Regarding the results of diet quality (calculated from the KIDMED score) and basal metabolism, no significant differences were observed for either males or females. Furthermore, no statistically significant differences were shown for diet quality and physical activity.

Figure 1 shows the differences obtained in the basal metabolism of schoolchildren according to their weight status (*normal weight vs. overweight*) and considering their diet quality (*improvable vs. optimal*) as well as the level of physical activity (*improvable vs. optimal*). It is observed that overweight schoolchildren had a higher basal metabolism than their normal-weight peers, independently of their diet quality (p<.001, for both) and physical activity (p<.001, for both).

Table 2 indicates a positive association between weight status and basal metabolism of schoolchildren (adjusted model) according to ordinary least squares regression. This pathway is identified as a direct effect [*B* = 49.53, 95% CI (confidence intervals) = -224.60 (125.53)], and was moderated by diet quality but not by physical activity. The effect of weight status on basal metabolism was moderated by diet quality [B = 24.51, 95% CI = 16.29 (-2.74)]. That is, for each point increase in the quality of the students' diet, basal metabolism will increase by 24.51 calories. Regarding goodness-of-fit, this model explains approximately 22% of the variance of basal metabolism, which refers to a medium effect

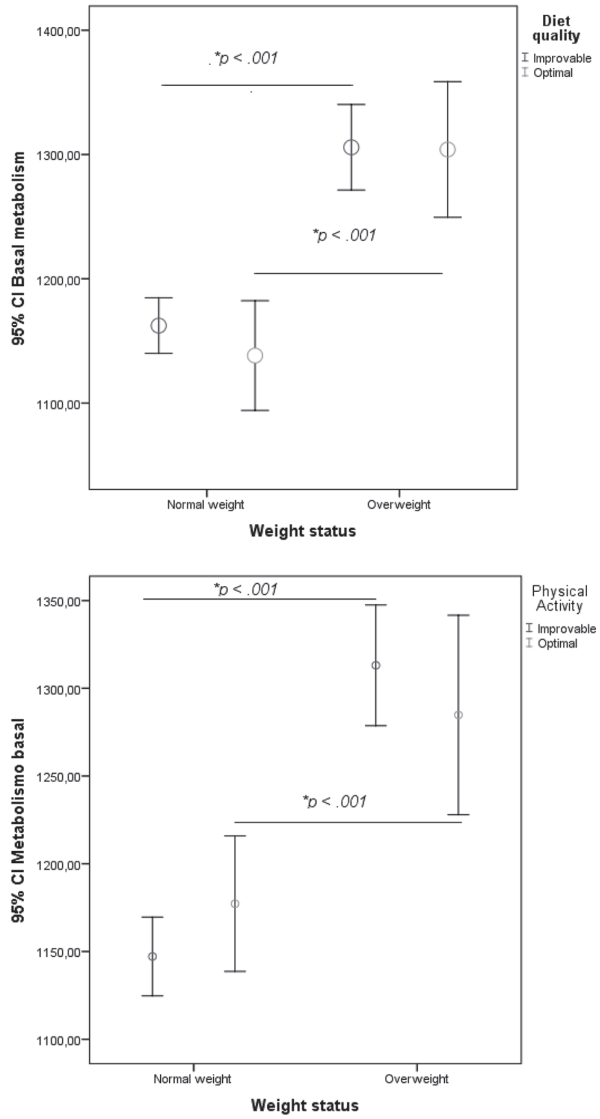

Figure 1. Differences in the basal metabolism of schoolchildren according to their weight status (normal weight vs. overweight) and considering their diet quality (improvable vs. optimal) and level of physical activity (improvable vs. optimal).

Table 1. Main characteristics of the sample analysed according to sex

	Males M ± SD (n = 130)	Females M ± SD (n = 151)	F	*p*	*d*
Age (years)	9.59 ± 1.33	9.67 ± 1.26	1.665	.623	0.05
Height (cm)	139.36 ± 11.17	138.30 ± 11.54	1.141	.274	0.09
Weight (kg)	38.43 ± 10.52	37.05 ± 10.54	1.294	.438	0.08
BMI (kg/m^2) [c]	19.43 ± 3.48	19.10 ± 3.70	3.196	.457	0.08
Normal weight (n = 174)	27.8%	18.5%	-	.311	-
Overweight (n = 107)	34.2%	19.6%		.151	
Diet quality[d]	11.65 ± 2.37	11.72 ± 2.20	2.451	.126	0.10
Improvable DQ[d] (n=227)	37.4%	43.4%	-	.641	-
Optimal DQ[d] (n=54)	8.9%	10.3%		.877	
Physical activity (PA) (0-10)	5.73 ± 1.88	5.64 ± 2.05	1.984	.344	0.09
Improvable PA (n=189)	32.4%	38.4%	-	.149	-
Optimal PA (n=92)	13.9%	15.3%		.753	
Basal metabolism	1229,66 ± 113,27	1200,83 ± 186,44	7.958	.697	0.06

Table 2. Regression model estimating effects on basal metabolism

	Basal metabolism (score) (*Y*)		
Predictors	B (SE)	95% CI	*p*
Weight status (*X*)	49,53 (88,93)	-224.60 (125.53)	.0481*
KIDMED (score) *(W)*	24,51 (11,06)	16.29 (-2.74)	.0298*
Physical activity (score) *(Z)*	21,68 (13,34)	4.5876 (7.96)	.1058
Constant	1.296,86 (131,33)	1.038.32 (1.555.41)	.0001**
Intercept *(X x W)*	16,82 (7,45)	2.15 (31.50)	.0201*
Intercept *(X x Z)*	-12,48 (8,82)	2.86 (4.89)	.1585

Note. Data are expressed as unstandardised coefficients (standard error; SE) and 95% confidence intervals (CI). * p≤.050; ** p≤.001.

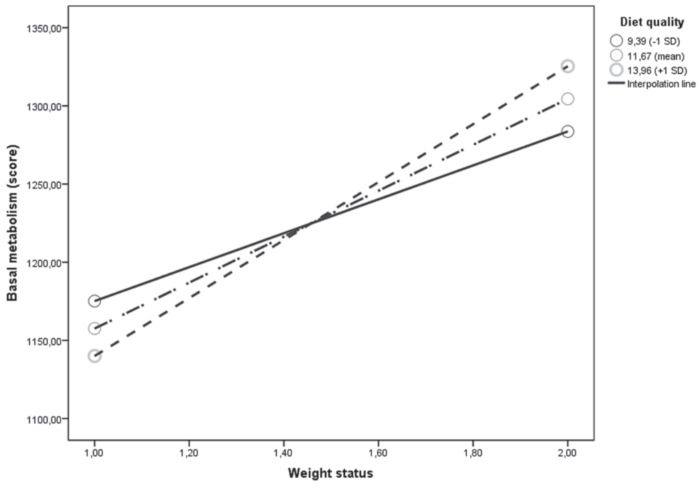

Figure 2. Moderating effect of weight status on basal metabolism through diet quality in schoolchildren. The estimated mean represents the values of different conditional effects (+1 SD, mean and -1 SD) on diet quality, after adjusting for sex and age.

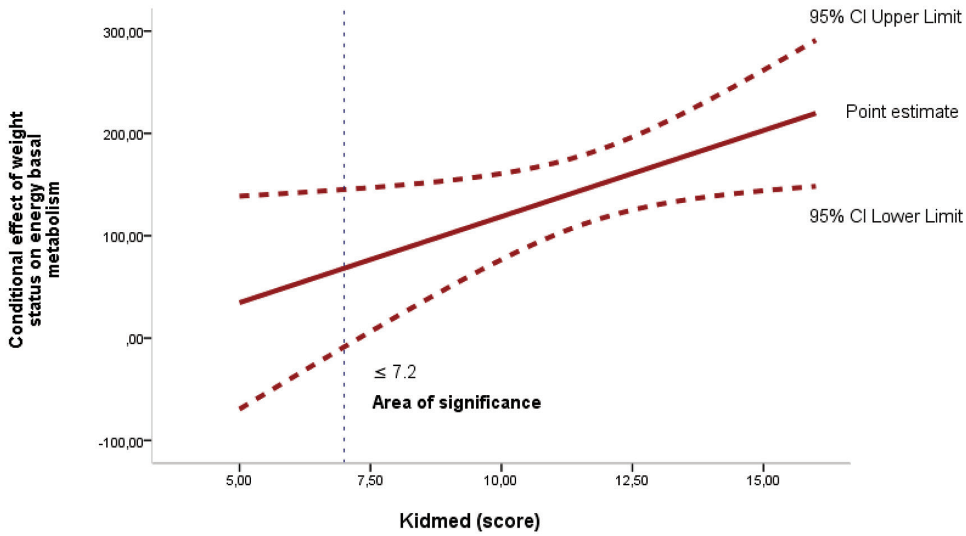

Figure 3. Estimation of regression slope and 95% confidence intervals for the association between moderator variable (diet quality) and the effect of weight status on basal metabolism, according to the Johnson-Neyman's method. The area of statistical significance at the moderator value (KIDMED score of ≤ 7.2) is shown by the red line.

size (Cohen, 1988). As for the RMSE, its value is low, indicating a low prediction error (1.645), with a statistical power of 90%.

Figure 2 shows the moderating effect of diet quality on the association between weight status and basal metabolism for different conditional effects (+1 SD, mean and -1 SD) after adjusting for age and sex. Thus, we observed that higher diet quality exerted a positive moderating effect on basal metabolism in overweight schoolchildren, with the largest effect in the category of higher adherence to DM (+1 SD) [(ß = .042, 95% CI = (.001, .069)].

To clarify an estimation point at which the value of the moderator could have an effect, the Johnson-Neyman method was used. Figure 3 shows the result. The moderator value (diet quality expressed as KIDMED score) is shown by the slope and the area of significance, the latter being ≤7.2, indicating that the determination of weight status on basal metabolic expenditure might be stronger for schoolchildren in this area. From this point estimate, a positive area is shown, expressing that the determination of weight status on basal metabolism might be lower for those above this point estimate on diet quality.

Discussion and conclusions

The aim of this study was to examine whether diet quality and physical activity moderate the association between weight status and basal metabolism in a sample of primary school children aged 8-12 years. The initial hypothesis was that normal-weight schoolchildren would have a lower metabolism than their overweight peers and that diet quality and physical activity would moderate this association. In this sense, it was found that: I) overweight schoolchildren had a higher basal metabolism than their normal-weight peers but II) only diet quality moderated this association between weight status and basal metabolism in schoolchildren.

Given that no studies have been found in the scientific literature in paediatric age groups that analyse the association between these variables by observing the moderating role of diet quality and physical activity, this prevents us from making direct comparisons. In this sense, studies analysing the relationship between weight status and basal metabolism are limited, hence the original focus of our study. These results take on greater importance given the age of the sample, since these are transcendental stages of life in which a healthy lifestyle, such as the quality of the diet, can have an impact on the individual's metabolic expenditure and, consequently, on a higher state of health.

The results found regarding the moderating role of diet quality may be due to physiological (Mohammadpour, et al., 2021; Zapata, et al., 2021) and genetic processes such as thyroxine and adrenaline hormones that can increase basal metabolic expenditure (Lee, et al., 2021; Ravussin, 1995; Rosa-Guillamón, 2015; Zawada, et al., 2021), derived from the assimilation of certain macronutrients in the diet. In other words, several studies have shown an influence of macronutrient intake on the metabolic profile, finding positive effects of the Mediterranean diet on BMR and on the abundance of microbial species associated with better macronutrient metabolism compared to those subjects with a different dietary pattern (Daniele, Scarfò, & Ceccarelli, 2021; Nadimi, Djazayery, & Hosseini, 2013). Methodologically similar research, which aimed to examine the relationship between BMR and dietary intake of micronutrients such as zinc, vitamin C and riboflavin in overweight and obese women, found a significant association between riboflavin intake and BMR, but no significant association between vitamin C, zinc and BMR (Sajjadi, Mirzababaei, Abdollahi, & Shiraseb, 2020). This study noted that zinc has different roles in energy metabolism and functions as a component of several enzymes crucial for the metabolism of carbohydrates, proteins and lipids, and the metabolism of hormones involved in the progression of obesity, especially insulin. Sajjadi et al. (2020) also point out that it appears to be related to the insulin resistance mechanisms generally present in people with obesity. They also show that these subjects with impaired glucose tolerance have higher BMR levels than those with obesity and normal glucose tolerance. Ambra, Canali, Pastore, and Natella (2021) add that an explanatory mechanism for this could be due to the role of ascorbic acid (antioxidants) in the expression of genes involved in adipogenesis, glucocorticoid metabolism and the inflammatory response. In other words, it has been shown, for example, that dietary supplementation with vitamin C does not affect daily energy expenditure or BMR. This finding underlines that the antioxidant effects of the vitamin are not being compensated by modulations in the rate of oxidative metabolism, which could affect the total rates of reactive oxygen species products.

However, Calcaterra et al. (2021) have highlighted that the underlying mechanisms regulating energy homeostasis and food intake are not fully understood, with little research on the relationship of body composition to habitual macronutrient intake among healthy populations (Bi, et al., 2019); therefore, more research is needed. As indicated at the beginning of the discussion, another finding is that overweight schoolchildren have a higher basal metabolism than their normal-weight peers, irrespective of their diet quality and level of physical activity. In this regard, Pannemans and Westerterp (1995) pointed out that energy expenditure, and therefore energy needs, tends to decrease with age due to a decrease in BMR and the level of physical activity. In this study they point out that the effect of physical activity level is twofold: firstly, it has a positive effect on BMR, and secondly, it has a positive effect on fat-free mass. Both effects imply an increase in total energy expenditure, which increases with a higher level of physical activity. In energy balance, this will lead to an increase in energy and nutrient intake. In this vein, Valenzuela, Sobarzo, Basoalto, Sillero-Quintana, and Basoalto

(2019) found a weak correlation between basal metabolism and C-reactive protein; however, they did find a moderate association between BMR and lean mass percentage, reaffirming the importance of this tissue as an active metabolic organ.

Likewise, another study showed that the difference between the weight of obese and normal-weight schoolchildren is partly due to low BMR; the lower BMR in obese schoolchildren could be due to their low cardiorespiratory capacity (Saleh, Afroundeh, Siahkouhian, & Asadi, 2021). In this regard, Diaz et al. (2021) found that BMR increased with increasing maximal oxygen volume regardless of adiposity level (normal weight and overweight). However, Yu, Lee, Arslanian, Tamim, and Kuk (2021) after conducting an intervention study did not detect significant changes in BMR among the physically active groups. However, visceral fat decreased in all subjects compared to those who were not physically active. In this sense, they point out that the change in fat mass but not in visceral fat or skeletal muscle mass was a significant determinant of changes in BMR, regardless of the mode of physical exercise in overweight or obese adolescents.

At the genetic level, the study by Martin-Hadmaș, Martin, Romonți, and Mărginean (2021) reported that by BMR measurements, maximal carbohydrate metabolism changed significantly as a function of proinflammatory cytokine values such as the IL-6 gene, which correlated significantly with respiratory quotient values. Similarly, on the basis of BMR, an increase in the IL-8 gene coefficient was related to the respiratory quotient value. BMR explained about 15% of the variation in biological drivers of feeding rate differences that was considered metabolically significant (Henry, Ponnalagu, Bi, & Forde, 2018). However, Westphal et al. (2021) found no significant differences between BMR per unit mass (BMR/kg) or per unit lean mass (BMR/MM) and weight status. This variability in results may be explained by discrepancies in the way to report the BMR and the fact that BMR is believed to be genetically determined (Ravussin, 1995); further research is needed.

In this sense, Sánchez et al. (2021) indicate that it would be necessary for teachers to be aware of the importance of most of the factors that influence an increase in obesity, not only lifestyle and a healthy diet, but also other indicators such as exposure to endocrine disruptors, genetics, chronodisruption or intestinal microbiota. In this sense, the authors points out that from the classroom, this problem is considered only as the increase in energy consumption, through foods rich in sugars and fats, giving it a simplistic approach. It is therefore necessary to approach the treatment of obesity from a holistic and multifactorial viewpoint. Meanwhile, health promotion professionals in the school environment should consider the positive role that an optimal weight status can play in the overall development of students and initiate programmes to promote a degree of adherence to healthy lifestyles such as healthy eating and physical activity among schoolchildren (Carrillo-López, 2022).

However, the results presented in this study should be interpreted with caution due to the fact that this study was cross-sectional, based on self-reported data, with unknown quality and quantity of physical activity and food consumed daily by schoolchildren. In addition, the low sample size is undoubtedly another limitation. Similarly, it is difficult to infer a cause and effect relationship between weight status and basal metabolism, since, as we have seen, there are confounding factors that are likely to influence these relationships and have not been considered in this study (such as psychological or genetic variables). Therefore, these effects could be related to environmental aspects and deserve to be further investigated in future studies. However, this study is valid and reliable by applying the use of internationally recognised formulae (Cole & Lobstein, 2012; Sanchez, et al., 2020). In addition, further limitations are recognized, such as the use of estimating equations to calculate BMR. It would also be interesting to include in future studies the use of accelerometers to calculate physical activity of the participants, and also compare the data provided by the KIDMED to any similar questionnaire completed by parents or legal guardians, as well as maturation measures to control for this important factor at this age. On a practical level, it is suggested that future studies assume the role of calculating the basal metabolic rate to consider the optimal energy intake and, therefore, individualisation in the prescription of nutritional strategies in healthy patients and those with chronic non-communicable diseases. In this respect, further research is needed.

Implications for practice

In line with the aim of the study, it has been observed that overweight schoolchildren have a higher basal metabolic rate than their normal-weight peers and how the effects of weight status on basal metabolic rate can be moderated by diet quality among primary schoolchildren. These results may be of particular interest to educational and health care personnel since generating strategies to improve schoolchildren's eating habits, especially towards higher diet quality, could be vital as a method to increase basal metabolic energy expenditure and their overall health. In addition, these interventions should not only target schoolchildren, but also parents and legal guardians as the main responsible persons for their children's diet in order to generate a fuller awareness of the degree of maintenance of a healthy lifestyle that will undoubtedly have an impact on their future health. Undoubtedly, it would be interesting for health professionals and primary care teams to give courses to families in the school environment to provide information on healthy eating by age, on the food wheel, among other aspects.

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NO RELATIVE AGE EFFECT AMONG BRAZILIAN ELITE FEMALE FUTSAL ATHLETES: AN ANALYSIS BASED ON TACTICAL INDIVIDUAL PERFORMANCE AND TEAM'S FINAL POSITION IN THE NATIONAL CHAMPIONSHIP

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Abstract:

Our aim in this study was to analyze: (i) the presence of the relative age effect (RAE) on the Brazilian elite female futsal athletes according to their team's final position in the National Championship, and (ii) the relationship between the presence of the RAE and the athletes' tactical individual performance. Participants were 77 female Brazilian elite futsal athletes that competed in the 2021 National Championship. Data included their dates of birth aggrupation by quartiles (Q1-Q4), their team's final position in the National Championship, and their tactical individual performance indicators (time played, goals scored, assists, steals, shots on goal, unbalanced passes, and challenges won in 1vs1). Analyses of the overall sample indicated that RAE was not prevalent in this context since the observed birthdate distribution was not different from the expected one (p=.796). When the final placement in the championship was considered, the birthdate distributions were also not different from the expected for both the top-ranked (p=.572) and low-ranked (p=.679) team athletes. Regarding athletes' tactical individual performance, no differences were found between the athletes with early and late birthdates for any of the variables analysed (p>.05). Our results suggest that RAE has no impact on this specific sport context, which should be interpreted as a positive factor since female futsal athletes seem to have the same chance of achieving the elite level in Brazil, regardless of their birthdates.

Key words: *birth date, player development, sports performance, futsal, female*

Introduction

Grouping athletes based on a cut-off date is very common in organized sports. Although this strategy aims at a fairer competitive environment, it ends up benefiting athletes who were born closer to the cut-off date (Leite, Arede, Shang, Calleja-González, & Lorenzo, 2021; Lidor, Maayan, & Arnon, 2021). This systematic overrepresentation of relatively older athletes in sports is known as the relative age effect (RAE) and has been reported especially among males in many competitive sports

(Cobley, Baker, Wattie, & McKenna, 2009), both among youth (Castro, et al., 2023; Figueiredo, Seabra, Brito, Galvão, & Brito, 2021; Maciel, et al., 2022) and senior athletes (Castro, et al., 2022c; Figueiredo, et al., 2022; Lago-Fuentes, Rey, Padrón-Cabo, Prieto-Troncoso, & Garcia-Núñez, 2020).

Previous investigations have associated RAE with the fact that coaches are more likely to perceive athletes born closer to arbitrary cut-off dates as more competent than those born in the last quartiles of the year (Lidor, et al., 2021), making relatively older athletes more frequent in many youth sports. The primary explanation for this selection preference is the increased likelihood of earlier maturation for older youth athletes, giving them physical advantages in team sports, such as greater height, speed, and strength (Hill, Scott, Malina, McGee, & Cumming, 2020), relative to their slightly younger peers. Nevertheless, the RAE phenomenon is influenced by the interaction of environmental, individual, and task constraints (Wattie, Schorer, & Baker, 2015). Indeed, RAE is generally smaller (Brustio, Boccia, De Pasquale, Lupo, & Ungureanu, 2022; Smith, Weir, Till, Romann, & Cobley, 2018) or even non-existent in many female sports contexts (Barreira, Bueno, & Chiminazzo, 2021; Goldschmied, 2011; Lidor, Arnon, Maayan, Gershon, & Côté, 2014; Smith, et al., 2018). In this line, it seems that RAE is dependent on how deep the competition for spots in the selection process is (Peña-González, Javaloyes, Sarabia, & Moya-Ramón, 2021).

RAE is prevalent in the futsal context, as demonstrated by Figueiredo et al. (2021) in a study that investigated young futsal athletes from both sexes. These authors observed an overrepresentation of athletes born in the first quartile of the year (Q1 vs Q4) in the Under-9 female and the Under-7 and Under-9 male categories. Similar results were reported among Brazilian elite male athletes (Castro, et al., 2022b; Morales Júnior, Alves, Galatti, & Marques, 2017) from the Under-17, Under-20, and senior categories. Additionally, this effect seemed to differ based on the athletes' playing positions (Castro, et al., 2022a). On the other hand, when the sample was composed of elite adult female futsal athletes from the Brazilian National Futsal League (Morales Júnior, et al., 2017) and Brazilian Cup (Ferreira, et al., 2020), RAE was not observed. Overall, these findings reinforce the need to investigate the relationship between sex and RAE in futsal, since the occurrence of this effect may be associated with the specific characteristics of the talent development and selection processes (Peña-González, et al., 2021).

The relationship between RAE and performance has also been of interest to researchers. For example, in the study carried out by Ribeiro et al. (2023) with U17, U20, and senior female soccer players, the authors investigated whether RAE was associated with the final ranking obtained by the athletes in the World Cup. Results indicated no relationship between RAE and collective success defined by ranking in the competition. Castro et al. (2022a) also aimed to investigate the relationship between RAE and performance. In their study, carried out with Brazilian elite male futsal players, the authors found no relationship between goals scored and RAE. Considering the central role of tactical performance in team sports' success (Santos, Mendez-Domínguez, Nunes, Gómez, & Travassos, 2019), it is imperative to investigate the relationship between individual tactical performance and RAE in women's futsal. Despite its relevance to performance in team sports, knowledge on tactical indicators is still scarce in futsal, which reinforces the importance of developing new research on the subject.

Since RAE may influence a young athlete's opportunity to obtain better training and performance conditions to reach elite levels in sports (Leite, et al., 2021; Lidor, et al., 2021), further studies with specific populations in different sports are still needed. Although RAE arouses interest among many researchers and publications have increased in recent years, investigations in specific sports contexts being underrepresented in this research are warranted, particularly including futsal (Bilgiç & Işın, 2022; Castro et al., 2022b, 2022c; Leonardi, et al., 2022). In fact, Méndez-Dominguez, Nakamura, and Travassos (2022) highlighted the importance of developing research on futsal, not only concerning physical, technical, or tactical variables, but also on research topics with practical applications, such as talent development, performance analysis, and psychological topics. This is particularly necessary for female futsal, where research is even scarcer (Alves, Da Graça, Feitosa, & Soares, 2021).

To the best of our knowledge, no previous study has analyzed the relationship between the RAE and futsal players' tactical individual performance or between the RAE and the team's final position in elite female futsal. Thus, this study aimed to: (1) analyze the presence of RAE in Brazilian elite female futsal athletes; and (2) analyze the relationship between the RAE and athletes' performance (final position in the National Championship and tactical individual performance). Considering the overall low prevalence of RAE in women's sports (Smith, et al., 2018), and previous reports of the absence of RAE in women's futsal in Brazil (Ferreira, et al., 2020; Leonardi et al., 2022; Perondi, Dalla Valle, & Bernardino, 2018), we expected that RAE would not be observed among female futsal athletes nor associated with the selected performance indicators.

Method

Participants

This sample was composed of 77 female Brazilian elite futsal athletes (age = 25.98 ± 5.59 years) from six out of the 13 teams that competed in the Brazilian Cup 2021, one of the most traditional competitions organized by the Brazilian Futsal Confederation (CBFS). The competition brings together representatives of the states (mostly the champions) of the country. The other seven teams participating in the championship did not provide the requested data and therefore were not included in the sample of this study. The inclusion criteria adopted were to participate in the competition and to have the data provided voluntarily by the teams. Those responsible/participants for the teams agreed to participate in the research and provided data on the athletes' date of birth. These are open-access data, and no ethical issues were involved in their analysis and interpretation. The videos of the analyzed games are available on the internet. All data used in this study were reported anonymously.

Data collection

Data referring to the players' date of birth and playing positions were made available by their respective teams. All information was kept confidential and was used specifically for this study. Videos of the games were obtained from YouTube® (CBFS channel: CbfsTv), as a publicly available content. The tactical individual performance indicators collected were the following: time played, goals scored, assists, steals, shots on goal, unbalanced passes, and challenges won in 1vs1. All the data were collected in the period between January and April 2022. Table 1 provides the definitions for each of these indicators.

Instruments and procedures

Data were tabulated in a spreadsheet, and the athletes were organized according to: (1) the quarter of the year in which the athlete was born (Carraco, Galatti, Massa, Loturco, & Abad, 2020; Castro, et al., 2022a): Q1 (the first quarter: January-March), Q2 (the second quarter: April-June), Q3 (the third quarter July-September), and Q4 (the fourth quarter: October-December); and (2) the team's final position in the competition (1st, 2nd and 3rd—top-ranked teams, vs 9th, 11th, and 12th—low ranked teams). Tactical individual performance was also analyzed according to birth quarters.

Athletes' tactical individual performance was analyzed in 20 games (4,662 minutes and 45 seconds in total), equivalent to all the games of the teams that composed our sample in the Brazilian Cup 2021. For the analysis, two futsal performance analysts, with an average experience of six years as physical education teachers and two years as performance analysts in national teams, used the Videobserver™ software, validated by Fortes, Gomez, Hongyou, and Sampedro (2015). Inter- and intra-observer confidence coefficients ranged between 1 and 0.76. Using this software, the time played, goals scored, assists, steals, shots on goal, unbalanced passes, and challenges won in 1vs1 were analyzed. The selection of these specific performance indicators was based on Santos et al. (2019) since these variables allowed the discrimination of performance in a sample of elite male futsal athletes.

For the reliability testing, 20% of the total games (four games) were re-analyzed within 20 to 25 days after the first analyses (Tabachnick, Fidell, & Ullman, 2007). The intra-observer kappa-values ranged between 0.91 and 0.97. The inter-observer kappa-values ranged between 0.90 and 0.97.

Statistical analysis

Athletes' birthdate frequencies were presented in relative values. Chi-square goodness-of-fit tests (χ^2) were performed to compare the observed and the expected birthdates distribution of all the athletes and according to team placement (top-ranked teams vs low-ranked teams). Athletes were divided into four quarters (Q1, Q2, Q3, and Q4), and 25% was assumed as the expected frequency for each quarter, as proposed by Cotê, Macdonald, Baker, and Abernethy (2006). For all analyses, the

Table 1. Definitions of tactical individual performance indicators

Variable	Definition
Time played	Minutes and seconds in which the athlete was on the court, with the ball in play.
Unbalanced passes	Pass performed by the attacking player generating a defensive imbalance in the opponent team, along with a significant advance in the attack.
Assists	Pass to a player who scores in the opponent's goal (the shooter must score without performing more than two dribbles before scoring).
Goals scored	Goal scored in the opponent's goal.
Shots on goal	Shots on goal that were saved by the goalkeeper.
Challenges won in 1vs1	Confrontation in which the defender wins the 1vs1 dispute.
Steals	The action in which the defender steals the ball from the attacking athlete and thus the defenders recover ball possession.

effect size (ω) of the chi-square tests was calculated. According to the nomenclature of Cohen (1988), 0.1 is considered a small effect, 0.3 is a medium effect, and 0.5 is a large effect. Odds Ratio (ORs) for Q1 versus Q4 and the 1st versus 2nd semesters were also calculated.

Each of the athlete's tactical individual performance variables was compared based on the birth quarter distribution. The criterion for inclusion in this analysis was to have participated in at least one match, regardless of the amount of time played. Thus, twelve athletes were excluded from this analysis for not playing any match in the competition. To a fair score that accounted for the amount of time played, the initial values for each of the tactical performance variables were divided by the time played (in minutes), resulting in an adjusted score for each variable, similar to Santos et al. (2019). Kolmogorov-Smirnov test indicated that tactical individual performance data did not present a normal distribution, thus performances were compared across the birth quarters using the Kruskal-Wallis test. The effect size (η^2) of the Kruskal-Wallis tests was calculated for all the analyses. As a reference, 0.01 was considered a small effect, 0.06 a moderate effect, and 0.14 a large effect, based on Cohen (1988). All the analyses were performed using the Statistical Package for Social Sciences (SPSS), version 21.0 (Chicago, USA). The significance level for all the analyses was 0.05.

Results

The tactical individual performance indicators analyzed were time played (>40,000 min played), goals scored (n = 105), assists (n = 62), steals (n = 472), shots on goal (308), unbalanced passes (89), and challenges won in 1vs1 (n = 119), resulting in 1,155 actions performed.

The overall analyses of the Brazilian elite female futsal athletes indicated RAE was not prevalent in this pool of athletes (χ^2 = 1.022; p=.796; ω = 0.11; OR – Q1:Q4 = 1.439; OR – 1st:2nd = 1.144). When the final placement in the championship was

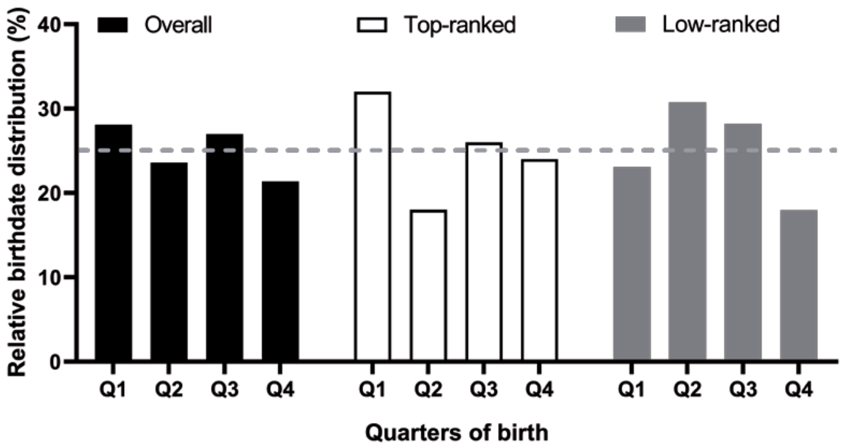

Figure 1. Relative observed and expected birthdate frequencies for overall, top-ranked, and low-ranked athletes.

Table 2. Adjusted tactical individual performance according to birth quarters

Variables	Q1 (P1-P3)	Q2 (P1-P3)	Q3 (P1-P3)	Q4 (P1-P3)	H	p
Time played	10.12 (2.43-18.29)	12.977 (2.22-20.05)	12.828 (4.78-21.6)	14.504 (5.3-17.35)	1.318	.725
Passes	0 (0-0.02)	0 (0-01)	0 (0-0.03)	0.008 (0-0.02)	0.628	.89
Assists	0 (0-0)	0 (0-0.02)	0 (0-0.01)	0 (0-0.01)	1.616	.656
Goals	0 (0-0.05)	0 (0-0.02)	0 (0-0.03)	0 (0-0.02)	0.544	.909
Shots	0.043 (0-0.08)	0.057 (0.01-0.1)	0.054 (0.02-0.12)	0.073 (0-0.11)	2.087	.555
1vs1	0.015 (0-0.02)	0 (0-0.03)	0.015 (0-0.06)	0.017 (0-0.04)	1.142	.701
Steals	0.083 (0-0.15)	0.052 (0-0.12)	0.088 (0.01-0.15)	0.103 (0.07-0.15)	2.605	.457

Note. Q1-Q4 = median values for each birth quarter; (P1-P3) = 25% and 75% percentile values; H = Kruskal Wallis; p = level of significance.

considered, once again no RAE was found, neither for the top-ranked ($\chi^2 = 2$; p=.572; ω = 0.2; OR – Q1:Q4 = 1.490; OR – 1st:2nd = 1) nor the low ranked ($\chi^2 = 1.513$; p=.679; ω = 0.17; OR – Q1:Q4 = 1.371; OR – 1st:2nd = 1.361) athletes (Figure 1).

Adjusted tactical individual performance (initial variable values divided by minutes played for each athlete) was analyzed based on the athletes' birth quarters. No differences were found (p>.05) for any of the variables (Table 2). Effect sizes were considered small for all the comparisons ($\eta^2<0.001$).

Discussion and conclusions

In this paper, we investigated the presence of RAE on Brazilian elite female futsal athletes according to the team's final position in the Brazilian Cup as well as the influence of RAE on athletes' tactical individual performance. We did not find the presence of RAE according to the final classification of the teams nor considering the tactical individual performance of the players. These results are in line with our hypotheses.

In our study, RAE was not observed in teams that were better placed in the competition analyzed, which is in line with the results found by Arrieta, Torres-Unda, Gil, and Irazusta (2015) in female basketball players and Ribeiro et al (2023) in female soccer players. On the other hand, Saavedra and Saavedra (2020) found a greater presence of older female handball athletes among the teams ranked from the first to the eighth places in the Under-18 World Championship, which is different from our results. Specifically, in futsal, Perondi et al. (2018) did not observe RAE in 410 athletes from an adult female competition in Brazil. Leonardi et al. (2022) also found no effects of RAE in 292 female futsal players aged 15 to 20, considering the teams' final classification. Our results reinforce these findings in female futsal, but now in the context of one of the most important Brazilian competitions. We believe these results are related to the influence of variables such as sex (Babić, et al., 2022) and competition level (Cobley, et al., 2009) of a sport modality. These are some of the aspects that may influence the intensity of competition in a given sport context, affecting the likelihood of a biased talent selection process that favours RAE (Peña-González, et al., 2021). Accordingly, futsal is more practiced by men in Brazil (data made available by CBFS on April 27, 2023: 356,831 male and 36,915 female athletes registered), and the sport is not as popular for females, which may reduce the competition for spots in teams and cause a reduction in the RAE likelihood. Indeed, Leonardi et al. (2022) investigated 140 male futsal teams aged between 9 and 20 years, while in the same study, only 19 female futsal teams were found, between 15 and 20 years, highlighting that the female practice of the sport modality is reduced. Another relevant aspect is the fact that in Brazil, women's futsal competitions start at later age, after 13 years old (Perondi, et al., 2018), which can lead to a later specialization in girls when compared to boys. Consequently, a lower impact of RAE is expected in female athletes, since RAE strongly operates near the beginning of puberty, where maturational differences are expected to be greater (Helsen, Starkes, & Van Winckel, 1998; Smith, et al., 2018).

Our results also indicated that RAE was not observed in relation to tactical individual performance, which indicates that RAE might not influence elite futsal female athletes' performance in terms of time played, goals scored, assists, steals, shots on goal, unbalanced passes, or challenges won in 1vs1. These results are not in line with the propositions that RAE influences performance in team sports where physical and anthropometrics attributes are important to performance such as basketball, soccer, and handball (Lupo, et al., 2019; de la Rubia, Lorenzo-Calvo, & Lorenzo, 2020). A possible factor that may have influenced our results is that coaches might stipulate the players' playing time as a function of technical criteria rather than aspects derived from RAE (Karcher, Ahmaidi, & Buchheit, 2014). In this rationale, Perondi et al. (2018) suggest that the technical aspect in women's futsal is more important than in men's, which would make it more appropriate to select technically superior players rather than physically superior ones (Helsen, Van Winckel, & Williams, 2005). Thus, the potential reduction in the importance of physical aspects for competition performance and the increased importance of tactical, technical, strategic, and even psychological qualities (de la Rubia, et al., 2020; Rampinini, Coutts, Castagna, Sassi, & Impellizzeri, 2007), can mitigate the impact of RAE.

Even though RAE is well established in many sports, especially in the male context, little is known about it in female futsal athletes (Mendes, et al., 2022). Studies have shown a prevalence of RAE in male futsal, highlighting that it influences talent identification and athlete development processes (Morales Júnior, et al., 2017; Perondi, et al., 2018). Nevertheless, this effect seems limited in the female context. One could argue that some characteristics of futsal may reduce the likelihood of RAE, such as the reduced playing area, which implies more emphasis on tactical-technical components to resolve game situations. Thus, less physically mature players would have more chances to develop technical and tactical skills, compensating for eventual physical disadvantages. Yet, these are speculative arguments, since research on the theme is still scarce and the pervasiveness of RAE seems context specific. This reinforces the importance of studies involving RAE and the tactical-technical qualities of futsal players. Indeed, Figueiredo et al. (2021)

highlighted that RAE could be better monitored to minimize the loss of valuable elite players during the youth phase of their careers for both sexes.

Regarding the tactical individual performance indicators, the average of the actions was higher than in studies with male futsal players (Yiannaki, Barron, Collins, & Carlinh, 2020). This probably stems from differences in physical and perceptual motor characteristics between men and women (O'Brien-Smith, Bennett, Fransen, & Smith, 2019), which in turn affects the properties of the futsal games played by male and female athletes (Agras, Ferragut, & Abraldes, 2016). A game that relies more on tactical-technical actions would be expected for females, compared to a more physical game played by males. However, it is important to note that studies aimed at performance analysis in female futsal are scarce in the literature, which makes it difficult to compare with our results.

Despite providing important evidence to the female elite futsal context, this study has some limitations. An important limitation is the context restriction, which imposes caution when generalizing the results. Another limitation concerns the number of evaluated athletes, since not all participants of the competition were analyzed due to difficulties imposed by some clubs. In addition, another limitation is that we evaluated only one national-level competition, not allowing the analysis of the RAE behaviour at different competitive levels. Thus, to overcome the limitations of the present study, we suggest that future investigations analyze more participants at different competitive levels. Additionally, analyzing the developmental pathway of each athlete may provide insightful information for futsal coaches and administrators.

The current research confirmed the absence of RAE among female futsal players according to the final classification of the teams and the tactical individual performance of the players. This conclusion was in line with a previous systematic review that suggested the absence of RAE in female futsal players. The present research suggests that RAE has no impact on this specific sport context, which should be faced as a positive factor since female futsal athletes seem to have the same chance of achieving the elite level in Brazil, regardless of their birthdates.

Based on our findings, Brazilian female futsal coaches should select athletes according to their technical and tactical performance rather than physical aspects, since the confound between biological maturation and sports talent is likely to favour relatively older athletes throughout sports development pathways (Peña-González, Fernández-Fernández, Moya-Ramón, & Cervelló, 2018; Peña-González, Javaloyes, Cervelló, & Moya-Ramón, 2022). Finally, in terms of practical applications, our results indicate that futsal coaches in charge of female teams in Brazil should invest a great deal of effort in developing all of their athletes' tactical capabilities, given the central role it plays in team sports and considering that RAE has no impact on performance for this population.

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200M BREASTSTROKE POST-COMPETITION BLOOD LACTATE REMOVAL CHARACTERISTICS: A CASE STUDY OF AN INTERNATIONAL FEMALE SWIMMER—AN EXAMPLE OF INDIVIDUAL MODELING IN RELATION TO POOL LENGTH

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Abstract:

The goal of this study was to define the individual model characteristics of lactic acid removal after 200m breaststroke competitive load in a female swimmer in relation to different pool lengths (25m vs. 50m). The second goal was methodological and referred to the presentation of newly applied metrological procedures for the Individual Lactate Recovery Profile modeling. Six races from the competitive season 2021/22 were selected, in which the athlete achieved the most valuable results in relation to the FINA score. To establish the metabolic response of the organism to the competition effort, the method of determining the level of lactate concentration in capillary blood (La in mmol/L) was used. Differences between the mean values of variables were established using ANOVA. The polynomial curve equation function was used to create a blood lactate concentration in a function of recovery time model (La-$t_{recovery}$). The ANOVA showed that there was no statistically significant difference between the monitored variables and the pool length function (p=.097). The maximum achieved blood lactate concentration in the acute race recovery phase was 13.17 ± 2.81 and 12.08 ± 1.80 mmol/L and the given concentration initially occurred in the time of 240.0 ± 85.6 s and 169.3 ± 79.9 s in the 25 and 50m pool, respectively. In relation to the time of complete passive recovery required to establish acidosis at the level of 2 mmol/L (25 and 50m pool) occurred in 1191.7 ± 481.3 s and 1326.7 ± 405.1 s, while the full index of intensity of blood lactate clearance was 135.7 ± 60.7 s/mmol/L and 124.0 ± 60.7 s/mmol/L for 25m and 50m pool, respectively, although no statistically significant difference was found between the parameters of recovery in relation to pool length. The offered mathematical models enabled a practical individual approach to controlling the specific adaptation to training for achieving a higher competitive level performance.

Key words: *swimming, adaptation, modeling, training control*

Introduction

In competitive swimming, especially when elite athletes are regarded, lactate tests are usually used not only to describe the level of current adaptation of athletes' metabolic performance, but also to define appropriate goals, intensity, and volume of training (Olbrecht, 2011). Considering the physiology of sports training and metabolic reactions of the body to training and competitive effort, lactate acid is one of the most studied metabolites in sports science (Åstrand, Rodahl, Dahl, & Stromme, 2003; Bishop & Martino, 1993; Bonifazi, Sardella, & Lupo, 2000; Bosquet, Léger, & Legros, 2001; Kachunov, 2018; Keskinen, Keskinen, & Mero, 2007). This is especially common in relation to cyclic-type of sports, such as swimming, running, cycling, triathlon, Nordic skiing, etc., where the intensity of physical exertion can be estimated via the blood lactate concentration (Baron, et al., 2008; Beneke, Leithäuser, & Ochentel, 2011; Greenwood, Moses, Bernardino, Gaesser, & Weltman, 2008; Menzies, et al., 2010). New field-testing equipment for determining the blood lactate concentration, due to a high reliability of the device in combination with improved standards of measurement procedures, has provided better objectivity and validity of assessing the training intensity by means of determining blood lactate concentrations of swimmers, and athletes overall (Hart, Drevets, Alford, Salacinski, & Hunt, 2013; Pelayo, Mujika, Sidney, & Chatard, 1996).

The system of swimming competitions is such that swimmers often participate in preliminary, semi-final and final races, or swim several different races per day, that is, the current competition format results in multiple races in one day. This may require swimmers to exert multiple maximal specific competition effort several times, i.e., to swim multiple races in a short period of time (Greenwood, et al., 2008). In this sense, the adaptive ability of optimal fast recovery is of crucial importance because it enables the swimmer to repeat high-competitive performance on daily bases. The preparation of swimmers (a traditional or an alternative concept, as well as the characteristics and types of the preparatory cycle) and the application of training strategies also depend on the mentioned number of daily races in the competition and on the individual swimmer's characteristics of recovery after the race. In other words, the training should be designed in a way to improve the swimmer's individual recovery profile by stimulating optimal specific adaptation to it (Issurin, 2016; Šiljeg, Sindik, & Leko, 2017).

Establishing a system for collecting information on the status of blood lactate concentration after typical workloads is important for optimizing training intensity in order to improve training efficiency and recovery monitoring practice (Pollock, et al., 2019). In this way, conditions will be provided for improving the metabolic adaptation of swimmers, which can have a direct positive effect on competitive performance (Dopsaj, Di Nino, Thanopoulos, & Kežman, 2018; Pyne, Lee, & Swanwick, 2001).

In the current practice of sports training of top-level swimmers, the method of measuring the concentration of lactic acid in the blood is commonly applied to achieve the following: to determine optimal work intensity in the process of aerobic and anaerobic capacity development (Costa, et al., 2013); in the process of training control, as a measure of metabolic load for all intensity zones (Anderson, Hopkins, Roberts, & Pyne, 2006; Dopsaj, et al., 2018; Pelayo, et al., 1996); as a control of training efficiency, for planning the next training cycles, and as a measure of the athlete's cumulative adaptation to the previously realized training cycles (Hooper, Mackinnon, & Ginn, 1998; Pyne, et al., 2001) at all stages of the competition (Greenwood, et al., 2008; Vescovi, Falenchuk, & Wells, 2011), as well as in the prevention of acute and chronic overtraining (Beneke, et al., 2011; Bosquet, et al., 2001; Pelayo, et al., 1996). An appropriate system of control of blood lactate concentration levels is, therefore, an important methodological procedure in assessing recovery after maximum loads, regardless of whether it is training, testing or competition (Beneke, et al., 2011; Dopsaj, et al., 2018; Greenwood, et al., 2008; Vescovi, et al., 2011).

It is a well-known fact that athletes generally adapt differently to the training process (Olbrecht, 2011). The given diversity is primarily caused by the individual metabolic characteristics of the person's body, but it also depends on the event and swimming styles (Gonjo & Olstad, 2021; Šiljeg, et al., 2017). Due to the mentioned diversity phenomenon, the characteristics of swimmers' recovery after acute maximal competitive load are also individually different (Greenwood, et al., 2008; Pelayo, et al., 1996; Pyne, et al., 2001; Vescovi, et al., 2011).

However, from the aspect of scientific methodology, the phenomenon of recovery has been examined only from the aspect of achieved metabolic acidosis of swimmers after the race and, in the context of the type of swim-out protocol, with the aim to define recovery efficiency (Greenwood, et al., 2008; Menzies, et al., 2010). The limited research in this area of swimming has tended to focus on passive out-of-water vs. active recovery by swimming and has found the active recovery to be better at reducing after-race metabolic acidosis (blood lactate) than the passive one (Lomax, 2012). Unfortunately, no fully methodological procedure or metrological standards have been established yet for complete structural analysis of the profile of blood lactate clearance as an acute recovery profile after a specific swimming competitive load. Developing the methodology of the procedure aiming at defining standardized scientific-applied-metrological data processing can provide new knowledge useful in sports science, in general, or it can provide specific procedures in terms of improving the technology of sports training in swimming (Maglischo, 2003; Šiljeg, et al., 2017). Also, knowledge and understanding of the results obtained by measuring the level of blood lactate concentration in relation to the dynamics of its change in the recovery after maximum competitive loads will provide conditions for individualized implementation or correction of training work, which will enable a more effective process of training individualization and optimization as a current approach to the technology of training work with top-level athletes (Anderson, et al., 2006; Bonifazi, et al., 2000; Carrard, Kloucek, & Gojanovic, 2020; Costa, et al., 2013; Gulbin, Croser, Morley, & Weissensteiner, 2013; Lomax, 2012; Šiljeg, et al., 2017).

The primary goal of this study was to define the individual lactate recovery profile (ILRP), i.e., individual model characteristics of blood lactate removal after competitive load of the best Croatian 200m female breaststroke swimmer in relation to different dimensions of the pool (25m vs. 50m pool). The secondary goal of the study was predominantly methodological and referred to the presentation of newly applied metrological procedures for the ILRP modeling.

Methods

The main method used in this research was the *ex-post-facto* method, while the field-testing method was used to collect experimental data (Ribeiro, et al., 2020). By nature, this research belongs to the applied ones, and was realized in accordance with the conditions of the Helsinki Declaration for Recommendations Guided by Physicians in Biomedical Research Involving Humans (http://www.cirp.org/library/etike /helsinki/).

Sample of variables

The following nine variables were used in the study:

1. La_Peak, a hypothetical equivalent of blood lactate concentration at the end of the race, or mathematically calculated lactate concentration in the first second after the race, expressed in mmol/L;
2. La_Max, a hypothetical equivalent of maximum blood lactate concentration in the passive recovery after a race, defined by mathematical modeling, expressed in mmol/L;
3. La_Max_time_1, the time point of recovery at which the hypothetical equivalent of the period with the maximum concentration of blood lactate begins after the race (La_Max), defined in seconds (s);
4. La_Max_time_2, the time point of recovery at which the hypothetical equivalent of the period with the maximum concentration of blood lactate ends after the race (La_Max), defined in seconds (s);
5. $La\_Max_{StedyState}$, time period of the maximum lactate concentration (La_Max) as a measure of the metabolic balance between the blood lactate production and blood lactate removal after the race, expressed in seconds (s);
6. La_Production_Int, a measure of the intensity of the lactate increment in the blood in the time interval from the end of the race to the beginning of La_Max_time_1, expressed in s/mmol/L;
7. La_Clearance_Int, a measure of the intensity of lactate removal from the blood in the time interval from the end of La_Max_time_2 to complete metabolic rest, i.e., to a lactate concentration of 2 mmol/L, expressed in s/mmol/L;
8. Full_rest_time_La2, the time interval of passive rest from the end of the race to complete metabolic recovery of the swimmer until the lactate concentration of 2 mmol/L, expressed in seconds (s);
9. Full_La_Clearance_Int, a measure of the intensity of full lactate removal from the blood in the time interval from the end of the race to complete metabolic rest, i.e., to a lactate concentration of 2 mmol/L, expressed in sec/mmol/L.

The sample of races and procedure for measuring blood lactate concentration

From the total sample of races swam in two consecutive competition seasons (2021 and 2022), six races were selected in which the monitored athlete achieved the most valuable results in relation to the FINA score (https://www.swimrankings.net). All races were swum in official competitions of FINA (World) and LEN (European Swimming Organization) in 25- and 50-meter pools (three for each pool length).

To measure the metabolic response of the organism to a specific competitive effort, the method of determining the level of lactate concentration in capillary blood (La in mmol/L) was used as a measure of acute metabolic acidosis (Bishop & Martino, 1993). For this purpose, in addition to sampling capillary blood, the exact time from the end of the race to each individual blood sample taken was measured. According to the applied procedure, the lactate concentration was measured from a sample of 0.2 μl of capillary blood taken from the finger at five time points of recovery: 3-, 5-, 7-, 10- and 15-minutes after the race (Dopsaj, et al., 2018). A Lactate Scout sensor blood lancet was used for blood sampling and lactate concentration was analyzed using a new generation portable lactate analyzer Lactate Scout 4 (EKF, Germany) (https://www.ekfdiagnostics.com/lactate-scout.html).

Statistical methods

All raw data were processed by descriptive statistical analysis for calculating basic statistical measures of central tendency (MEAN), absolute and relative dispersion of data – standard deviation (SD), coefficient of variation (%cV), and standard error of measurement (SEM) expressed in absolute and relative values. Differences between the mean values of the observed variables were established using the univariate analyses of variance (one-way ANOVA) with *post-hoc* multiple comparisons for the observed means of different swimming pool length post-race lactate recovery variables with corrections by Bonferroni criteria. The mathematical modeling method of applying the polynomial curve equation function was used to create an optimized individual model of the relation between the blood lactate concentration in the function of recovery time (absolute values: $La\text{-}t_{recovery}$, and relative values: $\%La\text{-}\%t_{recovery}$) (Dopsaj, et al., 2018; Pajić, Simović & Dopsaj, 2021). The statistical significance level was determined at the level of 95% of probability at the criterion of $p \leq .05$, while the IBM SPSS v23.0. software program was used for all statistical analyses (Hair, Anderson, Tatham, & Black, 1998).

Results

Table 1 shows the results of descriptive statistics as well as the differences between the analyzed variables of blood lactate concentration during recovery after swimming in different pools (25m and 50m). The ANOVA showed that there was no partial statistically significant difference between the monitored lactate recovery variables in the function of the pool length.

Based on the results (Table 1), the analyzed female swimmer's 200m breaststroke race in the 25m pool on average ended at the level of a metabolic acidosis of La_Peak = 10.95 ± 0.55 mmol/L, where the average race result was 808.7 ± 12.6 FINA points, i. e., with an average result of 2:24.43 ± 0:01.17 min:sec:hundred (swimming speed of 1.385 ± 0.007 m/s).

Considering the 50m-pool post-race recovery metabolic characteristics (Table 1), the analyzed swimmer on average ended a 200m breaststroke race at the metabolic acidosis of La_Peak = 11.62 ± 2.79 mmol/L, where the average race result was at 767.0 ± 19.3 FINA points, i.e., with an average result of 2:31.95 ± 0:01.27 min:sec:hundred (swimming speed of 1.316 ± 0.011 m/s).

The average value of the 25m-pool maximum blood lactate concentration (La_Max) after the race, in the acute recovery phase, was 13.17 ± 2.81 mmol/L and the given concentration occurred after the time span of 4:00.0 ± 1:25.6 and ended in 5:39.0 ± 1:44.5, i.e., the maximum lactate steady state lasted 1:39.0 ± 0:33.9 (min:sec:hundred, respectively) (Table 1).

After the 50m-pool race, the average value of the maximum blood lactate concentration (La_Max) in the acute recovery phase was 12.08 ± 1.80 mmol/L and this concentration occurred in 2:49.3 ± 1:19.9 after the race and ended in 5:11.3 ± 0:51.9, i.e. the, maximum lactate steady state lasted 2:22.0 ± 0:30.3 (min:sec:hundred,respectively) (Table 1).

In relation to the 25m-pool race, it was established that the average value of the index of intensity of blood lactate production (La_Production_Int) was 247.9 ± 135.0 s/mmol/L (production of 1 mmol/L lactate in the function of time, i.e., per 4:07.9 ± 2:15.0 min:sec:hundred), while the lactate removal on average occurred at an intensity of 78.7 ± 60.7 s/mmol/L (removal of the concentration of 1 mmol/L lactate as the function of time, i.e., per 1:18.7 ± 1:00.7 min:sec:hundred), i.e., from the La_max until the level of 2 mmol/L as the selected reference point of full metabolic rest. Considering the 50m-pool race, La_Production_Int was 288.3 ± 158.8, while lactate removal occurred on average with an intensity of 75.8 ± 12.1 s/mmol/L, respectively.

In relation to the time of complete passive recovery required to restore acidosis of 2 mmol/L, it was determined that it was at the level of 19:51.7 ± 8:01.3 and 22:06.7 ± 6:45.1 (min:sec:hundred), while the full index of intensity of blood lactate clearance (Full_La_Clearance_Int) was 135.7 ± 60.7 s/mmol/L (2:15.7 ± 1:00.7 min:sec:hundred) and 124.0 ± 60.7 s/mmol/L (2:04.0 ± 1:00.7 min:sec:hundred) for 25m and 50m pool (Table 1), respectively.

Figure 1 shows the defined models of blood lactate concentration-recovery rate (La-$t_{recovery}$) for the female swimmer A.B., and for the analyzed 200m breaststroke races in the 25m and 50m pools in 2021 and 2022 competition seasons considering absolute results. For the 25m pool, the obtained model of the polynomial model equation has the following form:

$$y = (-0.000013 \cdot X^2) + (0.004990 \cdot X) + 11.624929 \quad (1)$$

where y is blood lactate concentration, expressed in mmol/L, and X is time in post-race rest, expressed in seconds.

Table 1. Descriptive statistics in the function of determining recovery characteristics

Pool	25m pool				50m pool				ANOVA	
Variables	MEAN±SD	cV%	SEM (Abs.)	SEM (Rel.)	MEAN±SD	cV%	SEM (Abs.)	SEM (Rel.)	F	p
FINA_points	808.7±12.6	1.6	7.3	0.9	767.0±19.3	2.5	11.1	1.4	9.820	0.035
La_Peak (mmol/L)	10.95±0.55	5.0	0.32	2.9	11.62±2.79	24.0	1.61	13.9	0.172	0.700
La_Max (mmol/L)	13.17±2.81	21.3	1.62	12.3	12.08±1.80	14.9	1.04	8.6	0.036	0.858
La_Max_time_1 (sec)	240.0±85.6	35.7	64.9	27.0	169.3±79.9	47.2	52.9	31.2	0.131	0.735
La_Max_time_2 (sec)	339.0±104.5	30.8	75.8	22.4	311.3±51.9	16.7	47.7	15.3	0.020	0.895
$La\_Max_{SteadyState}$ (sec)	99.0±33.9	34.2	19.6	19.8	142.0±30.3	21.3	17.5	12.3	2.685	0.177
La_Production_Int (sec/mmol/L)	247.9±135.0	54.5	77.9	31.4	288.3±158.8	55.1	91.7	31.8	0.078	0.793
La_Clearance_Int (sec/mmol/L)	78.7±60.7	77.1	17.0	21.6	75.8±12.1	16.0	7.0	9.2	0.113	0.754
Full_rest_time_La2 (sec)	1191.7±481.3	40.4	277.9	23.3	1326.7±405.1	30.5	68.3	5.1	0.025	0.882
Full_La_Clearance_Int (sec/mmol/L)	135.7±60.7	44.7	35.1	25.9	124.0±41.3	33.3	23.8	19.2	0.075	0.797

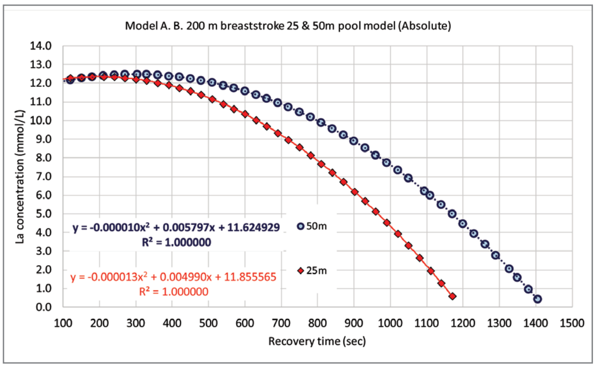

Figure 1. Defined models of the blood lactate concentration-recovery rate (La-$t_{recovery}$) dependence on the pool length (absolute values) for the swimmer A.B.

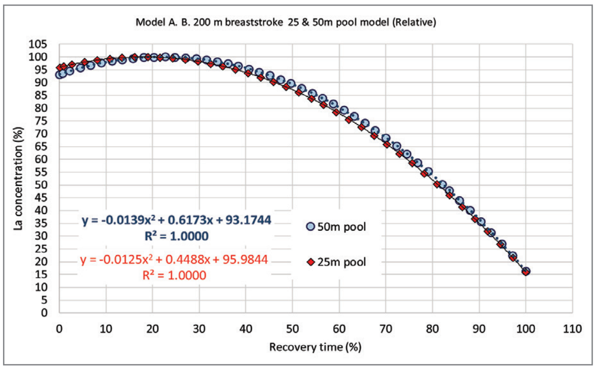

Figure 2. Defined models of the blood lactate concentration-recovery rate (La-$t_{recovery}$) dependence on the pool length (relative values) for the swimmer A.B.

The equation 1 had a high statistically significant power of explaining the variance (100.0%; $R^2 = 1.000$, p=.000).

For the 50m pool, the obtained model of the polynomial equation has the following form:

$$y = (-0.000010 \cdot X^2) + (0.005797 \cdot X) + 11.624929 \quad (2)$$

where y is blood lactate concentration, expressed in mmol/L, and X is time in post-race rest, expressed in seconds.

The equation 2 also had a high statistically significant level of explaining the variance at 100.0% ($R^2 = 1.0000$, p=.000).

Figure 2 shows the defined models of blood lactate concentration-recovery rate (La-$t_{recovery}$) for the analyzed swimmer A.B. in relation to the relativized curve values [La (%) – $t_{recovery}$ (%)], both expressed in %. For the 25m pool, the polynomial model equation has the following form:

$$y = (-0.0125 \cdot X^2) + (0.4488 \cdot X) + 95.9844 \quad (3)$$

where y is post-race lactate concentration expressed in %, and X is time in post-race recovery expressed in %, and with a high statistically significant level of explaining the variance at 100.0% ($R^2 = 1.0000$, p=.000).

For the 50m pool, the polynomial equation model has the following form:

$$y = (-0.0139 \cdot X^2) + (0.6173 \cdot X) + 93.1744 \quad (4)$$

where y is post-race lactate concentration expressed in %, and X is time in post-race recovery expressed in %, and also with a high statistically significant level of explaining the variance at 100.00% ($R^2 = 1.0000$, p=.000).

In relation to the defined model of relative values of La (%)-$t_{recovery}$ (%) (Figure 2), it was found that the swimmer in the analyzed seasons finished races on metabolic acidosis at 93.17 and 95.98% of La_Max, and that the value of maximum metabolic acidosis La_Max reached 22.8 %, or 19.1% of the time required for complete metabolic recovery down to 2 mmol/L, for 50m and 25m pool, respectively. Half (50.0% of La_Max) of metabolic acid recovery was achieved in the time interval of 82.4% (1094 s or 17:54.0), or 81.2% (902 s or 15:02.0).

Discussion and conclusions

The results shown in the research belong to the metrological presentation of applied statistical and mathematical methods in determining the dependence of blood lactate concentration and recovery rates in individual absolute and relative model for swimmer A.B. in relation to the analyzed 200m breaststroke races in the 25m and 50m pools for the 2021/2022 competition season. Although no statistically significant difference was found between the analyzed metabolic variables, descriptive as well as model characteristics were determined for the purpose of an individual approach to training efficiency control and metabolic adaptation for the monitored athlete.

Based on the results (Table 1) it can be concluded that the analyzed female swimmer's 200m breaststroke race in the 25m and 50m pool on average ended at the level of a metabolic acidosis of La_Peak = 10.95 ± 0.55 mmol/L and 11.62 ± 2.79 mmol/L, respectively.

The average value of the 25 and 50m-pool maximum blood lactate concentration (La_Max) after the race, in the acute recovery phase, was 13.17 ± 2.81 mmol/L and 12.08 ± 1.80 mmol/L, respectively (Table 1).

The measured maximum blood lactate concentrations are in line with the previously published studies for 200m breaststroke female senior swimmers because they are in the range between 11.0 and 13.0 mml/L, which was determined for Canadian swimmers (Vescovi, et al., 2011), almost the same as for the Bulgarian swimmers (12.89±2.29; Kachunov, 2018), which proves the external validity of the current results. Also, the results of the present study confirmed a previously established fact that, after races in the Olympic pool (50m) compared to races in short pools, swimmers have higher metabolic lactate acidosis by about 14.9% (Lowensteyn, Perry, Nash, & Salhanick, 1994), or 6.12%, as shown by the results of our study.

Based on the results shown in Table 1, it can be concluded that the highest level of coefficient variation (cV%) but also relative measurement errors (SEM rel) have the variables La_Clearance_Int 25m pool and La_Production_Int 50m pool (54.5 and 31.4%, and 55.1 and 31.8 %, respectively), which is certainly an indication that the given variables can be sensitive markers of the acute state of adaptation of athletes. In relation to the time of complete passive recovery required to restore acidosis of 2 mmol / L, it was determined that it was at the level of 1191.7 ± 481.3 (19:51.7 ± 8:01.3 min:sec:hundred) and 1326.7 ± 405.1 seconds (22:06.7 ± 6:45.1 min:sec:hundred), while the full index of intensity of blood lactate clearance (Full_La_Clearance_Int) was 135.7 ± 60.7 sec/mmol/L (2:15.7 ± 1:00.7 min:sec:hundred) and 124.0 ± 60.7 sec/mmol/L (2:04.0 ± 1:00.7 min:sec:hundred) for 25m and 50m pool (Table 1), respectively.

Pelayo and co-workers (1996) found that the intensity of lactate removal from the blood can be an efficient marker for monitoring the impact of aerobic and anaerobic training for the purpose of avoiding overtraining in elite 200m swimmers. Also, Greenwood and co-workers (2008) concluded that in after-race situations swimmers must have more than 10 minutes to recover. They found that 10 minutes of passive recovery reduced blood lactate from 9.2 to 7.1 mmol/L, which only suggests that a considerable recovery time would be required for the restoration of baseline blood lactate values. In our research, we found that for complete recovery (down to acidosis of 2 mmol/L) with a passive approach the examined athlete needed from 1191.7±481.3 to 1326.7±405.1 seconds (19:51.7 till 22:06.7 min:sec:hundred), for the 25m and 50m pool, respectively.

In the only study available, in which there was some quantification of post-race lactate clearance, the authors found that the given ability was at the level of 0.18±0.17 for passive and 0.43±0.17 mmol L/min for active recovery after swimming the 200m crawl (Rabelo Mota, et al., 2017). However, as they used a completely different method of calculating the given recovery variables, comparing their results with the current ones is not possible.

The ANOVA results showed that no statistically significant difference was found between the monitored metabolic recovery variables as the function of pool length at the partial level (Table 1, from La_MaxSteadyState - F = 2.685, p=.177, to La_Max_time_2 - F = 0.020, p=.895). The only difference was found between the levels of FINA points (Table 1; 808.7 vs. 767.0 points; the difference of 5.43%, F = 9.820, p=.035), which was expected because swimmers on average have better results in 25m compared to 50m pools by about 4.5% (Keskinen, et al., 2007).

In relation to the defined model of relative values of La (%)-$t_{recovery}$ (%) (Figure 2), it was found that the swimmer in the analyzed seasons finished races on metabolic acidosis at 93.17 and 95.98% of La_Max, and that the value of maximum metabolic acidosis - La_Max reached 22.8 %, or 19.1% of the time required for complete metabolic recovery down to 2 mmol/L, for 50m and 25m pool, respectively. Half (50.0% of La_Max) of metabolic acid recovery was achieved in the time interval of 82.4% (1094 s or 17:54.0), or 81.2% (902 s or 15:02.0).

High homogeneity of competitive performance (FINA_Score, 1.6 vs. 2.5%, Table 1) and analyzed metabolic parameters of recovery (La_Peak and La_Max, from 5.0 until 24.0%), and low homogeneity in other variables of time parameters (La_Max_time_1, La_Max_time_2, $La\_Max_{SteadySate}$, La_Production_Int, La_Clearance_Int, Full_rest_time_La2, and Full_La_Cearance_Int) can be explained by the fact that the athlete is in the category of swimmers with a competitive achievement of about 800 FINA_points, which denotes top-level swimmers (swimmers competing at a European and World Championships). In other words, in relation to achieved swimming results, a small variation in competitive performance indicates highly developed and stable physiological, physical, technical, tactical and competitive performance abilities of the observed swimmer.

The athlete was followed over a period of the annual macrocycle (March 2021—March 2022), where she completed different phases of preparation, i.e., she participated in races at different preparatory stages (Bonifazi, et al., 2000). In other words, the athlete participated in the competitions while being in different states of cumulative fatigue, i.e., in heterogeneous states of adaptation to different types of training, which means in different phases of fatigue and rest as different functional parts of the training annual cycle (Hooper et al., 1998; Pelayo, et al., 1996).

Comparing the intensity of blood lactate increase with the intensity of blood lactate decrease, it can be stated that A.B. should also work on the development of aerobic capacity, i.e., on faster removal of blood lactate in order to be ready for the next race as soon as possible and in order to maintain the efficiency of swimming to the last meter. The offered mathematical models enable a practical individual approach as a function of specific adaptation control of the effects of training for the purpose of achieving a higher competitive performance expressed in FINA points.

Finally, the obtained results, as the function of the innovative metrological procedure of monitoring the given phenomenon, important in the control system of training efficiency and the level of adaptation achieved by top-level swimmers, have a scientific and comparative practical value. The development of analytical methods in the function of improving sports scientific methodology for the purposes of achieving top sports results in swimming is one of the bases of the progress of the high-performance training system.

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THE POSSIBILITY OF PREDICTING THE PERFORMANCE OF ADVANCED SKI ELEMENTS BASED ON THE PERFORMANCE OF BASIC SKI ELEMENTS

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Abstract:

The aim of this research was to predict the success of the performance of advanced ski elements based on the level of performance of basic ski elements, with the ultimate purpose of improving training programmes for alpine ski beginners. The sample of participants consisted of 250 students of the Faculty of Kinesiology University of Zagreb who attended their mandatory classes of the university study subject of Skiing in the academic year 2021/22. The sample of variables consisted of the grades the students earned for their performance of four exam elements, two basic ski elements and the other two belonging to the advanced ski elements group. The basic ski elements were uphill turn (UT), for which the mean of two grades was taken for further analysis due to its performance to both sides – left and right, and snowplough turn (SPT). Advanced ski elements were parallel turn (PT) and short turn (ST). Besides descriptive statistics for each variable, two ordinal logistic regression models were constructed for determining the relationship between the performance of short turn based on the level of performance of snowplough turn, on the one hand, and on the other, between the performance of parallel turn based on the performance of uphill turn. The results of the first ordinal logistic regression analysis (short turn performance based on snowplough performance) showed the existence of a statistically significant linear association of the two ski elements performance (b=2.15, SE=0.72, p=.03). Similar results were obtained in the second ordinal logistic regression analysis for the other pair of ski elements (parallel turn performance based on uphill turn performance): b=2.36, SE=0.24, p<.001. Well acquired dynamic motor stereotypes, reflected in good performance of basic ski elements, are the basis for good performance of advanced ski elements, therefore skipping any step in the teaching process based on progression could have a negative impact on achieving the desired goals.

***Key words**: ski skills, training methodology, ski elements, ski learning*

Introduction

The teaching of alpine skiing is at the same time simple as well as a complex process the success of which depends on several factors. On one hand, there is a ski beginner, with the disposition of his/her motor abilities, and his/her expectations regarding the level of ski knowledge he/she wants to achieve. On the other side is the ski instructor who must adjust his/her instruction programme to the set requirements (Mladenović, Cigrovski, Stanković, Prlenda, & Uljević, 2015). The greater the requirements put up by the ski beginner, the more demanding the teaching process in which the instructor aims to teach his/her trainee basic ski knowledge to the highest level by leading him/her to adopting and mastering the elements through a great number of repetitions and then testing the learned in simpler and more complex situations characterised by ever greater dynamics (Scheiber, Seifert, & Müller, 2011). The instructor's experience in teaching, more precisely his/her knowledge of methodological procedures, appears to be an important factor for the success of the entire process. Choosing the exact specific exercises for the group or the individual at the right moment is what makes a teacher a good methodologist and therefore good at his/her job. According to Aćimović, Joksimović, Petković, and Stanković (2010) and Burtscher, Federolf, Nachbauer, and Kopp (2019), skiing is suitable as a recreational activity for people of almost all ages within their capabilities and ski knowledge provided the proper dosage of intensity and workload is being applied. Nowadays, there are more than 80 million people engaging in skiing and snowboarding, making them one of the most widespread leisure-time activities (Thiel, et al. 2009).

Skiers, skiing down the slopes, use the synergy of their motor abilities and acquired ski knowledge, or skill, to steer the skis. There are several ski techniques, but ski beginners will encounter two basic techniques in their training—the snowplough and the parallel technique (Cigrovski, Matković, B., & Matković, B.R., 2010). Also, they will be taught by means of three ski learning programmes: basic, advanced, and competitive. The programme names are generally accepted in the world, and they imply progressive mastering of the ski elements according to their complexity—from the simplest to more complex ones. The simpler elements are performed on easier slopes at a low speed. Beginners then gradually transit to the acquisition of more complex elements on steeper slopes with respective increases in the movement speed (Matković, Ferenčak, & Žvan, 2004). Progressivity of the basic three elements of the Slovenian national alpine ski teaching programme was tested in research by Lešnik, Žvan, Leskošek, and Supej (2013). The elements (wedge curves, turns with a wedge push off and basic swinging) showed to be placed correctly in terms of progressivity in time durations of individual turns and their phases.

There are three different approaches to learning alpine skiing—the conventional, combined, and direct one (Lešnik & Žvan, 2010). The conventional approach, also known as traditional, uses a great number of exercises for acquiring skiing skills accompanied by a large number of corrective exercises. The mentioned approach is intended for ski beginners and recreational skiers of all levels of motor abilities and prior ski knowledge. It also represents the longest-lasting way of teaching, and it implies the use of both the snowplough and parallel ski technique in exactly specified training phases. Next, the combined approach uses fewer exercises for acquiring skiing skills than the previous one, which makes it a faster way of teaching. This approach is intended for ski beginners with more developed motor abilities, and it uses the combination of the snowplough and parallel technique regardless of the teaching phase. Finally, the direct approach uses the least number of exercises and therefore represents the fastest way of teaching. It is intended for beginners with high motor potential and implies avoidance of the snowplough technique; it only uses the parallel technique. The most widespread approach in the alpine ski training process is the conventional, or traditional, one. Moreover, research performed with college students by Božić, Cigrovski, Očić, Bon, and Škovran (2019) showed that the performance of ski elements correlates with the overall travelled distance on skis, i.e., the greater distance travelled results in a greater number of ski turns, which enables the better acquisition of ski knowledge.

In addition, motor abilities as well as psychological characteristics of a skier influence the learning process and final success and should therefore be considered and improved during preparation for alpine skiing (Božić, Cigrovski, Bošnjak, Jakovljević, & Tešanović, 2017; Cigrovski, Božić, & Prlenda, 2012; Cigrovski, Matković, & Ivanec, 2008; Cigrovski, Matković, B., & Matković, B.R., 2008; Cigrovski, Radman, Konter, Očić, & Ruzic, 2018; Čillík & Razusova, 2014; Joksimović, D., Joksimović, A., & Stanković, 2010).

Research papers on teaching methodology of alpine skiing, i.e., on ways how to improve the alpine skiing learning process for ski beginners, are scarce. Therefore, the aim of this research was to gain insight into the possibility of predicting the level of performance of advanced ski elements based on the level of performance of basic ski elements, with the ultimate purpose of improving training programmes for ski beginners. The hypothesis was that a good level of basic ski elements performance, expressed as high grades ski experts awarded to students' performances, would manifest in a good performance level of advanced ski elements. If the hypothesis is going to be confirmed, it would help to expand methodological approaches to the teaching of alpine skiing by emphasizing the significance of a good basic ski elements skill/performance for the acquisition of advanced ski elements. This would imply that, in the practice of ski teaching, basic ski elements should not be superficially introduced just to move forward in teaching, but rather practiced in different situational conditions to the highest level of proficiency. In later stages of the ski teaching/learning process, they should also be continuously used as a teaching tool not just for mastering the advanced ski elements, but also for corrections in their performance.

Methods

Sample of participants

The sample of participants consisted of 250 students (22.8±1.14 years) of the Faculty of Kinesiology University of Zagreb who attended their regular classes of the university study subject of Skiing in the academic year 2021/22. Among the participants, 110 had some previous knowledge of skiing, and the rest were genuine beginners. They were all taught by the same ski programme. At the Faculty of Kinesiology University of Zagreb, Skiing is a mandatory course in the third year of the undergraduate university study, which is delivered as a conventional teaching programme lasting 10 days. In that period students are introduced to snowplough and parallel ski techniques, and through them they master the basic and advanced ski programme.

Sample of variables

The sample of variables consisted of the grades the students earned for their performance of four ski elements constituting the exam. Two ski elements belong to the alpine skiing basic skills, and the other two were from the advanced level. The basic ski elements were uphill turn (UT), for which the mean of the two grades was taken for data analysis due to its performance to both the left and right side; and snowplough turn (SPT). The advanced ski elements were parallel turn (PT) and short turn (ST). The students' performances were evaluated on a seven-point scale (2, 2.5, 3, 3.5, 4, 4.5, 5), where 2 meant satisfying and 5 excellent performance. Six judges were the university subject teachers and their expert associates with many years of experience in the field. All the students demonstrated their ski skills on the same slope. Each ski element was executed on a suitable terrain configuration. The judges were grading each student's performance while standing below him/her so they could see his/her execution up front, from the side and then from behind as he/she passed them by.

Statistical analysis

For each variable, the basic parameters of descriptive statistics were calculated (arithmetic mean, standard deviation, minimum and maximum value). Since the dependent variables (short turn and parallel turn) were expressed on an ordinal level and the independent variables (snowplough and uphill turn) were either continuous or ordinal, the assumptions of running an ordinal logistic regression were met. As there was only one independent variable included in every model, the assumption of no multicollinearity was not tested. Further data processing was done by two ordinal logistic regression models: one was used for determining the relationship of performance of the short turn based on the level of snowplough turn grade and the other for determining the performance of the parallel turn based on the uphill turn grade. The assumption of proportional odds was tested by the BRANT (Schlegel & Steenbergen, 2020) package. Even though the assumption of proportional odds did not hold (p=.01), it was argued that relaxing this assumption by fitting a multinomial logistic model or a partial proportional odds model is not always needed (Harrell, 2022a, 2022b, 2022c). The results of proportional odds models are meaningful even when the assumption of proportional odds is violated (Harrell, 2022a, 2022b, 2022c). Therefore, ordinal logistic regression models were kept and their results were interpreted through odds ratios (OR) and their corresponding 95% confidence intervals (CI).

Statistical analysis was carried out in RStudio ordinal logistic regression models constructed using the MASS (Venables & Ripley, 2002) package, and the ggplot2 (Wickham, 2016) package was used for visualizing the results. The alpha level of the statistical tests was set at .05.

Results

The results of basic descriptive statistics for the grades the students earned for their performances of four ski elements are shown in Table 1.

A stacked bar plot and a boxplot were constructed to visualize patterns of grades earned by the students for their performance of the advanced alpine ski elements based on the grades received for their performance of basic alpine ski elements (Figures 1 and 2).

The results of the ordinal logistic regression analysis for determining the relationship between the short turn performance based on the snowplough performance are shown in Table 2.

The results show that better performance of short turn depends linearly on the success in snowplough turn execution (p=.03), but no significant quadratic (p=.49) or cubic (p=.56) effects are present.

The results of the second ordinal logistic regression analysis for determining the relationship between the parallel turn performance based on the uphill turn performance to both sides (in the analysis the arithmetic mean of the left and right uphill turn was used) are shown in Table 3.

The ordinal logistic regression model results also show a statistically significant association (B=2.36, SE=0.24, p<.001).

Table 4 was constructed to present ORs and their corresponding 95% CI from both ordinal logistic regression models.

Based on the linear association between the success in the execution of snowplough and short

Table 1. Descriptive statistics of grades the students earned for their performance of ski elements

Variable	N	Mean±SD	Min	Max
UT	250	4.10±0.67	2	5
SPT	250	4.23±0.78	2	5
PT	250	3.83±0.79	2	5
ST	250	3.90±0.94	2	5

Note. N: number of participants; SD: standard deviation; Min: minimum value; Max: maximum value; UT: uphill turn; SPT: snowplough turn; PT: parallel turn; ST: short turn.

Table 2. The ordinal logistic regression results of the relationship between snowplough and short turn

	B	SE	t-value	p-value
Linear SPT	2.15	0.72	2.97	.003*
Quadratic SPT	0.49	0.68	0.72	.47
Cubic SPT	0.34	0.58	0.58	.56

Note. B: beta coefficient; SE: standard error; *significant at p<.05; SPT: snowplough turn.

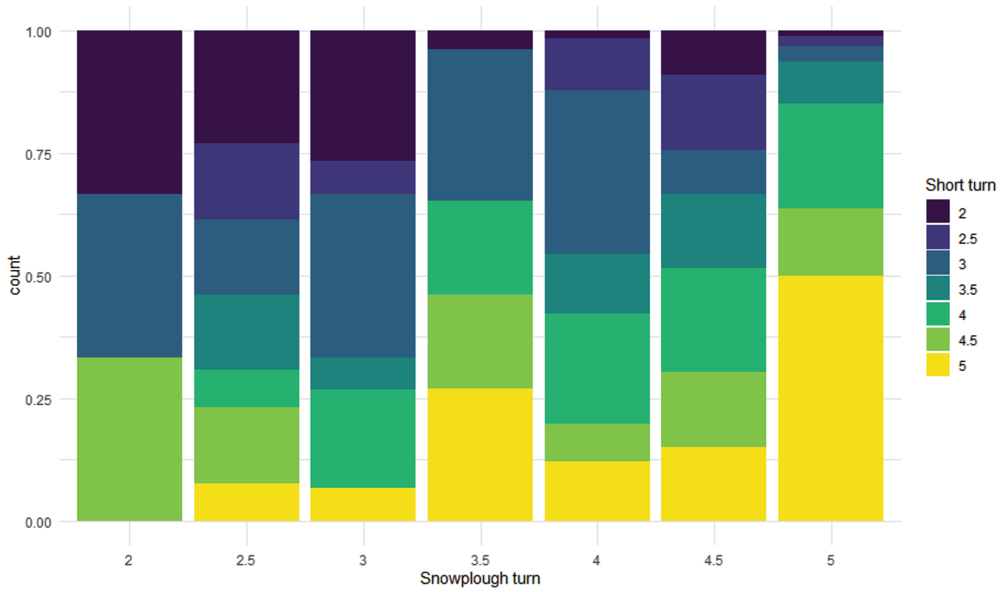

Figure 1. A pattern of grades the students earned for their performance of short turn based on the snowplough turn grades.

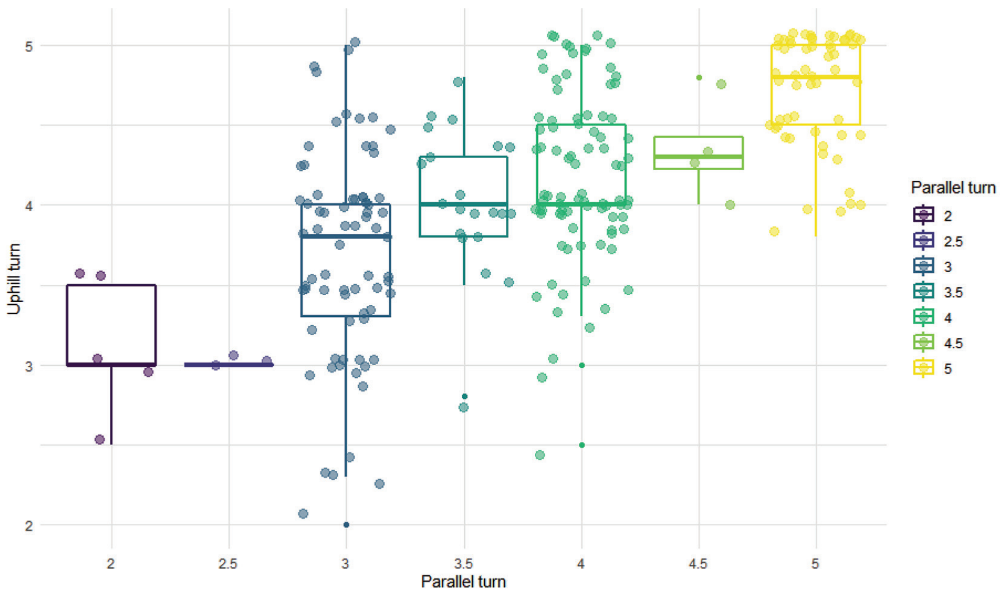

Figure 2. A pattern of grades the students earned for their performance of parallel turn based on the uphill turn grades.

Table 3. The ordinal logistic regression results of the relationship between uphill and parallel turn

	B	SE	t-value	p-value
UT	2.37	0.24	9.77	.000

Note. B: beta coefficient; SE: standard error; *significant at p<.05; UT: uphill turn.

Table 4. Odds ratios and their corresponding 95% confidence intervals from both ordinal logistic regression models

	OR	Lower 95% CI	Upper 95% CI
Linear SPT	8.57	2.10	37.44
UT	10.67	6.73	17.43

Note. OR: odds ratio; CI: confidence interval; *significant at p<.05; SPT: snowplough turn; UT: uphill turn.

turn, for the students who were more successful in snowplough turn, the odds of being more successful in performing short turn were 8.57 times that of the students who were less successful in performing snowplough turn.

Furthermore, for every unit increase in students' uphill turn evaluation, the odds of being successful in the parallel turn were multiplied 10.67 times.

Discussion and conclusions

The main findings on both pairs of ski elements confirmed our hypothesis that ski beginners with a good level of knowledge of basic ski elements would perform better in advanced ski elements. Skiing is a biomechanically determined activity in which more complex elements are built on simpler ones by the movement structure (Cigrovski, et al., 2010). The final manifestation is different, but at the same time, the ski steering mechanisms are completely identical. It follows that the biomechanical structure of ski steering in a snowplough and short turn is the same, which seems somewhat surprising at first glance (Matković & Ferenčak, 1996; Matković, et al., 2004). All movements existing in simple ski elements are also present in more complex ones, with a difference in their performance during a longer or shorter time interval. Therefore, in more complex ski elements, a skier will do all those movements in a much shorter time interval, which makes them biomechanically more complex and more demanding (Matković, et al., 2004; Kim, J.H. & Kim, J.N., 2017). The research aiming at determining the kinetic and kinematic differences between short and parallel turns confirmed a higher complexity of the short turn by analysing certain kinetic and kinematic parameters (Bon, Očić, Cigrovski, Rupčić, & Knjaz, 2021). The short turn is normally taught at the very end of an alpine ski training, after the parallel turn, and the mentioned research justifies that common practice in terms of the progression principle. The parallel turn is mostly used by recreational skiers to ski downhill because it offers an intermediate skier both a sense of security and pleasure (Cigrovski, et al., 2010). It is also used on intermediately steep slopes and in a wider corridor, which enables the skier to do all the necessary movements in a shorter time interval. The short turn is used on much steeper slopes; it is the most dynamic element of the alpine ski learning programme and, therefore, demands the skier to do the same movements much faster (Cigrovski, Rupčić, Bon, Očić, & Krističević, 2020). All the mentioned certainly makes the short turn more demanding and challenging in terms of maintaining body balance (Cigrovski, Matković, B., & Prlenda, 2009; Lešnik, Glinšek, & Žvan, 2015; Vaverka, Vodickova, & Elfmark, 2012). Nevertheless, despite the difference in complexity of the ski elements, the ski steering mechanisms, such as the circular knee function, the correct timing of the movements along all axis, and pressure on the outer ski, are still the same in each of them (Matković, et al., 2004). It is exactly because of the stated that statistically significant association could be explained. In other words, a ski beginner who has earned a high grade for his/her performance of a basic ski element, the snowplough in this case, will probably get a high grade for the performance of a more advanced ski element, the short turn in this research. The association of these two elements is perhaps most evident in the outer leg knee function and its circular motions that steer the skis actively into a turn (Matković & Ferenčak, 1996.; Matković, et al., 2004). Without these circular motions in the knee joint, there is no proper turn on the outer ski (Matković, et al., 2004). Surely the movements that lead to a turn are more complex than just the knee movement, but it is certainly the most important one. So, acquiring the proper knee movement at the very beginning of the ski training process is essential for all further ski element learning. The snowplough is precisely the first ski element where a ski beginner will get to know and learn the mentioned movements that he/she will then later use in the performance of all other ski elements, in different time intervals and corridors. Therefore, it could be said that the basis for successful short turn performance is good knowledge and performance of the snowplough turn with an active knee function (Falda-Buscaiot, Hintzy, Rougier, Lacouture, & Coulmy, 2017).

Omitting the learning of the snowplough turn from the ski learning process of ski beginners, with the goal of faster ski knowledge transfer, was the subject of research done with 126 university students (Cigrovski, et al., 2010). One group of students was taught using the parallel technique exclusively, while in the other group the teaching method combined the snowplough and parallel ski techniques. The participants were graded in five ski elements and the results showed statistically significant higher grades in short and parallel turns of the group taught by the combination of the two techniques. In the conclusions of the stated research higher grades of the group taught by the combination of techniques were attributed to a better adoption of basic ski knowledge, which is important in the later stages of ski training. Based on the obtained results, the authors stated that in the ski beginner training process it was more efficient to use both the snowplough and parallel techniques. These conclusions support the observations of our research based on biomechanical similarities and assumed relationship among all ski technique elements. Also, the greater variety of alpine ski movement, i.e., knowing as many ski techniques as possible, enriches the skier in terms of motor skills, which allows him/her to perform more safely and efficiently in all situational conditions. Skiing in different weather conditions, slope conditions, and off-road skiing, certainly requires the aforementioned (Hebert-Losier, Supej, & Holmberg, 2014).

However, research by Nurković, Kovač, and Idrizović (2011) came to different conclusions regarding the technique used for gaining better results in the adoption of ski knowledge. The research was also done with college students who were ski beginners divided into two groups. One group was taught by the “classical” method of alpine ski learning and the other by the “direct” method. The “direct” method implied learning ski elements without introducing the snowplough technique to the participants. The results showed the "direct" approach to be more efficient in the alpine ski learning process.

As for the other pair of the observed ski elements, uphill and parallel turn, similar conclusions can be made. Here, the relationship is even more emphasized since the uphill turn is an integral part of the parallel turn, or its final part, to be more exact. The accuracy of the stated is confirmed by a higher association obtained in the regression analysis results (Beta=0.75) of these two elements in comparison to the previous two. A less manifested association in some elements, as is the case in the previous two, lies in certain specificities of some ski elements, such as skies in the snowplough or parallel position, which can influence the association results. However, it is to be assumed that the relationship will exist among all ski elements, because successful ski steering in any one of them is the product of identical steering mechanisms, respecting already mentioned specificities of each ski element.

Limitations of this research may lie in the fact that the participants were students of kinesiology who were certainly a preselected group of people in terms of their motor abilities. Some, if not most of them, besides having a good level of motor and functional abilities, have also had previous experience in various sports. The fact that the students were not complete beginners could have impacted the results, although experience shows that sometimes it tends to be more challenging to correct automated wrong motor patterns than to teach them from the beginning (Shadmehr, Smith, & Krakauer, 2010). Also, the objectivity of judges when evaluating the students was not tested, although they had years of experience in grading generations of students. All the mentioned factors could have influenced the results so future research on similar topics should include as many in our research disregarded factors as possible to draw conclusions more accurately.

The teaching of alpine skiing, transferring the ski knowledge, as with any other specific motor knowledge, is based on the principle of gradual progression or learning from simpler to more advanced elements. In skiing, the stated means performing simpler elements on less steep ski slopes under slower movement dynamics at first, and then gradually transferring onto steeper slopes with increasing dynamics. The next step in the process includes learning more advanced elements on much steeper slopes followed by their testing in different situational conditions, with ever-increasing movement dynamics. For the ski beginner to reach that high level of ski motor knowledge will require a lot of time, patience, and practice in the utilitarian exercises that should be repeated an adequate number of times to satisfy the work volume, all under permanent control and correction by the teacher. Good knowledge and good performance of basic ski elements are the basis for successful performance of advanced ski elements, while skipping or bypassing any step in the teaching process based on progression could have a negative impact on achieving the desired goals. This research is valuable for ski instructors as it points out the importance of mastering basic ski elements in various situational conditions. Based on our results, it is suggested that all basic ski elements are used throughout all stages of alpine ski training as a form of didactic exercise for learning more advanced ski elements. This should improve the sole process and allow faster and more efficient acquisition of advanced ski technique elements.

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WHOLE-BODY VIBRATION TRAINING FOR CHILDREN WITH NEUROLOGICAL DISABILITIES: A META-ANALYSIS

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Abstract:

Over the years, the concern over bone health deterioration in children with neurological disabilities (ND) has caught the interest of the research community. As the current traditional exercise methods are considered too challenging for children with ND, it is essential to seek effective rehabilitation programs with minimum difficulties and movement restrictions for children with disabilities, ultimately improving their muscle and bone health. Therefore, this study was performed to evaluate the potential application of whole-body vibration training (WBVT) as a beneficial and effective approach to improving bone mineral density (BMD), total body bone mineral content (BMC), and lean mass in children with ND. The impact of WBVT on children with ND was investigated using a systematic review and meta-analysis approach following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA). A database search was conducted to screen and select previous literature sources published from January 2002 to July 2022 from EBSCO, PubMed, Scopus, and Web of Science databases that met the inclusion and exclusion criteria. Following the quality assessment (PEDro scale and NIH scale) and sensitivity analysis, the standardized mean difference (SMD) was conducted using the STATA 15.1 software with a 95% confidence interval (95% CI) (PROSPERO registration number: CRD42022343789). Eight studies (four randomized controlled trial [RCT] and four non-RCT studies) were selected, which involved 184 male and 130 female participants. Based on the PEDro scale, all RCT studies were classified as high methodological quality, while the NIH scale rated all non-RCT papers as "Good". In addition, the meta-analysis results indicated that WBVT substantially enhanced femur BMD [($p<.01$, $z = 3.37$), SMD (95% CI) = 0.47 (0.20, 0.74)], lumbar spine BMD [($p=.02$, $z = 2.32$), SMD (95% CI) = 0.32 (0.05, 0.58)], total body BMC [($p<.01$, $z = 3.42$), SMD (95% CI) = 0.29 (0.12, 0.46)] and lean mass [($p<.01$, $z = 2.80$), SMD (95% CI) = 0.25 (0.07, 0.42)] of children with ND. However, the effect of WBVT was insignificant on the total body BMD of children with ND [($p=.22$, $z = 1.24$), SMD (95% CI) = 0.14 (-0.08, 0.37)]. The meta-analysis demonstrated the significant effect of WBVT on the femur BMD, lumbar spine BMD, total body BMC, and lean mass in children with ND. Hence, WBVT can be suggested as a complementary treatment prescription for children with ND.

Key words: *neurological disabilities, whole-body vibration training, bone mineral density*

Introduction

The growing concern over the deterioration of bone health in children with neurological disabilities (ND) in recent years has gained the attention of the research community (Henderson, Lin, & Greene, 1995; Mergler, et al., 2012; Zacharin, 2004). It is a fact that children with Down syndrome (DS) and cerebral palsy (CP) exhibit a higher risk of developing low bone mineral density (BMD), which may be due to muscular hypotonia. Consequently, they are exposed to a higher risk of low-impact bone fractures (García-Hoyos, Riancho, & Valero, 2017; Mus-Peters, et al., 2019). Although increasing muscle mass and activity could substantially reduce the risk of bone fracture (Modlesky & Zhang, 2020; Ritzmann, Stark, & Anne, 2018), children with ND are at a disadvantage to adapt to and endure the current traditional exercise methods. Thus, the major challenge is to develop a compatible and effective rehabilitation program for them.

Recently, there is a growing interest in the development of whole-body vibration training

(WBVT) as a potential therapeutic approach to improve the function of lower limb muscle and bone mass among children suffering from neurological dysfunctions and compromised exercise (Matute-Llorente, Gonzalez-Aguero, Gomez-Cabello, Vicente-Rodriguez, & German, 2014; Saquetto, Carvalho, Silva, Conceiçao, & Gomes-Neto, 2015; Saquetto, et al., 2018). In a basic WBVT approach, the patient is asked to stand on a vibrating plate and either holding onto a support frame, hands-free, or equipped with additional devices to maintain their position on the plate (García-Hoyos, Riancho, & Valero, 2017). The vibration intensity of the plate can be further adjusted according to several parameters, including the amplitude, frequency, acceleration, and type of the vibration plate (Rauch, et al., 2010). It was inferred that the enhanced mechanical stress and activation of the proprioceptive spinal circuits from the WBVT session would trigger the Golgi tendon organs and muscle spindles, resulting in an enhanced muscular function (Cardinale & Bosco, 2003). Furthermore, it was believed that the increased mechanical load would induce bone adaptation via numerous pathways, which are mostly assumed as independent of the muscle response (Beck, 2015).

To date, the effect of WBVT on BMD and the lean mass of children with ND has yet to be discovered. Previously, a meta-analysis study was performed to explore the effect of vibration training on the BMD and lean mass of children with motor disabilities (Li, et al., 2022). Nevertheless, DS children were not included in the study and the findings overlooked the changes in BMD in the whole body. Chen, Ma, Lu, & Ma (2017) also carried out a meta-analysis and compared the influence of WBVT on the lean mass of thermally injured or DS children. The two studies recorded high heterogeneity and low stability. While several studies have reported a significant improvement in the bone mineral content (BMC) and lean mass of children with ND through WBVT (Duran, et al., 2020a; El-Bagalaty & Ismaeel, 2021), two other studies demonstrated opposing results (Matute-Llorente et al., 2015, 2016). Hence, our study reported the meta-analysis of the effect of WBVT on the BMD and lean mass among children with ND, with the aim of evaluating whether WBVT can be an effective treatment method.

Materials and methods

Protocol and registration

The review protocol was registered with the International Prospective Register of Systematic Reviews on July 12, 2022 (Registration number: CRD42022343789).

Data sources and study selection

Four research databases, namely EBSCO, PubMed, Web of Science, and Scopus, were utilized to search for previous literature studies containing the terms “WBV”, “whole-body vibration”, “down syndrome”, “cerebral palsy”, “exercise”, “training”, “children”, and “adolescents”. The publication range for the database search was set from January 2002 to January 2023 with the final day of retrieval being July 5th, 2022. Appendix A provides the search strategy and findings for each database. The retrieved titles and abstracts were first evaluated by two independent investigators. The selected papers were then thoroughly assessed based on the exclusion and inclusion criteria. The third investigator would assist in reaching a consensus should any dispute arise between the two investigators. After deciding on the inclusion of the study, the authors review its reference list again to prevent omissions of literature that can be included. Figure 1 illustrates the complete article selection process. Note that the systematic review and meta-analysis employed in the present study were in line with the suggested recommendations by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) (Li, et al., 2022).

Inclusion and exclusion criteria

The inclusion and exclusion criteria consist of six main features: 1) the paper should be based on randomized controlled trial (RCT) and cohort studies; 2) the age of participants was fixed within the range of 3–18 years; 3) the intervention programs should involve WBVT; 4) the output indicators must include the BMD and lean mass; 5) a dual-energy X-ray absorptiometry (DXA) was applied to evaluate the output index; and 6) the paper should be written fully in the English language. In addition, grey literature, including poster presentations, conference proceedings, or abstracts, was not selected and it was removed from the screening process.

Quality assessment

The PEDro scale (de Morton, 2009) was employed to assess the quality of the selected RCT studies. The quality evaluation was also completed by two independent researchers. If there was a difference in scores, the third researcher would assist in reaching a consensus. High methodological quality was indicated when the score was 6 or higher, while a low methodological quality (Suárez-Iglesias, Miller, Seijo-Martínez, & Ayán, 2019) referred to a score below 6. In contrast, the “Quality Assessment Tool for Before-After (Pre-Post) Studies with No Control Group” (NIH) scale

(Ma, et al., 2020) (available online: https://www.nhlbi.nih.gov/health-topics/study-quality-assessment-tools [accessed on 9th March 2022]) was applied to determine the quality of the selected non-RCT studies. The quality of each study was ranked as “good”, “fair”, or “poor”. The PEDro and NIH scales consisted of 11 and 12 questions, respectively.

Risk of bias assessment

The sensitivity analysis was performed by removing each study one by one to examine the stability of the meta-analysis findings. A funnel plot was then utilized to analyze the publication bias of the study.

Data analysis

The input of every applicable output variable was keyed into a STATA 15.1 software (version 21.0, College Station, TX, USA) for the meta-analysis examination. Despite that the selected studies exhibited continuous output variables, the equipment and test units in each study were different. Thus, the standardized mean difference (SMD) was adopted as the index of effect scale with a 95% confidence interval (95% CI). The I^2 statistic was used to determine the heterogeneity between the studies. Generally, an I^2 value that equals to or more than 50% indicates the presence of heterogeneity between the studies. Hence, the analysis should be conducted using a random effect model. Conversely, a non-heterogeneity between the studies is determined when the I^2 is lower than 50%, thus, the analysis should be conducted using a fixed-effect model.

Results

Eligibility of studies

A total of four RCT and four non-RCT studies were selected to determine the effect of WBVT on lean body mass and BMD in children with neurological impairments (Table 1). The selected studies comprised only the baseline and final data following the intervention program. The studies were ethically approved by their respective institutions and the two researchers recorded a Cohen’s kappa coefficient of 0.909. The eight selected studies involved 184 male and 130 female participants with a minimum and maximum of 12 weeks and 6 months of the intervention period, respectively. Four studies reported the femur BMD, while six studies described the lumbar spine BMD, total body BMC, and lean mass. The range of the vibration frequency was between 5 and 30 Hz.

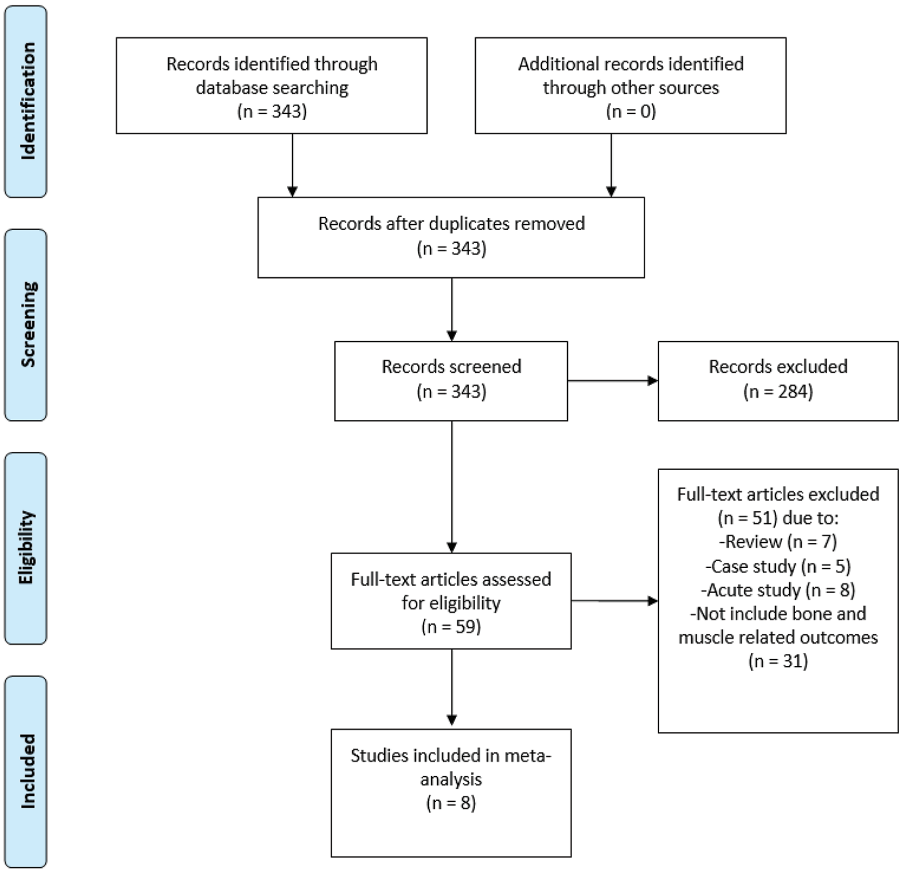

Figure 1. Flow diagram of the search results based on the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA).

Table 1. Characteristics of the selected studies

Reference	Type	Age (year)	Gender	Population	Duration	WBVT program	Index	DXA device
Bagalaty, 2021	RCT	5.0 ± 0.8	10M/13F	CP	12 weeks; 3x/week	5–25 Hz; OA = 0–3.9 mm; erect position, squatting, and side-standing for 20 min; side-alternating vibrations	Lumbar spine BMD; femur BMD	DP3, Lunar Corporation, USA
Duran, 2020	Cohort	11.9 ± 2.7	76M/52F	CP	6 months; 2181±564 min	8–20 Hz; OA = 1–2 mm; standing on a 40° inclined pedal and train for 15 min; side-alternating vibrations	Total body BMC; lean mass	GE, UK
Gusso, 2020	Cohort	15.5 ± 2.3	8M/3F	DS	20 weeks; 4x/week	12–20 Hz; OA= 1 mm; standing on a vibration pedal with knees bent and train for 9 min; side-alternating vibrations	Lumbar spine BMD; femur BMD; total body BMC; total body BMD; lean mass	GE Lunar Prodigy, USA
Gusso, 2016	Cohort	16.2	23M/17F	CP	20 weeks; 4x/week	15–20 Hz; OA = 1 mm; standing on a vibration pedal with knees bent and train for 9 min; side-alternating vibrations	Lumbar spine BMD; femur BMD; total body BMC; total body BMD; lean mass	GE Lunar Prodigy, USA
Matute-Llorente, 2015	RCT	15.0±2.0	7M/6F	DS	20 weeks; 3x/week	25–30 Hz; OA = 2 mm; the squatting position (bent knees at 90°) on the platform and train for 5–10 min; side-alternating vibrations	Lumbar spine BMD; femur BMD; total body BMC; total body BMD	QDR Discovery, Hologic Inc, USA
Matute-Llorente, 2014	RCT	15.5±3.0	8M/3F	DS	20 weeks; 3x/week	25–30 Hz; OA = 2 mm; the squatting position (bent knees at 90°) on the platform and train for 5–10 min; side-alternating vibrations	Lumbar spine BMD; femur BMD; total body BMC; total body BMD	QDR Discovery, Hologic Inc, USA
Ruck, 2010	RCT	8.2± 0.9	8M/2F	CP	6 months; 5x/week	12–18 Hz; OA = 4 mm; standing on a 35° inclined vibration pedal and train for 15 min; side-alternating vibrations	Lumbar spine BMD; femur BMD	QDR Discovery, Hologic Inc, USA
Stark, 2010	Cohort	9.8	44M/34F	CP	6 months; 1x/day	5–25 Hz; OA = 0–3.9 mm; standing on a vibration pedal and train for 15 min; side-alternating vibrations	Total body BMC; total body BMD; lean mass	GE, Germany

Note. RCT = randomized controlled trial; M = male; F = female; BMD = bone mineral density; BMC = bone mineral content; WBVT = whole-body vibration training; CP = cerebral palsy; DS = Down syndrome; OA = oscillation amplitude.

Quality assessment

Table 2 shows that the total scores of the PEDro scale for all the selected RCT studies (El-Bagalaty & Ismaeel, 2021; Genetos, Cheung, Decaris, & Leach, 2010; Matute-Llorente, et al., 2015, 2016) were higher than 5 points and classified as high methodological quality. For the non-RCT studies (Duran, et al., 2020; Gusso, et al., 2016, 2021; Stark, Nikopoulou-Smyrni, Stabrey, Semler, & Schoenau,

Table 2. Depiction of the risk of bias assessment

PEDro scale		1	2	3	4	5	6	7	8	9	10	11	Total
Bagalaty, 2021		Y*	Y	N	Y	N	N	N	Y	Y	Y	Y	6/10
Ruck, 2010		Y*	Y	Y	Y	N	N	N	N	Y	Y	Y	6/10
Matute-Llorente, 2014		Y*	Y	Y	Y	N	N	N	Y	Y	Y	Y	7/10
Matute-Llorente, 2015		Y*	Y	Y	Y	N	N	N	Y	Y	Y	Y	7/10
NIH Pre-Post tool	1	2	3	4	5	6	7	8	9	10	11	12	Total
Duran, 2020	Y	Y	Y	N	Y	N	N	N	Y	Y	Y	NA*	7/11
Gusso, 2016	Y	Y	Y	Y	Y	Y	N	N	Y	Y	Y	NA*	9/11
Gusso, 2020	Y	Y	Y	Y	Y	Y	N	N	Y	Y	Y	NA*	9/11
Stark, 2010	Y	Y	Y	Y	Y	Y	N	N	Y	Y	Y	NA*	9/11

Note. Y = yes; N = no; NA = not applicable; NR = not reported. * Not included in the total score.

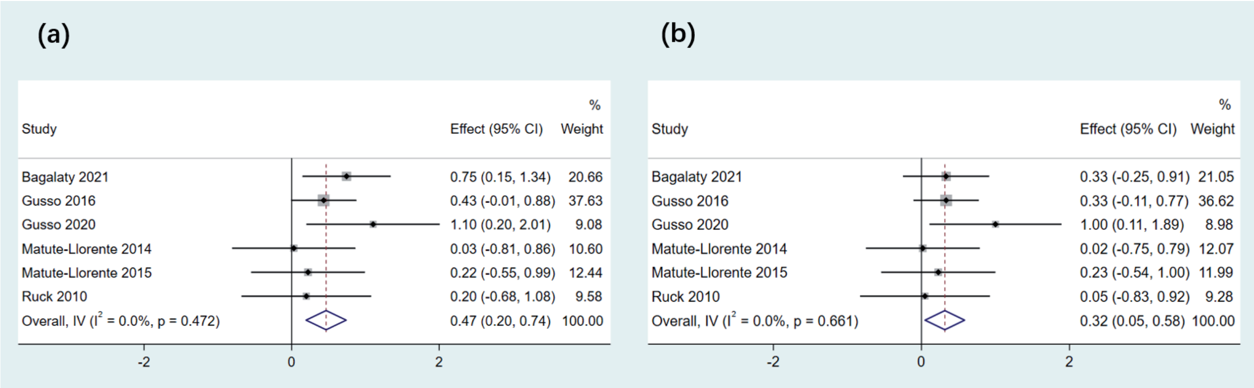

Figure 2. Forest plot illustrating the effects of WBVT on the (a) femur and (b) lumbar spine BMD of children with ND.

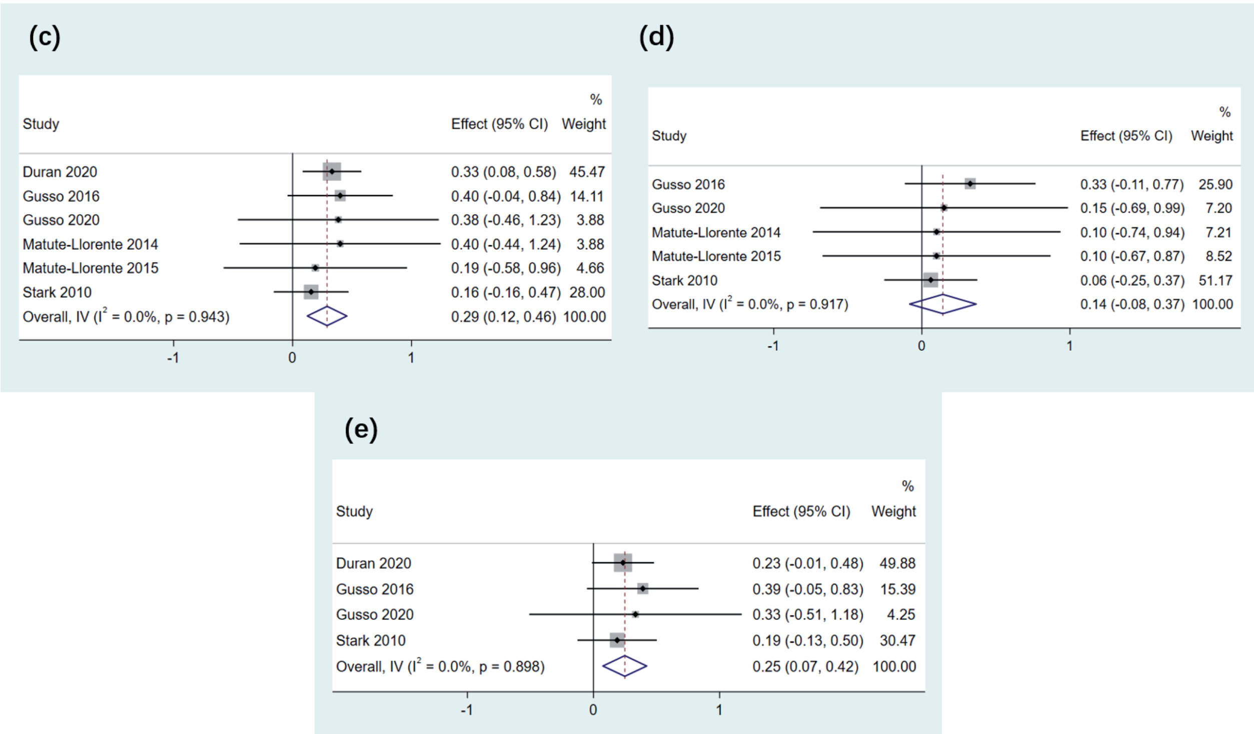

Figure 3. Forest plot illustrating the effects of WBVT on the (c) total body BMC, (d) total body BMD, and (e) lean mass of children with ND.

2010), the overall quality rating from the NIH scale was "good".

Quantitative synthesis

Six studies (n = 108) analyzed the effect of WBVT on the femur and lumbar spine BMD in children with ND. Based on the Forest plot in Fig. 2a, the WBVT significantly enhanced the femur BMD in children with ND (p<.01, z = 3.37), SMD (95% CI) = 0.47 (0.20, 0.74). However, the heterogeneity between the studies was insignificant (p=.47, I^2 = 0.0%) as well as across the studies (p=.66, I^2 = 0.0%). In contrast, the Forest plot in Fig. 2b illustrates the significant impact of WBVT on the lumbar spine BMD in children with ND (p=.02, z = 2.32), SMD (95% CI) = 0.32 (0.05, 0.58).

Furthermore, the effect of WBVT on the total body BMC, total body BMD, and lean mass in chil-

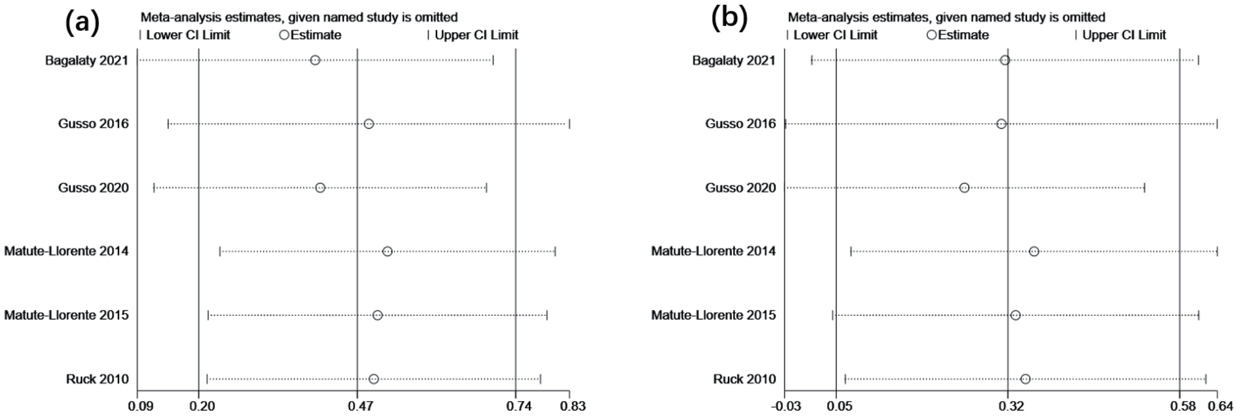

Figure 4. Sensitivity analysis illustrating the effects of WBVT on the (a) femur and (b) lumbar spine BMD of children with ND.

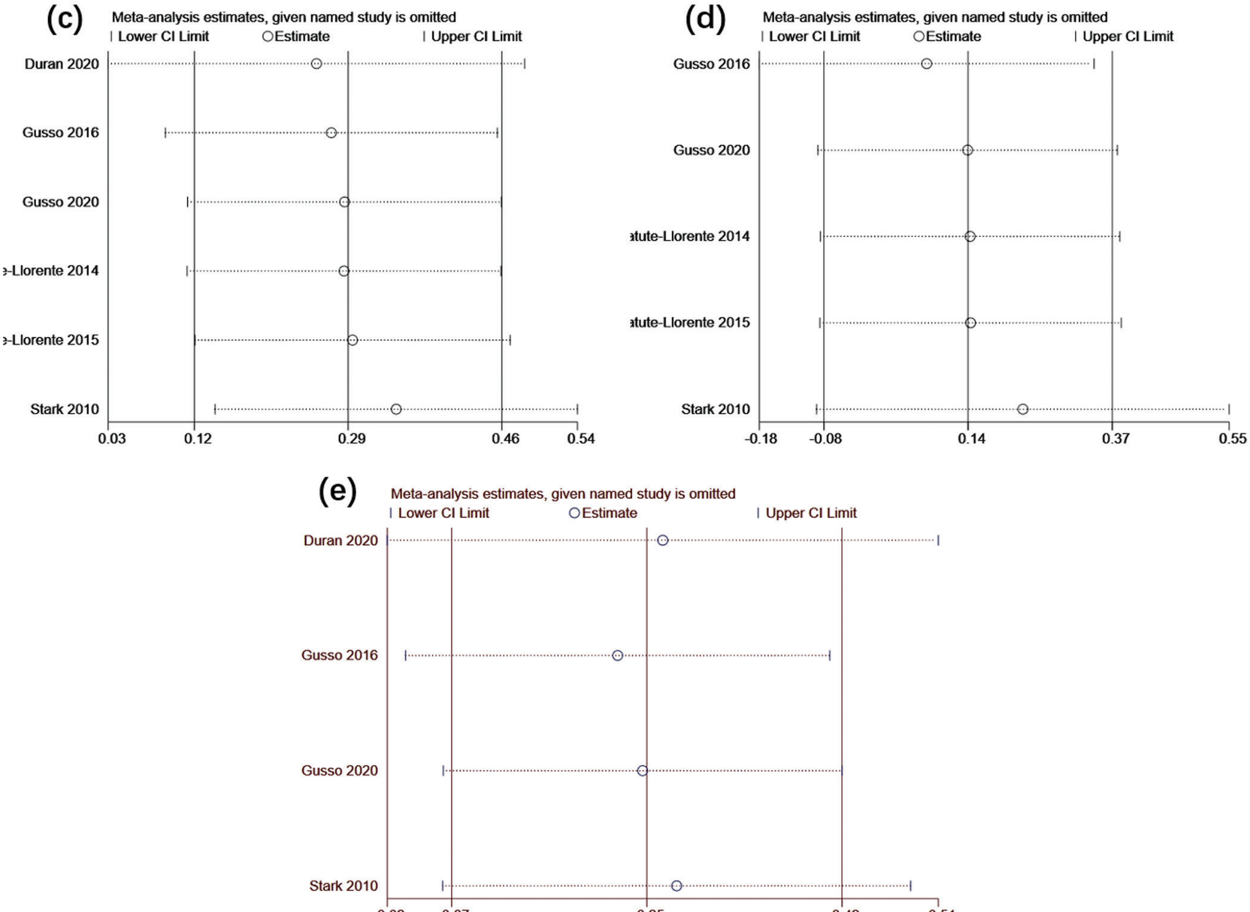

Figure 5. Sensitivity analysis illustrating the effects of WBVT on the (c) total body BMC, (d) total body BMD, and (e) lean mass of children with ND.

dren with ND was evaluated in six (n = 281), five (n = 153), and four studies (n = 257), respectively. The Forest plot in Fig. 3c portrays that the WBVT significantly enhanced the total body BMC (p<.01, z = 3.42), SMD (95% CI) = 0.29 (0.12, 0.46) as well as lean mass in children with ND (p<.01, z = 2.80), SMD (95% CI) = 0.25 (0.07, 0.42), as shown in Fig. 3e. On the contrary, the findings recorded an insignificant difference of the heterogeneity between the studies (p=.94, I^2 = 0.0%) and across the studies (p=.90, I^2 = 0.0%). Although the Forest plot in Fig. 3d displays a significant effect of WBVT on the total body BMD in children with ND (p=.22, z = 1.24), SMD (95% CI) = 0.14 (-0.08, 0.37), the heterogeneity was not detected across the studies (p=.92, I^2 = 0.0%).

Sensitivity analysis

Despite the undetected heterogeneity across all the studies, the sensitivity analysis was still carried out to ensure the stability and accuracy of the meta-analysis findings. The analysis model was adjusted

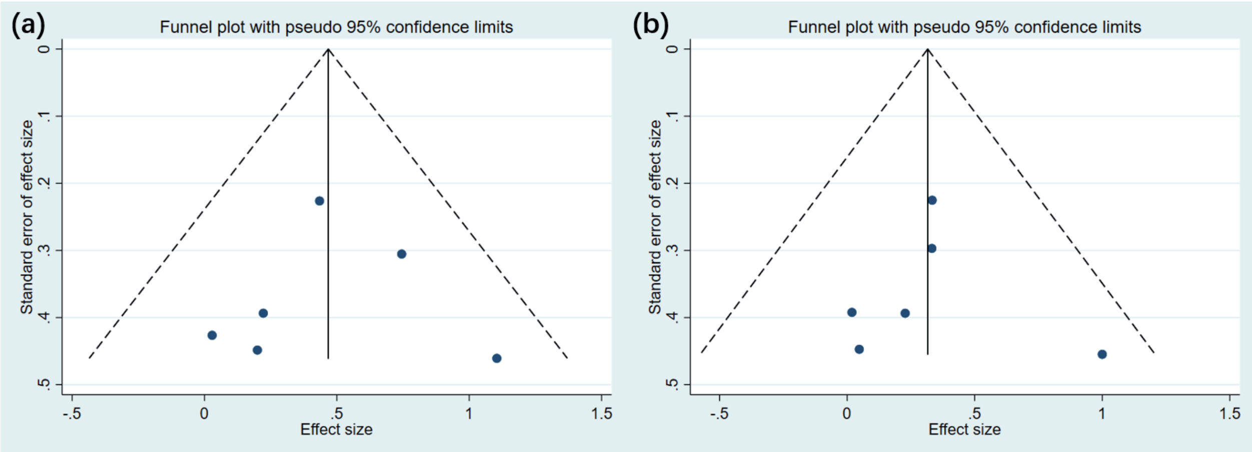

Figure 6. Funnel plot of the publication bias for the (a) femur and (b) lumbar spine BMD based on the WBVT.

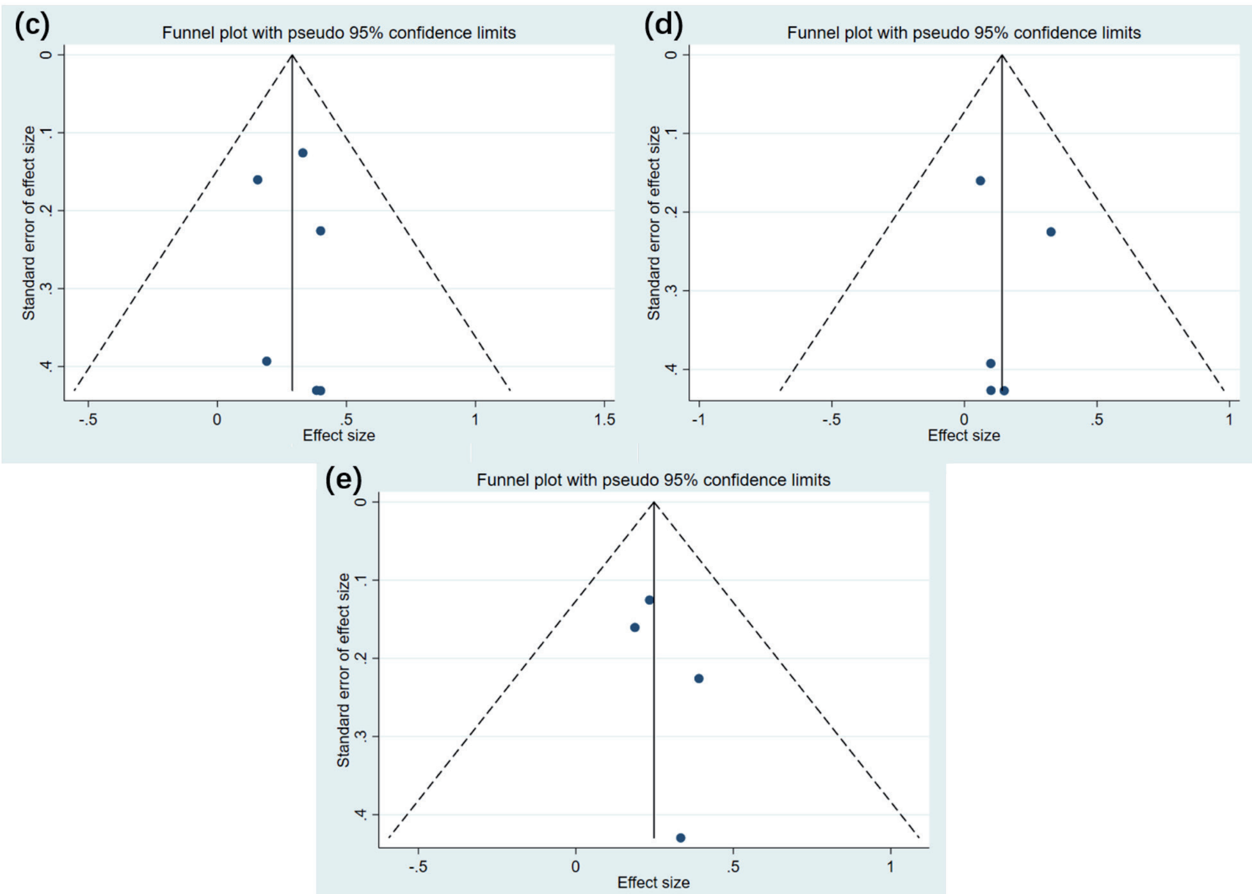

Figure 7. Funnel plot of the publication bias for the (c) total body BMC, (d) total body BMD, and (e) lean mass based on the WBVT.

by removing specific studies and selecting the effect size only. According to the results, each of the selected studies recorded a high level of agreement with the center line. Moreover, the combined effect size between the BMD and lean mass showed no major association change regardless of the removal of any study, signifying the exceptional stability of this study. Figs. 4a, 4b, 5c, 5d, and 5e illustrate the sensitivity analysis for the femur BMD, lumbar spine BMD, total body BMC, total body BMD, and lean mass, respectively.

Analysis of the publication bias

Due to the fairly small sample size of the WBVT studies on children with ND, the funnel plot analysis was conducted using only the eight selected studies. The overall sample size was also close to the minimum number of samples required for a funnel plot analysis. Nevertheless, the result was considered adequate to represent the publication bias to a certain degree with minimum risks. A recent study also demonstrated the effective use of small sample sizes to evaluate the funnel plot analysis (Lu, Wang, Ding, & Shi, 2020). Figs. 6 and 7 show the funnel plot of the effect of WBVT on the femur and lumbar spine BMD of children with ND.

Discussion and conclusions

The aim of the meta-analysis was to determine the effect of WBVT on BMD and lean mass in children with ND. Eight articles were selected in total. Six of the studies covered the femur BMD, lumbar spine BMD, and total body BMC as the output indicators, while four and five studies utilized the lean mass and total body BMD as the output indicators, respectively. Overall, the findings demonstrated that the WBVT significantly increased the femur BMD, lumbar spine BMD, total body BMC, and lean mass in children with ND. However, the WBVT showed no significant effect on the total body BMD. Thus, the WBVT provides an effective alternative rehabilitation program to improve the treatment conditions of children with ND.

The WBVT has been employed as an alternative rehabilitation program to minimize the defects and movement restrictions among children with disabilities (Leite, et al., 2019). The training approach utilizes a vibrating platform that generates high-frequency mechanical stimuli, which are then transmitted throughout the body of the patient to the loaded bone and activate the sensory receptors (Maher, Williams, Olds, & Lane, 2007). Previously, WBVT was shown to improve bone mass, lean mass, muscle strength, and exercise performance (Eid, 2015; Ibrahim, Eid, & Moawd, 2014; Lee & Chon, 2013). Despite that WBVT has been universally used in clinical practice by physical therapists, the exact efficiency of the training approach on children with ND remains debatable due to the limited methodological quality and precision that were applied in the respective studies (Li, et al., 2022). For instance, a recent study revealed that the effect of WBVT beneficially improved the health-related physical fitness of disabled children (Matute-Llorente, et al., 2014). Nevertheless, the study included low-quality studies, in particular non-RCT studies, while both the meta-analysis and the risk of bias of the included non-RCT studies were not performed. Additionally, the study revealed that the DXA was a reliable index to evaluate body composition with excellent precision and reproducibility. The BMD and lean mass indicators were evaluated via the DXA to enhance the homogeneity of the meta-analysis and examine the effect of WBVT on body composition.

Furthermore, lean mass showed a direct correlation with muscle growth and physical activities (Baptista, et al., 2012). Based on the findings of the present study, the lean mass of children with ND increased significantly following WBVT. The result was in agreement with the results of a recent study (Kruse, Schranz, Svehlik, & Tilp, 2019) that reported a substantial thickness increment of *musculus vastus lateralis* in children with CP following home-based progressive resistance training for eight weeks. Moreover, a number of studies have reported that the muscle mass in children with CP increased following comprehensive vibration-assisted training (Lee & Chon, 2013; Vesey et al., 2020). The physiological principle of the anabolic muscle effect of the vibration-assisted training was associated with the vibrational stimulation of the muscle spindles, which led to repetitive muscle contractions and training (Lebedev & Polyakov, 1992; Ritzmann, Kramer, Gruber, Gollhofer, & Taube, 2010). In contrast, a recent meta-analysis study (Saquetto, et al., 2015) demonstrated an insignificant difference between the muscle strength of WBVT and that of the control group, which could be due to the dissimilar indicators or test approaches. The muscle strength comparison ($p=.06$) was also close to the critical significant value, which could potentially represent false negative values due to the small sample size ($n = 3$).

Another study revealed that bone fragility in patients with ND, particularly among children, was associated with an increase in the rate of fragility fractures (Martínez de Zabarte Fernández, Ros Arnal, Peña Segura, García Romero, & Rodríguez Martínez, 2020). The WBVT was shown to significantly improve the femur BMD, lumbar spine BMD, and total body BMC in children with ND. Although the findings in the present study were correlated with that of a recent meta-analysis study related to the effect of WBVT on BMD and lean mass of children with motor disabilities (Li, et al., 2022), the WBVT did not affect the lumbar spine BMD.

It was speculated that the different populations in both studies resulted in the varying outcome. The findings in the present study were also supported by a case study by Dalen et al. (2012), where the BMC of the lumbar spine and legs in children with CP increased following the WBVT. Furthermore, a previous study utilized a WBVT plate from the same manufacturer as the present study and demonstrated a significant enhancement in the total body BMC and lower limb lean mass (n = 40) (Högler, et al., 2017). Following a 20-week training routine, which comprised three 3-min training sessions four times per week, the participants underwent vibration-assisted training for a total of 720 min at a frequency and amplitude of 20 Hz and 1 mm, respectively. Nevertheless, the study excluded the Z-score evaluation, and no control group was applied to compare the results. Meanwhile, a randomized controlled study was performed to explore the effect of WBVT on BMD in children with CP (n = 20) using a similar WBVT system from the same manufacturer (Ruck, Chabot, & Rauch, 2010). Both the treatment and control groups were subjected to a school physiotherapy program. Following an additional three 3-min training sessions five times per week, the treatment group underwent vibration-assisted physiotherapy training for a total of 737−914 min at a frequency and amplitude of 18 Hz and 4 mm (acceleration of approx. 28 m/s^2), respectively. Based on the results, the additional WBVT session on the treatment group showed no major effect on the distal femur and lumbar spine BMD.

It is crucial to highlight the distinct limitations of this study. Primarily, this study selected only eight studies with inconsistent output units, which is relatively a small sample size. Thus, the SDM was the only appropriate output for comparison purposes. Secondly, different intervention programs were adopted, which include the single WBVT and the combined WBVT with other intervention programs. Lastly, this study performed a single-arm meta-analysis evaluation without preparing a control group for comparison purposes due to the inadequate number of RCT studies. In addition, the study could not elucidate the exact mechanism of the WBVT that led to the increased lean mass and BMD. Thus, further studies are required to provide insights into the enhancement mechanism. It is also recommended for future studies to include a sufficient number of RCT studies so that a control group can be applied to achieve a thorough meta-analysis evaluation. While the present study emphasized the impact of WBVT on children with ND, further studies could potentially focus on comparing the impact of WBVT on other populations with different age groups and specific diseases.

This study demonstrated that WBVT is an effective training approach that significantly improved the femur BMD, lumbar spine BMD, total body BMC, and lean mass in children suffering from ND. The analysis was also considered adequate to represent the publication bias despite the relatively small sample size. Although the WBVT showed an insignificant impact on the total body BMD, the training approach can be considered a complementary treatment prescription for children with ND.

Appendix A

Search strategy

Databases	Search strategy	Result (Approximately)
Scopus	#1: Title-Abs-Key (Whole Body Vibration or Whole-Body Vibration) #2: Title-Abs-Key (“Cerebral Palsy” or “ Down syndrome”) #3: #1 and #2 Limiters—Publication date: 20020101-20230101	4,889 55,752 84
Pubmed	#1: [Title/Abstract] Whole Body Vibration or Whole-Body Vibration #2: [Title/Abstract] “Cerebral Palsy” or “ Down syndrome” #3: #1 and #2 Filters: Publication date from 2001/01/01 to 2023/01/01	2,234 36,098 52
Web of Science	#1: TOPIC: (Whole Body Vibration or Whole-Body Vibration) #2: TOPIC: (“Cerebral Palsy” or “ Down syndrome”) #3: #1 and #2 Refined by: PUBLICATION YEARS: (20230101-20010101) Indexes=SCI-EXPANDED, SSCI, CCR-EXPANDED,	4,963 47,472 109
EBSCO	#1: Abstract: (Whole Body Vibration or Whole-Body Vibration) #2: Abstract: (“Cerebral Palsy” or “ Down syndrome”) #3: #1 and #2 Year: 20010101-20230101	4,631 65,241 98

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GUIDELINES FOR CONTRIBUTORS

FOCUS AND SCOPE

Kinesiology – International Journal of Fundamental and Applied Kinesiology (print ISSN 1331- 1441, online ISSN 1848-638X) publishes twice a year scientific papers and other written material from kinesiology (a scientific discipline which investigates the art and science of human movement; in the meaning and scope close to the idiom "sport sciences") and other adjacent human sciences focused on sport and exercise, primarily from anthropology (biological and cultural alike), medicine, sociology, psychology, natural sciences and mathematics applied to sport in its broadest sense, history, and others. Contributions of high scientific interest, including also results of theoretical analyses and their practical application in physical education, sport, physical recreation and kinesitherapy, are accepted for publication. The following sections define the scope of the journal: Sport and sports activities, Physical education, Recreation/leisure, Kinesiological anthropology, Training methods, Biology of sport and exercise, Sports medicine and physiology of sport, Biomechanics, History of sport and Book reviews with news.

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Journals

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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

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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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