


JOURNAL OF HUMAN SPORT AND EXERCISE

Volume 19, Issue 2 – April 2024

EDITED & PUBLISHED BY

ASOCIACIÓN ESPAÑOLA DE ANÁLISIS DEL RENDIMIENTO DEPORTIVO

ISSN 1988-5202

ORIGINAL ARTICLE

Effects of transcranial continuous current stimulation (tDCS) associated with aerobic exercise in the treatment of food compulsion: A randomized clinical trial

MILENA ARTIFON , GABRIEL MAYER TOSSI, NATHÁLIA GRIEBLER, PEDRO SCHESTATSKY, FRANCESCO BOENO, CESAR MORITZ, JULIANA LOPES TEODORO, LUCAS BERALDO, LAUREN NAOMI ADACHI, ÁLVARO REISCHAK DE OLIVEIRA, CAROLINE PIETTA-DIAS

Exercise Research Laboratory. School of Physical Education, Physiotherapy and Dance. Federal University of Rio Grande do Sul. Porto Alegre, Brazil.

ABSTRACT

Introduction: Binge eating disorder (BED) is closely associated with obesity, characterized by the repeated consumption of large amounts of food accompanied by a feeling of loss of control during the episode of binge eating. Existing treatments are moderately effective with high rates of recurrence; thus, physical exercise and neuromodulation techniques have emerged with positive potential associated with self-control in reward brain regions. Objective: To investigate whether 20 sessions of transcranial direct current (tDCS) stimulation alone or combined with aerobic exercise (AE) could reduce food consumption and the perception of hunger and satiety in adult individuals with BED. Methods: Adult individuals with BED were included in a randomized, double-blind study. Participants received 20 sessions according to random randomization (1) active tDCS, (2) placebo and AE tDCS or (3) active tDCS and AE, simultaneously with videos of foods that cause fissures, such as sweets and fast foods. tDCS was applied at 2mA / 20 min, with the anode over the right dorsolateral prefrontal cortex and the cathode over the contralateral supraorbital region (Soterix Medical®). The AE was performed on a treadmill after tDCS, at an intensity of 60-65% of HRmax, repeating the evaluations at the end. Primary outcomes included measures of food intake and perceptions of hunger, satiety and desire. Secondary outcomes were assessed through body composition, biochemical markers (lipid, glycaemic and leptin profile) and maximum oxygen consumption. Results: The tDCS group had lower values of triglycerides and lean mass compared to the other groups. However, in relation to food intake, hunger, satiety throughout the day, and uncontrollable desire to eat, there was no difference between the groups. Conclusions: tDCS alone was able to improve more clinical outcomes such as adipose mass and triglycerides. To our knowledge, to date this is the first study to demonstrate that the association of tDCS with aerobic exercise can improve the symptoms of binge eating in the investigated population. Test record: ReBEC identifier RBR-3d8fd2.

Keywords: Sport medicine, Health, Transcranial direct current stimulation, tDCS, Exercise, Binge eating.

Cite this article as:
Artifon, M., Mayer Tossi, G., Griebler, N., Schestatsky, P., Boeno, F., Moritz, C., Lopes Teodoro, J., Beraldo, L., Naomi Adachi, L., Reischak De Oliveira, A., & Pietta-Dias, C. (2024). Effects of transcranial continuous current stimulation (tDCS) associated with aerobic exercise in the treatment of food compulsion: A randomized clinical trial. *Journal of Human Sport and Exercise, 19*(2), 436-450. https://doi.org/10.55860/b8rd1w97

Corresponding author. *Exercise Research Laboratory. School of Physical Education, Physiotherapy and Dance. Federal University of Rio Grande do Sul. Porto Alegre, Brazil.*
E-mail: milena.artifon@gmail.com
Submitted for publication July 13, 2023.
Accepted for publication September 07, 2023.
Published April 01, 2024 *(in press* December 26, 2023).
JOURNAL OF HUMAN SPORT & EXERCISE ISSN 1988-5202.

doi: https://doi.org/10.55860/b8rd1w97

INTRODUCTION

Binge Eating Disorder (BED) is classified as an Autonomous Eating Disorder (DSM-5) and is characterized by repeated consumption of exceptionally large amounts of food accompanied by a feeling of loss of control during the episode of binge eating (Sena, 2014). This disease is of particular interest due to its frequency in primary care, its link with obesity and its medical and psychiatric comorbidities, leading to a high socioeconomic impact due to the reduction in quality of life and increased use of health services (Higuera-Hernández et al, 2018, Solmi et al, 2018). Its prevalence in the general population is around 1.4%, however this estimate increases substantially among obese individuals without marked gender differences (Burrows et al, 2017). The prevalence is likely to increase, due to the increasing incidence of obesity as well as eating disorders worldwide (Amianto et al, 2015).

Deficiencies in inhibitory control have been considered a transdiagnostic mechanism of maintenance in a variety of clinical conditions, including obesity or BED (Siddiqui et al, 2008, Jáuregui-Lobera and Martínez-Quiñones, 2018). Cognitive control functions allow adaptive behaviour in the context of complex environments and are supported by prefrontal brain networks that can guide attention and influence neural and motor processes, including inhibitory control. This is an important component of cognitive control and refers to the ability to interrupt motor actions already initiated or planned (Siddiqui et al, 2008, Jáuregui-Lobera and Martínez-Quiñones, 2018).

In order to improve cognitive control in several contexts, transcranial direct current stimulation (tDCS) was proposed by directing a weak direct current through the cortical tissue through electrodes on the scalp, where the spontaneous triggering activity caused by a cognitive process may be slightly increased or attenuated, depending on the target brain region and the direct current flow (Wiegand et al, 2019). The positioning of the electrodes is considered an important determinant of the effectiveness of stimulation (Chen et al, 2019). For this protocol, the choice of anodic stimulation in the right CPFDL and cathodic stimulation in the left was based on previous studies that found a significant effect in reducing food intake and the desire for food associated with this position, both in healthy individuals and in individuals with overweight or obese (Fregni et al, 2008). Currently, tDCS has shown promising results as an alternative for the regulation of several clinical conditions, including acting on affective and appetite self-regulation. Therefore, this technique may be a possible approach to regulate food intake in patients with binge eating.

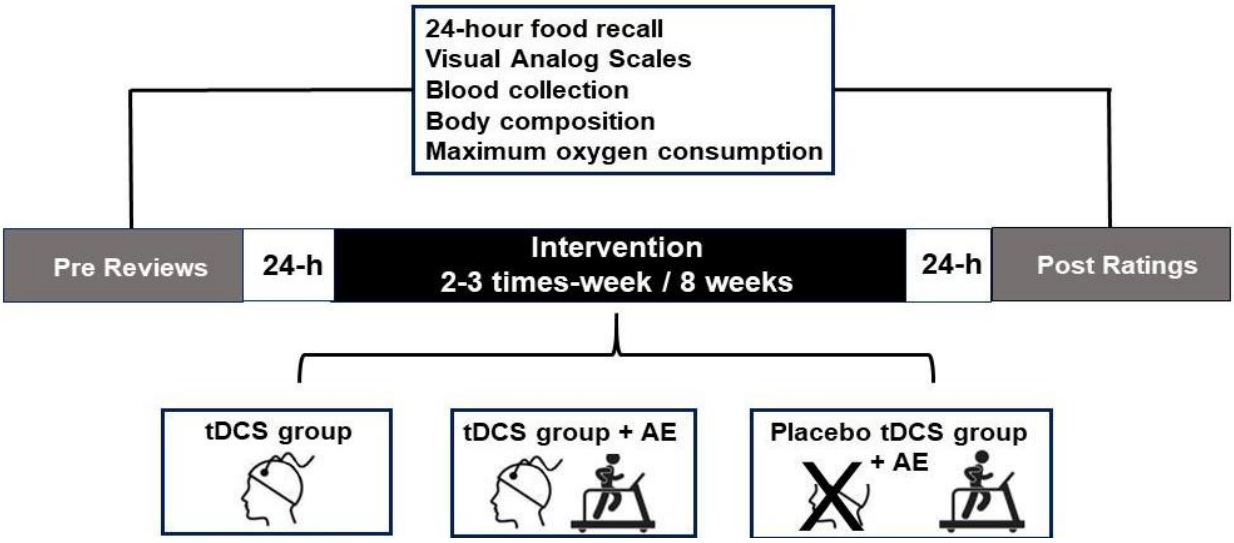
On the other hand, aerobic exercise is related to the improvement of eating habits due to the suppression of hormones linked to satiety, regulating binge eating (Mathisen et al, 2020). In this sense, a reduction in plasma leptin levels is observed after an aerobic exercise program in obese individuals, suggesting a beneficial regulatory effect on appetite (Fedewa et al, 2018). In fact, regular aerobic exercise promotes a protective environment, characterized by a reduction in the chronic inflammatory process of dysfunctional adipose tissue and an improvement in the oxidative capacity of skeletal muscle, reducing in the long run the risk of cardiovascular events (Sloan et al, 2018).

The management of non-pharmacological strategies such as tDCS and aerobic exercise in the treatment of BED, since they act in different mechanisms and do not compete with the combined application of the two therapies, can generate results superior to the isolated use of tDCS. On the other hand, the effect of the combination of the two techniques to date has been investigated only acutely on the sensation of appetite in overweight individuals (Montenegro et al, 2012). Thus, this study aimed to analyse the chronic effects of tDCS associated with aerobic exercise on the control and perception of food intake, satiety, body composition and cardiovascular outcomes in obese adults with BED.

MATERIALS AND METHODS

Experimental study design

The present study is characterized as a randomized, double-blind clinical trial. The study consisted of 20 sessions of active tDCS or placebo in the dorsolateral prefrontal cortex (DLPFC) associated or not with aerobic exercise (AE). Primary outcomes included measures of food intake and perceptions of hunger, satiety and desire. Secondary outcomes were assessed using body composition, biochemical markers (lipid, glycaemic and leptin profiles) and maximum oxygen consumption. All study procedures were approved by the local Research Ethics Committee and the study was registered with RebeC (RBR-3d8fd2). A timeline with the study design is shown in Figure 1.



Note. tDCS -Transcranial direct current stimulation; AE-Aerobic exercise; pl- placebo.

Figure 1. Timeline of the study.

Participants

Participants were recruited through public announcements and asked to complete an electronic questionnaire for initial screening according to the inclusion and exclusion criteria presented in Table 1.

Table 1. Study inclusion and exclusion criteria.

Inclusion criteria	Exclusion criteria
Between 20 and 49 years	Nutritional monitoring or intervention
Grade I overweight or obesity according to WHO criteria (15)	Women intending to become pregnant
	Pregnant or breastfeeding women
Binge eating diagnosis according to DSM-5 criteria (1)	History of severe depression or other serious psychiatric comorbidities
Not having exercised regularly for 6 months	Use of appetite-suppressing drugs
	History of cardiovascular disease
	Renal insufficiency
	Diabetes mellitus
	Inability to exercise

Note. DSM-5 - Diagnostic and Statistical Manual of Mental Disorders); WHO - World Health Organization.

Screening, randomization and general procedures

Evaluation procedures

Participants who met the inclusion criteria in the screening were invited to perform the initial assessment, where they signed the informed consent form. For the initial evaluation, they were instructed to perform an eight-hour fast and to prepare for the analysis of body composition, such as suspending calcium medications 24 hours before and not undergoing physical training on the day of the evaluation. Initial assessments included: blood collection, body composition assessment (Dual-Energy X-ray Absorptiometry-DXA), maximum oxygen consumption test (VO_{2peak}), food intake through the 24-hour food recall, visual analogue scales to assess hunger and satiety throughout the day, hunger at the time of testing and uncontrollable desire to eat. An independent researcher randomly designated the treatment condition of each subject by drawing envelopes. Thus, participants were randomized into three experimental groups: (1) active tDCS only - tDCS group, (2) active tDCS with AE- tDCS + AE group and (3) placebo tDCS with AE- tDCSpl + AE group. In the tDCS group, the subjects were submitted to 20-minute tDCS sessions. In the tDCS + AE group, the participants were submitted to 20-minute tDCS sessions and then performed an aerobic exercise protocol for another 20 minutes. In the tDCSpl + AE group, the subjects were submitted to 20 minutes of tDCS, but it remained active for 30 seconds and then the current was blocked, and the individuals performed the aerobic exercise protocol for another 20 minutes. For all groups, the intervention lasted 8 weeks with a frequency of twice in the first four weeks and three times in the subsequent weeks, with at least 24-hour interval between sessions, totalling 20 sessions. The study was blinded to participants and evaluators.

Biochemical markers

Venous blood samples were drawn in anticoagulant tubes containing 4 mL EDTA after an overnight fast of at least eight hours. The tubes were centrifuged, and plasma aliquots were frozen at -80ºC for further analysis. Glucose levels (mg / dL), total cholesterol (mg / dL), high-density lipoprotein-HDL (mg / dL), triacylglycerol (mg / dL) and glycated haemoglobin (%) were measured using an automatic analyser (Cobas C111, Roche Diagnostics, Basel, Switzerland), while low-density lipoprotein-LDL was calculated using the Friedewald equation. Plasma levels of insulin (µUI / mL) and leptin (ng / dL) were determined by ELISA, according to the manufacturer's instructions (BosterBio, Pleasanton, USA).

Body composition

Dual Energy Radiological Absorptiometry (DXA) was performed in the initial evaluation on an 8-hour fast. DXA performed cross-sectional analyses of the entire body, at intervals of 1 cm from head to toe, and based on its results, lean mass, adipose mass, body fat percentage and total densitometry - bone mineral density (BMD) could be quantified. For the day of the assessment, the subjects were instructed to wear light clothing, which allows for an adequate scan of body composition. After the exam, the participants received a standard meal before starting the other assessment protocols.

Assessment of food intake, hunger at the time of testing, hunger and satiety throughout the day and uncontrollable desire to eat

Food consumption was assessed by means of a 24-hour recall, with all food consumed in the 24 hours prior to the assessment being recorded, including the type of food and the amount consumed. Food intake was assessed 24 hours before the start of the protocol and 24 hours after the last session of the experimental protocol. The total energy (Kcal) and the composition of macronutrients: carbohydrates, proteins and lipids (g) of the intake were calculated using the Dietbox® program. Hunger and satiety throughout the day and desire were measured twice (pre- and post-interventions) with a subjective visual analogue scale (VAS) that ranged from 0 to 10. Hunger at the time of the test was assessed in the same way, however, on a scale that ranged from 0 to 7.

Maximum oxygen consumption

The participants' VO_{2peak} and maximum heart rate (HRmax) were determined using an incremental exercise test on a treadmill (Inbramed, Porto Alegre / Brazil). The test started with a 5min warm-up (from 3 to 5 km / h, increasing 0.5 km / h each min, up to 5 min), followed by increases of 2% in the inclination every min, maintaining a constant speed of 5 km / h throughout the test. To be considered a maximal stress test, participants should have met at least two of the following criteria: (1) HRmax predicted by age, (2) respiratory exchange ratio (RER) ≥1.1, (3) subjective perception of effort ≥ 17 (Borg scale 6-20), (4) signs of muscle fatigue, such as loss of motor coordination. Ventilatory parameters were measured continuously, breath by breath, using an open circuit spirometry system (Quark CPET, Cosmed Italy) calibrated according to the manufacturer's instructions before each test day. HR was also measured continuously using chest strap telemetry (Polar Electro Oy, Kempele, Finland). VO_{2peak} was identified as the highest VO_2 value in a trend line plotted against time. Participants were verbally encouraged to make the maximum effort during the test (Rodrigues-Krause et al, 2018).

tDCS procedures

Participants were instructed not to eat at least two hours before the intervention, which they hoped to increase the degree of desire during the tDCS session.

tDCS therapy system targeting CPFDL: The transcranial direct current stimulator- tDCS 1x1, model no. 1300A (Soterix Medical®). The direction to the stimulation site was performed from the anode or cathode positioned in area F3 or F4 according to the international electroencephalogram (EEG) system 10-20. This method of locating the CPFDL was previously used in studies with tDCS (Martin et al, 2018). The reference electrode was positioned in the contralateral supraorbital region.

Active tDCS: tDCS was administered at 2mA for 20 minutes, configuring the treatment session.

Placebo tDCS: the placebo system used in this study was that of the equipment itself, in which the sensation of active tDCS is imitated during the initial 30 seconds and subsequently blocked.

Virtual reality environment: using virtual reality glasses (Oculus®), structured exposure of images of food that usually cause cravings (sweet, salty, fatty) was used simultaneously with the tDCS session.

Aerobic exercise protocol

The aerobic exercise was performed on a treadmill (BF 601-Oneal) immediately after each tDCS session for the tDCS + AE group. The training started with five minutes of warm-up at a comfortable speed on the treadmill. Subsequently, aerobic exercise was performed with intensity related to the percentage of VO_{2peak} and monitored throughout the session by a frequency meter and subjective scale of perceived exertion (Borg Scale 6–20) (Howley et al, 1995). In the first four weeks, individuals performed 20 minutes with intensity of 60-65% of HRmax and subjective perception of effort from 12 to 14. In the following four weeks, individuals performed 20 minutes with intensity of 70-75% of HRmax and perception subjective effort from 13 to 15. At the end of each session, five minutes of stretching for the lower limbs were performed.

Sample calculation

The sample size calculation was based on the article by Lapenta et al (2014), which verified the effect of two sessions of tDCS (active or placebo) on calorie intake. The program used for the calculation was G * Power 3.1.9.2®, with $\alpha = 0.05$, $1-\beta = 0.8$ and effect size (f) = 1.0, totalling 30 participants, divided into three groups (10 per group).

Statistical analysis

Due to sample losses, only two individuals completed the intervention protocol in the tDCSpl + AE group. This sample made it impossible to execute any hypothesis test and, therefore, it was excluded from the research, leaving only two groups for the analyses. The verification of the normality of the distribution occurred by the Shapiro-Wilk test considering the data of the initial evaluation of the whole sample, complementarily the test was carried out with the sample divided according to the experimental groups and generated QQ graphs in order to investigate fragile violations of the normality in the groups. The descriptions and test hypotheses followed what was proposed in Field (2009) and Ulbricht, Ripka and Beraldo (2016). Thus, measures of mean ± standard deviation and median (interquartile range) are used. Intergroup comparisons were performed using the independent t test and the Mann-Whitney test. Intergroup comparisons were performed using the dependent t test and the Wilcoxon sign rank test. All tests have their effect size expressed by Pearson's r and their interpretation according to Santo and Daniel (2015). This was obtained through the one proposed by Rosenthal (1991) for the independent and dependent t tests. For the Mann-Whitney test, the equation proposed by Wendt (1972) was used, while the one indicated by Kerby (2014) was used to test the Wilcoxon signal stations. All hypothesis tests were performed using SPSS v.21.0 software, as well as descriptive statistics. Effect sizes were calculated in Microsoft Excel 2010. The level of significance was set at .05.

RESULTS

Characteristics of the participants

At the end of the eight weeks, 16 individuals (93.6% women) completed the 20 intervention sessions in the tDCS (n = 09) and tDCS + AE (n = 07) groups. The sample was aged 35.88 ± 7.99 years, weighed 82.23 ± 10.67 kg and BMI was 30.31 ± 2.43 kg / m².

Food intake

Food intake, according to the 24-hour recall, is shown in Table 2. Significant intra-group reductions were observed for carbohydrates and proteins in the tDCS group and lipids in the tDCS + AE group. Although the total energy reduction in the tDCS + AE group was not significant, it presented a moderate effect size. In intergroup comparisons, no significant differences were observed.

Table 2. Analysis of the chronic effect of interventions on food intake (n = 16).

Variables	Group	Pre	Post	Intergroup comparisons	Intragroup comparisons	
				p-value	*p*-value	Effect size (R)
Energy (Kcal)	tDCS	1776.2±443.6	1411.5±774.5	.70	.10	0.55
	tDCS+AE	1706.3±466.3	1277.5±476.5		.06	0.69
Carbohydrates (g)	tDCS	227.7±62.6	169.8±97.0	.98	.05*	0.63
	tDCS+AE	203.6±48.9	169.0±52.3		.20	0.50
Proteins (g)	tDCS	77.8±25.3	61.5±27.2	1.00	.02*	0.72
	tDCS+AE	77.6±30.1	61.5±37.2		.26	0.45
Lipids (g)	tDCS	61.7±20.1	54.0±35.7	.26	.53	0.23
	tDCS+AE	64.4±27.2	38.2±22.7		.05*	0.71

*Note. tDCS-Transcranial direct current stimulation; AE-Aerobic exercise. *p ≤ .05.*

Table 3. Analysis of the chronic effect of interventions on visual analogue scales of hunger, satiety and uncontrollable desire to eat (n = 16).

Variables	Group	Pre	Post	Intergroup comparisons	Intragroup comparisons	
				p-value	*p*-value	Effect size (R)
Visual analogue scale of hunger and satiety throughout the day						
Upon waking	tDCS	5.0 (1.5-9.0)	9.0 (4.5-9.5)	.38	.13	0.64
	tDCS+AE	5.0 (2.0-5.0)	8.0 (3.0-9.0)		.14	0.73
Before lunch	tDCS	5.0 (2.5-5.5)	5.0 (4.5-7.0)	.63	.12	0.58
	tDCS+AE	2.0 (2.0-3.0)	5.0 (3.0-6.0)		.04*	0.86
3 hours after lunch	tDCS	5.0 (3.5-7,0)	6.0 (5.0-7.5)	.33	.46	0.33
	tDCS+AE	4.0 (2.0-5.0)	7.0 (5.0-9.0)		.03	1.00
Before dinner	tDCS	2.0 (0.5-4.5)	5.0 (4.5-7.0)	.06	.02*	1.00
	tDCS+AE	1.0 (1.0-2.0)	4.0 (3.0-5.0)		.02*	1.00
3 hours after dinner	tDCS	7.0 (3.0-9.0)	8.0 (6.5-9.5)	.55	.05*	0.78
	tDCS+AE	5.0 (2.0-7.0)	9.0 (7.0-9.0)		.03*	1.00
At bedtime	tDCS	7.0 (4.5-9.0)	9.0 (8.0-10.0)	.91	.07	0.72
	tDCS+AE	7.0 (2.0-10.0)	9.0 (8.0-10.0)		.13	0.64
Visual analogue scale for hunger assessment						
At the time of testing	tDCS	2.0 (1.0-4.0)	3.0 (1.0-3.5)	.70	.93	0.04
	tDCS+AE	1.0 (1.0-2.0)	3.0 (1.0-3.0)		.10	1.00
Visual analogue scale of uncontrollable desire to eat						
Candy	tDCS	5.0 (0.0-9.0)	3.0 (0.5-5.0)	.63	.21	0.50
	tDCS+AE	8.0 (5.0-9.0)	3.0 (0.0-7.0)		.14	0.73
Salty	tDCS	8.0 (3.5-10.0)	5.0 (3.0-9.5)	.67	.73	0.14
	tDCS+AE	7.0 (6.0-8.0)	7.0 (5.0-9.,0)		.67	0.18
Tasty	tDCS	9.0 (3.5-10.0)	4.0 (2.5-7.5)	.22	.31	0.43
	tDCS+AE	8.0 (8.0-10.0)	6.0 (5.0-9.0)		.12	0.71
Fatty	tDCS	5.0 (0.5-9.5)	1.0 (0.0-2.5)	.34	.04*	0.86
	tDCS+AE	4.00 (2.0-8.0)	3.0 (0.0-5.0)		.14	0.80

*Note. tDCS-Transcranial direct current stimulation; AE-Aerobic exercise. *p ≤ .05.*

Assessment of hunger and satiety throughout the day

The tDCS group showed a significant increase in satiety only in the moments before dinner and three hours after dinner, while the tDCS + AE group in the moments: before lunch, three hours after lunch, before dinner and three hours after dinner (Table 3). There were no significant intergroup differences.

Assessment of hunger at the time of testing

There were no statistically significant differences in any of the groups (p > .05) (Table 3).

Assessment of uncontrollable desire to eat (desire for food)

There was less of an uncontrollable urge to eat fatty foods only in the tDCS group. Regarding intergroup comparisons, no significant differences were observed (Table 3).

Biochemical analyses

The tDCS group showed a significant reduction in the plasma concentration of HDL-cholesterol and a significant increase in the concentration of insulin, while in the tDCS + AE group, no significant differences

were observed after the intervention (Table 4). In the intergroup comparison, significant differences were observed in the concentration of triglycerides, with the tDCS group showing lower triglyceride values (Table 4).

Table 4. Analysis of the chronic effect of interventions on biochemical markers, body composition and maximum oxygen consumption (n = 16).

Variables	Group	Pre	Post	Intergroup comparisons	Intragroup comparisons	
				p-value	*p*-value	Effect size (R)
Biochemical analyses						
Glucose	tDCS	101.5±11.7	97.2±7.6	.24	.15	0.49
(mg/dL)	tDCS+AE	92.6±5.8	88.5±5.5		.37	0.37
Insulin	tDCS	20.4(17.6-31.2)	34.7(25.0-45.,4)	.27	.03*	0.82
(µUI/mL)	tDCS+AE	23.7(15.3-42.2)	27.6(21.9-31.6)		.87	0.07
Glycated	tDCS	5.9±0.2	5.75±0.22	.46	.27	0.39
haemoglobin (%)	tDCS+AE	5.9±0.2	5.7±0.2		.12	0.60
Total cholesterol	tDCS	175.5±37.7	177.3±36.1	.77	.83	0.08
(mg/dL)	tDCS+AE	197.2±34.1	181.7±17.1		.24	0.47
Triglycerides	tDCS	101.4(49.1-144.1)	84.6(53.2-115.9)	.05	.21	0.47
(mg/dL)	tDCS+AE	116.5(100.9-120.7)	160.1(112.7-176.0)		.31	0.43
LDL-cholesterol	tDCS	95.9±31.7	106.4±33.6	.80	.24	0.41
(mg/dL)	tDCS+AE	112.5±26.3	102.4±23.3		.14	0.57
HDL-cholesterol	tDCS	58.1±9.6	51.5±10.5	.93	.01*	0.81
(mg/dL)	tDCS+AE	47.4±14.0	50.9±15.9		.62	0.21
Leptin	tDCS	20.7±7.8	21.7±9.6	.59	.74	0.12
(ng/mL)	tDCS+AE	28.4±15.0	25.1±15.6		.48	0.29
Body composition						
Body mass	tDCS	78.5±9.4	78.4±7.6	.08	.94	0.03
(Kg)	tDCS+AE	87.0±10.9	86.9±10.2		.83	0.09
BMI	tDCS	29.7±2.6	29.4±2.1	.09	.48	0.26
(Kg/m²)	tDCS+AE	31.2±2.0	31.1±1.6		.87	0.07
Total fat mass	tDCS	43.8(42.8-45.3)	44.2(43.7-44.7)	.52	.44	0.29
(%)	tDCS+AE	44.6(42.7-46.1)	45.0(42.4-45.0)		.74	0.14
Fat mass	tDCS	48.1±5.1	33.8±5.3	.40	.00*	0.99
(Kg)	tDCS+AE	46.4±7.2	36.3±6.4		.03*	0.75
Lean Mass	tDCS	49.7±3.1	41.4±3.7	.02*	.00*	0.84
(Kg)	tDCS+AE	44.5±6.2	49.8±7.3		.20	0.51
Total densitometry	tDCS	1.2±0.1	1.2±0.1	.12	.48	0.25
– BMD (g/cm²)	tDCS+AE	1.3±0.1	1.3±0.1		.94	0.03
Maximum oxygen consumption test						
VO_{2peak}	tDCS	30.5±5.7	33.9±6.0	.87	.04*	0.67
(mL/kg/min)	tDCS+AE	31.5±5.6	33.4±4.8		.40	0.35
Absolute VO_2	tDCS	2380.2±382.1	2527.3±488.4	.08	.06	0.61
(mL/min)	tDCS+AE	2764.0±663.6	3009.7±547.1		.25	0.46
Maximum heart	tDCS	177.1±16.8	183.2±7.4	.47	.22	0.43
Rate (bpm)	tDCS+AE	177.1±14.0	179.1±13.9		.68	0.17

*Note. tDCS-Transcranial direct current stimulation; AE-Aerobic exercise; LDL-cholesterol- Low density lipoproteins; HDL-cholesterol- High density lipoproteins; BMI-Body Mass Index; BMD-Bone mineral density; VO_2peak-Peak oxygen volume; VO_2 absolute-Volume of absolute oxygen. *p ≤ .05.*

Body composition (DXA)

A significant reduction in adipose mass was observed for both groups and a reduction in lean mass only in the tDCS group (Table 4). In the intergroup analysis, significant differences were observed only for lean mass, with the tDCS group showing lower values for this variable.

Maximum oxygen consumption and maximum heart rate (FCM)

VO_{2peak} increased significantly only in the tDCS group, with no significant difference being observed in the intergroup comparison (Table 4). For FCM, no significant intra and intergroup differences were observed.

DISCUSSION

This is the first study to investigated whether tDCS in DLPFC with virtual reality associated with aerobic exercise can reduce food intake and improve symptoms of hunger, satiety and desire for food, in individuals with binge eating. After 20 experimental sessions, it was observed that both intervention protocols (tDCS alone or with exercise) were not able to reduce caloric intake, the same observed in a study conducted by Ljubisavljevic et al (2016).

A recent study showed that obese individuals who received anodic tDCS from the left CPFDL had a tendency to lower caloric intake and weight loss than with cathodic tDCS (Gluck et al, 2015, Heinitz et al, 2017), a protocol similar to that used in our study. On the other hand, in the present study, significant reductions were observed in proteins and carbohydrates consumption of for the tDCS group and of lipids for tDCS + AE, with no intergroup difference. It is known that stimulation of the prefrontal cortex can stimulate dopaminergic pathways by regulating food intake through appetitive motivational processes (Nitsche et al, 2006), thus being able to be related to the reduction in the consumption of two groups of macronutrients in the tDCS group. In a study by Evero et al (2012), magnetic resonance was used to verify the effect of exercise in brain regions related to food reward, activation of DLPFC was not observed during aerobic exercise. The authors suggest that exercise decreases neural activity in regions that are not necessary for maintaining that effort. This may explain why the tDCS + AE group showed a reduction in only one of the macronutrients, while the isolated tDCS reduced consumption by two.

The hunger measured at the test did not show a significant change in both groups, however, the measurements at this moment cannot represent the usual time of greatest hunger of the participants. At the same time, in the uncontrollable urge to eat, a reduction was observed only for fatty foods in the tDCS group. Fregni et al. (2008), also observed a significant reduction in the desire for food using the same positioning of the electrodes adopted in this protocol. Studies show that there may be a hemispheric laterality to the desire for food; and it can be speculated that the effects of left versus right stimulation may be qualitatively different (Goeders, 2002; Wang et al, 2004; Wang et al, 2006). Considering that the right hemisphere can suppress the desire to eat in general (or hunger), the left hemisphere can have a selective effect on the desire for food and decrease the desire for specific foods (Fregni et al, 2008). The tDCS + AE group, on the other hand, may not have improved in this parameter precisely because of the selectivity of activation of the brain regions during exercise, causing brain regions related to the desire for food to be less activated during exercise (Goeders, 2002).

There were no significant intergroup differences in the analysis of satiety throughout the day. However, significant reductions were seen in both groups post-intervention. Although hunger and satiety appear to be regulated by the hippocampus (Davidson et al, 2010), and it has connections with the prefrontal cortex, this area is a deep subcortical structure, and perhaps the tDCS was not able to modulate the neuronal activity of

this area (Lang et al, 2005) or the intensity and duration of the protocol applied in this study was insufficient to modulate it (Montenegro et al, 2012). On the other hand, the evidence that investigates the chronic effects of aerobic exercise on hunger parameters is quite conflicting. Some studies have shown that hunger increases after aerobic training (King et al, 2009; Caudwell et al, 2013; Martins et al, 2010), others have not reported any changes (Martins et al, 2013; Morishima et al 2014; Martins et al, 2007), or have shown a reduction in hunger (Guelfi, Donges and Duffield, 2013). Despite the lack of consensus, it has been suggested that chronic exercise alters the sensitivity of the appetite control system by regulating the urge to eat, causing an increase in satiety (King et al, 2009; Martins et al, 2010). This is corroborated by evidence that suggests that hunger and ad libitum energy intake are reduced after consuming a high, but not low energy density meal, in individuals undergoing a structured physical training program (Martins et al, 2013; Martins et al, 2007). In our study, the little effect of tDCS on regions that regulate satiety associated with the effect that exercise has on this parameter by other physiological routes, may partly explain the best results in the tDCS + AE group for satiety throughout the day.

Regarding biochemical markers, improvements were observed on cardiovascular outcomes in the tDCS group. A preliminary study identified changes in the intestinal microbiome in an overweight individual who underwent multiple sessions of tDCS (Artifon et al, 2020). It is possible that changes in the microbial composition may reduce intestinal permeability and, consequently, systemic inflammation, as well as contribute to the synthesis of neurotransmitters promoted by the intestinal ecosystem, which, in turn, could justify the change in cardiovascular markers and assist in the treatment of obesity and other relevant chronic diseases (Artifon et al, 2020; Peirce and Alviña, 2019). On the other hand, it has been reported that responses to plasma cholesterol are not always achieved with physical training and are especially difficult to demonstrate in previously sedentary women (Artifon et al, 2020), a predominant sample in our study. In addition, it has been observed that the main effect of exercise on plasma cholesterol is an increase in HDL-C as a result of resistance training related to increased activity of lipoprotein lipase (LPL) and triglyceride catabolism. This may justify the fact that we did not observe differences in these individuals, mainly due to the fact that we adopted an aerobic exercise protocol. A meta-analysis (Peirce and Alviña, 2019) demonstrated that long-term simultaneous exercise programs (aerobic and resistance) generate more significant improvements in LDL cholesterol, as well as in total cholesterol. Thus, it is believed that eight weeks of exclusively aerobic exercises were not enough to observe improvements in these markers. These findings suggest that this population requires interventions for longer periods so that significant changes in lipid variables can occur (Peirce and Alviña, 2019; Haskell, 1984).

Likewise, the tDCS group presented a large body mass decrease, which can lead to an insulin / glycemia imbalance, as well as an increased consumption of foods with a high glycaemic index, an uncontrolled factor in our study. In the tDCS + AE group, the effect of insulin-independent exercise on blood glucose favours the maintenance of insulin levels even with weight loss. Many studies have examined changes in two tonic appetite suppressants, leptin and insulin in response to physical training. These generally report reductions in leptin after aerobic and resistance training (Morishima et al, 2014; Guelfi, Donges and Duffield, 2013), while the findings for insulin are more variable, with some studies showing a reduction (Morishima et al, 2014; García-Hermoso et al, 2018) and other studies showing no change (Martins, Truby and Morga, 2007; Guelfi, Donges and Duffield, 2013) after exercise protocol. Studies suggest that leptin is released in the brain at an increased rate in obese humans, in which there is also activation of brain serotonergic and neuropeptide Y mechanisms (Fragala et al, 2014).

In the analysis of body composition, significant reductions were observed in both groups on fat mass. For lean mass, there was a decrease only in the tDCS group. This may have occurred mainly due to the fact that

in the context of weight loss, exercise strategies play a role in maintaining lean mass, even when the strategies used are predominantly aerobic (Rosenkilde et al, 2013). A significant change in VO_{2peak} was observed in the tDCS group. VO_{2peak} is a direct predictor of mortality, proving to be more effective than other risk factors (Swift et al, 2018). The increase in VO_{2peak} in the tDCS group is possibly attributed to the reduction in body mass found in this group (Δ -11%), since it is relativized by the total body mass, which is evidenced when observing that the absolute VO_2 did not present differences. Obesity and the autonomic nervous system are intrinsically related, demonstrating that a 10% increase in body weight is associated with a decline in parasympathetic tone, accompanied by an increase in average heart rate and, conversely, heart rate decreases during the reduction of weight. There is little data on the metabolic and autonomic effects of weight loss on the autonomic nervous system in obese individuals (Ross et al, 2016).

As eating behaviour is an important component that can increase adherence to prescribed diets, we believe that the potential of tDCS and aerobic exercise to modulate eating behaviour can contribute to better adherence to dietary treatment and, therefore, to weight loss and better quality of life. The present study has some limitations, the small sample size may have limited the inference of the data, in addition to the reduced number of experimental sessions associated with the short duration of the exercise protocol, which may have interfered with the observed results. However, the originality of the study and the reliability of the measures carried out in this work add relevant and reliable data to the literature.

CONCLUSION

The results of the present study demonstrate that multiple sessions of tDCS and simultaneous visual stimulation combined with aerobic exercise, reduced food intake and the uncontrollable desire to eat certain food groups, as well as reduced the perception of hunger by increasing satiety. On the other hand, isolated tDCS was able to improve more clinical outcomes such as adipose mass and VO_{2peak}. To our knowledge, to date this is the first study to demonstrate that the association of tDCS with aerobic exercise can improve the symptoms of binge eating in the investigated population.

AUTHOR CONTRIBUTIONS

Milena Artifon - project development and article writing. Gabriel Mayer Tossi - data collection and article writing. Nathália Griebler - data collection and article writing. Pedro Schestatsky - project development and article review. Francesco Boeno - data collection and article writing. Cesar Moritz - data collection and article writing. Juliana Lopes Teodoro - data collection and article writing. Lucas Beraldo - data collection and article writing. Lauren Naomi Adachi - data collection and article review. Álvaro Reischak de Oliveira - project development and article review. Caroline Pietta-Dias - project development, guidance and article review.

SUPPORTING AGENCIES

No funding agencies were reported by the authors.

DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

ACKNOWLEDGMENT

Universidade Federal do Rio Grande do Sul - UFRGS, for the financial support for carrying out the research.

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ORIGINAL ARTICLE

Battery test innovation for table tennis skills: Content validity

HARY WIDODO, TOMOLIYUS , ABDUL ALIM

Department of Sport Science. Yogyakarta State University. Indonesia.

ABSTRACT

Table tennis is a sport that requires skill as a determining factor in athletes competing at the elite level. This is inseparable from tests and measurements of athlete skills. This study's objective was to evaluate the battery test's content validity for table tennis skills. This study uses a mixed method of qualitative and quantitative, explorative sequential model design. The Delphi technique was utilized to collect the study data, with the subjects including thirty players of table tennis as well as four professional specialists in the sport as well as three academic experts. This study used an instrument with a rating scale of one to five. Furthermore, the data obtained were analysed using the Aiken formula. The qualitative results explained that the dominant variables of the battery test for table tennis skills that need to be measured included forehand drive, backhand drive, forehand topspin, backhand topspin, backspin service, and topspin service. The results showed that the table tennis skills battery test obtained a value of V = 0.969 for the first aspect, the second aspect obtained a value of V = 0.969, the third aspect obtained a value of V = 0.969, the fourth aspect obtained a value of V = 0.969, the fifth aspect obtained a value of V = 0.906, the sixth aspect obtained a value of V = 0.875, and the seventh aspect obtained a value of V = 0.844. Furthermore, the ICC results show that the average points of each athlete are categorized as good. Based on these results, the table tennis skills battery test has high content validity and has good reliability so the table tennis skills battery test can be used to measure table tennis skills.

Keywords: Performance analysis of sport, Table tennis, Skills, Battery test.

Cite this article as:
Widodo, H., Tomoliyus, & Alim, A. (2024). Battery test innovation for table tennis skills: Content validity. *Journal of Human Sport and Exercise, 19*(2), 451-460. https://doi.org/10.55860/m24w9527

Corresponding author. *Department of Sport Science. Yogyakarta State University. Indonesia.*
E-mail: tomoliyus@uny.ac.id
Submitted for publication October 07, 2023.
Accepted for publication November 16, 2023.
Published April 01, 2024 *(in press* December 26, 2023).
JOURNAL OF HUMAN SPORT & EXERCISE ISSN 1988-5202.

doi: https://doi.org/10.55860/m24w9527

INTRODUCTION

Table tennis is a primary example of a technique-based sport. Players aiming at the elite level need to develop extraordinary technical skills: the ability to switch quickly to match hitting technique, footwork, flexibility and speed, ability to anticipate and react, precise positioning, and control of balance (Akpinar et al., 2012; Emre & Koçak, 2010; Malagoli et al., 2011). Skill or technique ability is one of the supporting factors because table tennis performance is very complex, considering technical and tactical aspects that require a variety of technically different strokes (Munivrana et al., 2015). Ideally, table tennis skills include forehand drive, forehand topspin, backhand drive, backhand topspin, and services that are often used in games (He et al., 2021; Marsan, 2020; Suisdareni & Tomoliyus, 2021; Tamaki, 2021). Skills are considered a classic constraint in the early stages of development and at the stage of the 8 to 12-year age range, which is an important milestone of opportunity for young high potential players to develop their technical skills as a foundation for reaching elite level *("Critical Periods, Sensitive Periods, and Readiness for Motor Skill Learning*" David, Anderson, Richard, A. Magil, 2020). Therefore, mistakes that can hinder the development of player techniques must be considered in improving player skills (Lehrplanreihe, n.d.).

However, the training method used to determine the increase in table tennis technique skills in these studies has also been used in several previous studies, one of which included the instrument used to determine the technical skills of table tennis athletes (Le Mansec et al., 2018). Instruments also have an important role in the athlete development process. Measurement and evaluation tests in sports are used to determine weaknesses, and strengths, and to guide the design of training programs. This is reinforced by the literature that tests and measurements are important instruments in sports science and for evaluating athletes who are developing potential technical skills (Rietveld et al., 2019). Previous research used forehand and backhand topspin instruments that applied robots, providing 45 trials and target accuracy divided into three targets (Le Mansec et al., 2018). In other research, the service instrument was used to determine the accuracy of the player's serve, the target service was divided into six parts, and ten attempts were made (Van Biesen et al., 2010).

From the results of previous literature reviews, the skills instruments used in the previous studies needed fixing regarding their measurements. Generally, the instruments used had only one element of technical skills and were separate. Accuracy is the main parameter in measurement, but the weakness is in the target, which is only limited to one point (Faris et al., 2022). The game of table tennis requires placing the ball in a part that is difficult for the opponent to reach or makes it difficult for the opponent to return the ball (Djokić, 2020). Therefore, the instrument used has norms in accordance with table tennis performance to evaluate players to make training programs. When an instrument measures the intended outcome with high levels of accuracy and precision, it is considered to be effective or to have a high level of validity (Pojskic et al., 2022; Utama et al., 2023). Therefore, an instrument or battery test for table tennis skills is needed, which has good validity. These previous studies and literature reviews became the basis for this study to perform battery tests for table tennis skills. The purpose of this study was to assess the content validity and reproducibility of the battery test construction of table tennis skills.

MATERIAL AND METHODS

Mixed qualitative and quantitative methodologies were used in this study, using an exploratory type design included in the sequential model to obtain complete and valid data. The stages in this study consisted of four stages, namely: The first stage is a qualitative approach is used, with articles, journals, and textbooks reviewed as part of the literature review process (Ferrari, 2015), which have links with existing table tennis

skill instruments to develop conceptual and operational definitions of table tennis skill instruments. The second stage is applying the Delphi technique to collect the content validity (Cox et al., 2016; Green, 2014; Hsu & Sandford, 2007). To test the design of the table tennis skill battery test building, the Delphi technique was used with the note that the experts did not meet each other in assessing. This technique is used to reach the opinion of experts on a particular subject in a gradual and iterative process (Hasson et al., 2000). The third stage is qualitative analysis, where the input results from expert judgment are analysed for revision until the construction of the table tennis skills instrument is accepted without further improvement (Fraenkel, J. R., Wallen, N. E., & Hyun, 2017) and is given a mark. The fourth stage is testing the results of the experts' assessment with Aiken's formula. The fifth stage of testing the battery test with thirty table tennis athletes analysed using Intraclass Correlation Coefficients (ICC).

Participants

A The subjects in this study included seven qualified experts: four professional table tennis experts and three academic specialists, with a minimum criterion for a coach having a national trainer certificate or a coach who has brought athletes to regional and national level competitions. Thirty table tennis athletes aged 12-16 years with the criteria of having participated in national and regional matches.

Table tennis skills battery test procedure

The purpose of the battery test

The test aimed to measure forehand drive, backhand drive, forehand topspin, backhand topspin, backspin service, and topspin service skills.

Tools

- 20 tennis balls provided to perform the test and 10 spare balls.
- 1 bed.
- Tennis table board and the net.
- Test forms and pens.

Operators

- 1 note taker.
- 1 person as a counter and ball bounce observer.
- 1 person as ball taker.
- An operator for forehand and backhand drive, forehand and backhand topspin using the coach to pass the balls and operate the robot.

Forehand drive and backhand drive performances

- First, the examinees performed warming-ups.
- The examinees stood and held the bed, and when they were ready, they performed the forehand drive movement aimed to the signed area.
- The examinees performed the forehand drive by aiming the balls to Box A first, then to Box B, and then Box C, and performed it repeatedly by alternately directing the target.
- After that, a backhand drive is continued by directing the ball to box A first, after that it is aimed at box B, and then directed to box C, repeated by taking turns directing the target.
- The examinees given the opportunity 20 times in each test with techniques according to regulations.

Forehand topspin dan backhand topspin performances

- First, the examinees performed warming-ups.
- The examinees stood and held the bed, and when they were ready, they performed the forehand topspin movement aimed to the signed area.
- The examinees performed the forehand topspin by aiming the balls to Box A first, then to Box B, and then Box C, and performed it repeatedly by alternately directing the target.
- After that, a backhand topspin is continued by directing the ball to box A first, after that it is aimed at box B, and then directed to box C, repeated by taking turns directing the target.
- The examinees given the opportunity 20 times in each test with techniques according to regulations.

Backspin service performances

- First, the examinees performed warming-ups.
- The examinees stood and held the bed, and when they were ready, they performed the backspin service movement aimed to the signed area.
- The examinees performed the backspin service movement by aiming the balls to Box A first, then to Box B, and then Box C, and performed it repeatedly by alternately directing the target.
- The examinees were given 20 chances using the allowed technique.

Topspin service

- The examinees performed warming-ups.
- The examinees stood and held the bed, and when they were ready, they performed the topspin service movement aimed to the signed area.
- The examinees performed the service by aiming the balls to Box CC first, then to Box DD, and performed it repeatedly by alternatively directing the target.
- The examinees were given 20 chances using the allowed technique.

Marking

- The score taken is when the ball enters the box, it gets a value of 1, if it does not enter the box, it is considered a failure or gets a value of 0.
- Movements that fail and have a value of 0, apart from not entering the box, are as follows: Drive, Topspin and Service Movements that do not comply with the game rules, balls that go out of bounds, balls that do not cross the net (get stuck).
- The total score is the value obtained at each measurement.

Research instruments

The instrument used to collect data in this study was a questionnaire with a rating scale of 1 to 5 which was given at the expert judgment stage, namely 5 = very relevant, 4 = relevant, 3 = sufficient, 2 = not relevant, and 1 = very irrelevant. In addition, another instrument for this research was in the form of score sheets for material experts and sports evaluation experts. Expert assessment sheets were used to find out how relevant conceptual and operational definitions were, stimulus for respondents, (1) items, (2) suitability of the number of targets, (3) target width, and (4) procedures, (5) number of repetitions, (6) sequence stage, and (7) score calculation.

Data analysis

The expert judgement results were analysed using Aiken's formula (Aiken, 1985) as follows:

$$V=\frac{\sum(r_i-l_0)}{n(c-1)}$$

S = r – lo
Lo = lowest rating score
C = highest rating score
R = number given by rater

Figure 1. Formula Aiken's.

Data analysis of inter-point reliability test battery test obtained by athletes using (ICC). According to Fleiss (Fleiss, 1986), the ICC calculation results are divided into four groups as follows: ICC values of 0.40 or lower can be interpreted as a low level of agreement, ICC values of 0.41-0.75 as a good level of agreement, and ICC 0.76-1.00 as a high level of agreement.

RESULTS

Literature reviews results

The result is a collaboration between the results of qualitative analysis with systematic literature review techniques and some input from expert judgment regarding the construction of a table tennis skills battery test. The order of the variables and their images is as follows:

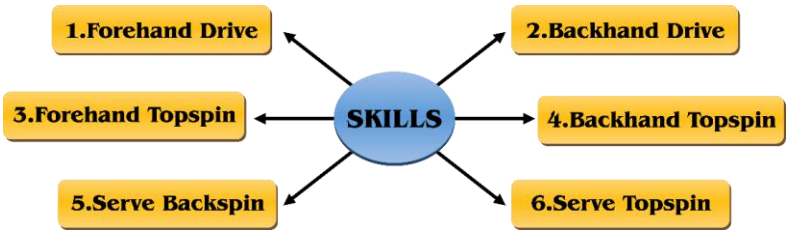

Figure 2. Table tennis skills battery test.

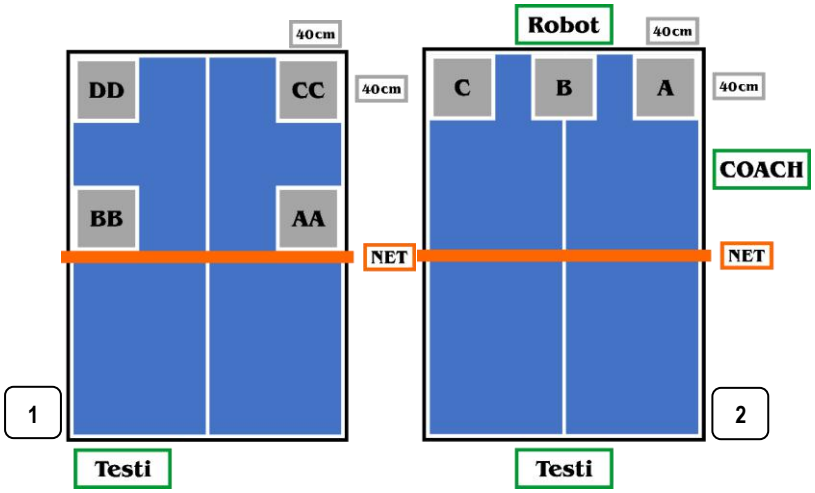

Figure 3. 1. Battery test for forehand drive, backhand drive, forehand topspin, and backhand topspin. 2. Battery test for backspin service and topspin service.

Based on the picture above the results of the literature review, the sequence of table tennis battery test variables includes 1) forehand drive, 2) backhand drive, 3) forehand topspin, 4) backhand topspin, 5) serve backspin, 6) serve topspin. This result is a variable order of implementation of the table tennis player battery test.

The picture above is a battery test instrument used in the assessment of table tennis skills, Figure 3 is the target used Battery test for forehand drive, backhand drive, forehand topspin, and backhand topspin, while Figure 4 is the target Battery test for backspin service and topspin service.

Aiken's validity result

Table 1. Aiken's validity results of tennis table skills battery test.

	Score evaluator							**Rater scale**									**∑ S**	**V**
Aspect 1	5	4	5	5	5	5	5	5	4	3	4	4	4	4	4	4	31	0.969
Aspect 2	5	4	5	5	5	5	5	5	4	3	4	4	4	4	4	4	31	0.969
Aspect 3	5	4	5	5	5	5	5	5	4	3	4	4	4	4	4	4	31	0.969
Aspect 4	5	4	5	5	5	5	5	5	4	3	4	4	4	4	4	4	31	0.969
Aspect 5	5	4	5	4	4	5	5	5	4	3	4	3	3	4	4	4	29	0.906
Aspect 6	5	4	5	4	4	4	5	5	4	3	4	3	3	3	4	4	28	0.875
Aspect 7	5	4	5	4	4	4	5	4	4	3	4	3	3	3	4	3	27	0.844

Based on the results of Aiken's analysis in Table 1, it can be concluded that the suitability aspect of the items used received a value of V = 0.969, the aspect of the number of targets used received a value of V = 0.969, the suitability aspect of target width received a value of V= 0.969, the aspect of the procedure used received a value of V = 0.969, the aspect of the number of repetitions of the implementation received the value of V = 0.906, the aspect of the sequence of tests carried out received the value of V = 0.875, and the score calculation aspect received the value of V = 0.844. The results of Aiken's V analysis calculations show that all aspects of the battery test for table tennis skills can be said to have good content validity because the value of V with eight expert judgments and a 1-5 Likert scale is obtained with a value of > 0.75 (Aiken, 1985).

The results of the battery test used thirty table tennis athletes with age criteria 12-16 years

Table 2. Table tennis battery test results.

Variable	**Participant (n = 30)**		
	Min	Max	Mean and S. D.
Forehand drive	14	20	1.416
Backhand drive	12	18	1.799
Forehand topspin	13	18	1.526
Backhand topspin	9	16	1.906
Serve backspin	8	17	2.128
Serve topspin	8	17	1.918
Total	**76**	**97**	**5.538**

ICC test results

After testing the table tennis test battery using thirty table tennis athletes followed by ICC analysis, the ICC test results are as follows:

Table 3. ICC test results.

Intraclass Correlation Coefficient							
	Intraclass Correlation	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.242	.119	.417	3.230	29	174	.000
Average Measures	.690	.486	.834	3.230	29	174	.000

Based on Table 3, the ICC test results show the results of the average points of athletes doing the battery test of 0.690. In other words, the ICC results can be categorized as having good criteria (Fleiss, 1986).

DISCUSSION

This study aimed to test the battery test's content validity for table tennis skills. According to this study, the battery test of table tennis skills showed good content validity and had good reproducibility and could be used to measure the ability level of an athlete. Based on the results of the perception of experts, the aspects of the suitability of items, the number of targets, the suitability of the target width, the procedures used get the same value of 97.5%. In addition, the aspect of the number of implementation repetitions gets a value of 92.5%, the test sequence stage gets a value of 90%, and the score calculation gets 87.5% these results show the perception of experts in assessing the battery test is feasible to use.

Measurement tests and exercises are inseparable activities (Büyükkarci, 2014). This becomes a series of activities in the sports process, especially tests and measurements closely related to sports achievement. Achievement sports require tests and measurements to see the success of the athlete's performance in carrying out a predetermined training program. The evaluation results are used when tests and measurements have been carried out Measurement activities for table tennis certainly require a more effective and efficient touch as an instrument's attractiveness. For this reason, battery tests were developed to simplify testing and measurement. Tools or test instruments that are more meaningful and innovative to support the achievement of athlete performance. According to previous research, the development of measurement instruments is one of the efforts to support individual and team achievements, which requires someone to continue to innovate to make tools with high novelty (Faber et al., 2014).

The battery test for table tennis skills has the advantage that it can include measurements of table tennis performance skills often used by players in matches and practice. These skills include forehand drive, backhand drive, forehand topspin, backhand topspin, backspin service, and topspin service (Wong et al., 2020). Athletes who can master every element of skill can compete at the elite level of table tennis (Zhang, 2021). It cannot be denied that mastery of athlete skills is the dominant factor in competing (Wong et al., 2020). One example is the accuracy of services which is the first step in playing and developing a playing strategy (Đukić & Ivanek, 2020). In addition, forehand and backhand topspin are offensive shots in table tennis performance and are decisive shots for points (Bánkosz & Winiarski, 2018; Hegazy et al., 2020). Therefore, table tennis performance skills need to be developed and can be improved so that athletes can reach peak performance.

Based on the results of this study, it can be stated that the battery test for table tennis skills has high content validity. Furthermore, the ICC test results show good results so that the table tennis skill battery test is needed in measuring the skills of table tennis athletes. The limitation in this study is a measurement test in the form

of a special table tennis battery test.

CONCLUSION

Based on the results and discussion in this study, it can be concluded that the table tennis skill test containing forehand drive, backhand drive, forehand topspin, backhand topspin, backspin serve, and topspin serve has high content validity and has good reproducibility so that it can be used in measuring the ability of table tennis athletes. For the table tennis skills battery test to be more perfect, further research needs to be continued to test the reliability of this battery test.

AUTHOR CONTRIBUTIONS

Hary Widodo, Tomoliyus, and Abdul Alim, conceived and designed the measuring instrument, collected data, analysed and interpreted the data, drafted the manuscript, and approved the final version submitted.

SUPPORTING AGENCIES

No funding agencies were reported by the authors.

DISCLOSURE STATEMENT

No potential conflict of interest were reported by the authors.

ACKNOWLEDGEMENTS

The researcher would like to thank Yogyakarta State University and the Indonesian Table Tennis Association (PTMSI) for providing the opportunity to collect data so that this article can be completed properly and can be used by coaches and athletes, especially table tennis.

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ORIGINAL ARTICLE

Health and skill-related physical fitness of physiotherapy students: An observational study

LARA AL-KHLAIFAT[1], EMAD AL-YAHYA[1], DANIA QUTISHAT[1], RASHA OKASHEH[2], MAHA T. MOHAMMAD[1], JENNIFER MUHAIDAT[1]

[1]Physiotherapy Department. School of Rehabilitation Sciences. The University of Jordan. Amman, Jordan.
[2]Keele University. United Kingdom.

ABSTRACT

Physiotherapy is a physically demanding profession. Health and skill-related physical fitness should be emphasized in physiotherapy students for both the personal benefit on their own health and injury prevention and for the sustainability of their ability to meet job demands. This study aims to assess levels of health and skill-related physical fitness in undergraduate physiotherapy students in Jordan. A cross sectional study of 109 physiotherapy students; 23 males aged 19.57 (1.44) years and 86 females aged 20.02 (2.61) years. The following health and skill-related physical fitness components were assessed: body mass index (BMI), modified sit and reach, partial curl-up, push-ups, vertical jump, 20-m shuttle run, handgrip strength, 4x10 shuttle run, and star excursion balance tests. Most of the students had normal BMI (65.1%) but levels of physical fitness were mainly poor and below average except for hamstring flexibility which was excellent. Lack of normative data on agility and dynamic balance in healthy adults who are not athletes limited determining their level in our students. The results mainly demonstrated poor levels of health-related physical fitness of Jordanian physiotherapy students, which could have a significant effect on their performance and increase their risk of injury. Dynamic balance and agility results are presented for the first time in healthy adults (not athletes) which could be used in future research. It is suggested to encourage commitment towards lifestyle modification and health behaviour and increase awareness of the physical demands of the profession.

Keywords: Sport medicine, Fitness assessment, Physiotherapy, Risk of injury, Injury prevention, Agility, Dynamic balance.

Cite this article as:
Al-Khlaifat, L., Al-Yahya, E., Qutishat, D., Okasheh, R., Mohammad, M. T., & Muhaidat, J. (2024). Health and skill-related physical fitness of physiotherapy students: An observational study. *Journal of Human Sport and Exercise, 19*(2), 461-472. https://doi.org/10.55860/neesf573

Corresponding author. *Physiotherapy Department, School of Rehabilitation Sciences, The University of Jordan, 11942, Amman, Jordan.* https://orcid.org/0000-0002-4271-3063
E-mail: l.khlaifat@ju.edu.jo
Submitted for publication October 10, 2023.
Accepted for publication November 16, 2023.
Published April 01, 2024 *(in press* December 26, 2023).
JOURNAL OF HUMAN SPORT & EXERCISE ISSN 1988-5202.

doi: https://doi.org/10.55860/neesf573

INTRODUCTION

Physiotherapists are role models in commitment to a healthy lifestyle, they have a significant role in health and physical activity promotion (Bello, Bonney, & Opoku, 2016; Multani, Bhawna, & Singh, 2013). Also, physiotherapy as a profession is physically demanding. Therefore, it is expected of physiotherapists to have high levels of physical fitness to fulfil their roles (Bello et al., 2016; Multani et al., 2013). Physical fitness is defined as "*the ability to carry out daily tasks with vigour and alertness, without undue fatigue and with ample energy to enjoy leisure pursuits and to meet unforeseen emergencies*" (Caspersen, Powell, & Christenson, 1985). It is divided into health-related physical fitness which includes body composition, cardiorespiratory endurance, muscle strength, endurance, and flexibility, as well as skill-related physical fitness which involves speed of movement, balance, agility, and co-ordination (Corbin, Pangrazi, & Franks, 2000).

Physical fitness is to be emphasized in physiotherapy students for both the personal benefit on their own health and injury prevention and for the sustainability of their ability to meet job demands. Health-related physical fitness is necessary as students are required to attend multiple and lengthy practical sessions in different courses in addition to full days in clinical placements which involve performing a wide range of therapeutic exercises, transfer techniques, and gait training. Skill-related fitness mastery is similarly important to be able to demonstrate what they are asking patients to do and to decrease risk of injury, as decreased balance increased the risk of lower extremity injury in healthy adults (Phillip A. Gribble, Hertel, & Plisky, 2012). Furthermore, achieving a good level of physical fitness might be one possible solution to decrease work-related musculoskeletal disorders. Musculoskeletal pain is common among physiotherapy students worldwide, with pain was mainly reported in the neck, low back, and shoulder regions followed by the knees and ankles (Mirza, Roslan, & Bahri, 2019; Multani et al., 2013; Nyland & Grimmer, 2003).

Studies assessing health-related physical fitness in physiotherapy students focused on the evaluation of level of cardiorespiratory fitness and found poor and below average results in both genders (Fotynyuk, 2017; Juhkam & Vaher, 2019; Mahajan & Rawat, 2020; Multani et al., 2013; Parmar & Vaghela, 2015; Pawaria, Kalra, & Pal, 2017). However, assessing other health-related fitness components is similarly significant to meet the demands of the profession. A few studies investigated strength, flexibility, and body composition with variable results which could be explained using different tests and cut off points (Bello et al., 2016; Juhkam & Vaher, 2019; Mirza et al., 2019). Skill-related physical fitness components have not been extensively assessed in physiotherapy students. One study assessed the change over 10 years and reported a decrease in right and left spinning co-ordination over time, but levels of performance were not reported (Lewandowski, Sarwinska, Siedlaczek, & Piekorz, 2020). Another study found poor results of speed-power using long jump from the spot test, however their normative data were not accessible as they were reported in Ukrainian (Fotynyuk, 2017). Likewise, levels of balance performance have not been previously assessed in physiotherapy students.

Therefore, the purpose of this study is to assess levels of health-related and skill-related physical fitness in undergraduate physiotherapy students in Jordan. This data can be used to provide an insight into physiotherapy students' fitness levels to raise awareness and help plan appropriate measures to improve these levels, such as launching campaigns to increase awareness, incorporating exercise sessions for undergraduate physiotherapy students during their studies, or to include assessment of physical fitness level before enrolling into physiotherapy degree.

MATERIAL AND METHODS

Participants

A convenience sample of 109 physiotherapy students from the School of Rehabilitation Sciences at The University of Jordan were recruited through social media. Students with health conditions that could affect their participation such as asthma or rheumatoid arthritis (confirmed by self-report) were excluded from the study. The demographic characteristics of the participants are presented in Table 1. Of the 109 physiotherapy students, six male students (26.1%) and four female students (4.7%) were smokers.

Table 1. Characteristics of the participants. Results are represented as mean (SD) unless otherwise stated.

Gender (n)	Males (n = 23)	Females (n = 86)
Age (years)	19.57 (1.44)	20.02 (2.61)
Weight (Kg)	75.34 (15)	59.32 (10.94)*
Height (cm)	176.35 (5.51)	162.42 (5.87)*
BMI (Kg/m^2)	24.15 (4.15)	22.48 (3.9)
Hand Dominance n (%)	Left 6 (26.1%) Right 17 (73.9%)	Left 3 (3.5%) Right 83 (96.5%)
Systolic blood pressure (mmHg)	124.78 (16.41)	109.56 (8.55)*
Diastolic blood pressure (mmHg)	71.96 (7.03)	66.57 (7.87)*
Resting heart rate (beats/minute)	76.87 (9.66)	80.70 (9.05)
Exercising n (%)	8 (34.8%)	17 (19.8%)
Type of exercise/ sport n (%)	Gym 5 (21.7%), Volleyball 1 (4.3%), Taekwondo 1 (4.3%), Martial arts 1 (4.3%)	Walking 6 (7%), Online videos 2 (2.3%), Gym 4 (4.7%), Yoga 1 (1.7%), Swimming 1 (1.7%), Taekwondo/karate 2 (2.3%), Table tennis 1 (1.7%)
Frequency of exercise/sport per week	4.25 (1.83)	4.76 (1.39)
Exercise duration/session (minutes)	84.38 (27.70)	66.76 (48.02)

*Note. *Significant difference between male and female students ($p < .001$).*

Procedures

Ethical approval was obtained from the research ethics committee (IRB) at Jordan University Hospital. All methods were carried out in compliance with the latest guidelines and regulations of the Declaration of Helsinki. The participants provided informed written consent prior to participation in the study. To avoid bias in data collection, a research assistance unfamiliar with the students performed the assessments. To ensure their anonymity, participants were assigned identification numbers. Finally, our results were reported based on the Strengthening the Reporting of Observational studies in Epidemiology (STROBE) guidelines (von Elm et al., 2007).

Demographic data were recorded in addition to systolic and diastolic blood pressure and resting heart rate. To control for confounding variables, students were informed to wear loose and comfortable clothing, to drink enough water in the 24 hours before testing, and not to smoke, eat, or have caffeinated drinks for at least three hours before testing (American college of sports medicine, 2014).

Measures

The following physical fitness assessments were performed:

Body Mass Index (BMI)

BMI is commonly used as an indirect measure of body composition (American college of sports medicine, 2014). The prevalence of musculoskeletal disorders increased with high BMI (Narendrasinh & Mulla, 2015). It was calculated and classified as recommended by the World Health Organization (Weir & Jan, 2019).

The modified Sit and Reach test

Low back pain was associated with tight hamstrings (Mistry, Vyas, & Sheth, 2014). The modified sit and reach test assess hamstring extensibility (Mayorga-Vega, Merino-Marban, & Viciana, 2014). The test uses a wooden box (dimensions 30cm x 30cm x 30cm) and 1-meter-long wooden ruler attached to the top of it where the zero point of the ruler would touch the tips of the middle fingers of the students' extended arms while long sitting against a wall (starting point). The students were requested to reach forward as far as they can on the ruler with their arms straight without bending their knees. One practice trial was performed followed by three test trials and the average distance was used for analysis. The students were instructed to exhale as they reach forward, avoid fast or sudden movements, and stretch till they feel mild discomfort. Results were compared with normative data (McArdle, Katch, & Katch, 2000).

The partial Sit-up/curl-up test

Strengthening the abdominal muscles, as part of the core muscles, decreased low back pain (Kumar, Kumar, Nezamuddin, & Sharma, 2015). Curl-up test was done to assess abdominal strength and endurance. Students started in a crook lying position on a mat with the middle finger of each hand placed on a strip of tape located at a distance of 12cm away from the end of the mat (starting position). Abdominal strength was determined based on the number of curl-ups that reached the end of the mat performed continuously at rate of 2-3 repetition/second using a metronome (40 beats/minute). The test was stopped if the students were unable to reach the end of the mat, cannot perform another repetition, cannot perform the test with regular cadence, or reached 75 sit-ups (Canadian Society for Exercise Physiology, 2003). Results were compared with normative data (Faulkner, Sprigings, McQuarrie, & Bell, 1989).

Push-ups

Upper limb endurance is negatively correlated with shoulder pain (Eraslan, Gelecek, & Genc, 2013), a common complaint in physiotherapy students. Therefore, push-ups were performed to assess upper limb endurance; male students performed standard push-ups whereas female students did the modified technique. The maximum number of push-ups performed without rest was recorded. The test was terminated if the student failed to perform the test two consecutive times or strained forcibly (Canadian Society for Exercise Physiology, 2003). Results were compared with normative data (Canadian Society for Exercise Physiology, 2003).

Maximum handgrip strength

Handgrip strength was positively correlated with shoulder function (Horsley, Herrington, Hoyle, Prescott, & Bellamy, 2016). It was assessed using the Jamar analogue hand dynamometer in kilograms according to the recommendation of the American Society of Hand Therapists (Fess, 1992). Both hands were assessed and the mean of three trials for each hand with 1 minute rest in between was used for analysis. The dominant hand was determined by self-report. Normative data are available to interpret the results (Shaheen, Omar, & Ali, 2021; Werle et al., 2009).

Vertical jump test

Lower limb strength was positively associated with dynamic balance (Forte, Boreham, De Vito, Ditroilo, & Pesce, 2014). A decrease in dynamic balance would increase risk of injury in healthy adults (Phillip A. Gribble

et al., 2012). To assess lower limb strength, the distance between the standing reach height and the highest distance the students could reach jumping vertically was recorded to the nearest 0.5 cm. Three jumps were performed with 1-minute rest in between and the longest distance was used for analysis (Payne, Gledhill, Katzmarzyk, Jamnik, & Keir, 2000). Normative data for young adults have been reported (Payne et al., 2000).

20-m shuttle run test

A valid test for the assessment of cardiorespiratory endurance is the 20-m shuttle run test (Mayorga-Vega, Aguilar-Soto, & Viciana, 2015). The students ran between 2 points, 20m apart, pacing themselves according to an audio signal starting with a speed of 8.5 km/h, which was increased by 0.5 km/h per minute (1-minute equals to one stage). The test finished when the student failed to reach the end lines concurrent with the audio signals on two consecutive occasions. Otherwise, the test ended when the student stopped because of fatigue. The maximal oxygen consumption (VO_{2max}) was calculated from this test according to the equations of Leger et al. (Leger, Mercier, Gadoury, & Lambert, 1988):

$$VO_{2max} \text{ (for 18 years and older)} = -27.4 + 6.0\ S$$

where S is the final speed (S = 8 + 0.5 x number of last stage completed).

Normative data in healthy adults using the 20-m shuttle run test are unavailable. However, our VO_{2max} data were compared with normative values for VO_{2max} calculated from treadmill testing (gold standard) (American college of sports medicine, 2014).

4X10m shuttle run test

Adding agility training to a balance exercise program significantly decreased risk of lower limb injury (Hrysomallis, 2007). To assess speed of movement, agility and coordination, students ran as fast as they could between two parallel lines 10 meters apart picking up a sponge after crossing the lines on each side. The time taken to cover a distance of 40m was recorded (Ortega et al., 2008). Normative data are currently unavailable.

Star excursion balance test (SEBT)

Improved dynamic balance would decrease risk of injuries such as chronic ankle instability and patellofemoral pain syndrome (Phillip A. Gribble et al., 2012). It was assessed using the original protocol described by Robinson and Gribble (Robinson & Gribble, 2008). The farthest distance the students could reach in the anterior, anterior-lateral, anterior-medial, medial, lateral, posterior, posterior-lateral, and posterior-medial directions was assessed. To decrease learning effects; the leg to start with, the direction to start with, and the order of testing (clockwise or anticlockwise) were randomized (Robinson & Gribble, 2008). To account for lower limb length variations between participants, excursion distances were normalized to lower limb length measured in supine from the anterior superior iliac spine to the medial malleolus (P. A. Gribble & Hertel, 2003). Each participant started with four practice trials in each direction followed by three test trials with two minutes rest in between. The average of the three trials was used for analysis. Normative data for dynamic balance normalized to leg length are unavailable. Results are presented for the right and left legs as balance is not affected by leg dominance (Schorderet, Hilfiker, & Allet, 2021).

Analysis

Data were checked for normality using the Kolmogorov–Smirnov test. Means, standard deviations, frequencies, and percentages were calculated to describe the sample and levels of physical fitness. To enable comparison with other studies, the difference between male and female students in demographic

characteristics and in each of the physical fitness tests was investigated using the independent sample t-test for parametric data or the Mann-Whitney U test for non-parametric data. To compare between sides for both the SEBT and handgrip strength test, paired t-test or Wilcoxon signed-rank test were used for parametric and non-parametric data, respectively. All statistical tests were performed using SPSS (version 25, IBM, New York, USA), and level of significance was set at $p < .05$.

RESULTS

Body Mass Index (BMI)

Table 2 demonstrates the classification of BMI. There was not a significant difference between genders ($p = .08$).

Table 2. Classifications of BMI according to the World Health Organization (n (%)).

BMI	Males (n = 23)	Females (n = 86)	Total (n = 109)
Underweight <18.5 kg/m^2	0 (0%)	13 (15.1%)	13 (11.9%)
Normal 18.5-24.99 kg/m^2	15 (65.2%)	56 (65.1%)	71 (65.1%)
Overweight 25-29.9 kg/m^2	6 (26.1%)	13 (15.1%)	19 (17.4%)
Obese > 30 Kg/m^2	2 (8.7%)	4 (4.7%)	6 (5.5%)

The modified Sit and Reach test

The majority of students had excellent flexibility (Table 3). However, male students had significantly better results compared to females ($p = .006$).

The partial Sit-up/curl-up test

Most students had poor and below average abdominal strength and endurance (Table 3). However, the male students had significantly better results compared to females ($p < .001$).

Push-ups

Below average and poor results were found for upper limb endurance in most students (Table 3). There was not a significant difference between genders ($p = .17$).

Maximum handgrip strength

Both genders had below average grip strength (Table 3). There was not a significant difference in grip strength between the dominant and non-dominant hands in male ($p = .14$) and female students ($p = .3$). On the other hand, male students had a significantly stronger grip strength compared to females ($p < .001$).

Vertical jump test

All students had poor and below average performance on this test with significantly better results for male students ($p < .001$) (Table 3).

20-m shuttle run test

Levels of cardiorespiratory fitness are presented in Table 4. All physiotherapy students had poor cardiorespiratory fitness. However, male students had significantly better results compared to females ($p < .001$).

Table 3. Results of health-related physical fitness tests.

Physical fitness test	**Males (n = 23)**	**Females (n = 86)**	***p*-value**
Modified sit and reach test(cm)			
Mean (SD)	28.8 (7.6)	24.1 (7)	
Excellent n (%)	20 (87)	70 (81.4)	
Above average n (%)	3 (13)	3 (3.5)	<.001
Average n (%)	-	1 (1.2)	
Below average n (%)	-	-	
Poor n (%)	-	12 (14)	
Partial sit-up test (number)			
Mean (SD)	33.6 (26)	17 (15.7)	
Excellent n (%)	2 (8.7)	1 (1.2)	
Above average n (%)	5 (21.7)	4 (4.7)	<.001
Average n (%)	1 (4.3)	9 (10.5)	
Below average n (%)	7 (30.4)	21 (24.4)	
Poor n (%)	8 (34.8)	51 (59.3)	
Dominant handgrip strength (Kg)			
Mean (SD)	39 (7)	21.8 (5.2)	
Above average n (%)	1 (4.3)	16 (18.6)	<.001
Average n (%)	3 (13)	3 (3.5)	
Below average n (%)	19 (82.6)	67 (77.9)	
Push-up test (number)			
Mean (SD)	24 (15.2)	18.9 (10.9)	
Excellent n (%)	6 (26.1)	16 (18.6)	
Above average n (%)	4 (17.4)	11 (12.8)	.17
Average n (%)	2 (8.7)	22 (25.6)	
Below average n (%)	1 (4.3)	26 (30.2)	
Poor n (%)	10 (43.5)	11 (12.8)	
Vertical jump test (cm)			
Mean (SD)	44.3 (11)	24.9 (6.3)	
Excellent n (%)	2 (8.7)	2 (2.3)	
Above average n (%)	5 (21.7)	3 (3.5)	<.001
Average n (%)	1 (4.3)	12 (14)	
Below average n (%)	7 (30.4)	16 (18.6)	
Poor n (%)	8 (34.8)	53 (61.6)	
Non-dominant handgrip strength (Kg)			
Mean (SD)	40.3 (7.1)	22 (5.7)	
Above average n (%)	2 (8.7)	31 (36)	<.001
Average n (%)	7 (30.4)	10 (11.6)	
Below average n (%)	14 (60.9)	45 (52.3)	

4X10m shuttle run test

It was not possible to stratify the data according to levels of performance as normative data using this test are lacking. The male students needed less time to complete the test (15.1 (1.6) seconds compared to 17.8 (2.4) seconds) and were significantly better than females ($p < .001$).

Table 4. Cardiorespiratory fitness using the 20m shuttle run test (mean (SD)).

	Males (n = 23)	**Females (n = 86)**	***p*-value**
Level (number)	3.4 (1.4)	1.7 (0.8)	< .001
Shuttles (number)	4.0 (1.2)	3.1 (1.4)	< .001
VO_{2max} ($ml.kg^{-1}.min^{-1}$)	30.9 (4.3)	25.8 (2.5)	< .001
Speed (km/h)	9.7 (0.7)	8.9 (0.4)	< .001

Table 5. Mean and standard deviation results of star excursion balance test normalized to leg length.

	Males (n = 23)		***p*-value**	**Females (n = 86)**		***p*-value**
Direction (%)	Right	Left		Right	Left	
Anterior	104.5 (12.1)	107 (15.7)	.21	103.2 (12.3)	103.5 (12.1)	.75
Anteromedial	96.8 (14.5)	101.2 (20.2)	.10	97.5 (16.2)	98.8 (17)	.29
Anterolateral	98.8 (28.8)	99.9 (29.7)	.76	97.6 (20.8)	96.9 (20.4)	.83
Medial	84.3 (33.3)	86 (32.2)	.54	82.3 (31.6)	86.1 (30.4)	.06
Lateral	94 (30.7)	92 (32.2)	.43	80.3 (27.3)	80.3 (26.2)	.69
Posterior	92.2 (15.6)*	90.7 (22.1)*	.58	77.6 (16.4)*	80.2 (17.2)*	.13
Posteromedial	91.5 (18.3)*	87.4 (24.4)	.10	79.8 (19.5)*	80.4 (18.8)	.69
Posterolateral	97.4 (22.2)*	87.5 (25.6)	.07	80.3 (16.4)*	81.2 (16.5)	.52

*Note. *Significant difference between male and female students.*

Star excursion balance test

The results of dynamic balance are presented in Table 5. Non-significant difference was observed between the right and left legs in males and females ($p > .05$). Moreover, there was a non-significant difference between genders in all directions except for the posterior, posteromedial, and the posterolateral directions on the right leg ($p < .001$) in addition to the posterior direction on the left leg ($p < .001$), where male students showed better performance.

DISCUSSION

Good level of physical fitness is essential for physiotherapists to meet the demands of the profession and decrease risk of injury. This is the first study to comprehensively assess health-related and skill-related physical fitness in physiotherapy students. Most of our students had normal BMI but levels of physical fitness were mainly poor and below average except for hamstring flexibility which was excellent. Lack of normative data on agility and dynamic balance limited determining their level in our students. However, male students performed significantly better than females.

The BMI of our participants was in the normal range; however, they demonstrated poor levels of physical fitness. Conflicting results were reported on the association between BMI and physical fitness; Parmar and Vaghela (Parmar & Vaghela, 2015) reported they were inversely correlated, whereas Mahajan and Rawat (Mahajan & Rawat, 2020) found an insignificant correlation and justified their results by the small sample size of previous studies. Moreover, results were contradictory on the association between BMI and work-related musculoskeletal disorders; one study reported the prevalence increased in physiotherapists with high BMI (Narendrasinh & Mulla, 2015), while another study found the prevalence increased in physiotherapists (61%) with normal BMI (Mirza et al., 2019). Our participants had normal BMI and poor fitness levels which could increase risk of work-related musculoskeletal disorders because of sustained static postures and repetitive movements for long periods of time.

Previous studies investigating hamstring flexibility in physiotherapy students demonstrated it ranged between good (Juhkam & Vaher, 2019; Multani et al., 2013) and poor flexibility (Bello et al., 2016; Fotynyuk, 2017), where females had better flexibility using the sit and reach test (Bello et al., 2016) explained by their increased muscle viscoelasticity (Spernoga, Uhl, Arnold, & Gansneder, 2001). Our participants had excellent flexibility with significantly better results in males compared to females (28.8 (7.6) cm and 24.13 (7) cm, respectively), which could be justified by the higher percentage of exercising males compared to females (34.8% and 19.8%, respectively).

Contrary to our results, good abdominal muscle strength and endurance (Juhkam & Vaher, 2019) and good upper extremity endurance and lower extremity strength (Mahajan & Rawat, 2020) were found in physiotherapy students in Estonia and India, respectively. Moreover, students in one college in Estonia had average and below average upper extremity endurance compared to excellent results in another college, which was explained by the students' training regime (Juhkam & Vaher, 2019). As for handgrip strength, like our results, poor handgrip strength of the dominant and non-dominant sides was reported in one college in Estonia whereas it was significantly better in another college. This difference between colleges was attributed to variability in level of physical activity and participation in sports in addition to inconsistencies in the assessment method and use of different dynamometers by both colleges.

Our participants had poor cardiorespiratory endurance when comparing their VO_{2max} results in the 20m shuttle run test with those of the gold standard. Like our results, students from different countries had poor and below average levels of cardiorespiratory endurance (Bello et al., 2016; Fotynyuk, 2017; Mahajan & Rawat, 2020; Parmar & Vaghela, 2015). One study only with a small sample size (n = 40) reported average cardiorespiratory endurance using the Harvard step test (Pawaria et al., 2017). Currently there are not published norms for the 20m shuttle run test on healthy adult populations. Future studies should establish normative values in adult populations to help determine levels of cardiorespiratory fitness.

Speed of movement, agility and coordination could improve performance and decrease risk of injury (Hrysomallis, 2007). Results of agility assessment in adults using the 4X10 shuttle run test have only been reported in athletes (39). Lack of normative data in healthy adults hindered determining our participants' levels of performance. Furthermore, dynamic balance could predict risk of lower extremity injury (Phillip A. Gribble et al., 2012). Normative data for dynamic balance assessed using the SEBT normalized to leg length in healthy adults not athletes are also lacking. Our study reported results of dynamic balance normalized to leg length in the eight directions of the SEBT in healthy physiotherapy students to enable future comparisons with other studies. The significant difference in the posteriorly directed excursions in males compared to females could be explained by the increased muscle activation of medial hamstring and biceps femoris in these directions (Earl & Hertel, 2001). However, those were not assessed in this study.

Variation in results among studies should be considered as numerous physical fitness tests and age groups were investigated, small sample size, and mandatory physical education classes in some studies with limited details possibly affect the generalization of the results. A limitation to our study is lack of normative data in Jordan therefore comparisons were made with other populations. Normative data are influenced by ethnic variations thus the results should be interpreted taking this into consideration. Moreover, details of exercises performed by the students and their commitment were lacking thus comparing the level of fitness between exercising and non-exercising students was not possible. On the other hand, this is the first study to assess health and skill-related physical fitness components including agility and balance in physiotherapy students. Future studies should investigate normative data in Jordan populations and assess variables such as level of physical activity to assist in interpreting the results.

CONCLUSION

Across studies, the variation in levels of physical fitness among physiotherapy students was large possibly due to factors such as different cultures, program entry requirements and enrolment policies in different countries. Our results mainly demonstrate poor levels of health-related physical fitness of physiotherapy students, which could affect their performance and increase their risk of injury. Dynamic balance results using SEBT and agility results using 4X10 shuttle run test are presented for the first time in healthy adults not athletes which could be used in future research. It is suggested to encourage commitment towards lifestyle modification and increase awareness of the physical demands of the profession possibly within the curriculum. Moreover, it is recommended to provide sustainable opportunities that offer physical activity campaigns, exercise programs and sport participation to students to improve or maintain their fitness level. A feasible exercise program was delivered to our students and its effect on physical fitness will be published in a future study.

AUTHOR CONTRIBUTIONS

Conception: Al-Khlaifat L. Methodology: all authors. Data collection: Al-Khlaifat, L., Muhaidat, J., Qutishat, D., & Okasheh, R. Statistical analysis and results interpretation: all authors. Manuscript preparation: all authors. All authors approved the published version of the manuscript.

SUPPORTING AGENCIES

This work was supported by The University of Jordan [grant number 2015-2014/143]. The authors report no involvement in the research by the sponsor that could have influenced the outcome of this work.

DISCLOSURE STATEMENT

No potential conflict of interest were reported by the authors.

ACKNOWLEDGEMENTS

The study complies with the current laws of the country in which they were performed.

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ORIGINAL ARTICLE

Mental strength assessment in combat sports practitioners and non-practitioners

LEANDRO LORENÇO-LIMA

Department of Psychology. Liberty University. Lynchburg, United States of America.

ABSTRACT

Mental strength is defined as a person's ability to persist through challenging situations and recover from hardships and failures. Due to combat sports (CS) vigorous nature, several authors have identified various psychological factors modified through CS engagement and experience. This research aimed to determine the psychometrics of the Mental Strength Scale, explore the correlations between mental strength and age, CS experience, and competitive engagement, and investigate the existing group differences in mental strength based on sex, age, CS engagement, competition engagement, and CS experience. The total sample included 431 participants from 18 to 67 years of age, including 373 CS practitioners and 58 non-practitioners. Results revealed that The Mental Strength Scale demonstrated good internal validity (Cronbach's alpha = 0.809) and convergent validity (Grit Scale correlation: $p < .001$, r = .539; Brief Resilience Scale correlation: $p < .001$, r = .551). A positive correlation was found between CS experience and mental strength. Group comparison demonstrated higher mental strength in CS practitioners than non-practitioners and in men compared to women. Moreover, CS participants in the >5, 2-5, and <2 years of experience reported higher mental strength than participants with no CS experience. In conclusion, the findings confirm that the Mental Strength Scale is a good psychometric instrument to assess the degree of mental strength, particularly in CS practitioners, and that CS engagement and experience positively influence the development of mental strength.

Keywords: Mental toughness, Perseverance, Resilience, Jiu-Jitsu, BJJ, Judo, Wrestling, Muay Thai, Martial arts.

Cite this article as:
Lorenço-Lima, L. (2024). Mental strength assessment in combat sports practitioners and non-practitioners. *Journal of Human Sport and Exercise, 19*(2), 473-482. https://doi.org/10.55860/gr2sf103

Corresponding author. *Liberty University, 971 University Blvd, Lynchburg, VA 24515, United States of America.* *https://orcid.org/0009-0003-9200-8965*
E-mail: lorenco.leandro@gmail.com
Submitted for publication October 16, 2023.
Accepted for publication November 28, 2023.
Published April 01, 2024 *(in press* December 26, 2023).
JOURNAL OF HUMAN SPORT & EXERCISE ISSN 1988-5202.

doi: https://doi.org/10.55860/gr2sf103

INTRODUCTION

From ancient war to contemporary society, strong individuals have been admired for their incredible ability to persist when faced with challenging situations and to spring back from extensive hardships, misfortunes, and failures. While great physical strength is a common attribute of many admired individuals, the interest in the psychological factors impacting performance has increased over the past 200 years (Lochbaum et al., 2022). In the military, Yerkes (1918) proposed over 100 years ago the development of psychological centres to address mental strength in training camps.

Several authors have presented comprehensive definitions of mental toughness (Dagnall et al., 2019; Madrigal et al., 2013). However, with numerous theoretical components, its field application becomes complex, and many constructs are overlooked when taking the theory into practice. Fundamentally, mental strength encompasses two main components: perseverance and resilience. Perseverance is rooted in the Latin word *perseverant* (abiding by strictly) and is defined as persistence in pursuing a task despite difficulty (Dagnall et al., 2019). Resilience is rooted in the Latin word *resile* (re = back, and salire = to jump) and is defined as a person's ability to bounce back and recover from hardships (Smith et al., 2008). Therefore, mental strength is defined as a person's ability to persist through challenging situations and to recover from hardships and failures. The Mental Strength Equation is expressed as: Mental strength = perseverance + resilience.

CS engagement has been shown to influence mental strength factors such as grit and resilience positively (Sawyer et al., 2018; Pujszo et al., 2019; Shamshirian et al., 2021; Lorenco-Lima, 2023; Sivan & Zeba, 2023). These relationships can be explained by the vigorous nature of CS (Franchini et al., 2017; Lorenco-Lima et al., 2020) and the direct impact of time spent in vigorous physical activity on grit (Daniels et al., 2021) and resilience (Dunston et al., 2022). However, no studies have addressed mental strength in combat sports as currently defined.

The relevance of improving mental strength factors can be credited to the positive correlations between grit and well-being (Datu et al., 2022) and life satisfaction (Li et al., 2018; Datu et al., 2022; Liu et al., 2022). Resilience greatly predicted higher life satisfaction and lower depression (Ye et al., 2022). Moreover, those engaged in sports are generally more satisfied with their mental health than non-athletes (Lorenco-Lima et al., 2023).

The purpose of this study was to 1) determine the psychometrics of the Mental Strength Scale, 2) explore the existing correlations between mental strength and age, CS experience, and competitive engagement, and 3) investigate the existing group differences in mental strength based on sex, age, CS engagement, competition engagement, and CS experience. It was hypothesized that mental strength would show H1) to positively correlate with age, H2) to positively correlate with CS experience, H3) to positively correlate with competitive engagement, H4) to be higher in males than females, H5) to be higher in CS practitioners, H6) to be higher in older participants, H7) to be higher in more experienced participants, and H8) to be higher in participants with higher competition engagement.

METHODS

Participants

The total sample included 431 participants from 18 to 67 years of age (40.83 ± 12.30), including 346 males and 85 females. Of the total sample, 373 were CS practitioners and 58 non-practitioners. CS group reported

engagement in grappling (i.e., Judo, Brazilian Jiu-Jitsu, and Wrestling) or striking (i.e., Muay Thai, Boxing, Taekwondo, and Karate) with an average experience of 13.91 ± 14.95 years in their CS.

A priory power analysis was performed with a medium effect size (.25), α = .05, and power criterion of .80. The analysis revealed a need for 200 participants as the minimum sample for age group comparison (5 groups), 180 participants for CS experience group comparison (4 groups) and 159 participants for competition engagement comparison (3 groups).

Procedures

In the present cross-sectional quantitative research, data was collected anonymously from May to October 2023 via Google Forms and disseminated through social media and email campaigns. No compensation was offered to the participants.

The Google Form contained the Mental Strength Scale, Grit Scale, Brief Resilience Scale, and questions about the participant's age, sex, CS experience, and competitive engagement (competitions over the previous 12 months).

Participants were divided into five age groups (18-27, 28-37, 38-47, 48-57, and >57 years old), four CS experience groups (0, < 2, 2-5, and >5 years of experience), and three competition engagement groups (non-competitors, 1-4 competitions, and >4 competitions). Correlations were performed using the participants' raw data (age, CS experience, and competition engagement).

Materials

The Mental Strength Scale (MSS) was used to assess the participants' explicit attitudes and behavioural responses when facing obstacles (perseverance) and failure (resilience). MSS was developed as a simplified tool for field applications containing negatively and positively worded items to mitigate the effects of response bias and social desirability. An initial analysis of the internal reliability coefficients, redundancy, and clarity of 20 statements resulted in eliminating eight items. An exploratory factor analysis with the remaining 12 statements led to the elimination of two additional statements to retain items with factor loadings above .40. The final Mental Strength Scale is composed of 10 items as a 5-point Likert scale (Appendix 1). Items 3, 6, 7, and 10 are positively worded, varying from 1 for "*strongly disagree*" to 5 for "*strongly agree*." Items 1, 2, 4, 5, 8, and 9 are negatively worded and reversely coded. Participants were instructed to mark the option that best described their thoughts over the past month while considering their sport or exercise engagement. Total scores were determined by the average of the ten items, with 5 representing high mental strength and 1 representing low mental strength.

The Grit Scale (GS) and the Brief Resilience Scale (BRS) provided convergent validity to the MSS in the present study. The GS is a 12-item, 5-point Likert scale, where participants were asked to mark the statement that best described them compared to most people (Duckworth et al., 2007). Answers for items 1, 4, 6, 9, 10, and 12 vary from 1 for "*not like me at all*" to 5 for "*very much like me*" (Duckworth et al., 2007). Items 2, 3, 5, 7, 8, and 11 were reversely coded. The total score was determined by the average of the 12 items (Duckworth et al., 2007). The maximum possible score is 5, representing extremely gritty individuals, and the lowest is 1 for not at all gritty (Duckworth et al., 2007).

The BRS is a 6-item, 5-point Likert scale, where participants were asked to mark one box per row that best described them, with answers varying from 1 for "*strongly disagree*" to 5 for "*strongly agree*" (Smith et al., 2008). Statements 1, 3, and 5 were positively worded, and statements 2, 4, and 6 were negatively worded

and reversely coded, with total scores determined by the average of the six items (Smith et al., 2008). Scores between 1.00 and 2.99 represent low resilience, 3.00 and 4.30 represent normal resilience, and 4.31 and 5.00 represent high resilience (Smith et al., 2013).

Statistical analyses

The primary analyses assessed the MSS's factor structure, reliability, and validity. An exploratory factor analysis was conducted with principal components analyses (PCA) with a fixed number of factors of 2 and Varimax rotation. Internal consistency was examined via Cronbach's alpha. Convergent validity was determined via Pearson's correlation with the GS and the BRS.

Correlations were performed via Pearson's *r*. Sex and CS engagement comparisons were performed through independent samples *t*-tests. Analyses of covariance (ANCOVA) with Fisher's Least Significant Difference (LSD) post-hoc and sex as covariate were performed to compare the age, CS experience, and competition engagement groups. IBM SPSS Statistics (Version 29) was used for data analyses with an alpha level of .05.

RESULTS

Mental strength scale psychometrics

Exploratory factor analysis revealed two dimensions. The first conceptual dimension contained six items addressing the "*risk of failure*," and the second dimension contained four items about "*facing obstacles*." Table 1 displays the factor loadings and commonalities of the MSS items. Cronbach's alpha was calculated, producing an overall reliability coefficient of .809 for the total sample and indicating good reliability. Cronbach's alpha of .806 was found for the CS practitioner group and .783 for the non-practitioners.

Table 1. Factor analysis of the mental strength scale with varimax rotation.

MSS Items	Varimax loading	Commonalities
Risk of Failure		
Challenges make me doubt myself [a]	.753	.578
I hate challenges [a]	.562	.485
I'm scared of failing [a]	.774	.600
It's hard to recover from failure [a]	.696	.491
I don't like to get out of my comfort zone [a]	.723	.531
If it's hard, I may not finish it [a]	.596	.465
Facing Obstacles		
I enjoy opportunities to challenge myself	.609	.524
Challenges make me stronger	.789	.626
I have overcome challenges in the past	.783	.617
I work hard to overcome challenges	.653	.434

Note. [a] Item reverse coded.

A validity coefficient of .539 ($p < .001$) was obtained, indicating a moderate correlation, and suggesting that the MSS is tapping into the same construct as the GS. MSS total scores were also correlated with the BRS, presenting a validity coefficient of .551 ($p < .001$), indicating a moderate correlation and suggesting that the MSS is tapping into the same construct as the BRS and, therefore, providing convergent validity evidence for the MSS.

Correlations

A significant correlation was found between experience and mental strength, $r(429) = .177$, $p < .001$ (one-tailed). The null hypothesis is rejected; 3.13% of the variation in mental strength is accounted for by CS experience (small effect).

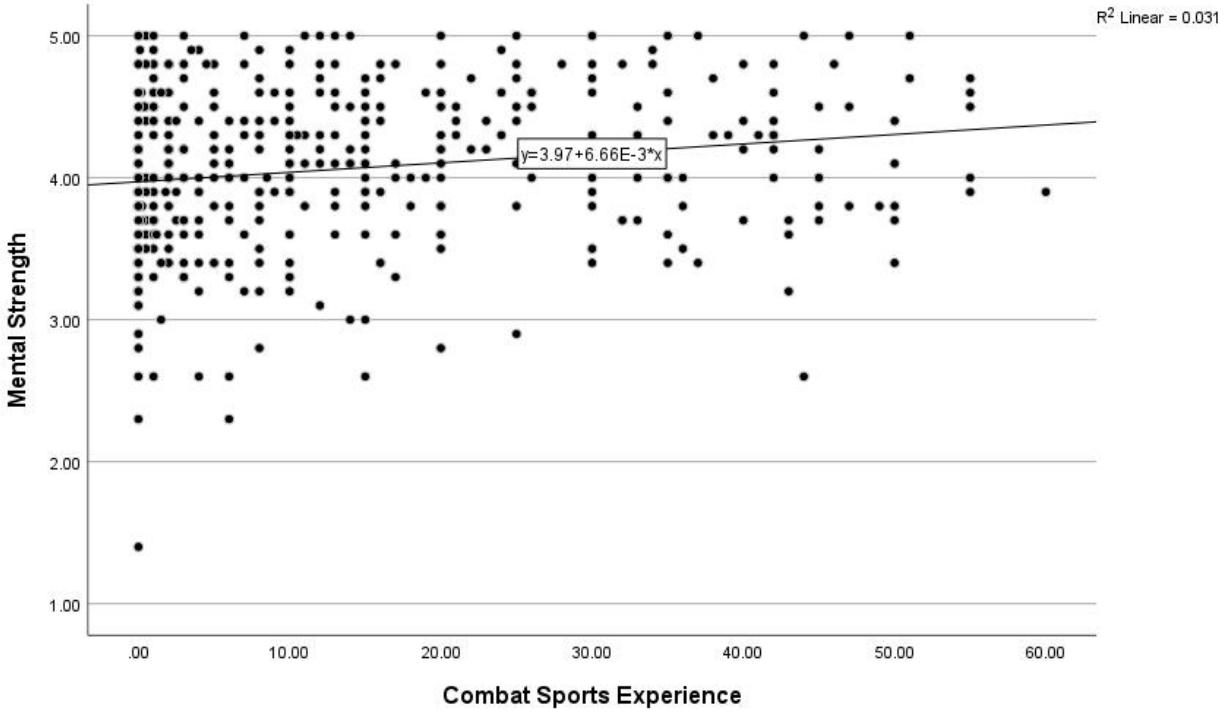

Figure 1. Scatterplot Depicting the Correlation Between CS Experience and Mental Strength.

No correlation was found between age and mental strength $r(429) = .042$, $p = .380$ (one-tailed). No correlation was found between competitive engagement and mental strength, $r(429) = .039$, $p = .422$ (one-tailed).

Group comparison

An independent samples *t*-test demonstrated a statistically significant difference in mental strength between males and females $t(429) = 2.962$, $p = .002$, $r^2 = 0.0200$, 95% CI [.06736, .33310] (one-tailed). The null hypothesis is rejected; men demonstrated higher mental strength than women (Table 2). An independent samples *t*-test demonstrated a statistically significant difference in CS experience between males and females $t(137.515) = 3.564$, $p < .001$, $r^2 = 0.0287$, 95% CI [2.69156, 9.39860] (one-tailed). The null hypothesis is rejected; men demonstrated higher CS experience than women (Table 2).

Table 2. Independent samples T-Test for sex comparison.

	Total	Males	Females
Sample size	431	346	85
Age	40.83 ± 12.30	40.74 ± 12.36	41.20 ± 12.13
Experience in years	13.91 ± 14.95	15.10 ± 15.01*	9.06 ± 13.75*
Competitions per year	0.90 ± 2.37	0.98 ± 2.43	0.56 ± 2.11
MSS score	4.06 ± 0.56	4.10 ± 0.54*	3.90 ± 0.62*

*Note. * p < .05.*

An independent samples *t*-test demonstrated a statistically significant difference in mental strength between CS practitioners and non-practitioners $t(429) = 4.247$, $p < .001$, $r^2 = 0.0403$, 95% CI [.17796, .48457] (one-tailed). The null hypothesis is rejected; CS practitioners presented higher mental strength than non-practitioners (Table 3).

Table 3. Independent samples T-Test for CS practitioners versus non-practitioners comparison.

	Total	**CS Practitioners**	**Non-Practitioners**
Sample size	431	373	58
Age (years)	40.83 ± 12.30	40.77 ± 12.45	41.24 ± 11.40
Gender (% male)	80.3	85.5	46.6
MSS score	4.06 ± 0.56	4.11 ± 0.54*	3.78 ± 0.64*

*Note. * p < .05.*

An analysis of covariance with CS experience as the independent variable demonstrated a significant difference in mental strength between groups, $F(3, 426) = 5.991$, $p < .001$, when adjusted for the covariate sex (Table 4). Fisher's Least Significant Difference post hoc analyses revealed that participants in the >5 ($p < .001$), 2-5 ($p = .011$), and < 2 years of experience ($p = .016$) reported higher mental strength than participants with no CS experience. No other post hoc comparison was significant ($p > .05$).

Table 4. Analysis of covariance (LSD post hoc) between experience groups.

	0	**<2**	**2-5**	**>5**
Sample size	58	53	59	261
Mental strength score	3.75 ± 0.62*,a,b	4.05 ± 0.60*	4.05 ± 0.51[a]	4.14 ± 0.53[b]

*Note. *a,b p < .05.*

No statistically significant differences were found in mental strength between age groups $F(4, 425) = 1.779$, $p = .132$, or competition engagement groups $F(2, 427) = .357$, $p = .700$.

DISCUSSION AND CONCLUSIONS

The present study aimed to present the psychometrics of the MSS; explore the correlations between mental strength and age, CS experience, and competitive engagement; and compare group differences in mental strength based on sex, age, CS engagement, competition engagement, and CS experience. The MSS presented good overall internal consistency (Cronbach's alpha = .809) and satisfactory evidence of convergent validity and, therefore, being a reliable instrument to assess mental strength in CS athletes.

Results rejected hypotheses 1 and 6, as no correlation between resilience and age or group differences were found.

Hypotheses 2 and 7 were retained, as results revealed a positive correlation between mental strength and CS experience (small effect). Group comparisons showed higher mental strength in the <2, 2-5, and >5 years of experience groups than the participants with no CS experience. These findings are congruent with the results found by Küçük (2020), who showed a significantly positive correlation between resilience and experience in karatekas. Pujszo et al. (2019) found a significant positive relationship between CS experience and resilience in adult practitioners. Moreover, Lorenco-Lima (2023) showed a significant positive correlation between CS experience and grit, with practitioners in the >5 years of experience group presenting significantly higher grit than participants in the <2 and 2-5 groups.

Hypotheses 3 and 8 were rejected as no correlation or group differences were found between mental strength and competition engagement. These results are partially incongruent with the findings of Lorenco-Lima (2023), who showed a positive correlation between competition engagement and grit, with athletes engaged in >4 competitions per year presenting higher grit than those engaged in 1-4 competitions per year but not than non-competitors.

Hypothesis 4 was retained as the comparison between sexes revealed higher mental strength in males than females. This finding is congruent with the results of Küçük (2020), Pujszo et al. (2019), and Lorenco-Lima (2023), who also found psychological (resilience and grit) differences between male and female CS practitioners.

Hypothesis 5 was retained as group comparison revealed higher mental strength in CS practitioners than non-practitioners. This result is compatible with Shamshirian et al. (2021), who found higher resilience in wrestlers than non-wrestlers and no significant difference based on the level of competition (national vs. international).

This study is not exempt from limitations. The cross-section nature of this research precludes any causality assumptions. The self-reported answers could potentially lead to social desirability bias. The author encourages future studies to explore mental strength in combat sports through a longitudinal design to establish causality and directionality. Moreover, the subcategorization of CS, including sparring versus no-sparring, could facilitate understanding the potential mechanism related to mental strength improvements.

In conclusion, the MSS is a simple and reliable instrument to assess mental strength in CS practitioners, given its good internal consistency and convergent validity. CS engagement and experience were shown to influence mental strength. These findings add to the combat sports literature, suggesting a positive role of combat sports in mental strength development. These findings provide strong evidence of the impact of combat sports in promoting mental strength and, therefore, all mental strength-related outcomes.

SUPPORTING AGENCIES

No funding agencies were reported by the author.

DISCLOSURE STATEMENT

No potential conflict of interest were reported by the author.

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APPENDIX A

Mental strength scale

Thinking about your athletic and exercise engagement, mark the box that best represents your thoughts over the past month. There is no right or wrong answer, just answer it to the best of your ability!

Mark one box per row that best describes your thoughts		Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
MSS 1	Challenges make me doubt myself	5	4	3	2	1
MSS 2	I hate challenges	5	4	3	2	1
MSS 3	I enjoy opportunities to challenge myself	1	2	3	4	5
MSS 4	I am scared of failing	5	4	3	2	1
MSS 5	It's hard to recover from failure	5	4	3	2	1
MSS 6	Challenges make me stronger	1	2	3	4	5
MSS 7	I have overcome challenges in the past	1	2	3	4	5
MSS 8	I don't like to get out of my comfort zone	5	4	3	2	1
MSS 9	If it's hard, I may not finish it	5	4	3	2	1
MSS 10	I work hard to overcome challenges	1	2	3	4	5

ORIGINAL ARTICLE

Effects of 4-week circuit strength combined with blood flow restriction training on muscle status and performance in Taekwondo athletes

WEIYE LI[1], ZHENDONG GAO[2] ✉, YUTONG LIU[3], JIAXU WANG[2]

[1]*Postgraduate Department. Xi'an Physical Education University. Xi'an, China.*

[2]*Department of Sports Studies. Faculty of Educational Studies. University Putra Malaysia. Selangor, Malaysia.*

[3]*Department of Sports Teaching and Research. Lanzhou University. Lanzhou, China.*

ABSTRACT

This study explored the effects of a 4-week circuit strength training with blood flow restriction on Taekwondo athletes. Six male athletes (age 20.6 ± 1.85, height 184.3 ± 7.63 cm, training duration 7.5 ± 2.07 years) were assessed for explosive strength, muscle recruitment, and sport-specific skills. The regimen encompassed evaluations of lower limb power, Isokinetic strength, force via electronic kicks, and Tensiomyography (TMG) measurements pre-and post-training. Outcomes revealed enhanced jumping abilities, improved knee muscles, and superior kicking skills. There was a notable increase in muscle fibre recruitment and a shift towards type II muscle fibres. Medial thigh muscle displacement showed a positive correlation with jump duration, while lateral thigh muscles indicated a connection with kick numbers. The regimen notably improved explosive power, muscle fibre distribution, and reduced muscle contraction times. Yet, no significant changes in lower limb bilateral symmetry or the link between TMG parameters and athletic prowess were observed.

Keywords: Performance analysis, Blood flow restriction training, Circuit strength, Taekwondo, Tensiomyography, Sports performance.

Cite this article as:
Li, W., Gao, Z., Liu, Y., & Wang, J. (2024). Effects of 4-week circuit strength combined with blood flow restriction training on muscle status and performance in Taekwondo athletes. *Journal of Human Sport and Exercise, 19*(2), 483-498. https://doi.org/10.55860/ad6rd932

✉ **Corresponding author.** *Department of Sports Studies. Faculty of Educational Studies. University Putra Malaysia. 43400 Serdang, Selangor, Malaysia.* https://orcid.org/0000-0002-6013-2385
E-mail: gs64145@student.upm.edu.my
Submitted for publication November 03, 2023.
Accepted for publication November 28, 2023.
Published April 01, 2024 *(in press* December 26, 2023).
JOURNAL OF HUMAN SPORT & EXERCISE ISSN 1988-5202.

doi: https://doi.org/10.55860/ad6rd932

INTRODUCTION

Taekwondo (TKD), as an official Olympic sport, has garnered global attention. It is a competitive sport where athletes, under equal weight conditions, primarily rely on lower limb attacking techniques to score. To excel in such competitions, athletes need outstanding explosive leg power, agile footwork, and effective kicking striking abilities (Jin & Liu, 2012). The prevalent method for athletes to enhance strength currently is through high-intensity training (≥70% 1RM) resistance training, which effectively promotes muscle hypertrophy and strength gain (Pescatello et al., 2009). However, such high-intensity training has its drawbacks. For instance, without proper athletic supervision and good training modalities, long-term high-intensity load training may increase the risk of sports injuries (Wei et al., 2019). Additionally, muscle hypertrophy from intense training may result in weight gain in athletes, reducing their competitive advantage within the same weight category (Li, 2022). Consequently, finding safe and effective ways to enhance athletic muscle strength and performance has become a pressing issue.

In recent years, Blood Flow Restriction Training (BFRT) has been garnering increased attention. It refers to a novel training approach where pressure devices are worn during exercise to achieve resistance. The principle behind BFRT is to restrict blood flow to the working muscles using pressure bands, stimulating the muscles to produce a series of responses, ultimately leading to increased muscle volume and strength (Spranger et al., 2015). A significant advantage of BFRT is that it promotes protein synthesis, stimulates muscle growth, and improves muscular fitness at relatively low exercise intensities. Preliminary studies have shown that resistance training under pressure offers better rehabilitation outcomes for injured athletes compared to low-intensity resistance training (Loenneke et al., 2013). Additionally, it has been found to effectively enhance explosive power, muscle strength, and anaerobic metabolic capacities in athletes across various sports, including handball, martial arts, soccer, and rugby (Luebbers et al., 2014; Wang et al., 2019; Liu et al., 2020; Sun et al., 2023). It also has positive effects on hormone secretion, vascular compliance, and bone health (Takarada et al., 2000; Karabulut, McCarron, et al., 2011; Karabulut, Bemben, et al., 2011). Owing to its versatile exercise modalities, high training efficiency, ease of operation, and relative safety, BFRT holds promising applications across various domains (Abe et al., 2006, 2010; Godawa et al., 2012; Cook et al., 2014).

Strength training in Taekwondo primarily emphasizes explosive power, rapid force, and foundational physical fitness. This training approach not only considers the growth of an athlete's muscular strength and endurance but also contemplates how to enhance their strength while simultaneously reducing body fat and weight during the training process. The objective is to provide athletes with a competitive advantage in their respective categories by maintaining a lower weight relative to their height (Li, 2022). The application of circuit strength training aptly meets the demands of this sport. It incorporates resistance training while also serving as an aerobic exercise. It can effectively increase lean body mass without altering bone density, reduce body fat, and elevate an athlete's base metabolism (Wang et al., 2011). This form of training subsequently enhances an athlete's muscular strength, endurance, and overall performance (Paoli et al., 2010; Rosety et al., 2015). Research indicates that circuit training significantly improves muscle strength, agility, metabolic capacity, and cardiorespiratory endurance in athletes from disciplines like soccer and tennis (Sumaryanti & Yudhistira, 2021; Belli et al., 2022; Francis & Lohar, 2022).

Tensiomyography (TMG) is a non-invasive testing method designed to study the contractile properties of muscles (Peng et al., 2017). It is specifically employed to analyse the ratio between Type I and Type II muscle fibres in a given superficial muscle and assess the fatigue or tension state of the tested muscle. TMG evaluates muscular function, as well as temporal and morphological symmetry. Clinically, it's also used for

rapid diagnostics during the onset of muscle injury and for continuous monitoring throughout rehabilitation (Dahmane et al., 2006). Several studies have described TMG as an effective tool for detecting muscle fatigue, fibre type composition, lateral symmetry, and muscle stiffness, and it has broad applications across numerous fields (Rey et al., 2012; Rodríguez-Ruiz et al., 2012). Its primary indicators are Contraction Time (Tc) and Maximal Displacement (Dm). Tc refers to the time the muscle takes to move from 10% to 90% of its maximum displacement, reflecting the contraction speed of the targeted muscle (Krizaj et al., 2008). Dm denotes the radial displacement of the muscle belly after electrical stimulation. A decreased Dm value suggests increased muscle stiffness or a more developed muscle, whereas a larger Dm indicates reduced muscle stiffness or fatigue (Valencic & Knez, 1997). Thus, some studies propose using this parameter as an indirect measurement method for muscle stiffness (Watsford et al., 2010).

While combined pressure strength training can achieve neuromuscular adaptation effects similar to high-intensity resistance training at relatively lower exercise loads (Ma, 2021), circuit strength training and blood flow restriction training have different mechanisms when it comes to improving muscle strength, endurance, and athletic performance. As a result, their impacts on muscle strength and related metrics vary. Although both training methods have been researched, there is a scarcity of studies that combine them for Taekwondo athletes. Therefore, this study selected six -68kg athletes from the Shaanxi Province Taekwondo Team to explore the impact of a 4-week blood flow restriction combined with circuit strength training on their muscle condition and athletic performance. Additionally, we analysed the changes in muscle structure before and after the experiment, along with the potential association between Taekwondo athletes' TMG parameters (Dm and Tc) and jumping, muscular strength, and specialized skills. This study aims to provide new perspectives and strategies for Taekwondo training and hopes to offer valuable insights for the training methods of other competitive sports.

METHODS AND MATERIALS

Participants

This study was approved by the Ethics Committee of Xi'an Physical Education University. From June 2021 to March 2022, six athletes (age 20.6 ± 1.85 years, height 184.3 ± 7.63 cm, training duration 7.5 ± 2.07 years) from the Shaanxi Province Taekwondo Team in the -68kg category were recruited (see Table 1). Among them, one was a national-level elite athlete, and five were first-level national athletes. This study adhered to the principles of the Helsinki Declaration and obtained informed consents signed by all participants. All participants were in good health, with no injuries or illnesses, and did not undergo high-intensity training three days prior to the experiment.

Table 1. Basic information of the participants.

Participants	Gender	Age	Height (cm)	Weight (kg)	Training Duration (Y)
6	Male	20.6 ± 1.85	184.3 ± 7.63	68.0 ± 2.45	7.5 ± 2.07

Primary experimental equipment

Fully Automatic Pressure Training Device and Pressure Bands (KAATSU Master, Made in Japan),3D Force Plate (Kistler, Made in Switzerland),Isokinetic Dynamometer (ISOMED2000, Made in Germany),Electronic Protective Gear (DAEDO, Made in Spain),Muscle Condition Analyzer (TMG S1, Made in Slovenia).

Training protocol

Under the condition of lower limb blood flow restriction, the participants completed circuit strength training for the lower limbs in the following sequence: barbell squats, barbell lunge squats, bodyweight squat jumps,

bodyweight alternating lunge jumps, deadlifts, and kettlebell swings. Specifically, athletes used 30% of their 1RM intensity for barbell squats, barbell lunge squats, and deadlifts, and employed a 16kg kettlebell for the kettlebell swing exercises.

For each of the exercises (squats, deadlifts, weighted lunges, bodyweight squat jumps, bodyweight alternating lunge jumps, and kettlebell swings), the participants performed 4 sets. The first set consisted of 30 repetitions, and the number of repetitions decreased with each subsequent set due to muscle fatigue. However, by the fourth set, the repetitions should not be fewer than 20. The rest interval between sets was 60 seconds. Before training, athletes wore pressure bands that were 5 cm in width, secured around the upper third of the thigh, perpendicular to the longitudinal axis of the thigh. They used a fully automatic pressure training device for inflation, with a dressing pressure of 40 mmHg and a training pressure of 200 mmHg.

Experimental test metrics

Isokinetic strength metrics and explosive power test

Isokinetic Knee Joint Strength Test: The peak torque of knee flexion and extension was tested using the ISOMED 2000 isokinetic strength training and testing system from Germany at an angular velocity of 60°/s. The test participants were seated, secured in place to prevent compensatory movements, such as lifting the buttocks off the chair during the test.

Three-dimensional Force Platform CMJ and SJ Test: Participants stood on a three-dimensional testing platform with their hands hanging by their sides. Upon a verbal command, athletes performed a semi-squat jump (SJ) and a counter-movement jump (CMJ). The jump height (H) and flight time (T) were calculated. Each test was performed three times, and the highest value was taken as the analysed metric.

Muscle condition diagnostic test

TMG Test: The TMG (Tensiomyography) was utilized to measure the Tc and Dm parameters of the dominant and non-dominant legs of the participants. The participants were instructed to lie supine on a bed, with a supporting cushion placed under the leg being tested. Manual palpation was used to identify the thickest part of the Rectus Femoris , Biceps Femoris, Vastus Lateralis, and Vastus Medialis muscles. The TMG sensor was then placed perpendicular to the skin surface at the point of the muscle's greatest belly (Ditroilo et al., 2013). Two self-adhesive surface electrodes were positioned 5 cm apart, centred on the sensor, ensuring they did not cross the muscle boundary to avoid stimulating adjacent muscles. A constant voltage of 30V was applied, starting with an initial intensity of 30mA. The stimulation amplitude was progressively increased until the linear sensor detected the muscle's maximum contraction. The interval between stimulations was set at 10-15 seconds. The TMG software was used to select the Dm parameter (indicating the maximum radial displacement of the muscle) and the Tc parameter (representing the time required for Dm to increase from 10% to 90% of its peak). These data were then used for subsequent analysis (Wilson et al., 2019). Additionally, using the calculation formula as follows, we computed the change in the proportion of slow-twitch (Type I) to fast-twitch (Type II) muscle fibres before and after the test:

$$\text{Slow - Twitch Fibers} = 1.63 \times \text{Tc} - 8.85$$

$$\text{Fast - Twitch Fibers} = 100 - \text{Slow - Twitch Fibers}$$

Sport-specific skills test

After warming up, participants executed left and right horizontal kicks against an electronic protective gear for 10 seconds. The force, frequency, and accuracy of the kicks against the electronic protective gear were

measured. This was tested three times with a 5-minute rest interval between tests, and the best result was selected for analysis.

Data analysis

All data were compiled and organized using Microsoft Excel software. Subsequent statistical analyses were conducted using SPSS Statistics 26.0. Data are presented as mean ± standard deviation (M ± SD).The Shapiro–Wilk test was employed to check for the normality of the data distribution. The internal consistency of the TMG parameters was computed using the Intraclass Correlation Coefficient (ICC). The paired sample T-test was applied to determine significant differences before and after the intervention. The Pearson correlation coefficient was used to examine the relationship levels between Tc and Dm of the dominant side Rectus Femoris (RF), Biceps Femoris (BF) , Vastus Lateralis (VL), and Vastus Medialis (VM) with isokinetic knee strength, electronic armour impact force, counter-movement jump (CMJ), and semi-squat jump (SJ) flight time and height. An independent samples T-test was utilized to examine the symmetry of the related muscles on both sides after the intervention. The above analytical approaches provide comprehensive insights into the effects of the intervention and any inherent relationships between the various muscular and athletic performance parameters studied.

RESULTS

After undergoing the Shapiro–Wilk test and the Intraclass Correlation Coefficient assessment, the data related to isokinetic strength, flight time, and flight height of both the counter-movement jump and the semi-squat jump, as well as the specific abilities, were found to be normally distributed (W = 0.866-0.978, $p > .05$). This allowed for the application of the Pearson correlation coefficient test. Based on the inquiry with the participants, the right leg was designated as the dominant side (Dom) and the left leg as the non-dominant side (Ndom). For the dominant side, the contraction time (Tc) ICC values for RF, BF, VL, and VM were 0.853, 0.901, 0.859, and 0.771, respectively. The maximum radial displacement (Dm) ICC values were 0.803, 0.748, 0.833, and 0.855, respectively. For the non-dominant side, the Tc ICC values for RF, BF, VL, and VM were 0.899, 0.867, 0.921, and 0.877, respectively, and the Dm ICC values were 0.854, 0.835, 0.886, and 0.789, respectively.

The comparisons of isokinetic strength, CMJ and SJ flight time and height, and the force, frequency, and accuracy of kicks against the electronic protective gear before and after the experimental intervention are shown in Table 2. After the intervention, there was a significant increase in the peak torque of left and right knee flexion, flight time and height of CMJ and SJ, and the force and accuracy of kicks against the electronic protective gear ($p < .05$). However, there was no significant improvement in the frequency of kicks after the intervention ($p > .05$).

As shown in Table 3, after the intervention, there was a notable decrease ($p < .05$) in the Tc and Dm for both the dominant and non-dominant sides across the following muscles: RF, BF, VL, and VM. Moreover, the difference for the RF of the non-dominant side post-intervention was significant ($p = .00$, $p < .01$). As depicted in Figures 1 and 2, there was no significant difference in the symmetry between the two sides after the intervention.

Table 4 indicates that the ratio of fast-twitch muscle fibres in RF, BF, VL, and VM increased significantly on both sides compared to before the experiment, while the ratio of slow-twitch muscle fibres decreased.

Table 2. Changes in isometric muscle strength, lower limb explosive strength, and specific abilities.

Variable	Pre-test	Post-test	*p*-value
60°Flexion Ndom	76.00 ± 10.73	94.17 ± 11.10	.04*
60°Flexion Dom	72.83 ± 13.77	97.17 ± 17.75	.00**
60°Extension Ndom	116.00 ± 18.07	149.33 ± 24.56	.00**
60°Extension Dom	134.00 ± 26.69	148.17 ± 17.86	.04*
CMJ Flight Time (s)	0.21 ± 0.01	0.23 ± 0.12	.00**
CMJ Flight Height (cm)	23.21 ± 3.52	25.92 ± 2.98	.01*
SJ Flight Time (s)	0.21 ± 0.14	0.22 ± 0.14	.00**
SJ Flight Height (cm)	22.05 ± 2.58	25.98 ± 4.26	.00**
Kick Force （bls）	46.20 ± 2.39	50.88 ± 2.75	.00**
Effective Hits	21.16 ± 0.82	23.50 ± 0.54	.01*
Number of Kicks	22.67 ± 0.82	23.17 ± 0.75	.08

*Note: * indicates p < .05, ** indicates p < .01, indicating statistical significance; Dom: Dominant side; Ndom: Non-dominant side; CMJ: counter-movement jump; SJ: semi-squat jump.*

Table 3. Changes in Dm and TC indicators.

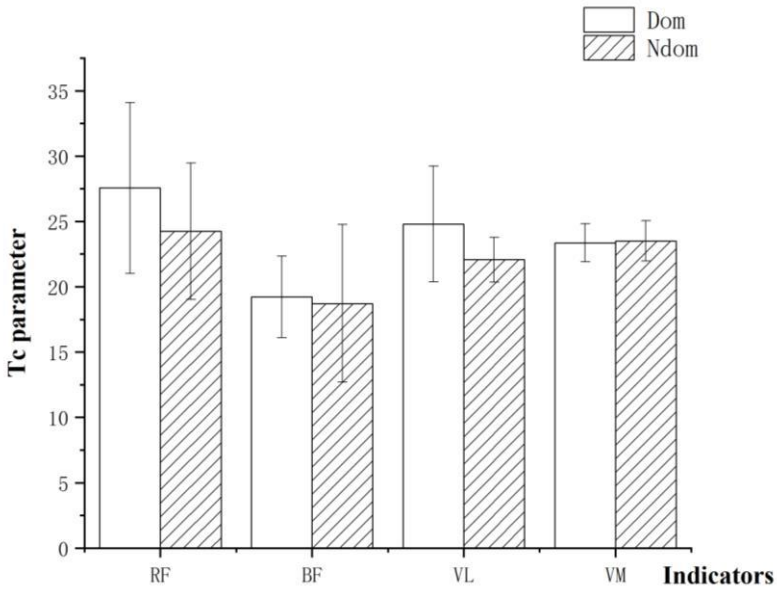
Indicators		Pre-test		Post-test	
		Dom	Ndom	Dom	Ndom
RF	Tc	31.65 ± 6.76	31.95 ± 7.62	27.56 ± 6.55*	24.25 ± 5.23**
	Dm	8.04 ± 4.43	8.01 ± 2.22	4.47 ± 3.63*	3.65 ± 2.51**
BF	Tc	29.15 ± 7.41	29.26 ± 10.43	19.23 ± 3.12*	18.72 ± 6.04*
	Dm	3.58 ± 1.16	4.26 ± 1.64	1.58 ± 0.62*	1.56 ± 1.22**
VL	Tc	26.50 ± 3.26	27.41 ± 4.67	24.81 ± 4.44*	22.07 ± 1.72*
	Dm	6.15 ± 1.52	5.93 ± 1.89	4.91 ± 1.71**	4.59 ± 1.38*
VM	Tc	25.06 ± 1.29	25.00 ± 1.89	23.36 ± 1.46*	23.50 ± 1.55*
	Dm	8.12 ± 2.61	8.58 ± 2.14	5.28 ± 2.15*	6.68 ± 1.87*

*Note: * indicates p < .05, ** indicates p < .01, indicating statistical significance; RF: rectus femoris; BF: biceps femoris; VM: vastus medialis; VL: vastus latissimus; Dom: dominant side; Ndom: nondominant side; Tc: time of contraction; Dm: maximum radial direction of contraction.*

Table 4. Changes in the proportion of fast-twitch and slow-twitch muscle fibres.

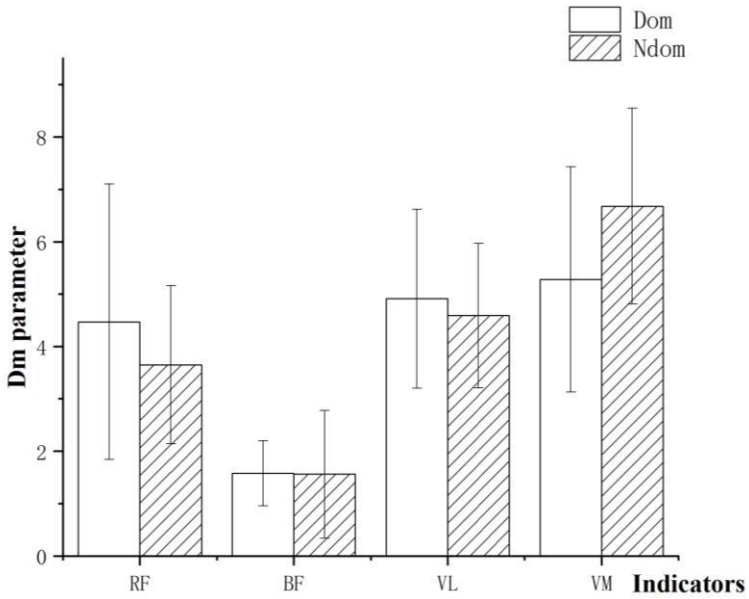
Indicators		Pre-test		Post-test	
		Dom	Ndom	Dom	Ndom
RF	ST	43.55 ± 9.52	43.23 ± 12.42	36.08 ± 10.68*	30.69 ± 8.52**
	FT	56.45 ± 9.52	56.77 ± 12.42	63.92 ± 10.68*	69.31 ± 8.52**
BF	ST	38.66 ± 12.07	38.74 ± 16.82	22.49 ± 5.08*	21.67 ± 9.85*
	FT	61.34 ± 12.07	61.26 ± 16.82	77.51 ± 5.08*	78.33 ± 9.85*
VL	ST	72.87 ± 2.80	35.83 ± 7.60	34.34 ± 5.31**	31.58 ± 7.24*
	FT	27.13 ± 2.80	64.17 ± 7.60	30.05 ± 2.46*	68.42 ± 7.24*
VM	ST	32.03 ± 2.11	31.89 ± 3.08	29.18 ± 2.29**	29.46 ± 2.52*
	FT	67.96 ± 2.11	70.54 ± 3.23	68.10 ± 3.07**	70.82 ± 2.29*

*Note: * indicates p < .05, ** indicates p < .01, indicating statistical significance; RF: rectus femoris; BF: biceps femoris; VL:vastus latissimus; VM: vastus medialis; Dom: dominant side; Ndom: nondominant side; ST: slow-twitch muscle fibres; FT: fast-twitch muscle fibres.*



Note: RF: rectus femoris; BF: biceps femoris; VM: vastus medialis; VL: vastus latissimus; Dom: dominant side; Ndom: nondominant side; Tc: time of contraction.

Figure 1. Changes in Tc parameter.



Note: RF: rectus femoris; BF: biceps femoris; VM: vastus medialis; VL: vastus latissimus; Dom: dominant side; Ndom: nondominant side; Dm: maximum radial direction of contraction.

Figure 2. Changes in Dm parameter.

As indicated in Tables 5, 6, and 7, several relationships emerged between the tensiomyography (TMG) parameters and athletic performance metrics for the Taekwondo athletes. The Dm of the VM on the dominant side demonstrated a significant positive correlation with the CMJ flight time (r = 0.844, *p* = .035). Conversely, it exhibited a significant negative correlation with the knee extensor strength (r = -0.844, *p* = .034).The Dm of the VL presented a significant negative relationship with the SJ flight time (r = -0.899, *p* = .015) and a

significant positive relationship with the number of leg kicks (r = 0.821, *p* = .045).The Dm of the BF showed a significant positive correlation with the kick force (r = 0.917, *p* = .010).

Table 5. Correlation analysis of lower limb explosive power and TMG indicators.

Indicators	CMJ Flight Time		CMJ Flight Height		SJ Flight Time		SJ Flight Height	
	r	*p*	r	*p*	r	*p*	r	*p*
RF Dm	-0.445	.376	-0.504	.308	-0.372	.121	-0.469	.280
RF Tc	-0.135	.798	0.022	.966*	0.700	.468	0.530	.348
BF Dm	-0.414	.414	-0.487	.328	-0.470	.347	-0.557	.251
BF Tc	-0.474	.342	-0.342	.506	0.680	.137	0.391	.443
VL Dm	-0.060	.910	0.041	.939	0.514	.297	0.325	.529
VL Tc	-0.648	.164	-0.683	.135	-0.745	.089	-0.899*	.015
VM Dm	0.796	.058	0.844*	.035	0.463	.320	0.535	.274
VM Tc	-0.015	.977	0.095	.857	0.493	.356	0.524	.286

*Note: * indicates p < .05, indicating statistical significance; CMJ: counter-movement jump; SJ: semi-squat jump; RF: rectus femoris; BF: biceps femoris; VM: vastus medialis; VL: vastus latissimus; Tc: time of contraction; Dm: maximum radial direction of contraction.*

Table 6. Correlation analysis of isokinetic muscle strength and TMG indicators.

Indicators	60°Flexion		60°Extension	
	r	*p*	r	*p*
RF Dm	-0.163	.757	0.286	.582
RF Tc	-0.111	.834	-0.057	.915
BF Dm	-0.028	.959	0.266	.611
BF Tc	-0.140	.792	-0.024	.964
VL Tc	0.431	.393	0.596	.212
VL Dm	0.201	.703	-0.355	.490
VM Dm	-0.506	.306	-0.844*	.034
VM Tc	-0.137	.796	0.283	.587

*Note: * indicates p < .05, indicating statistical significance; RF: rectus femoris; BF: biceps femoris; VM: vastus medialis; VL: vastus latissimus; Tc: time of contraction; Dm: maximum radial direction of contraction*.

Table 7. Correlation analysis of specific abilities and TMG indicators.

Indicators	Number of Kicks		Effective Hits		Kick Force	
	r	*p*	r	*p*	r	*p*
RF Dm	-0.345	.503	0.288	.580	0.117	.825
RF Tc	0.417	.411	-0.519	.292	0.734	.097
BF Dm	-0.318	.539	0.395	.439	0.917*	.010
BF Tc	0.492	.322	-0.521	.289	0.047	.929
VL Tc	-0.248	.635	0.483	.332	0.201	.702
VL Dm	0.821*	.045	-0.207	.694	0.546	.263
VM Dm	0.458	.361	0.343	.506	0.003	.995
VM Tc	-0.148	.780	-0.765	.076	0.227	.666

*Note: * indicates p < .05, indicating statistical significance; RF: rectus femoris; BF: biceps femoris; VM: vastus medialis; VL: vastus latissimus; Tc: time of contraction; Dm: maximum radial direction of contraction.*

DISCUSSION

The findings from this study reveal that after a 4-week circuit training regimen combined with blood flow restriction, participants exhibited improvements in knee joint flexor and extensor muscle groups, lower limb explosive power, and specific kicking capabilities. There was a significant enhancement in muscle fibre contraction and recruitment capacities compared to before the intervention. TMG data highlighted that after the intervention, the proportion of slow-twitch muscle fibres decreased, while that of fast-twitch muscle fibres noticeably increased. This implies that the training intervention had modified the muscle fibre composition in favour of those fibres typically associated with power and speed. The shift towards a higher percentage of fast-twitch fibres suggests that the athletes' lower limb strength, explosiveness, and overall muscle composition have been enhanced, all of which are beneficial for optimizing athletic performance.

Lower limb explosive strength

The experimental results suggest that circuit strength training combined with blood flow restriction has a positive impact on the lower limb explosiveness of Taekwondo athletes. Prior studies corroborate our findings. Cook et al. (2014) observed a 1.8% ± 0.7% improvement in jumping capability in rugby players after employing medium-load (70% 1RM) combined with BFR training for three weeks. Similarly, Wang et al. (2019) reported that after eight weeks of medium-load (70% 1RM) BFR training on handball players, the improvements in lower limb explosiveness matched those achieved through traditional high-intensity strength training.

A distinguishing feature of our study was the attainment of comparable results with a lower exercise load compared to medium loads. This suggests that the combination of circuit strength and blood flow restriction training not only enhances athletic performance but may also be safer than other training modalities. The aforementioned results can be elucidated through TMG data. Prior research posits that stronger forces and increased strength training are associated with lower Tc and Dm values, with Dm directly correlated to power and force capabilities (Loturco et al., 2015; Šimunic et al., 2018). A decreased Dm value implies heightened muscle stiffness, reflecting superior performance in activities involving stretch-shortening cycles. Zubac & Šimunič (2017) identified a correlation between the reduction in lower limb muscle Dm and increased jump height following an 8-week resistance training program. Therefore, after 4 weeks of BFR combined with circuit training, our participants displayed increased muscle stiffness and improved muscle function, which, in turn, bolstered their lower limb explosiveness.

Muscle fibre recruitment

The research results indicate that after a 4-week intervention, there was a significant increase in the peak torque of knee flexion and extension for both legs. Notably, the growth rate for the knee extensor muscles in both legs was larger than for the flexors, with increments of 39.17 ± 4.53 and 34.16 ± 10.11, respectively. This aligns with the findings of prior studies. Takarada et al. (2004) subjected 18 male athletes to an 8-week knee extension exercise regimen (totalling 16 sessions) at a load intensity of 20% 1RM. The results showed that after undergoing the 20% 1RM pressurized training, the experimental group experienced an increase of 9.2 ± 2.2 % in knee extensor muscle strength. Similarly, Sakuraba & Ishikawa (2009) performed an 8-session, 4-week knee flexion and extension exercise regimen on 21 athletes with thigh pressure set at 200mmHg. The results revealed a 13.6% increase in knee extensor muscle strength.

However, a distinct difference between our study and prior research is that according to the TMG and isokinetic strength data, the increase in the strength of the knee flexor and extensor muscles for the left leg was more pronounced compared to the right. This can be attributed to Taekwondo being a predominantly

unilateral sport. For many athletes, the right leg serves as the primary attacking leg, hence its flexor and extensor muscles are inherently stronger. Conversely, the left leg, primarily used for support and subjected to fewer flexion movements, tends to be weaker. This results in an imbalance in strength between the two legs. Yet, after the 4-week pressurized training, there was a significant improvement in the left leg, thereby reducing the asymmetry between the two legs and enhancing their balanced muscular strength.

Sport-specific skills

After the experimental intervention, participants showed a significant improvement in kick force and effective hits on the electronic protective gear. However, the number of kicks remained relatively consistent pre and post-intervention. A possible explanation for this outcome is that the circuit strength training, when combined with blood flow restriction, effectively enhanced the muscular strength and recruitment capability of the lower limbs. This increase in turn bolstered the athletes' explosive power in their legs (Gao & Yu, 2023). Consequently, athletes could deliver higher effective kick forces on the electronic protective gear, leading to a rise in the count of effective hits. This development can address the issue faced by Taekwondo athletes, where they might land a hit during competition but fail to score due to inadequate force (Li, 2022).

Our research data revealed only a minimal correlation between the specific ability parameters (number of kicks, effective hit counts, and kick force) and the TMG metrics following the combined pressure training. This might be attributed to the fact that the electronic protective gear, integral to taekwondo competitions, can be influenced by a myriad of factors such as lower limb strength, coordination, and core power (Guo, 2021). As our study primarily centred on the enhancement of lower limb power and explosiveness, it might have resulted in the observed lack of correlation between the two aspects.

Muscle status

The results of the study indicate that post-intervention, there was a significant decline in both the dominant and non-dominant sides' Tc and Dm for the RF, BF, VL, and VM. Concurrently, the data reveals a pronounced increase in the fast-twitch muscle fibre ratio for the left and right legs in these muscles post-intervention, with a notable decrease in the slow-twitch fibre ratio. This suggests that, after blood flow restriction training, the contraction speed of RF, VM, VL, and BF muscles increased, muscle fibre recruitment capability intensified, and the number of muscle fibres recruited also grew. However, this was accompanied by a concurrent increase in muscle tension and rigidity. The findings from this study align with these past research endeavours, suggesting that a period of strength training consistently results in a decrease in Tc and Dm of the relevant muscle groups. Existing research indicates that athletes with a higher level of strength training show TMG characteristics of shorter Tc and smaller Dm (Loturco et al., 2015; Šimunic et al., 2018). A study conducted by de Paula Simola et al (2015) on 14 male athletes, encompassing a range of lower limb strength exercises over 5 weeks, discovered that various leg training types could reduce respective muscle's Dm and Tc. García-García et al (2016) found that, following 10 weeks of speed and power training, there was a significant decrease in Tc, Dm, and Td of the knee extensor muscles.

Upregulation of IGF-1 (insulin-like growth factor-1) expression is a primary physiological mechanism that promotes muscle strength and hypertrophy (Yoshida & Delafontaine, 2020). Some studies have illustrated that low-load occlusion strength training significantly elevates the concentration of insulin-like growth factors (Abe et al., 2005).Blood flow restriction training operates by restricting blood flow, leading to hypoxia and an acidic environment in the body, resulting in a substantial accumulation of lactic acid. This condition inhibits the contraction of slow-twitch fibres, thereby mobilizing a large number of additional fast-twitch fibres to maintain the body's movement needs (Yasuda et al., 2006). Recruiting and stimulating these additional rapid-contracting fibres during exercise may be one reason for the muscle hypertrophy and strength enhancement

induced by occlusion training (Sumide et al., 2009). Consequently, after blood flow restriction training, there was a significant growth in the fast-twitch fibres of RF, VM, VL, and BF, while slow-twitch fibres saw a decline.

TMG parameters and sport-specific skills

This study's findings revealed: (1) There's a significant positive correlation between vastus medialis Dm and CMJ flight time, and a significant negative correlation with knee joint extensor muscles. The vastus lateralis Dm shows a significant negative correlation with SJ flight time and a notable positive correlation with the number of kicks. Additionally, biceps femoris Dm has a significant positive correlation with kick force. (2) There is no correlation between TC and any of the tests. (3) Post-experiment, an evaluation based on TMG parameters found no significant disparity in symmetry between the two sides.

Our study results differ from previous research. For instance, Loturco et al (2016) conducted a TMG test on football players and found a moderate negative correlation between the Dm of biceps femoris and rectus femoris with contraction time. There was also a moderate correlation between the Dm of the biceps femoris and the reaction intensity index. However, there was no connection between reactive jump height, jump height, sprinting ability, and TMG parameters, and there was no disparity in symmetry between the dominant and non-dominant legs. The reason for this discrepancy could be that, although TMG parameters reveal characteristics of muscle fibre excitation-contraction coupling and associated muscle contractions and mechanics, the TMG assessment is passively performed on isolated muscles. In contrast, all sports tasks are actively completed, involving multiple muscle groups and numerous dynamic variables, encompassing diverse contributing factors (Gil et al., 2015). This suggests that the conditions assessed in this current study are distinct from those in previous research, which might, to an extent, explain the lack of association between these variables.

Our study has several limitations that should be noted. Firstly, due to the objective circumstances and the limited number of athletes available for the study, the sample size was relatively small and somewhat homogeneous. Secondly, this research primarily focused on short-term effects, leaving mid-term and long-term training effects to be investigated in future studies. Lastly, the lack of a control group in this experiment might hinder an accurate assessment of the combined effects of blood flow restriction and circuit strength training.

Future research could further explore the efficacy of this training method for Taekwondo athletes of different ages, genders, and skill levels. It might also be worthwhile to extend the study to other sports disciplines, such as boxing or wrestling, to understand the generalizability and adaptability of this combined training approach across different athletic fields. Moreover, examining the long-term impacts of this training on athletes' muscle conditions, performance enhancements, and related biochemical indicators will be valuable directions for further research.

CONCLUSION

Our study indicates that combining blood flow restriction with circuit strength training has a positive effect on the lower limb explosive strength and specific kicking ability of Taekwondo athletes. Furthermore, this combination can shorten the contraction time of muscles relevant to Taekwondo athletes, alter muscle fibre ratios, and enhance muscle explosiveness. However, there was no observed correlation between TMG (Tensiomyography) and athletic performance. In addition, based on the TMG-related parameter evaluations, there was no significant asymmetry between the left and right lower limbs post-intervention, and the tensiomyographic parameters were unrelated to the athletic performance of the Taekwondo athletes.

AUTHOR CONTRIBUTIONS

LW and GZ designed the study, wrote the initial draft, and made revisions, managed data, conducted surveys, formulated methods, created visualizations, supervised, and managed the project. LY participated in software, data curation, formal analysis, visualization, and manuscript revision. WJ conducted formal analysis, supervision, validation and revision . All authors have contributed to the manuscript, approved the final version for submission, and consent to its publication in JHSE.

SUPPORTING AGENCIES

No funding agencies were reported by the author.

DISCLOSURE STATEMENT

No potential conflict of interest were reported by the author.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/Supplementary Material and further inquiries can be directed to the corresponding author.

ETHICS STATEMENT

The studies involving humans were approved by Ethics Committee of Xi'an Physical Education University. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study. Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

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ORIGINAL ARTICLE

Final pass and its relationship with final action for the creation of goal-scoring opportunities at EURO 2020

EFSTRATIOS KYRANOUDIS[1], KATERINA PAPADIMITRIOU[1], AGGELOS KYRANOUDIS[2], ANESTIS GIANNAKOPOULOS[1], XANTHI KONTSTANTINIDOU[1]

[1]*Department of Physical Education and Sport Sciences. Democritus University of Thrace. Greece.*
[2]*Department of Physical Education and Sport Sciences. Aristotle University of Thessaloniki. Greece.*

ABSTRACT

The purpose of this research was to study EURO 2020 goal scoring opportunities by recording the technique of the final pass, the technique of the final action and their zone of execution. A sub-objective was to test the relationship between the technique and zone of the final-pass, but also the relationship between the final-pass zone, the zone of final-action and its efficiency. The parameters studied were, a) the final pass zone, b) the final pass technique, c) the final action zone, and d) the result of the final action. Data collection was done with SportScout software. The correlation between variables was tested using the Crosstabs analysis and the Chi-Square statistic criterion. The results showed that most of the final passes were made from the zone outside the 18-yard box and the most common techniques used were the medium-range and the short-range passes. The independence or homogeneity test showed that the type of final pass was significantly influenced by the zone in which it was executed. The same was the case with the final action zone, which appeared to be significantly affected by the final pass zone. However, the effectiveness of the attacks depended only on the zone of final action (the final actions were more effective when taken from the zone between the six-yard box area and the penalty spot). An assessment of the opportunities that lead to goals and how they are created can help identify the tactical factors that increase efficiency and lead to more goals being scored.

Keywords: Performance analysis, Match analysis, Soccer, Penetration pass, Crosses.

Cite this article as:
Kyranoudis, E., Papadimitriou, K., Kyranoudis, A., Giannakopoulos, A., & Kontstantinidou, X. (2024). Final pass and its relationship with final action for the creation of goal-scoring opportunities at EURO 2020. *Journal of Human Sport and Exercise, 19*(2), 499-509. https://doi.org/10.55860/hf7g0141

Corresponding author. *Department of Physical Education and Sport Science, Democritus University of Thrace, Campus Thrace, 69150 Komotini, Greece. https://orcid.org/0000-0002-6013-2385*
E-mail: kpapadim@phyed.duth.gr
Submitted for publication November 03, 2023.
Accepted for publication November 28, 2023.
Published April 01, 2024 *(in press* December 26, 2023).
JOURNAL OF HUMAN SPORT & EXERCISE ISSN 1988-5202.

doi: https://doi.org/10.55860/hf7g0141

INTRODUCTION

Goal is the ultimate objective of a football game (Tokul & Mulazimoglu, 2018). As football is a low-scoring team sport, unlike other sports such as basketball or handball, the analysis of goals is of great importance and is therefore perhaps the most studied variable. A goal can affect the offensive philosophy of a team (Mitrotasios & Armatas, 2014) and, therefore, the identification of goal scoring actions and patterns is one of the most frequent topics in the analysis of a football match (Pratas et al., 2018). The technical-tactical action preceding the final action leading to a goal is called the final pass (penultimate action or more commonly known as an assist). According to Aranda et al. (2019) this can be an individual action (e.g. dribble) or a team action (e.g. penetrating pass, crossing, cut back pass). The importance of the final pass is very high in modern football as its frequent use increases the chances of teams to be in the top positions in the final standings (Longo et al., 2019). According to Lago-Ballesteros & Lago-Penas (2010), the top four teams in the Spanish La Liga (2008-09) executed, on average, more final passes than the teams occupying the next twelve positions in the league.

Although, as mentioned above, goals are the quintessence of football and their number in a match is the most objective measure of the offensive efficiency of any team (Sarmento et al., 2018), their individual analysis does not clearly represent a team's strategy (James et al. 2002). In contrast, the multifaceted analysis of actions that create goal scoring opportunities (regardless of their outcome) can help us identify the tactical factors that increase the chances of a team to score more goals (Gonzalez-Rodenas et al., 2020a). All of the above served as a trigger for the present study, in which emphasis was placed on the recording of the final pass, i.e. the pass preceding the final action, of the areas/zones of the field from which they were made as well as of the effectiveness of these actions. Such an assessment will highlight the parameters that lead to goals or scoring opportunities. In this way, coaches will be provided with useful information and tactical options adopted by high-level teams. They, in turn, will have useful and research-based material to tailor their training sessions to practicing final passes in order to increase their chances of scoring goals.

The aim of the study

Thus, thought the observation of high-level matches, the purpose of this research was to study the technique of the final pass, its zone of execution as well as the zone of final action. Its sub-objective was to test the relationship between, a) the technical final pass and the zone of its execution, b) the zones of final pass and final action, c) the zone of the final action and its effectiveness.

METHOD

Participants

The research sample consisted of 1,856 actions of 51 football matches from the 2020 European Men's Football Championship, which, due to the COVID-19 pandemic, was held in the summer of 2021. More specifically, all the actions that created chances for goals from open play, from all the matches of the group stage and knock-out stage of all the teams participating in the final phase of the European Championship were recorded and analysed. Thirty-two goals were excluded from the actions studied (such as own goals, goals following a challenge for the ball by two players with the ball accidentally ending up in the opponent's goal) because they could not be categorised in any of the categories of the observation protocol.

Measures

Data collection was carried out using the SportScout video-analysis software. The match analysis scheme was created by the observer under the guidance of a UEFA PRO coach and included the following categories and individual parameters:

1. **Final pass technique** (refers to the last pass made by a player before a goal-scoring opportunity is created): a. Short pass (up to 10 meters, Middle passes (from 10 to 20 meters), b. Long pass (more than 10 meters), c. Crosses, d. Cut back pass, e. Header.

2. **Zone of final pass & final action** (the specific area on the field where the last pass leading to a goal-scoring opportunity is made & the area where the receiving player executes the final action, such as shooting, dribbling, or making a decision to exploit the goal-scoring opportunity): a. Zone 1 (area on the left extending from the end line to the height of penalty area and within in), b. Zone 2 (goal area), c. Zone 3 (area on the right extending from the end line to the height of penalty area and within in), d. Zone 4 (area extending from the upper line of the goal area to the height of penalty spot), e. Zone 5 (area extending from the imaginary penalty spot line to the height of the penalty area), f. Zone 6 (area on the left extending from the end line to the imaginary penalty area line outside of it), g. Zone 7 (area on the right extending from the end line to the imaginary penalty area line outside of it), h. Zone 8, j. Zone 9, k. Zone 10 (area extending from the penalty area line to half distance from the centre line), l. Zone 11 (area extending from the half distance from the centre line to the centre line area), m. Zone 12 (behind the centre line).

Figure 1. Zone of final pass and final action.

3. **Outcome of the final pass**: a. Successful (the final handover has reached the player who will perform the final action), b. Cut by the opposing player, c. Save/caught by the goalkeeper, d. The ball passed without final action (the final pass was too strong, at the wrong height or at the wrong time causing it to go away from the attacking teammate).

4. **Outcome of the final action (**the final action encompasses the subsequent actions taken by the receiving player after the final pass): a. Goal scoring, b. Goal opportunity (the final actions that came very close to the goal scoring e.g. directly on the goalpost or very close to goalpost, difficult save by the opponent goalkeeper or player), c. Unsuccessful final action (easy save by the opposing goalkeeper, weak shot on goal, errors).

Procedure

The observation of each phase of the matches started when the final pass occurred and ended after the completion of the final action of the attack. In order to ensure the validity and reliability of the collected data

(observation of the actions), the following procedure was followed: the high level coach, who as mentioned above participated in the creation of the analysis scheme, trained the observer (main observer) to recognize the parameters of the analysis scheme during the observation of each match. The validity of data collection was tested through intra-observation agreement where the coach and the main observer observed 50 randomly selected actions independently, using the same analysis scheme for the same actions. The Cohen's Kappa value showed that the coach's and the main observer's observations were highly correlated (k = 1.000). This ensured the validity of the data collection. Then, in order to test the reliability of the observation, i.e. whether the main observer would record all actions equally correctly in all matches of the sample, he observed an additional 50 randomly selected actions and after one week he repeated their observation. In this case too, Cohen's Kappa value was extremely high (k = 1.000). In this way the observer was considered to be ready to collect valid and reliable data.

Analysis

The data were analysed using the SPSS 20.0 (SPSS, Chicago, IL) statistical analysis software. The calculation of the frequency of occurrence of the observed parameters was performed through the Frequencies analysis. The relationship (homogeneity or independence) between the variables/categories of the observation protocol was tested using the Crosstabs analysis and the Chi-Square test ($p < .001$). In cases where the expected value, even in a single instance of the analysis table, was less than 5, the Fisher's Exact Test value was taken into account.

RESULTS

Descriptive statistics

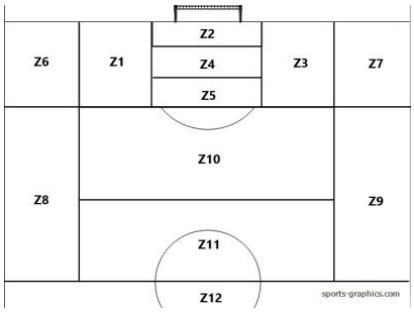
Statistical analysis of the data showed that of the total number of attacks observed (1,856 phases), 39% (728 actions) were completed. It was found that 11% of the completed attacks resulted in a goal, 38% in a goal scoring opportunity and 51% were ineffective (poor execution of the shot, easy clearance by the goalkeeper, turnover).

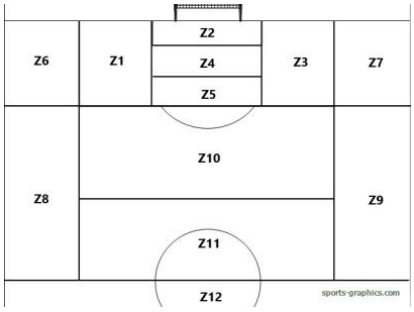
Studying all the attacks (completed and incomplete, Table 1) it was found that the most common 'Final Pass Technique' was the cross (42%) followed by the mid-range pass (20%). Short-range, long-range and cut-back passes had almost the same frequency with a rate of 11%, 13% and 12% respectively, while headers accounted for 4%. Regarding the zones from which the final passes were made, it was found that Zone 10 had the highest percentage (24%), followed by Zone 7 (12%), Zone 6 (12%), Zone 1 (11%) and Zone 3 (11%).Regarding the zones of final actions, it was found that most of them were performed from Zone 4 (36%), Zone 5 (18%), Zone 2 (17%) and 16% from Zone 10 (Table 1).

On the contrary, by only studying the completed attacks (regardless of their outcome) it was found that the most frequent techniques of the 'Final Pass' used were the Mid-range Pass (34%, 1/4) and the Short-range Pass (22%, 1/3). Those were followed by the Cross (17%, 1/6) and the Long-range Pass (14%, 1/7). With regard to the Final Pass Zone, it was found that most passes were executed from Zone 10 (37%). As for the remaining zones, final passes were completed at almost the same rate (7% on average) except for Zone 4 which counted for the lowest rate of all (2%). Regarding the 'Zones of Final Action' it was found that, again, the highest percentage was found in Zone 10 (32%) as well as in Zones 4 (21%) and 5 (18%). The remaining zones were used considerably less (Table 2).

Table 1. Percentage of pass technique, zone of final pass and zone of final actions in completed and incomplete attacks.

Categories	Parameters	Percent
Pass Technique (complete & incompleted attacks)	Short –range pass (up to 10 meters	11%
	Mid-range pass (from 10 to 20 meters)	20%
	Long-range pass (more than 10 meters)	13%
	Crosses	42%
	Cut back pass	12%
	Header	2%
Zone of final pass (complete & incompleted attacks)	Zone 1	11%
	Zone 2	0.2%
	Zone 3	11%
	Zone 4	2%
	Zone 5	3%
	Zone 6	12%
	Zone 7	14%
	Zone 8	7%
	Zone 9	9%
	Zone 10	24%
	Zone 11	5%
	Zone 12	4%
Zone of final action (complete & incompleted attacks)	Zone 1	7%
	Zone 2	17%
	Zone 3	5%
	Zone 4	36%
	Zone 5	18%
	Zone 6	0.1%
	Zone 7	0.1%
	Zone 8	0.2%
	Zone 9	0%
	Zone 10	16%
	Zone 11	0.1%
	Zone 12	0%





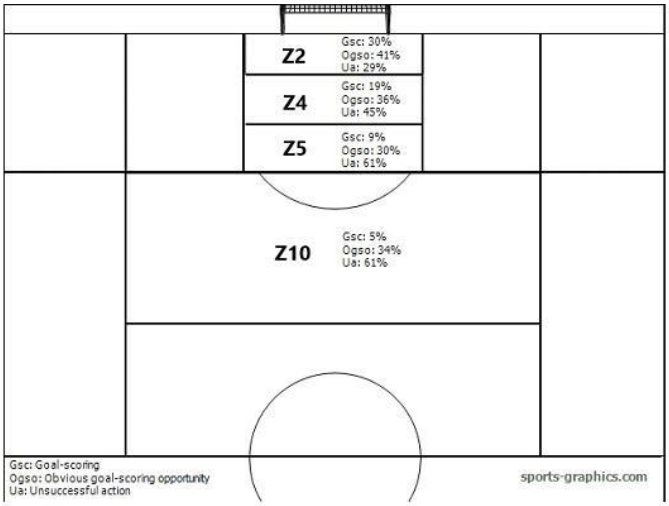
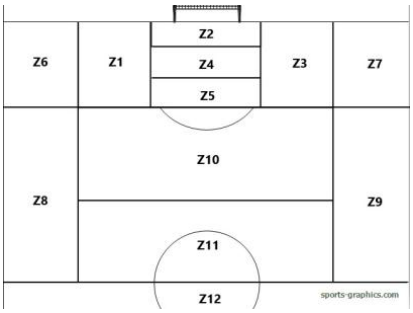
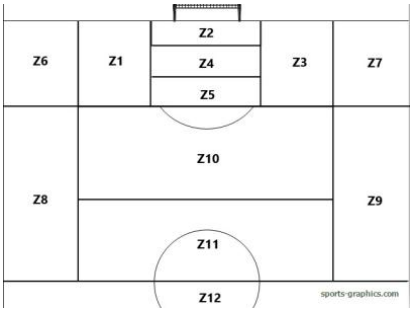


Figure 2. Relationship between zone of final actions and attack's outcome.

Table 2. Percentage of pass technique, zone of final pass and zone of final actions in completed attacks.

Categories	Parameters	Percent
Pass Technique (complete attacks/regardless of their outcome)	Short –range pass (up to 10 meters	22%
	Mid-range pass (from 10 to 20 meters)	34%
	Long-range pass (more than 10 meters)	14%
	Crosses	17%
	Cut back pass	9%
	Header	4%
Zone of final pass (complete attacks/regardless of their outcome) 	Zone 1	9%
	Zone 2	0.3%
	Zone 3	9%
	Zone 4	2%
	Zone 5	5%
	Zone 6	8%
	Zone 7	6%
	Zone 8	5%
	Zone 9	6%
	Zone 10	37%
	Zone 11	8%
	Zone 12	4%
Zone of final action (complete attacks/regardless of their outcome) 	Zone 1	11%
	Zone 2	9%
	Zone 3	8%
	Zone 4	21%
	Zone 5	18%
	Zone 6	0.1%
	Zone 7	0.1%
	Zone 8	0.4%
	Zone 9	0%
	Zone 10	32%
	Zone 11	0.3%
	Zone 12	0%

Relationship between observation parameters and the effectiveness of completed attacks

The analysis of the data showed that the outcome of the completed attacks was significantly dependent only on the 'Final Action Zone' category (Fisher's Exact test = 69.64, p = .000). In particular, 5% (1/20) of the final actions from Zone 10 resulted in a goal, 34% (1/3) came very close to a goal and 61% (1/6) were ineffective. As for Zone 4, 20% (1/5) resulted in a goal, 36% (1/3) came very close to a goal and 45% (1/2) were ineffective. Regarding Zone 5, 10% (1/10) resulted in a goal, 30% (1/3) came very close to a goal and 61% (1/2) were ineffective. The zone from which the most goals were scored in relation to the total number of final actions executed from it was Zone 2 (30%, 1/3). Also, 1/2 (41%) of the final actions from Zone 2 came very close to a goal while 1/2 (29%) were ineffective (Figure 2).

Final Pass Technique VS Final Pass Zone (completed attacks regardless of the attack's outcome)

According to the results, the 'Final Pass Technique' was significantly dependent on the zone from which it was executed (Fisher's Exact test = 1084.52, p = .000). In particular, most of the Medium-range Passes were

executed mainly from Zone 10 (53%), Zone 11 (10%) and Zone 1 (10%). Most Short Passes were executed mostly from Zone 10 (49%) but also from Zones 5 & 1 (16% & 11% respectively). On the contrary, most crosses were executed from Zone 6 (25%), followed by Zones 7, 10, 8, 9, (23%, 18%, 17%, 15%, respectively). As for Long-range Passes, most were executed from Zone 12 (32%), Zone 11 (24%) and Zone 10 (20%). Regarding the Cut Pass which had the lowest percentage, it was found that it was mostly executed from Zone 1 (46%) and Zone 3 (44%). The Head Pass was mostly executed from Zones 5 & 4 (24% & 21% respectively) and also from Zones 3 & 1 with percentages of 21% & 13% respectively (Table 3).

Table 3. Relationship between final pass technique and zone of final pass.

	Zone of final pass												
Final pass technique	**Z1**	**Z2**	**Z3**	**Z4**	**Z5**	**Z6**	**Z7**	**Z8**	**Z9**	**Z10**	**Z11**	**Z12**	**Total**
Short pass													
Count													
%Within pass technique	10%	1%	7%	7%	16%	2%	3%	2%	2%	51%	1%	0%	100%
Middle passes													
Count													
%Within pass technique	8%	0%	7%	0.4%	2%	5%	3%	33%	28%	49%	45%	7%	100%
Long pass													
Count													
%Within pass technique	1%	0%	2%	0%	0%	2%	2%	6%	13%	22%	27%	25%	100%
Crosses													
Count													
%Within pass technique	1%	0%	2%	0%	0%	31%	21%	13%	14%	17%	1%	0%	100%
Cut back pass													
Count													
%Within pass technique	43%	0%	43%	0%	0%	3%	11%	0%	0%	0%	0%	0%	100%
Header													
Count													
%Within pass technique	11%	4%	15%	22%	22%	0%	0%	0%	0%	0%	0%	0%	100%

Note. $p < .001$.

Final Pass Zone VS Final Action Zone (completed attacks regardless of the attack's outcome)

It was also found that the 'Final Action Zone' was significantly dependent on the 'Final Pass Zone' (Fisher's Exact test = 273.40, $p = .000$). The results show that most of the final passes made from Zone 10 ended up mainly within Zone 10 (48%) but also in Zones 5, 1 & 4, with a lower percentage (14%, 13% and 13% respectively). In contrast, the largest percentage of Final Passes executed from Zone 1 ended in Zone 4 (32%), Zone 2 (23%) and Zone 5 (20%). As for the final passes from Zone 3, 38% of them ended in Zone 4, 19% in Zone 5 and 16% in Zone 2. Regarding the final passes from Zone 6, most of them ended in Zone 4 (36%), 21% in Zone 5 and 19% in Zone 2 (Figure 2). With regard to the other zones, the final passes from Zone 7 ended mainly in Zone 4 (28%), from Zone 9 in Zone 10 (34%), from Zone 8 in Zone 4 (31%), from Zone 5 in Zones 11 & 5 (29% & 26%) while the final passes from Zone 4 ended in Zone 4 with a percentage of 56% (Figure 3).

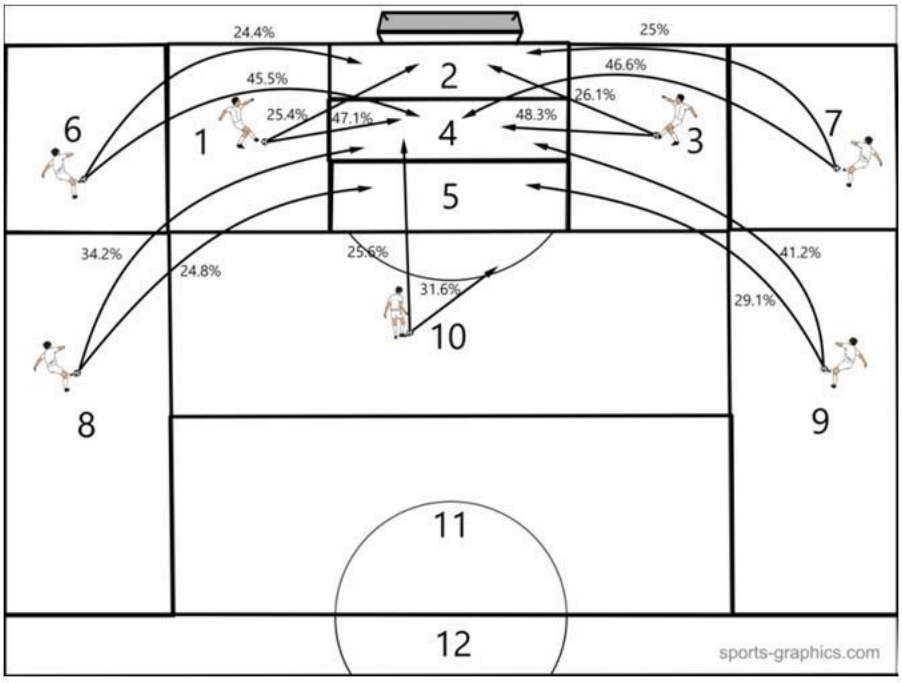


Figure 3. Relationship between zone of final pass and zone of final action.

DISCUSSION

By analysing a large number of completed attacks in EURO 2020, this study aimed to examine the final passes before the completion of these attacks by recording their technique, the zones from which they were performed, the zones of the final action as well as their effectiveness. It then proceeded to test the relationship between technique and the zone of final pass, the zone of final pass and the zone of final action as well as what the effectiveness of the attacks depended on.

According to international literature, one of the most popular actions in high-level matches, apart from the combination play (Mitrotasios & Armatas, 2014), is the cross (Michailidis et al., 2018). Analysing the 2018 World Cup matches, Vergonis et al. (2019) concluded that one in five goals scored in them came from a cross. According to the results of the present study, the cross initially appeared to be the most frequent final pass technique regardless of whether the attack was completed or not. Subsequently, when the analysis of the data was focused on the completed attacks, it was found that the most common final pass techniques were the middle-range and short-range passes. Furthermore, the correlation of crossing with the other passing techniques and their effectiveness showed that the middle-range and short-range passes were equally effective at creating goal-scoring opportunities but tended to be more successful at scoring goals. The effectiveness of these (penetrating) passes is highlighted in the research of Smith & Lyons (2017), who analysed high-level matches (World Cups 2002, 2006, 2010 and 2014) and concluded that the penetrating pass was the most frequent action that resulted in a goal. Also, the contribution of middle-range and short-range final passes in creating goal scoring opportunities has also been highlighted by other studies, according to which penetrating passes seem to be the most common ones (Gonzales-Rodenas et al., 2017; Sarmento et al.,2018). This confirms the tendency of top-tier teams to favour through balls (passing to the back of the defence) as well as crosses, something that was also confirmed in the sample of the present study (2020 World Cup).

Apart from the type of final pass, an equally important parameter is the zone from which it is executed. In his research, Cobanoglu (2019) found that most of the final passes were made from outside the 18-yard box and fewer from the side zones. The results of the present study seem to be similar in that most of the final passes were made from the central area outside the 18-yard box (Zone 10) as well as from the central zones within the 18-yard box (Zones 4 & 5). Perhaps this is related to the way the teams dealt with better organized defences. The main defensive styles in recent years have been on-the-ball or zone defence, creating defensive pressure in the space where the ball is located. Breaking down such a defence from the central axis is difficult and can be done either by a penetrating pass behind the defence or by an individual action of an attacking player (Gonzales-Rodenas et al., 2020a). As for the other zones, it was found that the final passes made from them had a much lower but comparable percentage (9% on average). In contrast, significantly fewer final passes were executed from the central zones near the goal (Zones 4 & 2). It seems that when the final pass was very close to the opponent's goal, the teams in the sample chose to complete the attack without any delay that could lead them to a turnover and, as a result, lose the opportunity to score a goal or lose possession of the ball.

The results of the present study showed that the final action zone was significantly affected by the zone of final pass. In particular, the final passes made from zone 10 ended up mainly inside zone 10. This shows the tendency of teams to take direct shots from outside the 18-yard box. The final passes, as well as crosses from the side zones outside the 18-yard box and passes from the side zones inside the 18-yard box, seemed to be directed towards the central zones of the 6-yard box and the 18-yard box (zones 2, 5 & 4). These findings seem to be in agreement with Gonzales-Rodenas et al. (2020a), whose study is probably the only one that has documented the correlation between these zones. Also, according to the same authors, parallel and cut back passes are the main technical actions of the final pass, usually executed from zones 1 and 3. The areas where these passes ended up in this study, as in that of the above authors, were the zone between the penalty spot and the 6-yard box (zone 4) as well as the zone of the 6-yard box (zone 2). The player entering these side zones has the above options (parallel and cut back pass) which create serious problems for the defending team. Moreover, the choice of passing parallel to the goal, mainly inside the 6-yard box (zone 2) causes big problems for the goalkeeper, who is exposed between the passer and the receiver, but also for the defenders who have to face the risk of an own goal. The increased number of own goals by the teams studied in this research is probably due to this fact. Also, the parallel pass and the cut back pass into the penalty area (zone 4) have the advantage of placing the attackers facing the goal, in close proximity and at a greater angle to it. Therefore, the chances of scoring a goal are higher, as the defenders don't have much chance and time to react and press.

Research indicates that the 16-yard box is the area from which most goals are scored with a percentage of more than 80% (Cobanoglu, 2019; Mitrotasios & Armatas, 2014; Pratas et al., 2018; Wright et al., 2011). As previously mentioned, in the present study the most popular zones from which the final actions were taken were zone 10, zone 4 and zone 5. However, the teams in the sample scored the majority of their goals when the final action originated mainly in Zones 2 and 4. Still, we should also take into consideration the attacks that came very close to scoring as well as those that were ineffective. In particular, the attacks that came very close to scoring were those in which the final action was initiated from the side zones inside the 16-yard box (1 and 3). These zones were characterized by the fact that one in two of the final actions initiated in them came very close to scoring while the other half were ineffective (resulted in a turnover, poor execution of the shot or an easy clearance by the opponent). It should also be mentioned that although the final actions from zones 10 & 5 came very close to scoring (the ball hit the crossbar, it was just out of bounds, there was an extremely difficult clearance by the opponent) these were also the zones from which most of the failed attempts were made (turnovers, poor execution of the shot, stealing the ball from the opponent).

CONCLUSIONS

The interpretation of the results of the present study, which was based on the analysis of completed attacks, shows that the area in the centre and outside the 16-yard box (Zone 10) was the area from which most of the final passes were made.

While the cross might seem to be the most popular passing technique, this is not the case if we consider the percentage of its occurrence in completed attacks. However, its effectiveness did not differ from the effectiveness of the other passing techniques studied.

The effectiveness of the completed attacks seemed to be affected only by the zones the final actions were carried out from, with zones 4 and 2 being the most favoured. The following could be further investigated in future studies: the relationship of the parameters of final pass technique, final pass zone, final action zone and efficiency, with a) the type of the team's offense, and b) the opponent's defence. This will allow us to examine whether the above parameters (offense, defence) influenced the parameters studied in this study.

Limitations

While the observation of the matches was valid and reliable, a limitation of the research was the separation of the stadium zones. Specifically, this restriction applies to the central and lateral zones outside the penalty area of the field where the recording was approximately done.

AUTHOR CONTRIBUTIONS

Efstratios Kyranoudis: Data collection. Katerina Papadimitriou: Training on the software used. Support and check of data collection. Aggelos Kyranoudis: Creating an observation protocol (observation parameters/variables. Anestis Giannakopoulos: Statistical analysis. Xanthi Kontstantinidou: Creating an observation protocol (observation parameters/variables).

SUPPORTING AGENCIES

No funding agencies were reported by the author.

DISCLOSURE STATEMENT

No potential conflict of interest were reported by the author.

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ORIGINAL ARTICLE

Comparison of the effect of passive recovery and self-myofascial release in post-match recovery in female soccer players

GERALDO OLIVEIRA CARVALHO JUNIOR[1], KARINE NAVES DE OLIVEIRA GOULART[2], EDUARDO MENDONÇA PIMENTA[1], SOPHIA LAÍS ARAÚJO FORTES[3], KARINA BRAGA GOMES[3], BRUNO PENA COUTO[4]

[1]*School of Physical Education, Physiotherapy and Occupational Therapy. Federal University of Minas Gerais. Belo Horizonte, Brazil.*

[2]*Department of Physical Education. Federal University of Mato Grosso. Brazil.*

[3]*Faculty of Pharmacy. Federal University of Minas Gerais. Belo Horizonte, Brazil.*

[4]*School of Health. University of the Sunshine Coast. Sippy Downs, Australia.*

ABSTRACT

The self-myofascial release is often included in football training routines the day after games to help athletes recover, but its effects when performed at this time have not yet been investigated. This study aimed to investigate the effect of a myofascial self-release protocol on post-match recovery in female professional soccer players. Ten players were included in the study, and all athletes underwent two study conditions: self-myofascial release (SMFR) and passive recovery (control). The SMFR was performed on the quadriceps, adductors, hamstrings, iliotibials, gluteus, and gastrocnemius bands, lasting approximately 25 minutes, on the day after the match. The study monitored various recovery markers, including the Total Quality Recovery Scale (TQR), delayed onset muscle soreness (DOMS), mood state, BRAMS (fatigue and vigour), vertical jump, countermovement jump (CMJ), 10 and 20m sprint, and creatine kinase (CK), before the game, 24 and 48 h post-match. The results showed no significant differences between the passive recovery and SMFR for any of the variables monitored. The results of this study indicate that a single session of self-myofascial release (SMFR), performed 24 hours after a female soccer match, has comparable efficacy to passive recovery for post-match.

Keywords: Physical education, Foam roller, Fatigue, Recovery strategy, Post-match recovery, Female soccer.

Cite this article as:
Oliveira Carvalho Junior, G., Naves De Oliveira Goulart, K., Mendonça Pimenta, E., Laís Araújo Fortes, S., Braga Gomes, K., & Pena Couto, B. (2024). Comparison of the effect of passive recovery and self-myofascial release in post-match recovery in female soccer players. *Journal of Human Sport and Exercise, 19*(2), 510-521. https://doi.org/10.55860/j6dyvg90

Corresponding author. *School of Physical Education, Physiotherapy and Occupational Therapy, Universidade Federal de Minas Gerais. Belo Horizonte (MG), Brazil.* https://orcid.org/0000-0003-2952-9007
E-mail: gocjunior@yahoo.com.br
Submitted for publication November 05, 2023.
Accepted for publication November 28, 2023.
Published April 01, 2024 *(in press* December 26, 2023).
JOURNAL OF HUMAN SPORT & EXERCISE ISSN 1988-5202.

doi: https://doi.org/10.55860/j6dyvg90

INTRODUCTION

The demands of soccer matches can lead to muscle damage, dehydration, and glycogen depletion, causing acute and residual fatigue that can negatively affect physical performance for several hours to days after a match (Andersson et al., 2008; Nédélec et al., 2012). It may take more than 72 hours for a complete recovery of athletes (Andersson et al., 2008), which poses a challenge for teams that often play multiple matches per week, congested schedule (Abaïdia & Dupont, 2018). This short recovery time may lead to chronic reductions in training and game performance and an increased risk of injury (Barnett, 2006). Therefore, implementing recovery strategies to accelerate the athletes' recovery process is crucial (Barnett, 2006; Nédélec et al., 2013). One such strategy commonly used by soccer players is self-myofascial release (SMFR) (Rey et al., 2019).

SMFR is a technique where an individual massage the myofascial tissue by applying pressure to the muscles using a foam roller (Cheatham et al., 2015). SMFR may have physiological effects, such as improving arterial and vascular endothelial functions and increasing parasympathetic nervous system activity, which is useful for the recovery process (Beardsley & Škarabot, 2015). Previous research has demonstrated that performing SMFR immediately after exercise can yield multiple benefits. These include reducing muscle pain (Macdonald et al., 2014; Pearcey et al., 2015; Rey et al., 2019), perception of recovery (Rey et al., 2019), increase range of motion (Macdonald et al., 2014; Grabow et al., 2018; Hodgson et al., 2019), and improve performance measures, such as sprint time(Pearcey et al., 2015; Kaya et al., 2021), agility (D'Amico & Gillis, 2019; Rey et al., 2019), vertical and horizontal jump (Macdonald et al., 2014; Pearcey et al., 2015), and positive effects on removal blood lactate (Adamczyk et al., 2020; Ali, Rahimi et al., 2020).

Despite the benefits of performing self-myofascial release (SMFR) immediately after exercise on the recovery of athletes, there is still a debate about the optimal timing of its application as a recovery strategy, and further investigation is needed in football. Particularly on match days, there may not be sufficient time to perform SMFR immediately after the match due to logistical and timing constraints. Instead, SMFR is often included in soccer training routines on the day following the match to aid athletes' recovery. Rey et al., (2019) demonstrated that SMFR performed immediately after soccer training can positively impact athletes' recovery. However, the effects of SMFR on recovery when performed 24 hours after a match have not been studied. Furthermore, some studies (Arabaci, 2008) showed that massage has a significant detrimental effect on athletic performance such as vertical jump, sprint time and acceleration. Freiwald et al., (2016), suggest that SMFR may cause harmful side effects due to the high load mechanical induced in the underlying tissue during foam rolling, which could potentially damage connective tissue, nerves, vessels, and bones. Therefore, investigating the potential positive or negative effects of SMFR on recovery can guide coaches and practitioners in selecting the most appropriate interventions to accelerate post-match recovery. Additionally, given that current evidence is limited in considering SMFR as a recovery tool (Wiewelhove et al., 2019), it is even more crucial to examine its effects.

Thus, this study aims to investigate whether SMFR performed 24 hours after an official women's soccer match interferes with athletes' recovery. The hypothesis is that SMFR will positively impact post-match recovery in female, compared to passive recovery, even when performed the day after the match.

MATERIAL AND METHODS

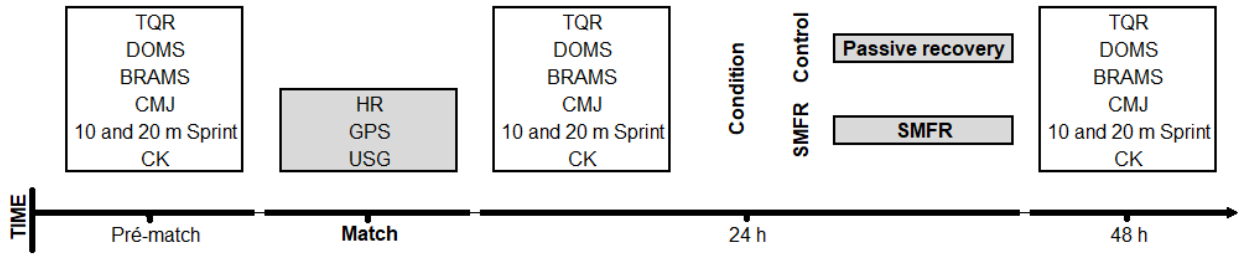
Participants

Ten Brazilian professional female soccer players (age 23.6 ± 5.4 years, height 161.7 ± 6.5 cm, body mass 58.5 ± 6.4 kg, body fat 18.7 ± 3.1%, VO2max 42.3 ± 1.7 ml.kg^{-1}.min^{-1}) participated in this study. The athletes were regularly training five times per week for approximately 2-3h per training session and participated in regional and national competitions organized by the Brazilian Football Confederation. Data collection was conducted in the second half of the season, during which the athletes played the main competition of the year and one match per week, without a congested calendar. The study was approved by the ethics committee of the Universidade Federal de Minas Gerais, UFMG - Brazil (approval reference number 13546619.6.0000.5149), and all participants provided both verbal and written informed consent forms prior to participation.

Procedures

This study compared two conditions, self-myofascial release (SMFR) and passive recovery (control), to assess their impact on athletes' perceptual, physiological, and performance measures pre, 24h and 48h post-match. The study used a within-subject cross-over design, with professional female soccer players being monitored during official championship matches held on Sundays between 10:00 and 11:00 am. Pre-match variables were collected two hours before the game, and performance tests were conducted two days before the match due to their lengthy nature. All tests were repeated 24h and 48h post-match. Athletes assigned to the SMFR condition performed an SMFR protocol after the 24h post-match tests, while those in the control condition underwent passive recovery (Figure 1).

The study was conducted in the same environment and at the same time of the day to reduce the effect of daytime variations on the monitored parameters.



Note. TQR = total quality recovery; DOMS = delayed onset muscle soreness; BRAMS = Brazilian mood scale; CMJ = countermovement jump; SMFR = self-myofascial release protocol; CK = creatine kinase; HR = heart rate; GPS = global positioning satellite; USG = urine specific gravity.

Figure 1. Experimental design.

One week before the competition, athletes underwent an anthropometric assessment and completed the Yo-Yo Intermittent Recovery Test - level 1 (Bangsbo et al., 2008). They were also familiarized with self-myofascial release protocol, vertical jump and sprint tests. During the competition, athletes wore a Polar® Team Pro System which included an integrated heart rate monitor, GPS device with a 10 Hz sampling frequency, and a 200 Hz 3D accelerometer, gyroscope, and magnetometer. The internal load variable, peak heart rate was recorded, along with external load variables such as total distance, distance covered at different speed ranges, (<7.9 km/h; 8 to 11.9 km/h; 12 to 17.9 km/h; >18 km/h and sprints: >25 km/h) number of sprints, accelerations, and decelerations (2.0 m/s^2 and - 2.0 m/s^2 respectively). Pre-match hydration status

was analysed using a portable RTP 20 ATC refractometer (Instrutherm, São Paulo - Brazil), with values ranging from 1.013 to 1.029 g/ml considered normal and values ≥1.030 g/ml classified as dehydration (Lustosa et al., 2017). Body mass was measured pre and post-match using a digital scale (model Glass 10, G-TECH, China). Ad libitum water intake during the match was not recorded. Environmental temperature and relative humidity were measured every 15 minutes using a digital thermo-hygrometer (TTH100, Incoterm, Porto Alegre - Brazil).

Perceptual variables

The study employed the Total Quality Recovery Scale (TQR), which was validated by Kenttä e Hassmén, (1998) and utilizes a 6-20 scale to measure participants' subjective perception of their recovery process. The level of Delayed Onset Muscle Soreness (DOMS) was assessed using a visual analogue scale (VAS) with mild pain (0) and severe pain (10) as endpoints. The Brazilian Mood Scale (BRAMS) a validated instrument consisting of 24 mood indicators and six subscales (anger, confusion, depression, fatigue, tension, and vigour), was used to evaluate participants' mood state (Miranda et al., 2008). Respondents rated each item on a Likert scale ranging from nothing (0) to extremely (4) to indicate their current emotional state. The fatigue and vigour subscales were the focus of the analysis since they were the most commonly reported mood states by the participants.

Performance variables

Athletic performance was evaluated using Countermovement Jump (CMJ) tests, which consisted of three submaximal jumps followed by four maximal jumps with 20 seconds of rest between each trial. The CMJ test was conducted on a Plataforma Jumptest® contact mat and measured using Multisprint® software. The test's reliability was high, with an ICC of 0.96 and a SEM of 0.6 cm. Sprint times over 10m and 20m were also recorded using Multisprint® software and three photocells. Athletes completed two trials after a low-intensity running warm-up with a 2-minute rest interval. The 20m sprint time had an ICC of 0.87 and SEM of 0.04s, while the 10m sprint time had an ICC of 0.85 and SEM of 0.021s.

Physiological variable

Creatine Kinase (CK) total - 200µL of peripheral blood was collected into a heparinized capillary tube. It was centrifuged at 2000 rpm for 5 minutes (BMC macro centrifuge, model 1123, Benfer, Brazil), and plasma was collected and frozen at -80°C until analysis. CK total was determined using a colorimetric method, with a semi-automatic biochemical analyser BIO 2000 (Bioplus, São Paulo - Brazil) and the CK-NAC kit for kinetic method – UV (Ebram, São Paulo - Brazil).

Self-myofascial release protocol

The athletes in this study followed a standardized SMFR protocol using a rigid, cylindrical roller with a uniform diameter of 14.5 cm and a height of 33.5 cm. The SMFR technique was applied unilaterally to the quadriceps, adductors, hamstrings, iliotibial, gluteus, and gastrocnemius muscle groups. Athletes were instructed to begin at the most distal part of the muscle and roll to the most proximal part, using body weight to apply pressure to the local musculature. Each muscle group was stimulated for 2 sets of 60 seconds on both right and left limbs, totalling approximately 25 minutes (Macdonald et al., 2014). Rolling motions were performed at a cadence of 1 every 1.2 seconds, as indicated by an audible signal from the Soundbrenner metronome application, version 1.2, for Android (Pearcey et al., 2015).

Statistical analysis

The data were reported as means and standard deviations. The normality of the data was verified using the Shapiro-Wilk test. Mauchly's test was used to check for violations of sphericity, and Greenhouse-Geisser

correction was applied if necessary. To compare internal and external match loads between conditions, a dependent samples t-test was used. A two-way (3x2) repeated-measures analysis of variance (ANOVA) was used to examine differences in dependent variables between the SMFR and control conditions, as well as changes over time (pre-match, 24h, and 48h post-match). The effect size (ES) for ANOVA was calculated using partial eta squared (ηp^2), with threshold values defined as small (≥ 0.01), medium (≥ 0.059), and large (≥ 0.138) (Fritz et al., 2012; Rey et al., 2019). Bonferroni post hoc testing was conducted when significant differences were found. The significance level was set at α = .05. For paired comparisons, Cohen's d was calculated to determine effect size (Hopkins, 2006). Statistical analyses were conducted using Statistical Package for the Social Sciences version 21.0 (IBM, Chicago, USA) and Prism 6.0 software (GraphPad Software, San Diego, USA).

RESULTS

Mean environmental temperature and humidity during matches were 25.1 ± 2.8°C and 59.7 ± 14.9%, respectively. Pre-match USG corresponded to 1.016 ± 0.008 g/ml and 1.017 ± 0.008 g/ml for control and SMFR conditions, respectively (p = .55, d = 0.17). Post-match body mass change was not significantly different between control (1.48 ± 0.75%) and SMFR (0.97 ± 0.60%) conditions (p = .53, d = -0.56).

Table 1 presents the values for external and internal loads during the match for both the control and SMFR conditions. There were no significant differences observed between the conditions.

Table 1. External and internal match loads during Control and SMFR conditions.

Match characterization	Control		SMFR			
	Mean	±SD	Mean	±SD	p < .05	ES
Playing time (min)	87.0	±9.7	86	±10.6	.66	-0.18
Total distance (m)	7610.0	±815.3	7607.8	±738.5	.99	0.00
Average speed/minute (m/min)	87.0	±7.3	88.2	±5.6	.49	0.15
Distance >25.0 km/h (m)	33.4	±46.7	24.4	±46.3	.57	-0.18
Distance >18.0 km/h (m)	411.7	±183.7	362.0	±183.1	.11	-0.25
Distance 12.0 to 17.9 km/h (m)	1356.3	±366.9	1359.6	±308.9	.95	0.01
Distance 8.0 to 11.9 km/h (m)	2068.7	±499.7	2083.4	±222.0	.91	0.03
Distance < 7.9 km/h (m)	3772.8	±405.6	3802.9	±563.4	.87	0.07
Sprint > 25.0 km/h (nº)	3.1	±3.3	2.2	±3.4	.43	-0.25
Accelerations >3.0 m/s2 (nº)	7.9	±6.1	8.6	±3.5	.71	0.10
Accelerations > 2.0 m/s2 (nº)	62.5	±18.8	64.1	±20.9	.75	0.23
Decelerations <-3.0 m/s2 (nº)	14.6	±9.0	14.8	±8.3	.87	0.02
Decelerations <-2.0 m/s2 (nº)	69.3	±20.6	71.2	±24.5	.76	0.08
Peak heart rate (bpm)	194.0	±10.9	191.0	±10.6	.08	-0.23

Note. (*) represents significantly different between conditions (p < .05); ES = Cohens' d effect size.

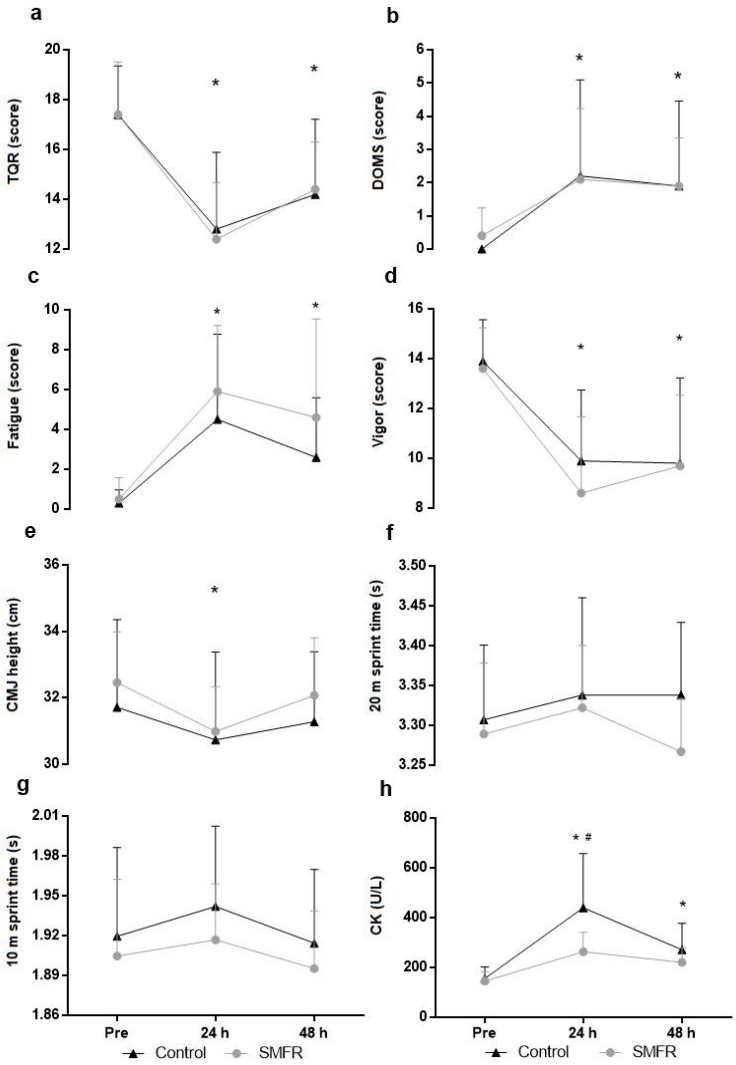
Table 2 presents the results of the repeated measures ANOVA for TQR, DOMS, BRAMS (Fatigue, Vigor), CMJ, 20m and 10m Sprint, and CK. The analysis did not reveal any significant condition x time interactions or main effects for condition on TQR, DOMS, BRAMS (Fatigue, Vigor), CMJ, 20m and 10m Sprint. However, a significant difference was observed for CK, where higher values were found for the control condition compared to SMFR at 24h post-match.

Figure 2 displays the mean values and standard deviations of the perceptual, performance, and physiological variables under both control and SMFR conditions.

Table 2. Results ANOVA of repeated measures.

Parameters	Interaction condition x time			Effect for condition			Effect for time		
	F	*p*	ηp^2	F	*p*	ηp^2	F	*p*	ηp^2
TQR	0.419	.664	0.044	0.220	.885	0.002	23.330	.001*	0.722
DOMS	1.70	.845	0.190	0.35	.856	0.004	8.111	.003*	0.474
Fatigue	0.705	.447	0.073	4.658	.059,	0.341	9.597	.001*	0.516
Vigor	0.451	.644	0.048	0.549	.478	0.057	17.661	.001*	0.662
CMJ	0.240	.789	0.026	1.226	.297	0.120	6.401	.008*	0.416
20m Sprint	2.968	.770	0.248	2.337	.161	0.206	2.404	.119	0.211
10m Sprint	1.486	.253	0.142	0.776	.401	0.079	4.264	.056	0.321
CK	10.696	.001*	0.543	8.979	.015*	0.499	18.049	.001*	0.677

Note. (*) represents significantly different ($p < .05$); ηp^2 = partial eta squared; TQR = total quality recovery; DOMS = delayed onset muscle soreness; Fatigue and Vigor = Brazilian mood scale; CMJ = countermovement jump; CK = creatine kinase.

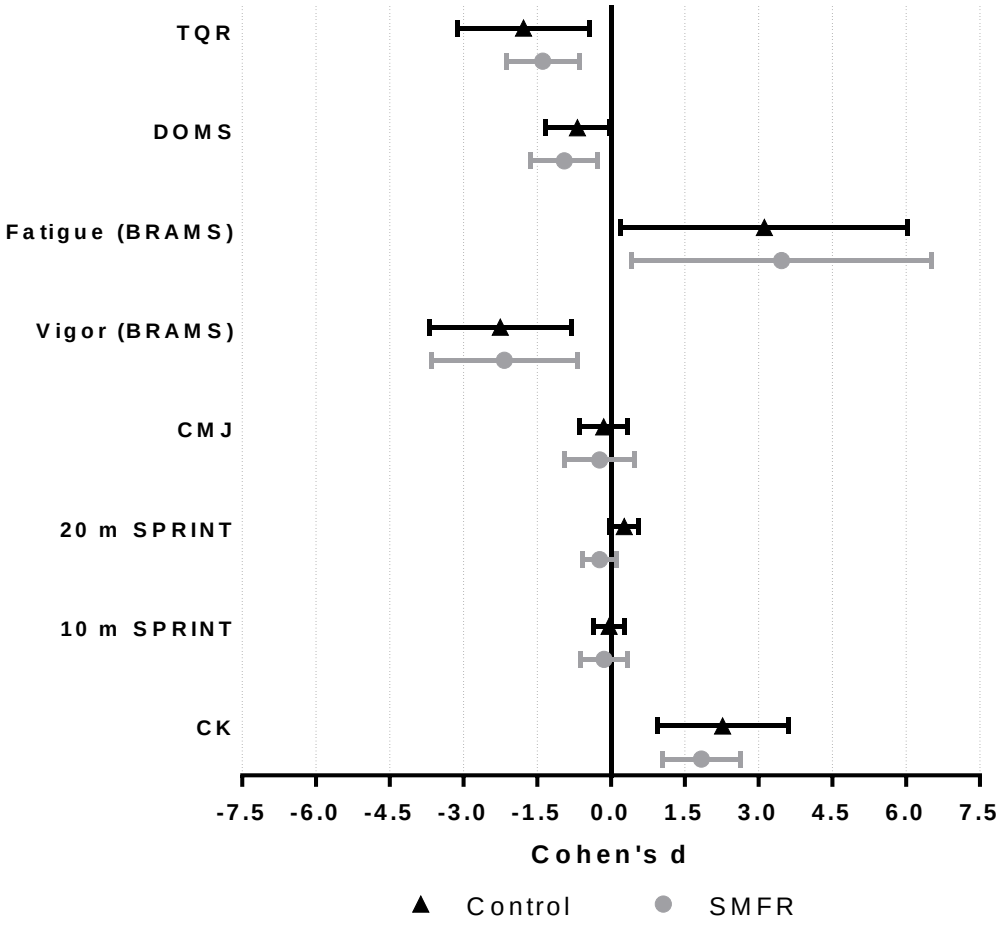


Note. Values are as mean and standard deviation, a. Total quality recovery; b. Delayed onset muscle soreness; c. Fatigue; d. Vigor; e. Countermovement jump; f. 20m sprint; g. 10 m sprint; h. CK. (*) represents significantly different from pre for all conditions (time main effect) ($p < .05$). (#) represents significantly different between conditions at 24h ($n = 10$, $p < .05$).

Figure 2. Perceptual, performance and physiological responses for Control and SMFR conditions at pre, 24h and 48h post-match.

The present study demonstrates significant time main effects for several parameters. Specifically, 24h and 48h post-match, TQR was significantly reduced for two conditions (p = .002, d = -2.15 and p = .005, d = -1.50, respectively), and DOMS was significantly higher for two conditions (p = .032, d = 3.04 and p = .035, d = 2.65, respectively) compared to pre-match (Figure 2a-b). Additionally, fatigue was significantly higher (p = .007, d = 5.22) and vigour was lower (p = .002, d = -2.67) at 24h post-match for all conditions (Figure 2c-d). At 48h post-match, fatigue remained significantly higher (p = .043, d = 3.48) and vigour remained significantly lower (p = .002, d = -2.37) for all conditions (Figure 2c-d). Furthermore, CMJ height was significantly reduced at 24h (p = .030, d = -0.55) for two conditions (Figure 2e), but not significantly different at 48h (p = .669, d = -0.18). No significant time main effect was observed for 20m and 10m sprints (Figure 2f-g). However, a significant time main effect was observed for CK, which was higher at 24h (p = .005, d = -0.45) and 48h (p = .005, d = 1.84) post-match for two conditions (Figure 2h). The effect sizes values were similar between control and SMFR conditions for all investigated parameters.

The effect size changes from pre to 48h were similar between control and SMFR conditions for all investigated parameters (Figure 3).



Note. Values are effect size (ES) and confidence interval (CI) change from pre to 48h post-match for control and SMFR. TQR = total quality recovery; DOMS = delayed onset muscle soreness; BRAMS = Brazilian mood scale; CMJ = countermovement jump; CK = creatine kinase.

Figure 3. Effect size changes from pre to 48h post-match for all variables in Control and SMFR conditions.

DISCUSSION

The present study aimed to investigate the effects of a self-myofascial release protocol on the recovery of athletes following a professional women's soccer match. The study found that a single session of myofascial self-release performed 24 hours after the match did not accelerate or impair the athletes' perceptual responses, physical performance, or physiological parameters 48 hours post-match. Therefore, SMFR did not interfere with the athletes' recovery, contrary to the initial hypothesis of the study.

TQR did not show significant differences between SMFR and control conditions, with large effect sizes for both conditions when comparing pre-and 48 hours post-match. Likewise, Barrenetxea-García et al., (2023) did not find improvements in variables related to recovery when using FR after water polo training in athletes of both sexes. The authors suggest that acute adaptations differ considerably from those observed in land and high-speed sports due to the nature of the aquatic sports environment. Contrastingly, a study by Rey et al., (2019) reported a large effect size on athletes' perception of recovery 24 hours post-SMFR. Differences in the timing of SMFR, gender differences, and stimulus type can explain this discrepancy in results. In the present study, SMFR occurred 24 hours after an official women's soccer match, while Rey et al., (2019) used the protocol immediately after a men's soccer training session. Therefore, the effect of SMFR may be conditioned to some of these factors.

The peak delayed onset muscle soreness (DOMS) value occurred 24 hours post-match and remained elevated at 48 hours with no differences between the control and SMFR conditions. Therefore, in the present study, self-myofascial release did not decrease athletes' perception of soreness. However, previous studies by Macdonald et al., (2014); Pearcey et al., (2015); Rey et al., (2019), have reported a decrease in the perception of muscle pain when using a foam roller protocol immediately after exercise. These results suggest that the benefits of self-myofascial release on recovery may be time-dependent.

Hart et al.,(2005) also reported no effects on DOMS when performing a massage intervention 24 hours after an eccentric exercise protocol in healthy male and female college-aged individuals. Biochemical processes related to inflammation begin to act a few hours after muscle damage. Therefore, performing an SMFR protocol 24 hours post-match might be too late to provide relief from signs or symptoms of muscle pain.

Fatigue was higher and vigour was lower during the 48 hours post-match with no significant differences between control and SMFR conditions. Furthermore, very large effect sizes were observed between pre and 48 hours for both conditions. The fatigue, control (d = 3.12) and SMFR (d = 3.47), and vigour, control (d = -2.25) and SMFR (d = -2.17). Of note, no studies investigating the effect of self-myofascial release on mood were found, making comparisons difficult. Nevertheless, SMFR did not change athletes' mood profiles.

The present study showed no significant differences in CMJ height between control and SMFR conditions, with small effect sizes observed from pre to 48h (d = -0.15 and d = -0.23, respectively). Consistent with these findings, previous studies have reported no significant differences in vertical jump performance following SMFR interventions after a soccer training (Rey et al., 2019) or a repeated sprint protocol (D'Amico & Gillis, 2019). However, other studies have shown beneficial effects of foam rolling on vertical jump performance after a squat protocol (10x10 repetitions, 60% 1RM), with authors suggesting that the improvements may be related to accelerated recovery of connective tissue, leading to enhanced communication of afferent receptors and the preservation of natural patterns of muscle sequencing and recruitment (Macdonald et al., 2014; Pearcey et al., 2015). Given the greater complexity of movements during soccer matches, including

multiple jumps, changes in direction, accelerations, decelerations, and sprints, the efficacy of SMFR may depend on the specific exercise protocol used to induce fatigue.

The SMFR did not influence the 20m sprint recovery, with a small effect size from pre to 48h for both control (d = -0.27) and SMFR (d = -0.23) conditions. Contrastingly, Pearcey et al., 2015, reported improvement in the 30m sprint performance at 24 and 72h post-exercise, when the SMFR protocol was performed immediately, 24 and 48h post-exercise, compared to the control condition. According to these authors, the improvement in recovery was likely due to a reduction in late muscle pain. In the present study, performing the myofascial release technique 24h post-match did not result in muscle pain relief and did not promote performance improvements in the 20m sprint. Further, SMFR did not change the 10m sprint performance, with no significant difference and trivial effect sizes from pre to 48h for both control (d = -0.04) and SMFR (d = -0.14) conditions. Similarly, Rey et al., (2019), found no significant differences for 5 and 10m sprint performance when a SMFR protocol was used immediately post-training in male soccer players. Of note, in the present study, similar sprint times were observed between pre and post-match, suggesting match loads did not reduce speed performance. Thus, SMFR may not promote beneficial effects on short-distance speed tests, since the assessed capacity shows a complete recovery.

The CK total is a commonly used parameter by soccer teams to indirectly assess muscle damage and recovery status of athletes (Ascensão et al., 2008). In the current investigation, CK levels were found to be significantly higher in the control condition as compared to SMFR, only at the 24h post-match time-point. Although the external match load was similar in both groups, no reports of athlete trauma or shocks were observed during the study, which could be a potential explanation for this observed difference (Brancaccio et al., 2007). To date, no other studies have specifically evaluated the effect of self-myofascial release on CK levels, thereby making it difficult to draw any definitive comparisons. However, Kargarfard et al., (2016) reported reduced CK values at 48 and 72h post-eccentric exercise with massage therapy. Therefore, massage therapy may offer potential benefits in assisting with athlete recovery, though the efficacy of SMFR remains unclear.

CONCLUSIONS

The results of this study indicate that a single session of self-myofascial release (SMFR), performed 24 hours after a female soccer match, has comparable efficacy to passive recovery for post-match. Although SMFR did not accelerate the recovery of perceptual, physical, and physiological variables, it did not impair the recovery process either. Therefore, the present results do not discourage the use of the SMFR technique, but its benefits when used 24h post-match in female athletes remain uncertain. The discrepancies with previous studies may be attributed to the moment of carrying out the SMFR post-exercise. Future research should investigate the effects of SMFR immediately after a women's soccer match and in male soccer players, thus providing additional information on the effectiveness of SMFR in promoting recovery in soccer players. The results of this study contribute to the growing knowledge about recovery techniques and can help coaches optimize their athletes' post-match recovery process.

AUTHOR CONTRIBUTIONS

Study design and methodology: G.C., K.G. and B.C. Data collection: G.C., K.G, E.P. and B.C. Laboratory analyses: G.C., K.G., S.F. and K.B.G. Data analysis: G.C., K.G and B.C. All authors participated in the writing and review.

SUPPORTING AGENCIES

This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brazil (CAPES) - Finance Code 001. The authors thank CAPES.

DISCLOSURE STATEMENT

No potential conflict of interest were reported by the author.

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ORIGINAL ARTICLE

Dynamic levels of hormonal, oxidants, insomnia, and stress in badminton athletes who practice morning and evening

ANDI ARIYANDY[1], M. ARYADI ARSYAD[1] ✉, ANDI RIZKY ARBAIM HASYAR[2], MEUTIAH MUTMAINNAH[2], NUKHRAWI NAWIR[3], AYUN DWI ASTUTI[4], MUHAMMAD IQBAL BASRI[5], RINVIL RENALDI[6], MOCHAMMAD ERWIN RACHMAN[7], ANDI AINUN ZULKIAH SURUR[1], WAHYU USMAN[1], FADLIANA UTAMI[1]

[1]*Department of Physiology. Faculty of Medicine. Hasanuddin University. South Sulawesi, Indonesia.*
[2]*Department of Physiotherapy. Faculty of Nursing. Hasanuddin University. South Sulawesi, Indonesia.*
[3]*Department of Sport Science. Faculty of Sport Science. State University of Makassar. South Sulawesi, Indonesia.*
[4]*Department of Pharmacy Science. Faculty of Pharmacy. Hasanuddin University. South Sulawesi, Indonesia.*
[5]*Department of Neurology. Faculty of Medicine. Hasanuddin University. South Sulawesi, Indonesia.*
[6]*Department of Psychiatry. Faculty of Medicine. Hasanuddin University. South Sulawesi, Indonesia.*
[7]*Department of Physiology. Faculty of Medicine. Muslim University of Indonesia. South Sulawesi, Indonesia.*

ABSTRACT

Circadian rhythms are internal mechanisms that regulate various aspects of the human body's physiology and behaviour that are influenced by activity, physicality, and change time in 24 hours. This study aims to compare oxidant levels and hormonal levels based on differences in training times, namely morning and evening, in badminton athletes. This research involved 44 badminton athletes using a purposive sampling technique who were divided into a morning group (n = 22) and an evening group (n = 22). Melatonin levels were measured using the Elabscience Kit (No. E-EL-H2016) and malondialdehyde (MDA) levels using spectrophotometry. All research procedures have received ethical approval from the Hasanuddin University Medical Faculty Ethics Commission (Number: 377/UN4.6.4.5.31/PP36/2023). The results of this study indicate that the athlete's melatonin value in the morning was 76.71 ± (29.05-247.45) higher than in the evening 80.43 ± (50.83-155.24) Meanwhile, the athlete's MDA value in the evening was 2.08 ± (0.74–4.57) higher compared to the MDA in the morning of 1.09 ± (0.33–3.71). Meanwhile, based on the insomnia value for evening training, a higher value was obtained compared to morning training, namely 9.50 ± (3-11). However, there was no significant difference in stress levels. The results of the study showed that badminton athletes who trained at night tended to experience sleep disturbances (insomnia) and increased oxidant levels, while hormonal levels, especially melatonin, were higher in athletes who trained in the morning.

Keywords: Sport medicine, Melatonin, Oxidative stress, Morning exercise, Night exercise, Insomnia, Stress level.

Cite this article as:
Ariyandy, A., Arsyad, M. A., Hasyar, A. R. A., Mutmainnah, M., Nawir, N., Astuti, A. D., Basri, M. I., Renaldi, R., Rachman, M. E., Surur, A. A. Z., Usman, W., & Utami, F. (2024). Dynamic levels of hormonal, oxidants, insomnia, and stress in badminton athletes who practice morning and evening. *Journal of Human Sport and Exercise, 19*(2), 522-535. https://doi.org/10.55860/wvm7n911

✉ **Corresponding author.** *Department of Physiology. Faculty of Medicine. Hasanuddin University. South Sulawesi, Indonesia.*
E-mail: aryadi.arsyad@med.unhas.ac.id
Submitted for publication November 16, 2023.
Accepted for publication November 28, 2023.
Published April 01, 2024 *(in press* December 26, 2023).
JOURNAL OF HUMAN SPORT & EXERCISE ISSN 1988-5202.

doi: https://doi.org/10.55860/wvm7n911

INTRODUCTION

Exercise has many health benefits, such as reducing the incidence and severity of metabolic diseases and increasing healthy life expectancy because it can provide many metabolic benefits through the liver, adipose tissue, and pancreas (Kim *et al.*, 2022; Mode *et al.*, 2023) However, excessive exercise activity can disrupt the production of free radicals and antioxidants, which is known as oxidative stress (Yunus, 2020). Someone who exercises in the right way, like by increasing the intensity of the exercise and choosing the right time to exercise, will get maximum benefits. In general, the best time to exercise is in the morning, and the best time to rest is in the afternoon. This is because some evidence shows that humans go through two different phases in their lives, namely the ergotropic phase when they carry out activities in the morning and the trophotropic phase when they rest at night (Andriana and Ashadi, 2019).

However, activities during the day can cause an increase in blood pressure and pulse rate. Furthermore, all body functions will slow down at night, resulting in drowsiness. However, if someone forces themselves to exercise at night, this schedule change can disrupt *the internal timekeeper,* whose function is to direct the body's abilities (Jensen *et al.*, 2016). A person who exercises before bedtime with maximum energy will experience an increase in physiological arousal characterized by symptoms of increased heart rate and increased breathing (Kline and Youngstedt, 2017; Andriana and Ashadi, 2019). Circadian rhythms are also disrupted when someone exercises at night. For example, melatonin levels are reduced when the circadian rhythm is disrupted, and its function as an antioxidant can increase reactive oxygen species (ROS) in cells (Mushab, Hairrudin, and Abrori, 2020).

There are also a lot more people doing badminton at night than in the morning. Several athletes' complaints that arise after exercising at night, such as muscle pain, easy injuries, and sleep disturbances, are of particular interest to us. Therefore, we want to look further at the influence of training time, which is associated with changes in oxidant levels and changes in levels of the hormone melatonin after exercise in badminton athletes both in the morning and at night. Researchers also compared the levels of insomnia and stress in badminton athletes.

METHODS

This research is an experimental study with a cross-sectional design to see the comparison of MDA, melatonin, insomnia, and stress levels that are associated with differences in morning and evening training times in junior badminton athletes aged 10–16 who regularly exercise at least 3 times a week. This research has received ethical approval from the ethics commission of the Faculty of Medicine, Hasanuddin University (Number: 377/UN4.6.4.5.31/PP36/2023) and was carried out in 2023. The process of taking athlete blood samples was carried out at the South Sulawesi Badminton Association. After ensuring that the athlete is in good condition, a 3 cc blood sample is taken from the median cubital vein.

15 minutes of morning and evening badminton practice. Then the blood sample is centrifuged to obtain serum, which will then be measured using the melatonin hormone levels *Elisa Kit* and a human Elisa reader tool. Oxidant levels are seen using the MDA biomarker by spectrophotometry. Whereas measuring stress level with the perceived stress scale (PSS)-10 and insomnia with a questionnaire insomnia rating scale Bivariate analysis to relate variables is an *unpaired T-test* if the data is normally distributed. Meanwhile, if the data is not normally distributed, the alternative, non-parametric *Mann-Whitney* test was used.

RESULTS

Table 1. Characteristics sample age.

		Morning Athlete		Night Athlete	
		Frequency	Percent (%)	Frequency	Percent (%)
Age	10	3	13.6	6	27.3
	11	4	18.2	1	4.5
	12	3	13.6	5	22.7
	13	6	27.3	6	27.3
	14	5	22.7	4	18.2
	15	-	-	6	27.3
	16	1	4.5	1	4.5
Total		**22**	**100**	**22**	**100**

Based on the Table 1 obtained, the characteristics of the subject studied were based on age. Group athlete morning on the range of 10–16 years, with donations by athletes 13 years old (27.3%). Likewise, in groups, evening athletes in the age range of 10–16 years Ages include group-age athletes in junior badminton.

Table 2. BMI characteristics sample.

		Morning Athlete		Night Athlete			
		Frequency	Percent (%)	Frequency	Percent(%)	Frequency	Percent (%)
BMI	16.0-18.0	13	58.6	-	-	-	-
	18.1-20.0	6	27	12	54.5		
	20.1-23.0	1	4.5	4	18.5	21	95.5
	23.1-26.0	2	9	6	27	1	4.5
Total		**22**	**100**	**22**	**100**	**22**	**100**

Based on the Table 2, the obtained description characteristics were subjected to study in accordance with the Body Mass Index. BMI in athletes Morning ranges from 16.0 to 26.0 kg/m^2, dominated by BMI, which ranges from 16.0 to 18.0 kg/m^2 (58.6%). Likewise, for group athletes, most nights ranged from 18.1-20.0 kg/m^2 (54.5%). Meanwhile, the non-athlete group evening with the most ranged from 20.1-23.0 kg/m^2 (95.5%). BMI group in each group, including the normal BMI category.

From Table 3, the mean ± SD value of melatonin levels for morning athletes is higher than that for evening athletes, namely 98.64 ± 61.30 and 80.43 ± 31.28. The results of the independent T-test are not significant; there is no difference with a value of $p = .707$ ($p > .005$).

From Table 4, the mean ± SD value of MDA levels for night athletes is higher than that for morning athletes, namely 1.45 ± 0.94 and 2.17 ± 0.95. The results of the independent t-test are significant; there are differences in MDA levels between athletes in the morning and athletes in the evening, with a value of $p = .012$ ($p < .005$).

Table 3. Melatonin levels in morning athletes and evening athletes.

Group	Mean ± SD	*p*-value
Morning athlete	98.64 ± 61.30	.707[a]
Night athlete	80.43 ± 31.28	

Note. [a]Independent T-test.

Table 4. MDA levels in morning athletes and evening athletes.

Group	Mean ± SD	*p*-value
Morning athlete	1.45 ± 0 .94	.012[a]
Night athlete	2.17 ± 0 .95	

Note. [a]Independent T-test.

Table 5. Stress questionnaire values for morning athletes and evening athletes.

Group	Mean ± SD	*p*-value
Morning athlete	12.09 ± 4.71	.124[a]
Night athlete	11.73 ± 1.12	

Note. [a]Independent T-test.

From Table 5, the mean ± SD value of the stress questionnaire indicates that stress for morning athletes is higher than that for night athletes, namely 12.09 ± 4.71 and 11.73 ± 1.12. The results of the *independent T-test* are not significant; there is no difference with a value of $p = .124$ ($p > .005$).

Table 6. Values insomnia questionnaire for morning athletes and evening athletes.

Group	Mean ± SD	*p*-value
Morning athlete	7.77 ± 3.02	.001[a]
Night athlete	14.95 ± 2.62	

Note. [a]Independent T-test.

From Table 6, the mean ± SD value of the insomnia questionnaire for the night is higher compared to morning athletes, namely 14.95 ± 2.62 and 7.77 ± 3.02. The results of the independent t-test are significant; there is a difference with a value of $p = .001$ ($p < .005$).

DISCUSSION

Melatonin levels

Rhythm circadian is a daily change in behaviour and activities biologically caused by the capacity to experience something synchronized in organisms with a 24-hour cycle of light and darkness in the environment. This rhythm originates from the biological clock inside the body, which regulates lots of elements of physiology in humans, including the cycle of sleep, variety of blood pressure daily, and temperature of the body (Refinetti, 2012). The suprachiasmatic nucleus (SCN) hypothalamus, which receives signals of light and dark in a direct way through the track retinohypothalamus, houses a known internal rhythm generator as a "*biological clock*." Circadian clock processes centre send information from outside to the peripheral clock various tissues and cells, whose functions may be simultaneous or independent (Refinetti, 2012). The pineal gland in the SCN mediates the circadian melatonin cycle, which is partially regulated by the light-dark process (Nobari et al., 2023).

Melatonin (N-acetyl-5-methoxytryptamine) is an endogenous pineal gland neurohormone whose secretions are controlled by light and dark cycles. Melatonin plays an important role in overcoming radicals and reducing damage to the oxidative level (Emens and Burgess, 2015). Melatonin receptors can be found throughout the body (e.g., muscles, skeleton, mitochondria, pancreas, tissue adipose, retina, brain, platelets, and skin) (Tan *et al.*, 2013). Melatonin also plays a role in the management of insomnia, obesity, diabetes, and metabolic syndromes. A number of studies support the effect of melatonin on oxidative stress, inflammation, and cellular apoptosis in living humans with obesity and animal models of obesity. Research conducted on young

footballers has shown that acute consumption of melatonin (6 mg) before intensity Keep going to continuously increase defence immunity and lipid metabolism and reverse damage resulting from oxidation after exercising with increased activity of total antioxidants that can cause enhancement of physique performance (Ben Dhia *et al.*, 2022) and also act as antioxidants with stimulated activity of antioxidant enzymes such as SOD (superoxide dismutase), CAT (catalase), and GPX (glutathione peroxidase).

This research reports that athletes' melatonin values at morning exercise are higher than at evening exercise. This thing, in line with Marrin et al., shows enhancement. Endogenous melatonin levels after sport are higher in the morning compared to the afternoon, which shows that the morning MLT administration day can increase the number of MLTs in the blood, so the increased effect will benefit him. Ghattassi et al. show melatonin consumption can influence cognitive performance Morning day (e.g., alertness and timing reactions) and some performance Specific period short from player football, however, performance measured in the afternoon still has not changed. In the morning, lipid peroxidation capacity total antioxidant, and activity enzyme certain higher than evening day. Other findings on *salivary* melatonin have been proven to increase during and after morning and evening exercise, with mornings producing more improvement (Marrin *et al.*, 2011). Physiological levels of melatonin have been found to contribute to the capacity of human serum antioxidants as a whole (Nobari et al., 2023).

Insomnia

Getting enough sleep is an important element for health and performance, especially among elite athletes. According to the National Sleep Foundation, there are consistent findings that exercise increases total sleep time and sleep quality. Sleep deprivation alters cognition, pain, mood, metabolism, inflammation, and immunity, which can ultimately have a negative impact on athletic performance (Kashefi, Mirzaei, and Shabani, 2014). Exercise is generally considered a non-pharmacological behaviour that can initiate sleep through hyperthermia. Enhancement of metabolism, which warms the pre-optic area and anterior hypothalamus, has proven to start sleep (Gong *et al.*, 2000). Exercise can induce both acute and delayed changes in melatonin secretion, although the changes induced by exercise vary according to when the exercise is performed. (Carlson *et al.*, 2019). Sleep deprivation of 6 to 7 hours (every 24 hours) can lead to many comorbidities, such as hypertension and diabetes, and a 12% higher risk of death. Adolescence is characterized by a high proportion of people frequently staying up late, pushing bedtime to one to three hours later than in pre-adolescence, with difficulty waking up early in the morning. This is due to one of them: biological reasons: Circadian biological rhythms are unbalanced, so that melatonin secretion is delayed in the morning while increasing in the afternoon (Chahine, Chahine, and Nader, 2022).

The negative impacts associated with exercising at night include sleep disturbances. Increased production of the hormone adrenaline, which has an impact on increasing heart rate and body temperature, can cause difficulty falling asleep immediately after physical activity at night. High-intensity exercise in the hours before bed increases physiological responses. Heart rate increases, lactic acid builds up, and breathing rate increases, all of which can disrupt normal sleep patterns. Badminton is one of the most popular sports with an anaerobic energy system. The ATP-PC and lactic acid energy systems are used in as much as 70% of badminton matches. The energy system poses a significant threat of creating a hypoxic environment. In fact, after playing badminton, a person's cells and muscles will be damaged, causing feelings of tiredness. Therefore, recovery is very important to prevent injury and other negative effects (Romadhan, Purnama, and Sabarini, 2023).

Other research has proven that sleep plays a major role in physiological recovery, especially with regard to cardiovascular and endocrine function. Conversely, short sleep duration is associated with increased cortisol

levels and systemic inflammation. In general, regular physical exercise can improve sleep quality. These beneficial effects are lost with vigorous exercise, which is basically done at night, as a result of exposure to bright light. Accumulating evidence suggests that intense exercise in the evening during the phase of increased melatonin secretion can blunt melatonin levels, increase cortisol levels, and induce hyperthermia (Banzet *et al.,* 2012). As a result, youth athletes' rest and recovery are hampered. It has been observed that changes in sleep quality and quantity affect sports performance the following day (Cooper, 2005; López Flores *et al.,* 2018). For example, a reduction in total sleep time can cause fatigue, reduced aerobic capacity (Skein *et al.*, 2011), sub-maximal strength, and precision (Reyner and Horne, 2013). Thus, the importance of sleep for optimal athletic performance and recovery, cognitive/academic performance, and well-being, as well as reducing the risk of injury and disease in athletes (Bergeron *et al.*, 2015) (Cheikh *et al.*, 2020), Melatonin acts as an antioxidant capable of protecting against potential molecular damage (Brancaccio et al., 2007; Maldonado et al., 2012). Additionally, the ability of melatonin to influence immune function has been demonstrated (Brancaccio et al. 2010). Numerous studies show that melatonin manifests its anti-oxidative properties by increasing the activity of antioxidant enzymes, producing molecules that protect against oxidative stress, and decreasing the amount of reactive oxygen species. Exercise that has been performed at night or in the dark at night with either moderate or high intensity results in delayed melatonin secretion (Rastegar et al. 2018). The result of research by Cheick et al. (2020 on 14 volleyball players found that melatonin levels were higher in the morning day compared to the evening day after exercises. (Cheikh *et al.*, 2020).

The results of this research showed that evening athletes achieve higher insomnia scores than athletes who train in the morning. In line with other findings, physical activity improves sleep quality by increasing melatonin levels at night, especially in participants who exercise in the morning (Chahine, Chahine, and Nader, 2022). It has been reported that aerobic exercise in the morning or evening stimulates the earlier release of melatonin and shifts the circadian rhythm. This is associated with increased melatonin at night and decreased cortisol levels—the perfect physiological pattern for these two hormones (Youngstedt, Elliott, and Kripke, 2019). In fact, an important marker of hypothalamic-pituitary adrenocortical function is cortisol levels, with increases in cortisol levels peaking in the afternoon and a sharp decline in the evening (Morita, Sasai-Sakuma, and Inoue, 2017). The importance of melatonin, secreted by the pineal gland, has been emphasized in sleep disorders from the perspective of endocrine biochemical systems. This hormone associated with sleep is secreted more often at night and is closely related to the onset of sleep, deep sleep, and maintenance of good sleep quality (Vitale et al., 2017). In fact, morning exercise can improve sleep quality, leading to the maintenance of stable sleep throughout the night, thereby triggering improvements in overall sleep pattern architecture (Chahine, Chahine, and Nader, 2022).

An imbalance between oxidative stress and antioxidant defence is one of the mechanisms underlying cardiovascular complications (New et al., 2013). Oxidative stress is a condition where there is an imbalance between antioxidant defences and free radicals. Increased levels of free radicals will oxidize proteins, lipids, and nucleic acids. Lipid oxidation produces lipid peroxides, which can be measured at MDA levels. (Arslan et al., 2014). Decreased antioxidant capacity will cause oxidative stress, which predisposes to cardiovascular disease complications (Akhigbe and Ajayi, 2021).

Under oxidative stress, reactive oxygen species (ROS) trigger endothelial dysfunction through disrupting nitric oxide (NO) signalling, a vasoprotective agent. Superoxide reacts with NO to form peroxynitrite, a powerful vasoconstrictor. ROS are also associated with structural changes in blood vessels, such as wall thickening and lumen narrowing (Kawamura and Muraoka, 2018). The redox system experiences a circadian rhythm, where antioxidants are more efficient in the morning and lipid peroxidation levels are higher in the

afternoon. Oxidative stress was higher in the afternoon, with peak MDA concentrations occurring at 18:00 (lower values at 06:00). Meanwhile, antioxidant status parameters (total antioxidant status (TAS), total bilirubin (TBIL), uric acid (UA), CAT, and GPx activity) are higher in the morning, with peak concentrations at 06:00 (Powers et al.,, 2020).

The results of this study are in line with the results of research by Hammouda et al. They concluded that antioxidant status was more efficient in morning exercise than in morning exercise in the afternoon in young soccer players. Circadian rhythms regulate all activities in the body, including the antioxidant system, where antioxidant system activity is higher in the morning. High GPx levels in the morning will increase even higher with regular moderate-intensity exercise. The mechanism of the greater increase in GPx-1 in the morning group may be related to higher levels of melatonin in the morning compared to the afternoon. Melatonin secretion is still ongoing at 08.00 and is no longer secreted at 16.00. Melatonin has been shown to increase more after exercise in the morning than in the afternoon. Afternoon exercise blunts or reduces melatonin secretion compared to morning exercise. Melatonin is an antioxidant hormone that can stimulate other antioxidant enzymes (SOD and GPx). Melatonin contributes to increasing the body's total antioxidant capacity. The antioxidant capacity of melatonin is 10 times more efficient than that of other antioxidants (Sato et al., 2020).

The results of this study showed that MDA levels were higher in athletes who trained at night compared to athletes who trained in the morning. This is in line with research by Jusup et al. (2022 showing that the decrease in MDA levels after regular exercise in the morning is significantly greater than in the afternoon. This decrease was associated with a greater increase in the antioxidant enzyme GPx-1 in the morning group compared to the morning group in the afternoon group. Previous research involving health respondents showed a significant increase in MDA levels after exercise in the afternoon (Jusup et al., 2022).

Stress level

Performance and well-being of athletes are influenced by internal and external demands. In some years, space-scope training, density competition, pressure social and media, as well as efforts to increase performance, have increased in various disciplines of sport. However, practice combined with too much recovery is not adequate, and a level of stress can give rise to the risk of overreaching or overtraining syndrome. These things be marked with change psychological negative period short and term long (e.g., atmosphere heart depressed, attitude apathetic in a way general, decline price self, instability emotions, anxiety, easy offended, annoyance sleep, decline weight, loss lust eat), change biological (increase rest). beat heart, increase vulnerability to injury, hormonal changes), and be accompanied by a decline in capacity performance (Heidari *et al.*, 2018). If it occurs in athletes who experience it, nonconformity between recovery and stress is not enough to tolerate the burden of high training.

According to Kellmann and Kallus, from a perspective-oriented system, stress reflects destabilization or deviation from internal norms (biological or psychological) (Kellmann and Kallus, 2016). Stress model transactional cognitive emphasizes the importance of the assessment process. Someone who strengthens or weakens the effect of a potential situation gives rise to stress. Rather, recovery describes multilevel processes (including factors psychological and social), where ability performance is built back. However, many athletes tend to ignore symptoms and not make enough recovery because they are possibly afraid to skip exercise and/or competition (Van Tonder *et al.*, 2016).

This study discovered that athletes' stress levels were higher in the morning than in the evening. That thing in line with the study by Gerber *et al. (*2013 that level of recovery is low and level of stress is high in a way

significant predicts problem-marked mental health with symptoms of depression, fatigue, and insomnia (Gerber *et al.*, 2023) Strength predictions, circumstances, recovery, and stress are similar for symptoms of depression and fatigue. Although elite athletes report higher levels of recovery when compared to levels of stress. This has become a problem for elite athletes who have a low recovery rate or a high stress level.

Our findings are an encouraging study from previously found that recovery is not only the main performance athlete's main factor; matter this also contributes to minimizing the risk of negative mental health impacts like depression, fatigue, or insomnia (Heidari *et al.*, 2019). Because of variations in potency recovery, capacity to endure stress, genetics, background behind training, or health status moment here, athletes with standard performance may show different responses to the training stimulus provided. As a consequence, the burden exercise is certain possible in accordance with one athlete, but it results in excessive exercise in others (Emens and Burgess, 2015). This thing highlights the importance of monitoring (psychological), which describes a systematic process of collection and interpretation of information about recovery and condition stress in athletes. (Heidari *et al.*, 2019).

Although the importance of sleep for performance and health in athletes is already well known, the latest evidence shows that most big athletes often fail to fulfil recommendations for this sleep moment (Fullagar *et al.*, 2015). Under review, it was reported that 50–78% of elite athletes experience disturbance sleep and 22–26% have a timetable of very disturbed sleep (Kölling *et al.*, 2015). Likewise, latest Research finds that 88% of athletes do not get enough sleep—as much as 8 hours (Kölling *et al.*, 2015). Although there are a number of obstacles to optimal practice for athletes, such as situational place stay, travel, itinerary exercise, and hygiene, the schedule sleep an athlete often does not prioritize moment in timetable practice and practice developed, which can cause scheduling more beginning session exercise in the morning. Unfortunately, research has previously shown that this, in turn, can negatively impact the quantity and quality of sleep obtained by student-athletes in college at night before exercise in the morning, causing sleepiness and fatigue during the day (Filho *et al.*, 2015).

Apart from that, there are a number of outside factors that limit schedules and itineraries that also affect sleep status and recovery. Studies previously showed that circumstances and anxiety situations can negatively impact athletes sleep (Brink *et al.*, 2012), for example, before competition essentials and travel. Next, before the session morning exercise, there was pressure to fall asleep, but you didn't get lots of sleep, so you can give rise to worry situational, potential bother sleep. In the environment of work, when workers are currently on duty, they report frequently higher levels of anxiety because they are afraid of excessive sleep or are not awakened due to alarm (Walsh *et al.*, 2021). Enhancement level of worry This often worsens quality sleep, which is associated with declining cognitive and performance. Unknown is the same phenomenon that can occur in athletes when face-to-face exercise occurs on a morning, and the fear of sleeping excessively or missing the alarm can increase level anxiety at night. Therefore, increased anxiety can influence quantity and quality of sleep, and so on, evaluate perceived recovery on the next day if sleep turns out to be disturbed (Heidari *et al.*, 2019).

In other studies, the level of anxiety increased at night before session exercise in the morning compared with non-exercise days. In turn, higher levels of anxiety may also have a negative impact on total sleep and the measurement of perceived recovery status by the next day. Interestingly, the effect This was only observed in males, but the magnitude of the effect was the same. What is the total time Sleep affects recovery status Possible comparable in both types of gender. Is it known in studies that reflection from the level of anxiety reported higher before days of exercise morning day because enhancement level worry possible has caused sleep to be more restless? Because the perceived recovery status is lower on days of session exercise and

mornings, and the recovery status ratings are lower linked with reduced total time sleep, not enough sleep is possible, which bothers the athlete's ability to recover in a way adequate and feel ready to do practice. train tomorrow. There is also a possibility that there is more high anxiety at night before the morning session of exercise. The day also has a negative impact on recovery status, as shown by the negative relationship between recovery status and level of anxiety. Similar findings were noted before competition, where total time reduction sleep was linked with enhancement level fatigue and low level strength the next day. Simultaneously with the results of the study moment this and the findings before, apparently total time reduction sleep impact negative on various index recovery before session training and competition. Possible implications can be acute and chronic after total time reduction. Sleep with often-session exercise on the morning. Even athletes in studies This only reports perceived recovery status; research previously also observed declines in physical performance, ability, cognitive ability, and time reaction after disturbance sleep (Walsh *et al.*, 2021). In extreme cases, when sleep is limited to evenings before exercise sessions, athletes tend to report a more heartbreaking atmosphere, a higher level of fatigue, and a greater perception of effort during exercise compared to evenings, when athletes take notes and 8 hours of sleep is recommended (Ritland *et al.*, 2019). Over time, less sleep can cause persistent fatigue, which is a general symptom of recovery that is not adequate and is frequently reported by athletes who exercise excessively. In addition, athletes who sleep less than 8 hours per night found 1.7 times more likely to experience injury compared to a sleeping athlete for more than 8 hours (Milewski *et al.*, 2014). However, the total increase in sleep through intervention-repair targeted sleep has been directly linked with various aspects of enhancement performance among athletes (Kirschen, Jones, and Hale, 2020). This shows that a continuous focus on improving quality sleep has the possibility of reversing a negative trend in pattern-induced recovery and performance-disrupted sleep (Merfeld *et al.*, 2022).

Stress is a situation faced by an individual. Man will experience good stress that is sourced from inside and outside himself. Stress can cause conflict, pressure, frustration, and crises. However, excessive stress will make individuals distressed or experience suffering, a sense of disconnection, hope, even depression, or worry. On the contrary, if the stress is very light or they are not experiencing stress, they will easily feel bored and unmotivated. According to a number of studies, regular exercise can have lots of benefits for the body, like preventing obesity, diabetes, hyperlipidaemia, stroke, hypertension, and stress (Andalasari and Berbudi, 2018). Sport has become a need for the public in a wide sense. Proven with its growing centre health and sports as well as fulfilled spaces public on the day holidays by people who want to exercise. This demonstrates that sport is no longer just a necessity but has evolved into a way of life. In general, the public does sport to guard their fitness bodies as well as their health, so they can operate activities daily with fitness, but there are also a few of them who do it because of a hobby or chase performance in the event or sporting events (Andalasari and Berbudi, 2018).

Based on data from Riskesdas, a lot of Indonesia's population is suffering stress, especially the elderly. But there are some strategies for managing stress, among other things, through sports (Chandra and Lontoh, 2022). Sports, besides, can help Managing stress can also increase a person's mental health. Sport not only reduces stress and depression but is also beneficial to guard individual mental health. Someone who frequently exercises their own level of trust has more satisfaction and happiness (Astuti, Surmantika, and Rubai, 2021).

Based on the results of research on the groups, athletes in the morning and evening, respectively, have a low stress level. This thing is possible to relate to a number of studies previously that stated that sports are effective in reducing stress. Regular and planned exercise works for looking after movement function and dealing with stress. Regular exercise can lower the incidence and severity of stress-related mood disorders,

including anxiety and depression. This thing relates to existing changes in chemistry in the brain after exercise, like an increase in neurotransmitters, especially serotonin and dopamine, as well as secretion endorphins (Wahyudi, Freeari, and Nazriati, 2015). Hormone endorphins produced during exercise will replace hormone stress, making emotions more stable. You can do sports to stimulate the release of serotonin and dopamine hormones, which give rise to feelings of happiness and lower stress. People who have the habit of exercising can lower their stress. When exercising, hormones cortisol and epinephrine, which are hormone stress, will decrease, so those who are routinely doing sports will be more exposed to stress, both physical and mental (Stevens, RE et al., 2013).

Our research results state, there is no difference between practicing morning and evening athletes. This is because in research on student-athletes, accumulation triggers stress from roles they as students and athletes often consider not strong. Remember that pattern? Think stress reflects somebody's view of the stress process. That alone, and not simply evaluation to trigger stress, there is a certain possibility that, although student-athletes and non-athletes have the same stress pattern, there is no difference in stress patterns. Optimization model stress is also aware that the internal and external worlds can influence system values, perceptions, or confidence about stress (Crum, 2020). We don't investigate impact variables external to pattern thinking stress or perception stress in this study; however, we recommend researchers integrate variables external in the study next to explore pattern thinking stress in athletes. For example, understanding role trigger stress organization, like culture team, procedure selection, or trainer's interpersonal skills (Arnold, Fletcher, and Daniels, 2013) in influence pattern think stress or evaluation to stress can be useful moment designing intervention pattern think stress (Avery *et al.*, 2022).

Apart from that, the athlete's stress value in the morning is higher than that of the afternoon athlete. This is possible because one of them requires more sleep for athletes who train in the morning. In another research study, Heishman *et al.* (2017) reported sleep alone at night before morning (time from 07:00) and sessions of afternoon practice (time from 13:45) on 10 college basketball players height (21 ± 1 year) for five weeks of training pre-season. Duration Sleep more short at night before session exercise morning compared to afternoon session (-42 minutes, $p < .029$) (Jensen *et al.*, 2016) Mah *et al.* also reported an impact of time from start of the morning to duration of sleep alone in 628 college athletes (20 ± 1 year), with 71% of the team showing duration less sleep on average of 7 hours and time reported wake-up before 07:30, which is no direct influence of time from start of training to duration of sleep (Mah *et al.*, 2018).

CONCLUSIONS AND RECOMMENDATIONS

Based on this research, it can be concluded that there is an increase in oxidant levels (MDA) and insomnia at night. Meanwhile, levels of the hormone melatonin were higher in athletes who exercised in the morning. A part of this is that stress levels did not differ significantly between athletes who trained in the morning or evening.

Research limitations

This research was only conducted on junior athletes and did not involve senior athletes. In this study, we only looked at oxidant levels after exercise but did not compare them with antioxidant levels.

Suggestion

Future research should look at oxidant levels, inflammation, and muscle damage in senior athletes as well. Future research should compare oxidant and antioxidant levels in athletes and non-athletes who train in the morning and evening.

AUTHOR CONTRIBUTIONS

AA, MAA, ARAA, MU, NR, AYD, AIZR, WU and FU conceived the study. AIZR, WU, FU collected samples and prepared the initial draft of this manuscript. AA, MAA, ARAA, MU, NR, AYD, MIB, RR, MER conducted further reviews and provided scientific input on this manuscript. All authors read and approved the final manuscript.

SUPPORTING AGENCIES

This research was supported by the Hasanuddin University research and community service institute (LPPM) in the Chancellor's Decree Number: 00323/UN.4.22/PT.01.03/2023.

DISCLOSURE STATEMENT

No potential conflict of interest were reported by the author.

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ORIGINAL ARTICLE

Development of mental education through sports to enhance adolescent personal resilience

EDDY MARHENI[1], EKO PURNOMO[1] ✉, ARDO OKILANDA[1], IRFAN OKTAVIANUS[1], BURHAN HAMBALI[2], RIZKI BURSTIANDO[3], FIRUNIKA INTAN CAHYANI[1], NINA JERMAINA[1]

[1]*Department of Coaching. Faculty of Sport Science. Padang State University. Padang, Indonesia.*

[2]*Department of Physical Education. Faculty of Sport and Health Education. Indonesian University of Education. Bandung, Indonesia.*

[3]*Physical Education, Health and Recreation Department. Faculty of Health and Science. University Nusantara PGRI Kediri. Kediri, Indonesia.*

ABSTRACT

Objective: Based on the problem at hand, the aim of this study was to investigate how adolescents' personal resilience is understood in the context of developing mental education through sports activities. Research Methods: This study used a quantitative research method with an experimental approach. This study used a sample of high school students (SMA) class XI which was taken by randomized sampling. The total sample of this study amounted to 50 students. Students who became the research sample were assumed to have the ability (in class XI) and the same age (average 16 years). Research results: The results show that there is an average difference between the Pre-test and Post-test physical education learning outcomes, which means that there is an average difference in students' personal resilience scores between the pre-test and post-test. These results indicate the influence of the results of mental education intervention through physical education in increasing students' personal resilience. In the implementation of the post-test, the average value is 100.3 while the average value of the post-test is 49.5, or if you look at the difference (gain) between the post-test and the pre-test of 50.4 which shows a significant result of increasing student resilience from the results of mental education interventions in sports education learning at school. Conclusion: Mental education development programs in adolescents should be tailored to the health interests of the adolescent generation. Sports clubs have the potential to be an arena for health improvement.

Keywords: Mental health, Personal resilience, Mental education, Sports, Youth.

Cite this article as:
Marheni, E., Purnomo, E., Okilanda, A., Oktavianus, I., Hambali, B., Burstiando, R., Cahyani, F. I., & Jermaina, N. (2024). Development of mental education through sports to enhance adolescent personal resilience. *Journal of Human Sport and Exercise, 19*(2), 536-549. https://doi.org/10.55860/5vantg56

✉ **Corresponding author.** *Department of Coaching, Faculty of Sport Science, Universitas Negeri Padang, Padang, 25131, West Sumatra, Indonesia.*
E-mail: ekopurnomo@fik.unp.ac.id
Submitted for publication October 21, 2023.
Accepted for publication November 28, 2023.
Published April 01, 2024 *(in press* December 26, 2023).
JOURNAL OF HUMAN SPORT & EXERCISE ISSN 1988-5202.

doi: https://doi.org/10.55860/5vantg56

INTRODUCTION

Resilience is the capacity to face and overcome adversity, through personal transformation and growth (Tempski et al., 2015). Resilience can also be interpreted as self-readiness in dealing with stress and protecting oneself from the negative effects of stress, so that it can become a foundation in life to be able to produce greater life satisfaction (Robbins et al., 2018). In a Student Resilience Survey (SRS) conducted on 7663 adolescents aged 11-15 years stated that, external support and internal characteristics are potentially viewed as protective factors and important in exploring adolescent resilience mechanisms such as family relationships, school relationships, community relationships, participation in home and school life, participation in community life, peer support, self-esteem, empathy, problem solving, and goals and aspirations (Lereya et al., 2016). In school life, it is important for educators to be able to recognize students' daily interactions in an effort to build student resilience at school, this will be a possibility or opportunity to protect or reduce the risk of mental disorders in school adolescents (Morrison & Allen, 2007).

Adolescence is a transition period between childhood and adolescence to adulthood, consisting of evolutionary phases with their own characteristics and problems. Adolescence is known as a time of emotional instability, with physical and psychosocial changes, which can be exacerbated by changes in global values, as it is a phase that is sensitive to factors that affect its transformation into adulthood (Rodrigues et al., 2018). Overall, adolescents' experiences in junior high school and their relationships with others may be influenced by unstable moods (mental health) that impact learning outcomes at school (Bond et al., 2007). Teenagers are often associated with the mass of self-discovery, not infrequently adolescents often experience psychological problems, especially those related to personal life (romance) and relationships between family members (Parent et al., 2021). The development of mental education through sports is considered as one of the best alternatives in improving the mental well-being of adolescents. This is because sport is an important part of the process of forming and developing a person's character and mentality.

Many students with emotional and behavioural disorders in educational settings lack personal resilience and are prone to failure in school (Zolkoski et al., 2016). Students who have weak personal resilience can disrupt their academic mission and hinder their emotional and personal development at school. (Gray, 2015). The idea of resilience building becomes a project between teachers and students in understanding the value of change in terms of perspective as well as a companion in improving students' mental well-being (Farquhar et al., 2018). This is because mental health is a major concern among adolescents. Most mental illnesses emerge during adolescence, and while about 14% of all adolescents aged 12 to 17 experience mental illness within a 12-month period, only 65% of these adolescents access health services to address their mental health problems (Liddle et al., 2017). Mental disorders, leading to substance use, are an impactful public health problem and are particularly common among adolescents from low-income neighbourhoods (Donohue et al., 2020). Engagement with sporting activities is an important part of life and has health benefits as well as enhancing mental well-being in an era of urbanization, the challenges of modern life, and environmental degradation leading to reduced quantity and quality of adolescent psychology (Shanahan et al., 2019).

In a study examining the effects of a training program for physical education teachers, it was found that engaging students in sport activities improved students' psychological well-being such as motivation and self-esteem (Tessier et al., 2010). Sports becomes a driving tool or instrument in which it has the power to change mindsets and mindsets in order to lead to noble human beings (Endrianto, 2019). The positive impact of sport and physical activity can be considered an important factor in improving the quality of life of adolescents (Ilham et al., 2013). Physical activity in adolescence can contribute to the development of a healthy lifestyle,

thereby helping to reduce the occurrence of chronic diseases (Hallal et al., 2006). Adolescent participation in sports activities is related to the psychological, social and motor fields towards a more positive direction (Moesch et al., 2018). As for if it is related to adolescents who join professional sports, it will have a positive impact on the ability to analyse, the ability to work in multi-disciplinary teams and experience in improving the welfare of life in the future (Wylleman, 2019).

A study shows that sports activities can indirectly improve mental toughness as a part of adolescent psychology (Mahoney et al., 2014). The importance of supporting wellbeing and improving adolescents' mental health in an effort to reduce functional impairment and equip adolescents how to cope with stress, which also enables adolescents to better manage the transition to the future (Schinke et al., 2016). However, while sport participation provides many benefits to an individual's health and well-being, adolescent athletes involved in professional sports also have additional risk factors that can affect their mental health, thus according to counselling experts it is important for adolescent athletes to adjust to risk factors for mental health disorders and monitor the adolescent athlete's environment that can trigger or exacerbate psychological problems (Chang et al., 2020).

Mental health literacy has included concepts related to knowledge of effective self-management strategies, challenging the stigma of mental illness, self-awareness and the use of mental health first aid to help others (Gorczynski et al., 2021). Thus adolescents who have good mental health will also contribute positively to people who are likely to have mental health problems. Sports activity interventions are an appropriate approach to developing mental health education in adolescents (Richards & Foster, 2013). The results show that patterns of involvement in extracurricular activities, especially sports, are an important aspect of personal resilience among vulnerable youth (Peck et al., 2008). Other findings also show that adolescent boys perceive exercise as an attractive means to support mental health (Swann et al., 2018).

Coaches have the potential to support athletes' mental health, yet many are unsure of what to do and are concerned they may inadvertently engage in behaviours that negatively impact their athletes. Education has the potential to help coaches engage in primary, secondary and tertiary preventive behaviours related to athlete mental health; however, there is no empirical basis or consensus to determine the target behaviour's that should be included in such education (Bissett et al., 2020). Motivating boys to be active in sports is important from an early age. Research has shown that boys who are habitually involved in sports activities are more likely to face challenges positively and avoid negative peer influences (Ramirez-Granizo et al., 2020). Sport is not only a physical activity but sport is also able to strengthen the personality of adolescents not to engage in all forms of negative behaviour. Sports can be one way to prevent a negative mindset that can disrupt the personal resilience of adolescents (Thompson et al., 2015). The results of a study show that personality development is an internal factor of adolescents that is influenced by positive activities, such as sports (Stepanchenko & Briskin, 2018).

Adolescent personality is one of the important factors that influence adolescents' mental health. Mental health is characterized by a state of psychological, emotional, and social well-being in which individuals are able to feel, think, and act in ways that allow them to enjoy life, realize their potential, cope with normal life stresses, work productively, and contribute to the community and club (Slingerland et al., 2019). Based on an analysis of mental health research and practice, the International Society of Sport Psychology states that adolescent mental health is heavily influenced by environmental factors. (Schinke et al., 2018). So it is not uncommon for adolescents to experience many mental health problems whose source of influence comes from the surrounding environment, both family, school and social environments. The study results state that young

people describe how environmental factors can trigger serious mental health problems that will have an impact on adolescents' lives in the future (Chapman et al., 2022).

Mental health is an important bridge in building adolescents' personal resilience. Resilience is strongly linked to mental health, especially in children and adolescents (Mesman et al., 2021). In performance sports, psychological resilience is important because athletes must constantly withstand various pressures to achieve and maintain high performance (Sarkar & Fletcher, 2013). Adolescents who have good psychological resilience will be able to bounce back after facing difficulties, and continue to function well despite continuing to face risks (Gilligan, 2000). The experiences experienced by adolescents and the way adolescents process their experiences are related to how the level of adolescent mental health, which can then be an important factor in adolescent personal resilience, especially in facing problems or challenges. The results of a study conducted on female students showed that there was a positive correlation between mental health and psychological resilience and forgiveness (Toktas, 2019). This is in line with a study which states that good mental health will lead to high adolescent resilience, enabling adolescents to control negative mindsets, reduce symptoms of depression and increase life satisfaction over time (Gerber et al., 2013).

Adolescent participation in sports activities is heavily influenced by social media, which then becomes a time trend based on existing socio-cultural determinants (Scheerder et al., 2007). Social media is the best alternative in promoting the benefits of sports that will be useful as "*self-development*" for teenagers. The development of mental education through sports is one of the best ways to improve the personal resilience of adolescents because, sports become an attractive means that is naturally able to provide positive emotions to adolescents (Yook et al., 2017). In this study, researchers tried to conduct mental education interventions through sports in order to increase adolescents' personal resilience. This effort is done as a way to improve the personal quality of adolescents by engaging in sports activities that can later be useful in the future. The involvement of adolescents through sports can be a means of channelling negative emotions that can later affect adolescents' personal resilience. The development of mental education programs through sports can also be a foundation in increasing productivity among adolescents.

Research hypothesis

H_o: There is no difference in the average value of students' personal resilience between the pre-test and post-test. Which means there is no effect of the results of mental education intervention through physical education in increasing students' personal resilience.

H_a: There is a difference in the average value of students' personal resilience between the pre-test and post-test. Which means there is an effect of the results of mental education intervention through physical education in increasing students' personal resilience.

MATERIAL AND METHODS

Design

The type of research is quantitative research with an experimental approach. Experimental research aims to reveal the cause-and-effect relationship between variables by manipulating the independent variables (Mustafa, 2022). Experimentation is a research design that provides the most rigorous and careful hypothesis testing. This study used a sample of high school students (SMA) class XI which was taken by randomized sampling. The total sample of this study amounted to 50 students. Students who became the research sample were assumed to have the ability (in class XI) and the same age (average 16 years).

Program

Researchers deliberately include mental education in the implementation of physical education that has been designed and adapted to the characteristics of students. The design and interventions used in this study are as follows:

Table 1. Mental education intervention program in sport.

Features	Description	To be avoided
Physical and Psychological Safety	The availability of facilities that support safety and health, and practices that increase safety in interactions with the group and reduce unsafe or confrontational interactions with the group.	Physical and health harm; creating fear; feelings of insecurity both sexual and physical abuse; and verbal abuse.
Appropriate Structure	Limit setting; clear and consistent rules and expectations; sufficiently strong controls; continuity and predictability; clear limits; and age-appropriate monitoring.	Chaotic; disorganized; neglectful; rigid; overly controlled; and autocratic.
Supportive Relationships	Warmth; closeness; connectedness; good communication; caring; support; guidance; safe affection; and responsiveness.	Cold; distant; over-controlling; ambiguous support; untrustworthy; focused on winning; lacking attention; unresponsive; and rejecting.
Opportunities to Belong	Opportunities for meaningful inclusion, regardless of gender, ethnicity, sexual orientation, or disability; social inclusion, social engagement, and integration; opportunities for socio-cultural identity formation; and support for cultural and bicultural competence.	Exclusion; marginalization; and intergroup conflict.
Positive Social Norms	There are rules of conduct; expectations; commands; ways of doing things; values and morals; and obligations to serve.	absence of norms; anomy; neglectful practices; antisocial and immoral norms; norms that encourage violence; reckless behaviour; consumerism; poor health practices; and conformity.
Support for Efficacy and Mattering	Youth-based; empowerment practices that support autonomy; make a real difference in one's community; and are taken seriously. Practices that include enabling, responsibility-giving, and meaningful challenge. Practices that focus on improvement rather than on current relative performance levels.	Unchallenging; over-controlling; disempowering and disabling. Practices that undermine motivation and the desire to learn, such as excessive focus on current relative performance levels instead of improvement.
Opportunities for Skill Building	Opportunities to learn physical, intellectual, psychological, emotional, and social skills; exposure to intentional learning experiences; opportunities to learn cultural literacy, media literacy, communication skills, and good habits of mind; preparation for adult employment; and opportunities to develop social and cultural capital.	Practices that promote bad physical habits and habits of mind; and practices that damage schools and learning activities.
Integration of Family, School, and Community Efforts	Concordance; coordination; and synergy between family, school, and community.	Divisions; lack of communication; and conflict.

Research instruments

The instrument in this study used the Connor-Davidson Resilience Scale (CD-RISC) (Connor & Davidson, 2003), to then adjust the sample directed to school students then the researcher uses the instrument that has been made with students as a sample (Singh & Yu, 2010) with the level of reliability coefficient in the context of CD-RISC is 0.89, the internal consistency alpha value of the 4 factors is: α = .80 for factor 1, α = .75 for factor 2, α = .74 for factor 3 and α = .69 for factor 4. The Table 2 questions are as follows.

Table 2. Item Connor-Davidson Resilience Scale (CD-RISC) (Connor & Davidson, 2003; Singh & Yu, 2010).

Item no.	Abbreviated item
1	Able to adapt to change
2	Close and secure relationships
3	Sometimes fate and God can help
4	Can deal with whatever comes
5	Past success gives confidence for new challenge
6	See the humorous side of things
7	Coping with stress make stronger
8	Tend to bounce back after illness, injury or hardship
9	Things happen for a reason
10	Best effort no matter what
11	One can achieve one's goals
12	When things look hopeless, I don't give up
13	Know where to get help
14	Under pressure, focus and think clearly
15	Prefer to take the lead in problem solving
16	Not easily discouraged by failure
17	Think of self as strong person
18	Make unpopular or difficult decisions
19	Can handle unpleasant feelings
20	Have to act on a hunch, without knowing why
21	Strong sense of purpose in life
22	In control of my life
23	I like challenge
24	One works to attain one's goals
25	Pride in my achievements

Analysis

Paired sample t-test is a test of the difference between two paired samples. Paired samples are the same subjects but experience different treatments. This different test model is used to analyse the research model before and after. Paired sample t-test is a testing method used to assess the effectiveness of treatment, characterized by differences in the average before and the average after treatment is given. The basic assumption for using this test is that the observation or research for each pair must be under the same conditions. The mean difference must be normally distributed. The variance of each variable can be the same or not. To carry out this test, data on an interval or ratio scale is needed. What is meant by paired samples is that we use the same sample, but the test is carried out on the sample twice at different times or at certain time intervals. Testing was carried out using a significant .01 (α = 1%) between the independent variable and the dependent variable.

RESULTS

Before carrying out analysis at a further stage, the data results that have been obtained are then tested for normality as the main requirement. The results of the normality test can be seen in Table 3 below.

Table 3. Normality test (Shapiro-Wilk).

		W	*p*
Post-test	Pre-test	0.957	.064

Note. A low p-value suggests a violation of the assumption of normality.

Based on the normality calculations in Table 3 that have been carried out, a *p*-value of .064 > .05 is obtained, which states that the data obtained through data collection is normally distributed. Next, the results were analysed using the Paired Samples t-test which can be seen in Table 4 below.

Table 4. Paired samples T-Test.

			Statistic	df	*p*	Mean difference	SE difference
Post-test	Pre-test	Student's t	70.9	49.0	< .001	50.4	0.711

Note. H_a μ *Measure 1 - Measure 2* $\neq$ *0*

Based on Table 4, guidelines for decision making in the Paired sample t-test. Based on the "*Paired Samples Test*" output table above, the Sig value is known. $p < .01$, then HO is rejected and Ha is accepted. So, it can be concluded that there is an average difference between the pre-test and post-test learning outcomes, which means that there is an average difference in students' personal resilience scores between the pre-test and the post-test. This means that there is an influence on the results of mental education intervention through physical education in increasing students' personal resilience. Apart from looking at the results of the paired tests above, more detailed data can also be seen in Table 5, the following statistical description.

Table 5. Descriptives statistic.

	N	Mean	Median	SD	SE
Post-test	50	100.3	100.0	3.92	0.554
Pre-test	50	49.9	49.5	3.55	0.502
Gain		50.4			

Based on Table 5 above, it is true that in terms of average value there has indeed been an increase in results. In carrying out the post-test, an average score of 100.3 was obtained, while the average post-test score was 49.5, or if you look at the difference (gain) between the post-test and pre-test, it was 50.4, which shows a fairly significant result. increasing student resilience from the results of mental education interventions in sports education learning at school.

DISCUSSION

Resilience is an area of increasing interest in educational literature, this is because resilience is linked to students' health, well-being and employability (workplace readiness) (Brewer et al., 2019). Personal resilience is an important protection in improving the quality of life related to health and mood disorders in individuals who experience injuries or mental health problems (Rao et al., 2015). The findings show that many sports organizations recognize the importance of the mental component in sport as an effort to improve youth's personal achievements and well-being (Liddle et al., 2017). Mental education program intervention

through sports is an alternative in improving the physical and psychological aspects of teenagers who are under academic pressure.

Based on the paired sample t-test, the Sig value is known. $p < .01$, then Ho is rejected and Ha is accepted. So it can be seen that there is an average difference between physical education learning outcomes. Pre-test and post-test, which means there is a difference in the average score of students' personal resilience between the pre-test and post-test, which means there is an influence on the results of mental education intervention through physical education in increasing students' personal resilience. In implementing the post-test, an average score of 100.3 was obtained, while the average post-test score was 49.5, or if you look at the difference (gain) between the post-test and pre-test, it was 50.4, which shows a sufficient result. significant results of increasing student resilience from the results of mental education interventions in sports education learning at school.

Sports-based program interventions to improve mental health and help overcome mental health disorders as well as provide psychological resilience among adolescent sports participants (Vella et al., 2021). Sports activity interventions designed for teenagers in America reflect two different views, the first is that activities should improve physical fitness and the second that activities should improve social, emotional and intellectual development. The research results show that sport promotes the emergence of mental function in adolescents, especially executive function, optimizes physical fitness, encourages health-related behaviour to compensate for obesity, and facilitates mental development (Tomporowski et al., 2011). The results of other research also show that teenagers who are actively involved in sports are able to increase their knowledge as well as mental health literacy in increasing self-confidence for teenagers who have mental health problems (Sebbens et al., 2016).

Sport is known as a driving tool or instrument which has the power to change the mindset and mindset of teenagers in order to become people with noble character (Rusdin et al., 2022). Mental training program emphasizing that the foundation of mental skills, personal development abilities, and team skills, as well as performance skills, is an integral part in the development of the well-being of adolescents in the future (Vealey, 2012). Mental health is associated with a variety of positive behaviour's (Lin et al., 2017). Physical activity has the potential to have beneficial effects in reducing depression. Interventions in one study stated that physical activity has been shown to have beneficial effects in reducing anxiety, increasing self-esteem, and improving cognitive function (Biddle & Asare, 2011).

The use of exercise programs in children and adolescents can provide the physical activity experiences necessary to form healthy habits and develop executive functions, especially those related to cognitive flexibility (Contreras-Osorio et al., 2021). Sports activities in adolescents are considered the best way to develop mental health, especially those related to self-efficacy, where a study states that there is a significant correlation between commitment to exercise and self-efficacy (Tan & Shao, 2021). A study on a group of teenagers proved that fitness and mental health simultaneously improved, as a result of engaging in competitive sports (Richards J et al., 2014). In addition, the participation of children and adolescents in physical education and sports curricular activities has the potential to contribute to social inclusion and the development of social skills (Bailey, 2005).

Longitudinal and cross-sectional studies show significant associations between physical activity and lower levels of psychological illness (i.e. depression, stress, negative affect, and total psychological distress) and greater psychological well-being (i.e. self-image, satisfaction with life and happiness , and psychological well-being) (Rodriguez-Ayllon et al., 2019). Sport is the best means of mental development for teenagers who

have the opportunity to be exposed to difficulties and life experiences so that they have the personal resilience to rise even better (Hu et al., 2015). The development of mental education is not necessarily carried out in schools, but family involvement in supporting mental health is considered the best therapy in reducing mental health problems and delinquency in adolescents (Corcoran, 2016). Research findings state that adolescent mental health is related to parental parenting patterns at home (Sağkal & Özdemir, 2019). A study states that the younger generation's sports participation reflects the effects of prolonged socialization as a habit given to them by their parents (Strandbu et al., 2020). This shows that parents are the main role models in promoting the benefits of sport to their children.

Teenagers' involvement in sports clubs should be accompanied by feelings of joy, a learning process, having fun friends and feeling healthy. Teenagers will stop if sports become too serious, inflexible, time consuming and too competitive. So mental education development programs for teenagers should be tailored to the health interests of the teenage generation. Sports clubs have the potential to become an arena for improving health, but the focus must be on changing the sports club environment, not focusing on changing the younger generation (Jakobsson & Lundvall, 2021). This means that the sports environment should adapt to the capacities and needs of young people, without losing the essence of the sport. The development of mental education through sports clubs has an important function in the lives of the younger generation by enabling them to have a sports lifestyle and a sense of coherence in sports activities (Jakobsson, 2014). Creating a superior, physically and mentally healthy generation requires coaching and developing sports as a place for self-appreciation and potential development (Rahadian & Ma'mun, 2018). The development of mental education is carried out as an effort to continuously maintain and increase the personal resilience of teenagers, one of which is through sports activities (Haris et al., 2021).

CONCLUSION

The results of the intervention show the influence of mental education through physical education in increasing students' personal resilience. The results of the post-test and pre-test show quite significant results in increasing student resilience from the results of mental education interventions in sports education learning at school. There is significant potential to improve youth mental health through sport-based interventions. Mental education development programs for adolescents should be tailored to the health interests of the adolescent generation. The sports environment should adapt to the capacities and needs of young people, without losing the essence of the sport. Sports clubs have the potential to become an arena for improving health.

AUTHOR CONTRIBUTIONS

Conceptualization – E. P., and E. M.; Methodology – E. M., B. H., and R. B.; Formal analysis – A. O., and I. O.; Data curation – E. P., N. J., and B. H.; Writing – original draft preparation – F. I. C., and R. B.; Writing – review and editing – N. J., F. I. C., and I. O.

SUPPORTING AGENCIES

Directorate of Research, Technology and Community Service, Directorate General of Higher Education, Research and Technology, Ministry of Education, Culture, Research and Technology, in accordance with Research Implementation Contract Number: 143/E5/PG.02.00.PL/2023.

DISCLOSURE STATEMENT

No potential conflict of interest were reported by the author.

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ORIGINAL ARTICLE

Comparison between mobile fitness apps users and gender on exercise intensity in university students

BAYU AGUNG PRAMONO[1], ABDUL HAFIDZ[2], MUHAMMAD KHARIS FAJAR[2], WIJONO[2], FIFIT YETI WULANDARI[2], I DEWA MADE ARYANANDA WIJAYA KUSUMA[1], LIM BOON HOOI[3]

[1]*Deparment of Sport Coaching Education. Faculty of Sport Science and Health. State University of Surabaya. Indonesia.*
[2]*Faculty of Vocational Studies. State University of Surabaya. Indonesia.*
[3]*Faculty of Education, Languages, Psychology and Music. SEGi University. Malaysia.*

ABSTRACT

University students are an exclusive subcategory because most of them are young adults at a transformation period, training to stay independently while concurrently working toward completion of their professional degrees. Previous research reported that only 30% to 50% of university students meet the recommended proportion of exercise for health advantage. Mobile fitness apps are invented on purpose to support exercise. Many health advantages like preventing cardiovascular diseases and diabetes, it will marshal exercise and as mobile motivational tools because motivation is a major barrier to exercise. The present study was designed to investigate and compare the exercise intensity between the mobile fitness app users and none-users. The secondary purpose was to examine and compare the exercise intensity between gender from the university students. A total three hundred fifty-five university students were recruited in the study. The International Physical Activity Questionnaires- Short Form (IPAQ-SF) was used to collect exercise intensity of the participants in current study. All participants have been briefed on the objectives of this study and agreed to answer the International Physical Activity Questionnaires (IPAQ) and signed an informed consent form. The independent t-tests to determine the differences of the exercise intensity between mobile fitness app users and nonmobile fitness users. Independent t-tests also to find-out differences exercise intensity between gender in the university students, the statistical significance was set at $p < .05$. There were significant differences of exercise intensity level between nonmobile fitness apps users and mobile fitness apps users [t (352) = 2.82, p = .005, d = 0.28]. It means the nonmobile fitness apps users had a significant higher exercise intensity if compared to the mobile fitness apps users. There were significant differences of exercise intensity level between male and female university students [t (352) = 4.54, p = .001, d = 0.48]. Current results are similar to many studies found that female students participated in less exercise than their male counterparts.

Keywords: Performance analysis, Mobile fitness apps users, Gender, Exercise intensity, University students.

Cite this article as:
Pramono, B. A., Hafidz, A., Fajar, M. K., Wijono, Wulandari, F. Y., Kusuma, I. D. M. A. W., & Hooi, L. B. (2024). Comparison between mobile fitness apps users and gender on exercise intensity in university students. *Journal of Human Sport and Exercise, 19*(2), 550-559. https://doi.org/10.55860/rtdqjs88

Corresponding author. *Department of Sport Coaching Education. Faculty of Sport Science and Health. State University of Surabaya. Indonesia.* https://orcid.org/0000-0002-9308-1289
E-mail: bayupramono@unesa.ac.id
Submitted for publication October 17, 2023.
Accepted for publication November 28, 2023.
Published April 01, 2024 *(in press* December 26, 2023).
JOURNAL OF HUMAN SPORT & EXERCISE ISSN 1988-5202.

doi: https://doi.org/10.55860/rtdqjs88

INTRODUCTION

University students are an exclusive subcategory because most of them are young adults at a transformation period, training to stay independently while concurrently working toward completion of their professional degrees (Keating, Guan, Castro-Piñero, & Bridges, 2005). Previous research has indicated that it is important to help university students adopt a healthy lifestyle consisting of adequate exercise and a healthy diet. They may play a censorious part in developing social and cultural norms because they may well become decision-makers and opinion leaders in future. But, past research revealed that many university students decrease their exercise levels in university (Keating et al., 2005).

Previous research reported that only 30% to 50% of university students meet the recommended proportion of exercise for health advantage (Keating et al., 2005). Additionally, this group should be targeted for intervention because the young adulthood exercise and diet habits have valuable carry-over effects. As such, maintaining exercise during university may generate positive advantage on university student lifestyles in the years after graduation (Jenkins, Jenkins, Collums, & Werhonig, 2006).

Also, promoting exercise and increasing opportunities for exercise has intimations to support academic achievement. Exercise and physical activity have been related to positive effects on cognition and concentration in the lecture hall (Etnier et al., 1997). The findings are supported that exercise has been associated with higher levels of self-esteem and lower levels of anxiety, which are contribute to higher academic performance in the university (Flook, Repetti, & Ullman, 2005).

Mobile fitness apps are invented on purpose to support exercise. The support can be influential (problem-solving knowledge and skills) and psychological (encouragement), namely informational and psycho-social support (Wu, Mai, & Huang, 2021). In spite of so many health advantages like preventing cardiovascular diseases and diabetes (Reiner, Niermann, Jekauc, & Woll, 2013), it will marshal exercise and as mobile motivational tools because motivation is a major barrier to exercise (Glowacki, Duncan, Gainforth, & Faulkner, 2017). As such, when tailored to user needs, it may help build exercise habits for the mobile users.

Based on current literature, mobile fitness app functions are designated into five subject matters: Education (Guo, Saab, Post, & Admiraal, 2020), Tracking (Wang & Collins, 2020), Social (Lu, Lin, Raphael, & Wen, 2023), Gamification (Wang & Collins, 2020), and Motivation (Guo et al., 2020).

In term of mobile fitness app users between gender, men and women encounter indistinguishable motivational regulation and social influences, some systematic differences between genders are found in motivations and gratifications related to exercise (Jiang, Zhang, & Teo, 2021). The developmental point of view can partially justify these differences, by which women mainly engage in exercise for surfacing maintenance and weight management, but, men are prompt by strength, competition, and challenges (Craft, Carroll, & Lustyk, 2014). In fact, men normally report higher body satisfaction and higher preferences for exercise than women disregarding of culture (Dumitru, Dumitru Dumitru, & Maher, 2018). Comparison between gender; mobile fitness apps users and none-users on exercise intensity remain relatively unexplored (Utesch, Piesch, Busch, Strauss, & Geukes, 2022).

Therefore, the present study was designed to investigate and compare the exercise intensity between the mobile fitness app users and none-users. The secondary purpose was to examine and compare the exercise intensity between gender from the university students.

METHODS

This study employed a survey method which involves the collection of data through a questionnaire.

Participants

A total three hundred fifty-five university students were recruited in the study. All participants of this study were recruited from the Faculty of Sports and Health Science, Universitas Negeri Surabaya, Surabaya, East Java, Indonesia. Demographic of the participants in this study displayed in Table 1.

Table 1. Demographic of the participants in this study.

Demographic	Male (n = 134)	Female (n = 221)	Total (n = 355)
Gender	134 (38%)	221 (62%)	355 (100%)
Age (years)			
16-17	11 (8%)	18 (8%)	29 (8%)
18-19	116 (87%)	191 (86%)	307 (86%)
20-21	7 (5%)	5%)	17 (5%)
Above 22	0 (0%)	2 (1%)	2 (1%)
Weight (kg)			
35-55	59 (44%)	163 (74%)	222 (63%)
56-76	65 (49%)	48 (22%)	113 (32%)
77-97	7 (5%)	7 (3%)	14 (4%)
Above 98	3 (2%)	3 (1%)	6 (2%)
Height (cm)			
141 – 150	1 (1%)	28 (13%)	29 (8%)
151 – 160	17 (13%)	133 (60%)	150 (42%)
161 – 170	75 (56%)	57 (26%)	132 (37%)
Above 171	41 (31%)	3 (1%)	44 (12%)
App users	59 (44%)	89 (40%)	148 (42%)
Non app users	75 (56%)	132 (60%)	207 (58%)

Procedures

To collect the data needed in this study, the researcher obtained written consent from the university authority, faculty management and the participants prior to conduct surveys. The researcher also informed participants about the study, they volunteered to participate in this research and ethical approval was obtained from the Ethics Committee for Research Involving Human Subjects from Universitas Negeri Surabaya, Surabaya, East Java, Indonesia.

Before the data collection, all participants have been briefed on the objectives of this study and agreed to answer the International Physical Activity Questionnaires (IPAQ) and signed an informed consent form. Participants' demographic attributes such as age, gender, weight, height and status of mobile fitness app user were recorded.

Physical activity is any movement that is carried out by the muscles that require energy. In other words, it is any movement a person does. Exercise is, by definition, planned, structured, repetitive and intentional movement. Exercise is also intended to improve or maintain physical fitness (Thompson, 2023). Since most of the mobile fitness apps are related to improve or maintain physical fitness from exercise. As such, in the IPAQ questionnaire whereby the physical activity intensity will be reflecting exercise intensity in current study.

The questionnaire used to collect exercise intensity of the participants in current study was the International Physical Activity Questionnaires- Short Form (IPAQ-SF)(Chaskar, Loh, & Babs, 2017), it comprises a set of 7 questions, the short version of the questionnaire was transfer into a Google form and sent to all the recruited participants of this study via mobile social media platform such as WhatsApp, Facebook messenger and e-mail addresses. The seven-item short form which involve a seven-day recall of exercise. It was designed to estimate the time spent performing exercise (moderate to vigorous) and inactivity (Chaskar et al., 2017). Test-rest reliability indicated good stability High reliability (α = .80) (Chaskar et al., 2017), the criterion validity of the IPAQ was tested by using an accelerometer. Based on intraclass correlation coefficients, the reliability of the total IPAQ was 0.65 and 0.57 for men and women, respectively (Chaskar et al., 2017).

Data from each question were summed within the item (i.e. moderate and vigorous) to estimate the total amount of time spent in exercise in the last 7 days. The participants only take less than 5 minutes to provide answers for the questionnaire and submit their feedback via mobile phone. The researchers classified the MET scores based on previous research suggestion (Chaskar et al., 2017). The total exercise was calculated based on the number of days, the duration of the minutes, and the intensity of the activity. The final results of the exercise intensity were break down into 3 levels (low, moderate, high) exercise intensity.

Statistical analysis

Data analysis was performed using the IBM SPSS Statistics for Windows, version 26 was used. The demographic background of the participants was presented in percentages for the categorical data and mean with standard deviation (SD) for the continuous data. The independent t-tests to determine the differences of the exercise intensity between mobile fitness app users and nonmobile fitness users. Independent t-tests also to find-out differences exercise intensity between gender in the university students. The statistical significance was set at $p < .05$.

RESULTS

Table 2 presents the exercise intensity level (MET min/week) of participants in this study from IPAQ Questionnaire.

Table 2. Exercise intensity from IPAQ Questionnaire.

Exercise Intensity Level	Description	Male (n = 134)	Female (n = 221)	Total
Low	<600 MET min/week.	85 (63%)	185 (84%)	270 (76%)
Medium	600 – 2999 MET min/week	30 (22%)	26 (12%)	56 (16%)
High	≥3000 MET min/week	19 (14%)	10 (5%)	29 (8%)

Table 3 displays the descriptive group statistics of mobile fitness apps users and nonmobile fitness apps users.

Table 3. Descriptive group statistics of mobile fitness apps users and nonmobile fitness apps users on exercise intensity.

Users	N	Mean (M)	Standard Deviation (SD)
Non-Mobile fitness apps users	143	1.43	0.70
Mobile fitness apps users	211	1.25	0.55

An independent-samples t-test was conducted to compare exercise intensity on mobile fitness apps users and nonmobile fitness apps users. The results as shown in Table 4.

Table 4. Independent sample t-test of exercise intensity between mobile fitness apps users and nonmobile apps users.

Variable	Levene's Test of Equality of Variances		t-test for Equality of Means			
	f	Sig.	t	df	Sig. (2-tailed)	Mean Difference
Exercise intensity	23.66	.001	2.82	352	.005	1.87

There were significant differences of exercise intensity level between nonmobile fitness apps users and mobile fitness apps users [t (352) = 2.82, *p* = .005, d = 0.28].

Descriptive group statistics on the exercise intensity for male and female university students in this study as shown in Table 5.

Table 5: Descriptive group statistics on exercise intensity for male and female university students.

Gender	N	Mean (M)	Standard Deviation (SD)
Male university students	134	1.51	0.73
Female university students	221	1.21	0.51

Another independent samples t-test was conducted to compare exercise intensity on male university students and female university students. The results as shown in Table 6.

Table 6: Independent samples t-test between male and female university students.

Variable	Levene's Test of Equality of Variances		t-test for Equality of Means			
	f	Sig.	t	df	Sig. (2-tailed)	Mean Difference
Exercise intensity	56.39	.001	4.54	352	.001	.30

There were significant differences of exercise intensity level between male and female university students [t (352) = 4.54, *p* = .001, d = 0.48].

DISCUSSION

Regarding exercise intensity, current study found that majority of university students categorized in the low level of exercise intensity, which below 600 MET min/week with 85 (63%) males, 185 (84%) females from the total of 270 (76%) in the three categories of exercise intensity ranking (Chaskar et al., 2017). The results of current study similar to previous research which monitoring university students' changes in the first two years in university indicated that 30% of students reported no exercise during freshman year and no significant changes were found at the second year (Racette, Deusinger, Strube, Highstein, & Deusinger, 2010). Moreover, significantly fewer students took part in aerobic and more students just performed stretching exercises from the freshman to sophomore year (Racette et al., 2010).

The participants of current study were recruited from the Faculty of Sports and Health Science, Universitas Negeri Surabaya, Surabaya, East Java, Indonesia. They were enrolled in sport science programme, this group should be more active compared to other university students. Interestingly, only 19 (14%) males were categorized as high exercise intensity which more than 3000 MET min/week (Chaskar et al., 2017), 10 (5%) from the females with a total of 29 (8%) students from the overall, 355 university students in this study. This

group of students should be encouraged to participate in regular exercise because exercise will increase the amount of oxygen delivered to the brain, which increases student's capacity to learn (Lagally & Robertson, 2006). Allowing oxygen to flow to the brain enables one to cognitively function and make decisions. Exercise is also contributing to lowered risks of obesity, increased cardiovascular fitness, improved health, and academic achievement in university (DeBate, Pettee Gabriel, Zwald, Huberty, & Zhang, 2009).

The findings of current study also comparable to other studies which have examined university student exercise (Aelterman et al., 2012; Corder, Ekelund, Steele, Wareham, & Brage, 2008). As anticipated, they found that one to two thirds of university students did not engage in exercise for at least three days weekly (L. D. Elliott et al., 2022; Zarei, Mohd Taib, Zarei, & Abu Saad, 2013). The results of current study also supported previous studies on the topic indicating that university student exercise levels decreased as years in university increase (Elliott, Munford, Ahmed, Littlewood, & Todd, 2022; Racette et al., 2010).

Additionally, from the literature search in this area, the health fitness and educational professionals believe that physically active students perform better in the classroom. As one studies reported a statistically significant relationship between fitness and academic achievement (Chomitz et al., 2009). The relationship between fitness and academic achievement were supported by a few studies that positive associations between physical fitness and academic performance (Kim et al., 2003; Lipscomb, 2009).

Research has shown that mobile apps are effective tools for administering health and fitness interventions and changing user behaviours in key lifestyle areas, such as exercise (Stiglbauer, Weber, & Batinic, 2019). Fitness mobile apps to produce their intended effects, users need to use the apps for a continuous period of time, during which the desired behaviour changes are incorporated into their daily routines (Austin-McCain, 2017).

Current study revealed that the exercise intensity of nonmobile fitness apps users comprises of 147 participants (M = 1.43; SD = 0.70) and mobile fitness apps users with 211 participants (M = 1.25; SD = 0.55). An independent-samples t-test was conducted to compare exercise intensity on nonmobile fitness apps users and mobile fitness apps users. Results indicated that there were significant differences of exercise intensity level between nonmobile fitness apps users and mobile fitness apps users [t (352) = 2.82, p =.005, d = 0.28]. It means the nonmobile fitness apps users had a significant higher exercise intensity if compared to the mobile fitness apps users.

Another independent samples t-test was conducted to compare exercise intensity on male university students (n = 134 students) and female university students (n = 221 students). Results of current study found that male students had higher (M = 1.51; SD = 0.73) of exercise intensity compared to the female students (M = 1.21; SD = 0.51). There were significant differences of exercise intensity level between male and female university students [t (352) = 4.54, p = .001, d = 0.48] in current study. Current results are similar to many studies found that female students participated in less exercise than their male counterparts (McArthur & Raedeke, 2009). The results of current findings supported the previous finding that females performed significantly less moderate exercise, and vigorous exercise than males (McArthur & Raedeke, 2009).

Current findings supported that the importance of mobile device-based health & fitness apps, particularly, are revolutionizing the ways in which smartphone users self-manage their health & fitness. These apps aim at disease management such as diabetes (Goyal & Cafazzo, 2013) and prevention such as promoting healthy food and physical activities (Bice, Ball, & McClaran, 2015).

Also, the findings similar to another study examined 15 fitness apps that perform GPS tracking, workout planning, and workout performance assessment (Kranz et al., 2012). The study highlighted user-app interaction through playful, social, and long-term motivation. Users adhere to a fitness app more if they find it fun, interesting, trendy, cool (Huang & Ren, 2019).

Fitness apps are mHealth tools that provide information and guidance on health enhancement in weight loss, diet, and exercise, and they are considered a feasible, low-cost solution for self-health management (Chu et al., 2022). As a means of health interventions, fitness apps differ from other social media in their specialized foci (Gui, Fasoli, & Carradore, 2017). Accordingly, fitness app users tend to focus on exercise levels tracked by the apps. Besides, fitness app users primarily share fitness data and exercise information rather than generic posts. They facilitate the social comparison process regarding exercise within social networks formed in the app-based community (Mulgrew & Tiggemann, 2016).

As with most survey studies, this study has the following limitation, the data were collected using a self-reported survey and it is well-known that people tend to over-report (Wilson, Papalia, Duffey, & Bopp, 2019). Caution, therefore, needs to be exercised when generalizing the results of the study to the wider population.

CONCLUSION

The present findings suggest that students in the university under study did not meet the exercise objectives. New and more innovative efforts to increase physical activities participation among university students are needed. Exercise is beneficial to the university students, especially in their academic performance. Thus, university authorities should recognize the positive aspects of exercise on students and encourage them to participate in various extra-curricular activities.

AUTHOR CONTRIBUTIONS

Bayu Agung Pramono: preparation and research design, data collection, statistical analysis, result interpretation, manuscript writing, supervision of the study, and review of the final version. Abdul Hafidz, Muhammad Kharis Fajar, and Wijono: data collection, manuscript writing (introduction). Fifit Yeti Wulandari, manuscript writer and result interpreter, reviewed the manuscript. I Dewa Made Aryananda Wijaya Kusuma: manuscript writing (introduction) and discussion. Lim Boon Hooi was the manuscript writer and reviewed the manuscript. All authors have read and agreed to the published version of the manuscript.

SUPPORTING AGENCIES

No funding agencies were reported by the authors.

DISCLOSURE STATEMENT

No potential conflict of interest were reported by the authors.

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ORIGINAL ARTICLE

Body appreciation as a multifactorial construct in adolescent athletes and their athletic achievements

ISABEL CRISTINA ROJAS-PADILLA[1,2], IAGO PORTELA-PINO[3]

[1]*Faculty of Education and Sports Sciences. National School of Sports. Cali, Colombia.*
[2]*Department of Special Didactics. Faculty of Education and Sports Sciences. University of Vigo. Vigo, Spain.*
[3]*Department of Sport Sciences. Faculty of Health Sciences. Isabel I University. Spain.*

ABSTRACT

Given the strong cultural and social messages that encourage men and women to feel dissatisfied with their bodies, the cases of affection are increasing, since the standards and stereotypes imposed by society are not always adequate when talking about health or are even so far from reality and encourage some people to attempt against their health and physical integrity for the mere fact of complying with them, and adolescent athletes are no strangers to this situation. This was a quantitative cross-sectional observational study with a participation of 354 adolescent athletes between 10 and 19 years of age, of whom 51.4% were male and 48.6% female. A sociodemographic survey and the Body Appreciation Scale were applied. The results showed a high level of body appreciation in the participants and significant relationships with the years of sports practice and the result of the last competition. To conclude, although this research found variables that can influence the level of body appreciation, it is important to investigate further and include other aspects such as relationships with peers, coaches, family members and social networks, since the feelings and thoughts of adolescent athletes about their bodies influence their mental health and consequently their sports performance.

Keywords: Body appreciation scale, Body image, Sports health, Adolescent.

Cite this article as:
Rojas-Padilla, I. C., & Portela-Pino, I. (2024). Body appreciation as a multifactorial construct in adolescent athletes and their athletic achievements. *Journal of Human Sport and Exercise, 19*(2), 560-569. https://doi.org/10.55860/1pms0r61

Corresponding author. *Faculty of Education and Sports Sciences. National School of Sports. Cali, Colombia.* *https://orcid.org/0000-0001-8994-6529*
E-mail: isabelcrojasp@gmail.com
Submitted for publication December 04, 2023.
Accepted for publication January 07, 2024.
Published April 01, 2024 *(in press* January 26, 2024).
JOURNAL OF HUMAN SPORT & EXERCISE ISSN 1988-5202.

doi: https://doi.org/10.55860/1pms0r61

INTRODUCTION

Thoughts, feelings, and actions about the body have become a focal point of interest for society, since they generate the adoption of healthy lifestyles or, on the contrary, retaliation to punish the body and comply with ideas of beauty that undermine personal integrity (Hepburn & Mulgrew, 2023). This refers specifically to body appreciation, which is a multifactorial and dense construct, in terms of self-perception and attitude towards the body; that is, thoughts, feelings and behaviours directed towards the evaluation and orientation of appearance, body esteem and the accuracy of size perception (Thompson et al., 2002).

Thus, positive body image appreciation is related to the acceptance of one's own body regardless of its size, shape, imperfections and stereotypes, respecting and caring for it through healthy lifestyles accompanied by resistance to the internalization of unrealistic beauty standards (Baladia, 2016). Consequently, those with positive mental health behaviours can use their social support systems to cope with and manage social pressure in a way that decreases the risks of depression and anxiety, feelings that can lead to demotivation, health problems, and poor school and sports performance (González et al., 2023).

Studies show advantages of high body appreciation, represented in women by high levels of optimism, self-esteem and coping through positive rational acceptance and lower levels of self-presentational perfectionism (Williams, 2004).

In adolescents, body dissatisfaction has been found in the range between 12 and 16 years of age without significant differences between sexes (Baile et al., 2002); significant relationships between body appreciation and body mass index, as well as body appreciation and self-esteem (Jauregui & Bolaños, 2011); greater body appreciation but high indices of body pressure by context (Sundgot et al., 2021) and greater body appreciation in those who practice some sport, than in those who do not (Fischetti et al., 2020; Soulliard et al., 2021); similarly, high levels of body appreciation have been found in those adolescents who have high levels of physical activity (Rosa, 2019).

Although adolescent athletes are believed to be protected from mental health problems due to a higher self-esteem, sense of connectedness, and social support from teammates (Armstrong & Oomen, 2009), they may be more susceptible to body dissatisfaction due to the demands of sport participation (Wolanin et al., 2015), probability of injury (Rogers, et al., 2023), expectations versus sport outcomes, and critical comments from parents or coaches about weight or body shape (Scott et al., 2022).

Regarding the sex of adolescent athletes, studies show that the male sex has a greater body appreciation (He et al., 2020; Lagos et al, 2022; Reyes, 2020; Ripalda, 2022), especially in those who practice water sports and team sports; likewise, in relation to females, greater body appreciation has been found in sprinters than in volleyball players; in athletes who train less than 5 times a week over those who train more than 9 times a week; female athletes in disciplines of indirect competition (rowing, athletics) than direct competition against the opponent (field hockey, volleyball, sumo, judo) (Budzisz & Sas-Nowosielski, 2021).

The justification for this study of body image perception aimed at identifying body appreciation in Colombian adolescent athletes lies in the fact that it could help the athlete's interdisciplinary team to prevent the alteration of body appreciation by discovering strengths to face the thoughts that threaten it, identifying work strategies to counteract to a large extent those ideas that may threaten this well-being and generating a specialized accompaniment by the coach and the people of the family and social circle closest to the athlete. For all the above, the objective of this research is to evaluate body appreciation by characterizing sociodemographic

variables (sex, housing area, educational level, study sector, socioeconomic stratum and means of transportation) and sports profile (training, years of sports practice, hours of training, result of last competition, sports sector, and type of discipline) in Colombian adolescent athletes.

MATERIALS AND METHODS

Study design and participants

This was a quantitative descriptive observational study. The participants of this study were 354 Colombian athletes of collective and individual disciplines; 182 male and 172 female, aged between 10 and 19. This sample was part of a population of adolescent Colombian athletes enrolled in the National Talent Selection Program of Colombia carried out during 2022. To calculate the sample, a 95% level of reliability and a 5% margin of error were considered. Inclusion criteria for this study were that the athletes had been practicing sports for at least two consecutive years at the date of the survey, that they had signed assent and informed consent and filled out the questionnaire in its entirety, had not had injuries, medical treatments, or surgeries in the last year, belonged to a sports league in Colombia and were enrolled in the National Talent Selection program.

Procedure

First, the sociodemographic survey was designed to obtain the personal and sporting information of the participants and was completed with the scale to determine whether the athletes had a high or low level of body appreciation. Through the database of the National Talent Selection program, we had access to the coaches and methodologists in charge of the athletes who were contacted and put in context of the research. A pilot test was carried out to establish adjustments of comprehension, call and time of diligence and the invitation to participate was sent to all the athletes of the program. Finally, both the demographic and body appreciation instruments were applied, as specified below.

Study questionnaire

To identify the level of body appreciation of the study participants, the Body Appreciation Scale was used which has been developed and validated (Avalos et al., 2005); revised and evaluated (Tylka TL & Wood-Barcalow, 2015) and translated and adapted for the Spanish context (Swami, 2017). It is a 13-item instrument with a single dimension in factorial structure. It has adequate internal consistency with a Cronbach's α coefficient of 0.94 and construct validity. Its objective is to study the positive aspects of body image. The items are rated on a 5-point scale (1 = never; 2 = rarely; 3 = sometimes; 4 = often; 5 = always) and averaged to obtain a Body Appreciation score. The Body Appreciation scale has several core aspects of positive body image. It has psychometric support with internally consistent and stable scoring, demonstrating evidence of incremental and construct validity; it is useful for predictive investigations of variables that contribute to possessing a positive body image, is short, is quickly administered, requires only a few minutes to complete, and is easily scored.

The adaptation of this scale for the Colombian population was carried out by Tibasosa in 2020 in a study that sought to establish the agreement of seven experts in the evaluation of the adequacy, coherence and clarity of the survey translated into Spanish in athletes from a university in the Colombian capital, students between 10 and 22 years of age. The kappa value was 0.94% with 95.7% comprehensibility. This version was then adapted to Spanish, supported by the validity of appearance and comprehensibility with idiomatic, conceptual, and semantic equivalence in relation to the original version (Tibasosa, 2020).

Statistical analysis

The Statistical Package for Social Science - SPSS Version 20 was used for the analysis of the information collected and the calculation of measures and frequencies.

To indicate the sociodemographic characteristics of the Colombian adolescent athletes participating in this study, descriptive statistics were used. In the univariate analysis, for quantitative variables, measures of central tendency (mean, standard deviation, minimum and maximum) and frequencies and percentages were used for qualitative variables. For the bivariate analysis, the correlation of different variables was observed, these being: body appreciation, years of sports practice and result of the last competition; these were worked with Pearson's correlation test, this having verified that the normality assumption was met, which was carried out by means of the Shapiro Wilk test.

The T-student test was used to review the possible existence of statistically significant differences between body appreciation and its stratification by sex. ANOVA was used to determine the existence of statistically significant differences between the mean body appreciation and the variables educational level, sector of study, socioeconomic stratum and means of transportation used by Colombian adolescent athletes.

Ethical consideration

The participation in this study was voluntary and accepted by signing an informed consent and assent form ensuring confidentiality through numerical codes and file encryption. This research was approved by the ethics committee of the National School of Sports from Colombia by number 17.133 of May 22, 2022.

RESULTS

Sociodemographic data

The research participants were 354 athletes, 51.4% (n = 182) were male while the remaining were female (n = 172), with a mean age of 15.59 years, maximum of 19 and minimum of 10 (standard deviation [SD], 1.938). The majority lived with their grandmothers and siblings 51.1% (n = 181) and 37.3% (n = 132) respectively. Considering schooling, 87.6% (n = 310) of the population was studying at the time of the survey; 64.4% (n = 228) of the participants studied in public institutions and 23.2% (n = 82) in private institutions. As for their level of schooling, 86.2% of the athletes (n = 305) were studying in secondary school, grades six to eleven, and only 0.3% (n = 1) were pursuing professional studies. On the other hand, the predominant means of transportation among the participants was walking (feet) with 39.8% (n = 141), the second most used was motorcycle with 22.6% (n = 80) and the least used was bicycle for 10.2% (n = 36) of the athletes.

In terms of health, 95.5% (n = 338) of the participants reported not having any diseases and of those mentioned were 5 athletes with obesity, 4 with a chronic disease (diabetes, arterial hypertension, or dyslipidaemia), 3 with depression, 2 with pulmonary disease, 1 with epilepsy and another with hydronephrosis. On the other hand, 76.9% (n = 272) of the athletes indicated having no family health history and within 23.7% (n = 82), the most reported disease was cardiovascular disease in 8.2% (n = 29) and having more than one of these diseases mentioned in 6.5% (n = 23).

With regard to the sports practiced by the adolescents surveyed, it was possible to differentiate between running sports (roller skating, athletics, para-athletics) 32.4% (n = 115); ball sports (basketball, soccer and volleyball) with 30.2% (n = 107), combat level sports (boxing, judo, karate do, wrestling and taekwondo) with 13.8% (n = 49), strength sports (rugby and weightlifting) 12.1% (n = 43), water sports (underwater, diving, conventional swimming, para swimming) 3.2% (n = 11); art and movement sports (rhythmic and artistic

gymnastics) 2% (n = 7); racquet sports (badminton and tennis) 0.8% (n = 3); table sports (chess) 0.8% (n = 3) and bicycle sports (BMX cycling and road cycling) with 4.5% (n = 16). Additionally, it was evidenced that 67.8% (240) of the athletes practice an individual discipline, 64.4% (n = 228) of the participants reported having been on the podium in their last competition, which were managed in 91% (n = 322) at the national level. Finally, with respect to training time, the years of practice according to the participants were around 6; the training sessions were several days a week, with at least one per day with an approximate of 2 hours per training session per day.

Body appreciation

To determine the body appreciation of Colombian adolescent athletes, the Body Appreciation Scale (BAS) was used. The descriptive statistics showed a mean of 43.56 and a standard deviation of 8.460. With respect to the body appreciation variable, the means stratified by sex were 41.47 for females and 45.53 for males (Table 1).

Table 1. Body appreciation means stratified by sex. n = 354.

	Sex	N	Means	Standard deviation
Body appreciation	Female	172	41.47	9.65
	Male	182	45.53	6.598

When applying Pearson's correlation with the objective of correlating the body appreciation variable with the sports profile (training, years of sports practice, hours of training, result of the last competition) of the Colombian adolescent athletes, an indirect relationship was obtained between the body appreciation variable and the result of the last competition, as well as with years of practice; for the former a value -0.115 and a *p*--value of .031 being significant and for the latter a direct relationship with a value of 0.124 and a *p*-value of .019 being statistically significant. No correlations were found between body appreciation and the categories hours of training per day, number of workouts per day or days of training per week (Table 2).

Table 2. Correlation of body appreciation with sport profile. n = 354.

		Age	Last Competition result	Training hours a day	Training times a day	Training days a week	Years of sport practice
Body appreciation	Pearson correlation	-0.103	-0.115*	-0.043	-0.093	0.101	0.124*
	Sig. (bilateral)	0.052	0.031	0.416	0.081	0.058	0.019

*Note. *. The correlation is significant at the .05 level (bilateral). **. The correlation is significant at the .01 level (bilateral).*

When comparing the body appreciation variable with certain characteristics of the athlete (sex, housing area, podium, type of last competition, sport sector, type of discipline), the comparison of means of the variables stratified by sex was performed, identifying equality of variances by means of the Levene test, yielding a *p*-value of .000. Therefore, when analysing the T-student test for the body appreciation variable, it yields a value of .000 with respect to not equal variances, concluding that the mean of the body appreciation variable is statistically significant. On the other hand, when comparing the body appreciation variable stratified by housing zone, there were no significant differences between each one of them comparing rural and urban housing, nor were there significant differences with podium, sport sector (conventional and Paralympic), type of sport (individual and team) (Table 3).

Table 3. Comparison of the variable body appreciation with sex, housing area, podium, type of last competition, sport sector and individual or team sport. n = 354.

	t	Sig. (bilateral)	Means differences	95% Confidence Interval for the difference	
				Lower	Upper
Sex	0.001	.001	-4.068	-5.788	-2.348
Housing area	0.718	.639	-0.539	-2.799	1.721
Podium	0.104	.093	-1.579	-3.421	0.263
Type of last competition	0.012	.077	2.776	-0.298	5.851
Sport sector	0.198	.065	3.174	-0.204	6.553
Individual or team sport	0.939	.672	-0.408	-2.303	1.486

To compare the body appreciation variable with the variables educational level, sector of study, socioeconomic stratum and means of transportation used by the Colombian adolescent athletes participating in this study, ANOVA, and the homogeneity test (p-value < .05) were performed with the body appreciation variable and the categories. Regarding this variable, no significant differences were found, yielding a value of .488 (Table 4).

Table 4. Results of the mean differences between the variables body appreciation and the variable type of institution. n = 354.

One-factor ANOVA		Sum of squares	Mean squared	Sig.
Body appreciation	Inter-groups	103.024	51.512	.488
	Intra-groups	25162.346	71.688	
	Total	25265.37		

DISCUSSION

When correlating body appreciation with the sport profile, in which training days and hours, years of sport practice up to the time of participation in the study and the result of the last competition were analysed, a relationship was found only with the result of the last competition, The same was found with years of practice, but no correlations were found between body appreciation and the categories of hours and number of training sessions per day, nor days of training per week, as was found in the study by Budzisz and Sas-Nowosielski (2021) in which body appreciation was higher in athletes who trained five or fewer times per week.

On the other hand, when comparing body appreciation with sex, urban or rural area of residence, obtaining a place on the podium in their last competition, type of last competition, sport sector and type of discipline, in this research only a relationship with sex was found. In fact, the revised body appreciation in adolescents has shown differences between sexes in several studies. In some it has been large, being much higher in males than in females (Banasco et al., 2021; Jáuregui & Bolaños, 2011). In others, although not very wide, it has been differentiated being higher in men with marked factors such as age and types of studies (He et al., 2020). On the other hand, merely being a woman, having a high body mass index and not exercising have generated an increase in body dissatisfaction in women (Reyes, 2020), but BMI has been discussed in another way since it has been seen that this is not associated with body appreciation (Kennedy et al., 2020). Another factor related to this differentiation between sexes is the addiction to social networks and concern for body image because it has been seen to be noticeable and evident in the female sex (Budzisz & Sas-Nowosielski, 2021; Ripalda, 2022). In this regard, in this study a slight differentiation was found being higher in men, so it is not so far from the findings of the literature and one more factor was regarding comments

received by their environment, an aspect in which women perceived the severity of the comment significantly worse than men (Scott et al., 2022).

In our study, no significant differences were found with the area of residence, nor with having won or not a medal in the last competition, being a conventional or Paralympic sport, or practicing an individual or team discipline. According to the type of sport, Budzisz & Sas-Nowosielski (2021), found that body appreciation was higher in women, in those sports of indirect competition, i.e. in those sports in which the confrontation was not face to face but using means such as rowing, for men it was higher in water sports disciplines than in those who practiced the sport indoors and there was greater body appreciation in athletes of individual disciplines than in collective sports in women, but strikingly the opposite was true for men (Budzisz & Sas-Nowosielski, 2021).

In our study, no significant differences were found between body appreciation and the variables of educational level, sector of study, socioeconomic stratum and means of transportation, contrary to other findings with greater body appreciation in adolescents enrolled in an educational institution (Morales, 2017) highlighting in them a positive attitude towards challenges, active search for solutions to problems and support from others to solve problems. Greater body appreciation has also been found in students from public than private educational institutions (Tacca et al., 2017), although the opposite could be thought, since having greater economic accessibility would facilitate the search for resources and strategies to have a better body and thus increase their body appreciation.

Therefore, it is important to work on the development of a satisfactory body image in all people regardless of age, sex, race, and social status. Especially in adolescent athletes, considering that this can contribute to this population possessing a sense of confidence in sport and generating sporting performance with high achievements (Ricketts, 2023).

CONCLUSIONS

In the Colombian adolescent athletes participating in this study, positive body esteem predominated, which was related to the result of the last competition and years of practice. On the contrary, socioeconomic stratum, housing area, study sector, educational level, and type of discipline did not show any influence.

There are different factors that can affect the perception of body image that a person may have. Among them are the comments that their peers, trainer or family may make about their body, impacting on the psychopathology of exercise and nutrition and generating mental health problems that affect their physical well-being. This type of research is useful for the early identification of alterations in the perception of body image in order to focus efforts on the design and implementation of promotion and prevention programs, especially in adolescents.

According to the research reviewed, body appreciation is a positive sign for athletes as it intrinsically contributes to personal value and a feeling of self-esteem, factors that the literature has shown to be positive for adolescents. It is also interesting to note that previous research shows that this body appreciation factor tends to be higher in males than in females.

These problems could be less or perhaps be solved if the person who wanted a certain physical appearance, sought the help of a professional and if these athletes had a follow-up and control from the nutritional and psychological field to avoid these mental alterations. What undoubtedly needs a general recognition from

each of the actors in the context of the athlete; family and coach, and in turn, the latter could benefit from the many tools that professionals from other areas could offer for the enrichment of the sporting and personal process of each of their athletes, this to contribute to the achievement of sporting achievements.

AUTHOR CONTRIBUTIONS

I.C.R.P.: conceptualization, methodology, investigation, resources, formal analysis, writing—original draft preparation. I.C.R.P, I.P.P.: writing—review and editing. All authors have read and agreed to the final version of the manuscript.

SUPPORTING AGENCIES

No funding agencies were reported by the authors.

DISCLOSURE STATEMENT

No potential conflict of interest were reported by the authors.

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ORIGINAL ARTICLE

Validity and reliability of the volleyball serve accuracy-test

CICERO LUCIANO ALVES COSTA[1], NADIA CRISTINA VALENTINI[2], EMANUEL MOITA DO NASCIMENTO[3], HERBERT UGRINOWITSCH[4]

[1]*Department of Physical Education. Regional University of Cariri. Crato, Brazil.*

[2]*School of Physical Education, Physiotherapy and Dance. Federal University of Rio Grande do Sul. Porto Alegre, Brazil.*

[3]*Department of Physical Education and Sports. Federal Institute of Education, Science and Technology of Ceará. Limoeiro do Norte, Brazil.*

[4]*School of Physical Education, Physiotherapy and Occupational Therapy. Federal University of Minas Gerais. Belo Horizonte, Brazil.*

ABSTRACT

This study aimed to examine the content, face, and sensitive validity, and test-retest reliability of a volleyball overhand serve accuracy-test. Four experts – university professors evaluated the content validity; 50 volleyball coaches, teachers, and athletes were enrolled in the face validity. Thirty-three undergraduate students (18 experienced and 15 novices) participated in the study to assess the test capability to detect different performance levels. The sensitive validity was examined by comparing differences in the serving accuracy among experience levels using the t-test for independent samples. A cluster analysis (hierarchical cluster) was conducted using the between-groups linkage method and the Euclidean quadratic distance measure. The test-retest reliability was analysed using intraclass correlation coefficients and the standard error. Satisfactory results were found for experts' agreement regarding the test's accuracy and content validity. Face validity was adequate regarding clarity, pertinence, and applicability (78% to 86% of agreement). A high degree of test-retest reliability was observed for both novices (ICC = 0.81) and experienced (ICC = 0.84) participants; experienced group (p = .001) had higher means. The volleyball serve accuracy-test is a viable alternative to assess beginners' performance in a teaching-learning context.

Keywords: Performance analysis, Sport performance, Test-retest, Motor learning.

Cite this article as:
Costa, C. L. A., Valentini, N. C., Do Nascimento, E. M., & Ugrinowitsch, H. (2024). Validity and reliability of the volleyball serve accuracy-test. *Journal of Human Sport and Exercise, 19*(2), 570-578. https://doi.org/10.55860/jj2b1p83

Corresponding author. *School of Physical Education, Physiotherapy and Occupational Therapy. Federal University of Minas Gerais. Belo Horizonte, Brazil.* https://orcid.org/0000-0003-0317-1940
E-mail: herbertu@ufmg.edu.br
Submitted for publication December 06, 2023.
Accepted for publication January 07, 2024.
Published April 01, 2024 *(in press* January 26, 2024).
JOURNAL OF HUMAN SPORT & EXERCISE ISSN 1988-5202.

doi: https://doi.org/10.55860/jj2b1p83

INTRODUCTION

Researchers of motor learning have aimed to run experiments with complex motor tasks. Some studies used a daily motor task such as salon dart throwing (Coca-Ugrinowitsch et al., 2014; Romano Smith et al., 2019). Other studies used complex motor skills from different sports, such as golf (Porter et al., 2007), tennis (Buszard et al., 2017; Hebert et al., 1996), badminton (Goode & Magill, 1986), baseball (Hall et al., 1994) and volleyball (Afrouzeh et al., 2020). Regarding volleyball, some studies adopted open motor skills such as the bump and two-hand volley/set (Bortoli et al., 1992; French et al., 1990), but the volleyball serve was the most used motor skill. The volleyball serve is characterized by the environment stability while it is executed, resulting in solid generalizability and specific practical applicability.

Although some tests assess volleyball skills such as spike or bump (Gabbett & Georgieff, 2006; Palao & Valadés, 2012; Palao & Valades, 2016), most motor learning studies have used the volleyball serve (Alishah et al., 2017; Costa et al., 2018; Cruz et al., 2018; Ghorbanzadeh et al., 2017), adopting the performance accuracy as the dependent variable. However, few instruments were submitted to a validity process. Test validity is essential to improve the ecological soundness of tests for teaching contexts (Robertson et al., 2014; Silverman, 1994).

Regarding validated tests for the volleyball serve, few instruments are available, such as the AAHPERD Serve Test (AAHPERD, 1969) and the Serve Test of the Volleyball Skills Test Battery (Bartlett et al., 1991); the score in these tests is related to the most challenging areas for reception in the actual game situation. Although the court area is a relevant feature considering the context of the game, it brings limitations in measuring changes in the accuracy characteristics of the learning process. For instance, the highest score when the ball reaches the back edge of the court (Bartlett et al., 1991) may impair the reproducibility and validity of the test because experienced individuals may attempt to reach the back edge of the court and miss by one centimetre, resulting in a score of zero. On the other hand, novices can aim for areas with lower scores, ensuring a minimum score (Morrow Jr et al., 2015). Thus, in the initial learning phase characterized by inaccuracy and lack of performance consistency (Fitts & Posner, 1967), low-sensitivity tests can make it difficult to assess the learning process of the serve.

Developing new tests and examining their validity and reliability are necessary to assess learning processes and verify the differences in performance related to the novice's accuracy are critical to practitioners. This investigation is also relevant to motor learning researchers since few validated instruments to assess accuracy in complex skills with adequate sensitivity to identify small changes in performance are available. The present study examines the content, face, and sensitive validity, and test-retest reliability of a volleyball overhand serve accuracy-test.

METHODS

Participants

Four university professors (three experts in Motor Behaviour and one in Sports Pedagogy with emphasis on Volleyball) assessed the validity of the test regarding clarity, pertinence, and applicability; a Likert scale (4 points) was used. Further, 50 professionals, volleyball coaches' youth and adults' teams (N = 21), volleyball teachers working in schools (N = 13), and volleyball athletes (N = 16) independently participated in the face validity procedure using the same Likert scale to assess the face validity of the volleyball overhand serve accuracy-test. All coaches and teachers had large professional experience (5 to 10 years = 43%; 10 to 20 years = 12%; 20 to 30 years = 30%; 30 to 40 years = 15%), they also had previous experiences as athletes

(14% professionals, 86% amateurs). To analyse sensitive validity, 33 volunteers, undergraduate students, self-declared right-handers, aged between 18 and 35 years, participated in the study. Two groups were formed, characterized by two-level of experience. The experienced group had 18 volunteers who participated in regular volleyball training (minimum of two weekly training sessions during the last two years) enrolled in a local university. The novice group had 15 volunteers with no volleyball training experience. The Ethics Committee in Research of the Federal University of Minas Gerais approved the project (Code: 1.939.735), and all procedures followed the APA ethical guidelines 7th Edition.

Measures

The volleyball serve was performed with participants positioned five meters away from the "*A*" side of the court, with both feet resting on the ground and facing the target laid on the floor on the "*B*" side (Figure 1). The task required to perform the overhand volleyball serve and hit the target bull's eye (located four meters from the net on the "*B*" side of the court).

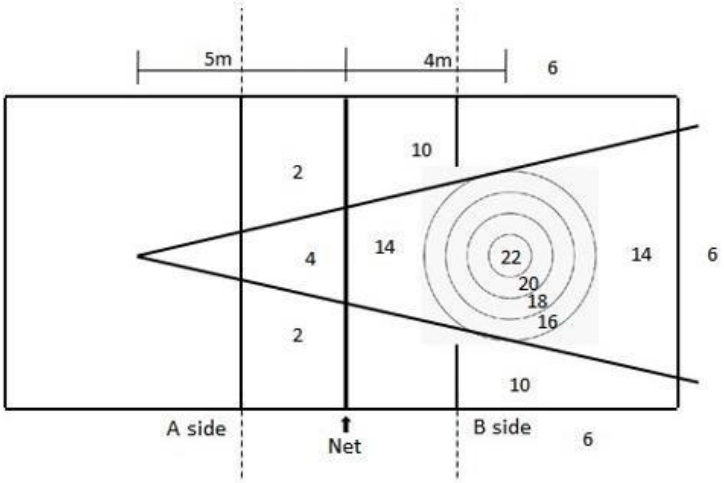

Figure 1. Representation of the area for execution of task.

The target had four circular areas of 1, 2, 3, and 4 meters in diameter. Scores related to accuracy concerning the target's bull's eye ranged from 2 to 22 points. Adhesive tape delimited a triangular area whose vertex originated at the position of the serve and passed through the side of the target. The width of all lines was five centimetres, and if the ball landed on a line, a higher score was obtained. Along with the trials, the serves that reached the target's central area scored 22 points, and as the graduations moved away from the central region, the score decreased by 2 points. The serves that reached the triangular area outside the target and within the court scored 14 points; if the serve touched the upper band of the net and landed toward the target; the score was 12 points. The serves that reached the areas in the court and outside of the triangle scored 10 points – if the serve touched the net and went over the net but did not land in the target's direction, the score was 8 points. Off-court serves were equivalent to 6 points. The triangular area on the "*A*" side of the court scored 4 points. The areas on the "*A*" side outside the triangle were 2 points. The experiment was run on an official volleyball court with the net set at the height of 2.24 m, using adhesive tape, a target, and official volleyball balls.

Procedure

Experts were invited to be a part of the content validity. After the final version was obtained, the target population (volleyball coaches, teachers, and athletes) were invited to assess face validity. Then, volunteers

were invited to participate in the study. Information regarding the study objectives, procedures, and risks was provided; all participants signed the informed consent. Before trials started, participants were instructed about the task goal and with a clear description of the kind of serve to be performed - overhand. After this initial instruction, each participant was directed individually to the serve position; each participant's performance was private. One researcher stranded on the left side of the participant and provided a ball, controlled the inter-trials interval (six to eight seconds), and prompted the action with the commends "*prepare*" and "*go*" before each trial. Another researcher stood on the court at side "*B*", close to the net and the triangle line, and scored each serve immediately after the trials. The experimenter did not provide feedback regarding the trials, but the location where the ball hit the ground was available throughout the trials. After seven days, the retest was conducted following the same protocol. Three participants from the experienced group and one participant from the novice group did not attend the retest; no information was provided regarding the reasons; their data were not included in the data analysis.

Analysis

Content and face validity were conducted using a Likert scale, ranging from 1 (totally disagree) to 4 (totally agree), with experts and the target public (coaches, teachers, and athletes) to assess test pertinence, clarity, and applicability. For content validity coefficient (CVC) was calculated (Hernández-Nieto, 2002), adopting above .80 as a satisfactory coefficient (Landis & Koch, 1977). Percent agreement was used to analyse the face validity of the professionals' responses.

Descriptive statistics of mean and standard deviation were provided. The normality of the data was verified with the Shapiro-Wilk test; parametric inferential statistics were used. The discriminant validity of the test was examined by comparing differences in the serve accuracy between experienced and novice groups using independent t-tests. A hierarchical cluster analysis was conducted using the between-groups linkage method and the Euclidean quadratic distance measure, with 2 clusters through the single solution method. A Chi-square test was used to verify associations between groups and clusters. The test-retest reliability was analysed using intraclass correlation coefficients (ICC) and the standard error of measurement (Weir, 2005). The statistical package SPSS for Windows (version 22.0) was used for all analyses, and the level of significance was set at $p < .050$.

RESULTS

Content and face validity

Initially, experts assess the test content validity. According to the experts' recommendations, the original test underwent two evaluations, undergoing modifications in its description and punctuation. After the two rounds, the final version was obtained. Experts agree that the test measures the accuracy of the volleyball serve; satisfactory levels of the agreement were obtained for clarity (CVC = .93), pertinence (CVC= 1.0), and applicability (CVC = .93). The face validity evaluated by the 50 professionals resulted in 78% concordance among them for clarity, 78% for pertinence, and 86% for applicability.

Sensitive validity

For sensitive validity, the independent variable - levels of experience - was analysed and the results showed the accuracy of the serve test. The t-test showed higher scores for the experienced group than the novice group at the test and the retest, with a large effect size(J, 1988). Cohen's index d showed a high magnitude effect of experience level on volleyball serve accuracy for both the test (d = 2.20) and retest (d = 1.59).

Table 1. Groups comparisons: Means, standard deviations, p values and Cohen's effect size (d).

	Groups	N	Mean	Standard deviation	*p*	Cohen's d
Test	Novice	15	15.92	1.47	.001*	2.20#
	Experienced	18	18.84	1.17		
Retest	Novice	14	16.54	1.93	.001*	1.59#
	Experienced	15	19.10	1.21		

*Note: * Student's t-test p-values; # Cohen's d large effect size.*

Table 2 shows that the cluster analysis grouped most participants in a similar way to the original division of the groups by level of experience. In the cluster analysis by the level of experience groups, a high number of the cases were correctly classified (90.9%). Only one participant from the experienced group was grouped in cluster 1, whereas among the novices, two participants were grouped in cluster 2. A significant association between clusters and groups was found (Chi2 p = .001).

Table 2. Test-retest reliability.

Groups	N	ICC	CI (95%)	SEM	%SEM
Novice	14	.81	.41 – .94	.74	4.60
Experienced	15	.84	.53 – .95	.49	2.58
Total	29	.91	.81 – .96	.59	3.38

Note: N = participants; ICC = Intraclass Correlation Coefficient; CI = Confidence Interval; SEM = Standard Error Measure; % SEM = percentage of SEM in relation to the mean.

Reliability

Intra-class correlation coefficients, their respective confidence intervals, and the standard error of measure are presented in Table 3. A high degree of test-retest reliability was observed for both novice and experienced groups. For the temporal stability, the confidence interval was smaller for the total sample and experienced groups than for the novice groups; consequently, although adequate for novices, the test-retest was more robust for experiences and the total sample.

Table 3. Frequency distribution of clusters according to the level of experience.

	Cluster 1	Cluster 2	Total	*p*
Inexperienced	13 (86.7%)	2 (13.3%)	15	*.001
Experienced	1 (5.6%)	17 (94.4%)	18	

*Note. * Pearson's Qui-square = 22.037. Ninety-one percent of the originally grouped cases were correctly classified.*

DISCUSSION

This study examined the content, face, and sensitive validity, and test-retest reliability of a volleyball overhand serve accuracy-test. The results demonstrate that the target accuracy-test is a valid and reliable alternative for motor learning research and monitoring players' progress. The experts agreed that the test could assess the serve accuracy, and the CVCs results for clarity, pertinence, and applicability were satisfactory - all results above recognized cutoffs (Hernández-Nieto, 2002; Landis & Koch, 1977). The group of professionals confirmed face validity; the test was considered to have pertinent content to assess serve accuracy with clear and understandable instruction.

The results also demonstrated the sensitivity of the volleyball serve accuracy-test to differentiate the experience levels. This form of validity is as essential as other psychometric criteria (Milne & Reiser, 2011).

As observed in the present study, concerning to accuracy tasks such as volleyball serve and other sports skills, it is expected that experienced practitioners perform better than the novice. A plausible explanation is related to a greater capacity of the experienced individuals to identify, remember, and handle the relevant information of the environment (Arroyo et al., 2016). In addition, cluster analysis demonstrated that almost all participants were grouped consistently with their original group, and the serve test for accuracy was able to differentiate the participants' performance levels.

Volleyball coaches have used skill tests in different stages to assess the performance level of young athletes on the basic skills (Lidor et al., 2007). Regarding serve skill, accuracy tests have focused on the game demands, with higher scores in areas that impose greater difficulty for reception (AAHPERD, 1969; Bartlett et al., 1991). These kinds of assessments are consistent with the specific demands of the sports and are highly relevant for monitoring the athletes' performance. Improvements in the parameterization of aspects such as strength, speed, and direction of the ball are relevant to the motor learning process. Instruments used to assess motor skills acquisition within sport contextual goals need to identify improvements in performance accuracy, and the present test achieves this objective. It is vital to note that although Bartlett et al. (1991) test differentiate athletes' performance accuracy during the volleyball game, the one-centimetre difference between the maximum and minimum score (as mentioned early) is a problem in distinguishing performance during early learning. Thus, the relationship between the level of experience and the test sensitivity was examined in the present study might be considered in future studies. For example, the no difference in performance accuracy of elite and near-elite players (Lidor et al., 2007) may occur due to the lower sensitivity of the instrument. The accuracy test proposed in the present study overcomes these limitations, besides presenting suitable validity and reliability indexes.

The findings related to test-retest reliability were considered suitable for both groups and excellent for the total sample (Koo & Li, 2016). Good and excellent levels of reliability, like those obtained in the present study, have been restricted in several tests that assess sports motor skills performance, around only 41% of 22 studies analysed in a systematic review achieve similar indexes (Robertson et al., 2014). The indices of the present study are also superior to those obtained by the NCSU test (Bartlett et al., 1991) and resemble those found by Gabbett and Georgieff (2006) in a proposal for assessing volleyball skills for junior players. However, the latter study did not use a specific target to assess the accuracy of the serve, only whether the ball hit the opposite side of the court or not. Therefore, as well as the NCSU Volleyball Skills Test Battery (Bartlett et al., 1991), the test proposed by Gabbett and Georgieff (2006) also runs the risk of underestimating the performance of players with a better technical level and overestimating the performance of beginners.

The present study's strength relates to the test applicability in teaching-learning context. The instrument is a viable alternative to evaluate an extensive range of performance, from novices to experienced players. One limitation of the present study was the small sample size regarding the sensitive validity, restricting our generalization capability.

CONCLUSIONS

The volleyball serve accuracy-test presents adequate validity and test-retest reliability and is a feasible alternative for motor learning research on complex motor skills; the results from this line of research may support sports intervention more than lab tasks (Christina, 1987). We recommended that in early learning, due to the difficulty in reaching the opposite side of the court because of structural and functional constraints, a shorter distance from the net can be used to facilitate the testing process - this alternative needs to be investigated regarding its psychometrics capabilities. We also suggested that other studies continue

examining the psychometrics of the serve accuracy-test regarding criterion validity and the strength of the relationship between test accuracy and movement patterns quality.

AUTHOR CONTRIBUTIONS

Costa and Ugrinowitsch designed the study. Costa and Valentini performed the data collection and data analysis. All the authors wrote the paper and approve the final submission.

SUPPORTING AGENCIES

No funding agencies were reported by the authors.

DISCLOSURE STATEMENT

No potential conflict of interest were reported by the authors.

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ORIGINAL ARTICLE

Tourism in a protected natural area (PNA): Sports hunting and hiking from the perception of strategic actors

CYNTHIA MILAGROS APAZA-PANCA[1], CYNTHIA HARUMY WATANABE CORREA[2], JOYCE MAMANI CORNEJO[1], ANTHONY PAUL TÁVARA RAMOS[3], RONALD ADRIÁN GIRÓN VALENZUELA[1], ANGIE BEATRIZ ORTIZ CALOPINO[1], ALFREDO IVAN OLAGUIVEL QUISOCALA[4]

[1]*National of Frontera University. Sullana, Peru.*
[2]*University of São Paulo. São Paulo, Brazil.*
[3]*César Vallejo University. Piura, Peru.*
[4]*National University of the Altiplano. Puno, Peru.*

ABSTRACT

Tourism activity in natural protected areas is increasing worldwide. These areas belong to the country's heritage and their natural conditions should be preserved, taking advantage of the resources and the sustainable use of the area. The general objective of the study was to analyse the perception of travel agencies and visitors to a natural protected area and the specific objectives were to determine the image of the natural protected area from the perspective of visitors and to learn about the travel agencies' perception of the natural protected area as a tourist destination for sport hunting and hiking. The study is a mixed approach, basic, non-experimental, descriptive, cross-sectional design. A probabilistic sampling by convenience and intentional was estimated, considering 100 visitors and 5 formal travel agencies in the city of Mancora with interest in providing tourist services to the protected natural area. The study found that 12% of the visitors agree that the area has an image of an ecological and restful place, a place for tourism activities such as trekking, sport hunting, hiking, bird watching, biking, and photography. On the other hand, travel agency representatives have little knowledge of the destination; however, they show interest in considering the destination as part of their tourism packages, given that there is evidence of potential demand because the destination is innovative and offers sports tourism practices.

Keywords: Travel agencies, Protected natural area, Sport hunting, Hunting preserve, El Angolo, Hiking.

Cite this article as:
Apaza-Panca, C. M., Watanabe Correa, C. H., Mamani Cornejo, J., Távara Ramos, A. P., Girón Valenzuela, R. A., Ortiz Calopino, A. B., & Olaguivel Quisocala, A. I. (2024). Tourism in a protected natural area (PNA): Sports hunting and hiking from the perception of strategic actors. *Journal of Human Sport and Exercise, 19*(2), 579-599. https://doi.org/10.55860/k7x6ck53

Corresponding author. *Universidad Nacional de Frontera. Sullana, Perú.* https://orcid.org/0000-0002-5524-2627
E-mail: cynthiamilagros9@gmail.com
Submitted for publication January 04, 2024.
Accepted for publication January 30, 2024.
Published April 01, 2024 *(in press* March 04, 2024).
JOURNAL OF HUMAN SPORT & EXERCISE ISSN 1988-5202.

doi: https://doi.org/10.55860/k7x6ck53

INTRODUCTION

Tourism activity is one of the main pillars in the development of a population (Huaman et al., 2022). Furthermore, tourist activity is an experience that involves the desires of each tourist, and helps with economic growth, making some countries dependent and allocating resources to permanently enhance their attractions. (Ticse-Villanueva et al., 2022).

Likewise, tourist resources are located in various natural spaces, being part of the community's heritage and the tourist potential of the area. However, it is not enough for a place to have many tourist resources if they are not appreciated, valued and conserved by the receiving residents, by the local, regional and national government; and by all the actors involved, because they are sources of development and positioning in the tourism market.

Peru is considered the most attractive tourist destination in Latin America. (Ticse-Villanueva et al., 2022). That is, a variety of tourist resources with great potential, which must be used sustainably and with greater reach for potential visitors; where sustainability is an important factor for the productive system, because it helps not to damage and conserve resources (Gómez-Suárez & Yagüe, 2021).

One way to provide sustainable services to tourists is through ecotourism, also called green tourism or nature tourism, which proposes enjoying nature at its best, which is untouched by civilization and in a pristine state. It is related to adventure tourism because the tourist carries out activities such as swimming, walking and appreciating the landscape (Ugarte & Portocarrero, 2013). However, the perception of travel agents about a destination is a fundamental tool that is taken into account to analyse marketing and create strategies that satisfy the needs of potential visitors (Bustillo & Mendoza, 2013).

Now, the tourism industry identifies the needs of potential tourists, to provide services that satisfy their desires and expectations (Silva-Escobar & Raurich, 2020). Furthermore, it is necessary to mention that, given the excessive increase in visitors and increasingly more informed, tourism managers have to provide innovative services and products so that visitors can choose according to their conditions and preferences, choosing the Internet as their main medium (Huerta, 2020).

Therefore, the digital medium, especially social networks, such as Facebook, tends to be an important tool for dissemination and information about tourism, because through images and videos the capture of potential tourists is achieved. That is why travel agencies must incorporate the use of digital media into their services to expand the target audience and in this way potential tourists have access to a different offer. On the other hand, tourism and recreation activity in the surroundings of Protected Natural Areas (hereinafter ANP) are increasing worldwide (Pickering et al., 2018).

So much so that, in Peru, the management to promote and strengthen tourism in protected natural areas in a sustainable way is vital to conserve and protect resources, this being possible with nature tourism or also called ecotourism, which since the last decades has been growing significantly, this type of tourism is considered one of the strategies implemented for the ANP in the sustainable development of the country. Likewise, Travel Guard Update mentions that Peru is the fourth country in which tourists opt for nature tourism, mainly in protected natural areas (SERNANP & WCS, 2020).

At a regional level, Piura has been characterized by sun and beach tourism, that is, mass tourism, however, it is necessary to establish new destination routes, with attractions in rural spaces (Maldonado-Erazo et al.,

2018). For this reason, the El Angolo Hunting Reserve (hereinafter CCEA) is presented as a tourist offer that can be disseminated through travel agencies in the city of Máncora, which are interested in expanding and offering a different service than the one they usually offer. They're used to it.

The CCEA is a Protected Natural Area and was recognized by UNESCO in 1977, as part of the Biosphere Reserve of Northwestern Peru. What this management seeks is to conserve the biodiversity of vegetation and animals that inhabit this area. In addition, there are several tourist resources that must be used sustainably, with the most related type of tourism being ecotourism and adventure tourism, where tourists have the option to rest, interact with nature and practice adventure sports. To visit the Coto Caza El Angolo ANP can be done from the city of Máncora, the tour lasts two hours, where you can observe the presence of animals (white-tailed deer, crab-eating bear, mate's head) and tree species (carob trees, hualtacos, charanes, palo santo, etc). Likewise, there are two large spaces where national and foreign tourists visit, which is the Sauce Grande and Fernández ravine, which include resources for trekking, observing flora and fauna, enjoying the water, hunting and horseback riding, which is why it is necessary that the Máncora (Martinez et al., 2017)travel agencies include services that involve activities of interest to potential visitors to this area.

Therefore, the general objective of this research was to identify the perception of the strategic actors of tourism in the ANP Coto Caza El Angolo. In addition, specific objectives are to determine the image of the ANP Coto Caza El Angolo from the perspective of visitors and to know the perception of travel agencies regarding the ANP Coto Caza El Angolo as a tourist destination.

Literature review

Tourists are increasingly demanding with the environments they want to visit, they opt for more sustainable resources, for this reason the organizations that adapt to the requirements and expectations are the most in demand. That is why it is necessary to incorporate sustainable companies and identify potential resources to promote tourism.

On the other hand, the development of tourism does not only depend on having an appropriate tourist plant and resources, but also on the actors involved playing a very important role. Likewise, the cooperation of interested parties in the management of tourism activity helps both tourism development and the identity of the community.(Pulido-Fernández & López-Molina, 2023).

According to the UNWTO (2020), tourism activity in a locality tends to be one of the main sources of economic development and employability (Rocha et al., 2020), always being present in the population, through various activities and services (Varón et al., 2021), leading to the improvement of the economic conditions of a country. and as a recognized sector that causes economic growth in the world(Rocha et al., 2020).

Likewise, the UNWTO states that the tourism system has four important components: supply, demand, tour operators and geographical space, which guarantee the increase in visitors (Zambrano et al., 2017). Furthermore, it is essential that strategies be established that involve intermediary organizations, which help provide different services in order to satisfy the needs of tourists (Varón et al., 2021).

One of the main intermediary tourism organizations that is directly related to tourists and the environment are travel agencies (Rocha et al., 2020). Tourists go to travel agencies to obtain information and buy tourist packages of interest. (Cheung & Lam, 2009)By opting for a tourist package, the visitor will have the

opportunity to obtain an organized trip and enjoy the stay in the place visited, which will provide pleasure, shopping and knowledge (Lojo, 2016).

On the other hand, to have an excellent image of the tourist destination, the attractions must be disseminated through social media (Caldevilla-Domínguez et al., 2023). The website must be visually attractive, having promotions to attract greater traffic and convert them into visitors to the destination (Luna-Nevarez & Hyman, 2012). For this reason, websites, social networks or any digital media are important factors in travel agencies, because they provide information and content that is relevant and appreciated by tourists. Therefore, these organizations must have products and services that meet the needs of the tourist. The consumer, in this way, would have a greater participation in the competitive market (Rodríguez Pallas, 2018).

Now, tourism activity must offer economic profitability to the protected natural areas, to the local communities and to all those involved who are part of the management of the ANP. (SERNANP, 2009). The Law of Protected Natural Areas (Law No. 26834) mentions that they are terrestrial and marine spaces of a national nature, which preserve biodiversity and culture, contributing to the sustainable development of the nation (SINANPE, 2009). The most important function of protected natural areas is to conserve nature and spaces of interest to tourists (Salvadeo et al., 2022), as well as species of humanity, because they do not have due appreciation of the population to which they belong.

In Latin America there is little participation of the State in rural areas, because there has been a lack of attention and few services (Rasmussen, 2022), therefore, it is necessary to establish alliances with the actors involved (public, private sector and host community), with the objective of helping to protect natural areas and create environmental governance (Coria et al., 2019).

Consequently, the proper management of the ANP allows the conservation and use of resources appropriately, increasing the economic income of all the participants involved, based on the tourist offer that can be provided to visitors such as the sale of various inputs, crafts, products made with local resources, among others. However, tourism has benefits as well as harmful factors. If adequate planning is not carried out, it can generate deterioration of natural resources, contamination of soil and water, and social difficulties such as cultural exchange between tourists and residents. In this sense, it is necessary to assign due importance to the preservation of its resources, which would help create valuable relationships between nature and visitors, carrying out various recreational and tourist activities (Perez-Ramirez, 2016).

On the other hand, if tourism is focused on these protected areas, the tourist influx that may exist must be controlled; Also provide constant training to tourist guides and, above all, raise awareness among the host population about the care of resources (Salvadeo et al., 2022).

It should be noted that it is necessary to exploit resources in a sustainable way and recognizing the traditional value to conserve nature (Gorriz & Pardo-de-Santayana, 2021), because each natural area that a population has influences the improvement of the quality of life of the inhabitants (Karis & Ferraro, 2021). In this way, sustainable tourism is spoken of as a new paradigm that involves raising awareness of nature and improving the conditions of host residents (Monsalve-Pelaez et al., 2023).

SERNANP states that there are 76 ANP in Peru, of which two belong to the Coto de Caza classification (Sunchubamba and El Angolo).

Now, the El Angolo Hunting Reserve (CCEA) is an area of direct use (allows the use of resources) (SERNANP, 2009), it is located in the department of Piura, between the provinces of Sullana and Talara, inhabited by different wild species, such as: anteater , puma, jaguar and white-tailed deer (SERNANP, 2019).

One of the tourist routes where wildlife is used is precisely the CCEA, specifically in the Large sector, this area is managed by the Piura Hunting, Fishing and Tourism Club (Piperis & Ruesta, 2016), with white-tailed deer being the main resource that is used. According to the Club, this hoofed mammal is found on the coast and mountains of Peru (Elias et al., 2021). Furthermore, within this protected area, tourist activities are carried out such as sport hunting in season from May to November, only for hunting adult male deer; Go hiking, where you can observe the flora, fauna, landscapes and fish (SERNANP, 2019).

Likewise, there is the route of the Fernández sector, managed by the Fernández Ecotourism Association, highlighting the pillars of Fernández and Jaguay Grande, these resources are in optimal states for bird watching, horseback riding and other related activities, in the same way. , there are tourist potentials such as Madre de Agua and Caña dulce, where adventure tourism and bird watching can be carried out. In addition, to improve the tourist experience, an interpretation room has been implemented based on local materials (Martinez et al., 2017). Another type of tourism that can be carried out in this ANP is ecotourism, considered as an activity that conserves nature. (Mejía & Santiago, 2021)and being a main factor in generating employment and income for the community (Toriz et al., 2021), as well as other types of tourism, as long as there is good dissemination of the tourist resources and activities that can be carried out in the tourist destination.

Focusing on the city of Máncora, there is an excessive development of tourism (González, 2020). This city is considered part of the tourism dynamics of the Piura region and is part of one of the routes to access the CCEA. For this reason, the existing travel agencies in this city must disseminate these tourist resources, publicizing the activities that can be carried out and forming part of strategic alliances with the representatives of each area, given that it has great tourist potential that should be promoted as an alternative destination for those who visit the beach route of the Piura region, mainly Máncora, (Martínez et al., 2017)and who, in turn, want to enjoy something different with the purpose of preserving the ecosystem. Due to the above, the CCEA is a potential tourist destination, where the participation as part of the tourist offer of travel agencies will facilitate the tourist influx to the place.

METHODOLOGY

It is research with a mixed approach, of a descriptive type, which is based on collecting information on the research variables and seeks to specify the characteristics of a community or group that is analysed, to effectively show the dimensions of that study situation (Hernández et al., 2014). Regarding the sampling, it was non-probabilistic for convenience and intention, considering 100 potential tourists and 5 representatives of formal travel agencies from the city of Máncora who knew and were interested in offering services to the CCEA protected natural area. The quantitative data were analysed using the SPSS statistical program and the qualitative data were organized based on categories to have a better information focus. The questionnaire used included 22 closed questions with suggested options, dichotomous and on a Likert scale.

Descriptive statistics, parametric and non-parametric tests were used to analyse the results. Meanwhile, the interview guide has been designed structured. Voice recorders and notepads were used. To process the interviews, first the answers were transferred to an Excel matrix, then the 20 questions were organized into 4 categories, ordering through similarities, being business recognition, opportunity of the place, development

of tourism and the green tourism product, Each question was analysed and a subcategory was designated, which were the answers that the interviewees had mentioned. It was decided to count all the answers and place the number of agencies that were similar in their answers, to finally present them in tables. and figures.

RESULTS

Below, the results obtained through the interviews and surveys are presented, which in the case of the quantitative approach was worked through the SSPS program, with descriptive statistics (frequencies, average, standard deviation, Pearson's Chi-square and exact Fisher) and with non-parametric tests (U-Mann-Whitney and Kruskal-Wallis). To associate the questions, some showed a non-parametric distribution, therefore, Mann-Whitney U (gender and question 2) and Kruskal-Wallis (age, marital status and origin) were used. It is worth mentioning that a different sample was used for each associated question (Table 1). Likewise, for the qualitative approach, they were ordered in an Excel matrix, based on 4 categories to have a better organization and analysis of the interview questions (Figure 1).

Table 1. Sample to consider.

Questions	Sample
Question 1, 2, 13 to 22	100 potential tourists
Question 3, 4, 12	12 tourists who have visited the ANP
Question 5 to 11	11 tourists who have visited and at the same time heard information about the ANP from other people

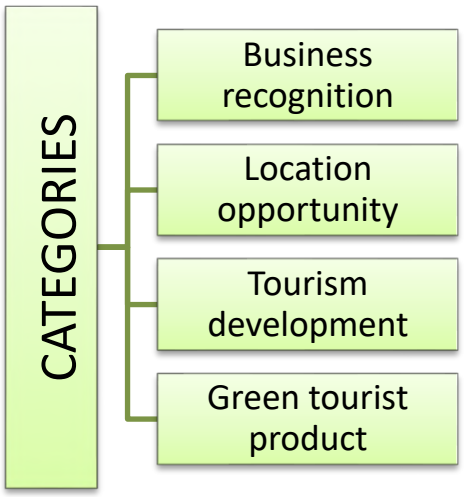


Figure 1. The 4 categories based on the interviews.

The following Table 2 shows the percentages according to each question:

Question 1 referring to "*The factor that influences the choice of the tourist destination*", of the total number of people surveyed, 71% mentioned that it is the place that influences the moment of their choice, while the least important factor for the respondents It is the product with 7%.

Based on the sample of 12 people who have visited the ANP, question 3 is presented "*What image did you have of the ANP CCEA before meeting it?*", 50% (6 people) expressed that the ANP has an image of an

ecological place, almost similar to the 41.7% (5 people) who indicated that it has an image of a resting place, meaning that both the ecological and resting place has been the highest perception of those surveyed about the ANP.

Table 2. Summary in percentages of the questions with suggested options.

Alternative	**Item**
	1. What do you think is the factor that influences the choice of your tourist destination (%)
Price	10
Product	7
Promotion	12
Place	71
	3. What image did you have of the ANP Coto de Caza El Angolo before meeting it (%)
Ecological place	fifty
Resting place	41.7
Family place	8.3
	6. Indicate other sources through which you have received information about the ANP Coto de Caza El Angolo (%)
Advertising in mass media (press, radio, television)	45.5
Printed material (tourist guides, brochures)	18.2
Internet (Web page, blogs, emails, social networks)	27.3
Travel agency	9.1
	7. What is the social network you use the most to choose a tourist destination (%)
Facebook	27.3
Instagram	18.2
WhatsApp	54.5
	8. How do you regularly buy tourist packages or tours (%)
In person	90.9
Virtual	9.1
	9. How would you like the advertising content about the ANP Coto de Caza El Angolo to be related (%)
Messages	54.5
Product	9.1
Promotions	36.4
	12. Which of the following tourist activities do you consider you can carry out within the ANP Coto de Caza El Angolo (%)
Cycling	8.3
All of the above	91.7
	13. What is the average expense that you consider you could allocate for tourism in the ANP Coto de Caza El Angolo (%)
S/ 100 to S/ 200	52
S/ 300 to S/ 400	28
S/ 500 to S/ 600	eleven
S/ 600 or more	9
	20. How would you like the advertising content about the ANP Coto de Caza El Angolo to be related (%)
Yape	13
Blim	3
Transfer of credits/due	22
Cash	62

In question 6 "*Indicate other sources through which you have received information about the ANP CCEA*", 45.5% (5 people) stated that one of the sources of information is advertising in mass media, such as: press, radio and television, however, 54.5%, (6 people) opt for the Internet (3), printed materials (2), and only 1 chose travel agencies as a source where they have received information about the ANP.

For question 7 "*What is the social network you use the most to choose a tourist destination?*", 54.5% (6 people) expressed that WhatsApp was the most relevant to choose a destination, while 45.5% (5 people) indicated that they use Facebook (3) and Instagram (2) the most. Grouping the question by gender, it is shown that ladies (5) are the ones who opted for WhatsApp the most.

Likewise, in question 8 "*How do you regularly buy tourist packages or tours?*", the majority of respondents, that is, 90.9% (10 people) thought that they buy their packages in person and only 9.1% (1 person) He stated that he does it virtually.

Furthermore, in question 9 "*How would you like the advertising content about the ANP CCEA to be related?*", 54.5% (6 people) indicated that it is the messages that should be related, however, 45.5% The remaining 5 people opted for the promotion (4), and 1 chose the product, considering that both the messages and the promotion are important to present ANP advertising content.

Question 12 "*Which of the following tourist activities do you consider you can carry out within the ANP CCEA?*", the vast majority, that is, 91.7% (11 people) expressed that the tourist activities they could carry out are: trekking, sightseeing of birds, cycling and photographs, that is, all the options.

In question 13 "*What is the average expense that you think you could spend on tourism in the ANP CCEA?*", with respect to the total (100 people), more importantly, 52% of respondents indicated that they could spend between S/100 to S/200 to carry out tourist activities in the ANP, however, 28% thought that they can spend from S/300 to S/ 400.

Finally, for question 20 "*What is the payment method currently used?*", the majority (62%) stated that cash has been the payment method they use to make their purchases; and 22% opt for credit/debit transfer.

Table 3. Summary in percentages of the dichotomous questions.

Alternative Items	Yeah	No	Total
2. You have visited the Coto de Caza El Angolo Protected Natural Area	12	88	100
4. Have you heard at some point from friends, family and/or acquaintances information about the ANP CCEA?	91.7	8.3	100
5. They recommended you visit the destination	81.8	18.2	100

Table 3 shows the percentage of dichotomous questions:

In question 2, "*Have you visited the Coto de Caza El Angolo Protected Natural Area?*", it was evident that only 12% of people surveyed have visited the ANP, while 88% of potential visitors have not visited it yet.

Regarding question 4 "*Have you heard at any time from friends, family and/or acquaintances information about the ANP CCEA?*", a large part (91.7%), that is, 11 people indicated that they have heard others comment about the ANP CCEA. and 8.3% (1 person) have not heard information about it.

Question 5 being "*Did they recommend visiting the destination?*", based on the sample of 11 people, 81.8% (9 people) stated that they recommended visiting the destination, however, 18.2% (2 people) of respondents They stated that although they have gone to the place, they did not recommend that they visit the ANP, because they did not like it.

Table 4. Summary in percentages of the questions with Likert scale.

Items	Scale of worth					
	Strongly Disagree	In disagreement	Neither agree nor disagree	OK	Strongly agree	Total (%)
10. Do you think that an influencer would have more impact when choosing the ANP Coto de Caza El Angolo as a tourist destination (%)	9.1	0	0	45.5	45.5	100
11. Do you believe that there is enough advertising or tourist advertisements in the ANP Coto de Caza El Angolo (%)	36.4	36.4	9.1	18.2	0	100
14. The price of the tourist services (accommodation, restaurant, etc.) offered at the ANP Coto de Caza El Angolo are affordable (%)	15	35	8	37	5	100
15. The price of transportation to get to the ANP Coto de Caza El Angolo is accessible (%)	10	30	21	31	8	100
16. Receive prior information about the prices of the various tourist services offered at the ANP Coto de Caza El Angolo (%)	8	4.5	13	26	8	100
17. The information about the ANP Coto de Caza El Angolo provided by travel agencies is complete (%)	13	41	24	17	5	100
18. Travel agencies are a means by which tourism development is generated in the ANP Coto de Caza El Angolo (%)	1	7	8	48	36	100
19. You believe that if the price of a product or service is low, it corresponds to low quality (%)	17	27	26	18	12	100
21. I would be interested in spreading or communicating to other people about the existence of the ANP Coto de Caza El Angolo (%)	1	5	6	36	52	100
22. The information on the various tourist resources available in the area where the ANP Coto de Caza El Angolo is located is complete (%)	15	4.5	24	10	6	100

Table 4 shows the percentages of the questions on a Likert scale, considering the following:

In question 10 "*Do you think that an influencer would have more impact when choosing the ANP Coto de Caza El Angolo as a tourist destination?*", 90% (10 people) stated positively, because a similar percentage agree (5) and strongly agree (5), however, 9.1% (1 person) expressed that they strongly disagreed that the influencer affects the election of the ANP.

Question 11 being "*Do you think there is enough advertising or tourist advertisements in the ANP CCEA?*", 72.4% (8 people) indicated negatively, since in similar percentages they disagree (4) and strongly disagree. (4) if there is a lot of publicity or announcements about the ANP.

For question 14 "*Are the prices of the tourist services (accommodation, restaurant, etc.) offered at the ANP CCEA accessible?*", 50% gave a negative opinion, because their answers were between disagree (35%) and strongly disagree (15%), while 42% mentioned that they agreed (37%) and strongly agreed (5%) that the price is affordable in the tourist services offered in the ANP.

Similarly, in question 15 "*Is the price of transportation to get to the ANP CCEA accessible?*", to a large extent, 40% responded negatively, because they disagreed (30%) and strongly disagreed. (10%), on the contrary, 39%, expressed themselves positively, since they agreed (31%) and strongly agreed (8%) that the price of transportation is affordable to visit the ANP. It is worth mentioning that the majority of those who have gone (disagree) have a different opinion than those who have not gone (disagree and agree).

In question 16, "*Do you receive prior information about the prices of the various tourist services offered in the ANP CCEA?*", 53% of respondents stated negatively, because they disagreed (45%) and strongly disagreed (5%). with which they receive the price information for tourist services in the ANP before, while 34% expressed positively, their answers agree (26%) and strongly agree (8%) with respect to the question.

For question 17 "*Is the information about the ANP CCEA provided by travel agencies complete?*", the majority (54%) expressed that they disagreed (41%) and strongly disagreed (13%) that the information that travel agencies offer is complete about the ANP. However, associating with age, those between 31 and 50 years old have expressed the opinion that they disagree with the question because the number of people of that age has been greater, hence the difference.

Regarding question 18 "*Are travel agencies a means by which tourism development is generated in the ANP Coto de Caza El Angolo?*", 84% affirmed positively, since they agreed (48%) and strongly agree (36%) that tourism in the ANP is developed through travel agencies.

In question 19 "*Do you think that, if the price of a product or service is low, it corresponds to low quality?*", 44% disagreed with their answer, since they disagreed (27%) and strongly agreed. disagreement (17%) that if the product has a cheap price it means low quality, while 30% expressed that they agreed (18%) and strongly agreed (12%) regarding the question.

Based on question 21 "*Would you be interested in disseminating or communicating to other people about the existence of the ANP Coto de Caza El Angolo?*", most of the respondents (88%) strongly agreed (52%) and agreed (36%) about telling others about ANP.

Finally, question 22 "*Is the information about the various tourist resources available in the area where the ANP CCEA is located complete?*", considerably (60%) the respondents did not agree that the information is complete about the tourist resources of the ANP, since their responses were in disagreement (45%) and strongly in disagreement (15%).

On the other hand, regarding the descriptive statistics, Table 5 shows the average (M) based on the Likert scale questions, as follows:

In Q.10 (M = 4.18) it was evident that the respondents "*agreed*" that the influencer had an impact on the election of the ANP.

Similarly, in Q.11 (M = 2.09) it was shown that potential visitors "*disagree*" about whether there is enough publicity about the ANP, so it follows that there is little dissemination about the ANP CCEA.

Table 5. Results of the average and standard deviation, taking into account the Likert scale questions.

Items	M	Yes
Do you think that an influencer would have more impact when choosing the ANP Coto de Caza El Angolo as a tourist destination (P.10)	4.18	1.17
Do you believe that there is enough advertising or tourist advertisements in the ANP Coto de Caza El Angolo (P.11)	2.09	1.14
The price of the tourist services (lodging, restaurant, etc.) offered at the ANP Coto de Caza El Angolo are affordable (P.14)	2.82	1.23
The price of transportation to get to the ANP Coto de Caza El Angolo is affordable (P.15)	2.97	1.16
Receive prior information about the prices of the various tourist services offered at the ANP Coto de Caza El Angolo (P.16)	2.81	1.15
The information about the ANP Coto de Caza El Angolo provided by travel agencies is complete (P.17)	2.60	1.07
Travel agencies are a means by which tourism development is generated in the ANP Coto de Caza El Angolo (P.18)	4.11	0.9
Believes that, if the price of a product or service is low, it corresponds to low quality (P.19)	2.81	1.26
I would be interested in spreading or communicating to other people about the existence of the ANP Coto de Caza El Angolo (P.21)	4.33	0.88
The information on the various tourist resources available in the area where the ANP Coto de Caza El Angolo is located is complete (P.22)	2.47	1.058

Note: M means average and S means standard deviation; for some cases are considered the median for greater precision.

In the case of P.14 (M = 2.82) the average cannot be considered because there is no differentiation between the results. That is why the median (2.50) was taken into account, because it is close to the "*disagree*" value, which indicates that 50% of respondents have a position of disagreement regarding the price of the services. tourism is accessible.

In Q.15 (M = 2.97), it is considered as if the respondents have chosen on average "*Neither agree nor disagree*", however, it has been compared with the median due to the distribution of the data, because given The percentage results show that both 50% had a positive opinion and the other 50% had a negative opinion regarding whether the price of transportation is affordable to go to the ANP.

In Q.16 (M = 2.81), if applicable, the median (2.00) was considered more precisely, because the result was that 50% of the respondents thought that they disagreed with the fact that they receive price information about the services. tourist services offered in the ANP CCEA, so it is inferred that more information should be disseminated about the prices of the tourist services offered to the ANP.

On P.17 (M = 2.60) it was shown that the respondents disagree that the ANP information offered by travel agencies is complete, so it follows that more information is necessary in the agencies about the ANP CCEA.

In Q.18 (M = 4.11) it was observed that on average potential visitors opt for the "*agree*" option depending on whether travel agencies have been a means to develop tourism in the ANP.

In Q.19 (M = 2.81) it was presented that on average they "*disagreed*" that if the price has been economical it means low quality, so it is inferred that a low price does not necessarily mean that the product or service is bad.

In Q.21 (M = 4.33) it was shown that on average potential tourists "*agreed*" to inform others about the existence of the ANP.

In Q.22 (M = 2.47) it was shown that potential visitors on average "*disagreed*" that the information on the ANP's tourist resources is complete. It follows that it is essential that there is more information about the tourist resources of the ANP CCEA so that tourists have greater reach.

Table 6. Results of the Pearson Chi-Square and Fisher's exact tests to observe the relationship between the questions based on gender, age, marital status and origin (for some cases).

Items		**Pearson Chi-Square**	**Fisher's exact**
	Associate	***p***	***p***
They recommended visiting the destination (P.5)	Origin	.026	.182
What is the social network you use the most to choose a destination? (P.7)	Gender	.6	.041

Note. Pearson's chi-square and Fisher's exact were applied to all questions with suggested and nominal answers, not considering the Likert scale (ordinal), in addition, the Fisher Test is taken into account when the percentage value is greater than 20% in the Chi-Square test.

Table 6 presents the questions that are related to the moment of associating them (gender, age, marital status and origin). It is necessary to mention that the two statistical tests were carried out for each question (suggested and dichotomous answers), but in the For the most part, this associativity has not been relevant.

For question 5, it was shown that for the Pearson Chi-square test (p = .26) there is a relationship between the question and the origin, however, the validity is 75%, that is, it exceeds the 20% that is considered. For this reason, we took into account Fisher's Exact Test (p = .182) because it has greater precision, which showed that there is no relationship between respondents from different places depending on whether they recommended visiting the destination. This infers that the perspective that the respondents have of the different places in Peru and abroad is the same, because they did recommend the place to other people.

Similarly, for question 7 the Fisher exact test is taken into account (p = .041), because the Pearson Chi square test (p = .6) is higher and its result is 100% valid, for this reason is discarded. So, we can say that based on the question and the generated, it turned out to be related, so it can be deduced that women mostly use WhatsApp when choosing a tourist destination.

Table 7. Results of the Mann-Whitney U test to observe the differences between the questions based on gender and question 2 (for some cases).

Items	**Associate**	***p***
Do you believe that there is enough advertising or tourist advertisements in the ANP Coto de Caza El Angolo (P.11)	Gender	.017
Travel agencies are a means by which tourism development is generated in the ANP Coto de Caza El Angolo (P.18)	Question 2	.03

Note: Non-parametric data , which have been significant, have a P (test value) of less than 5%

Table 8. Results of the Kruskal-Wallis test to observe the differences in the questions depending on age, marital status and origin.

Items	Associate	*p*	RE	Sig
Do you think that an influencer would have more impact when choosing the ANP Coto de Caza El Angolo as a tourist destination? (P.10)	Age	.027	18 to 30 - 31 to 50	.009
The Price of transportation to get to the ANP Coto de Caza El Angolo is affordable (P.15)	Origin	.026	North-Central	.016
			North-International	.03
The information on the various tourist resources available in the area where the ANP Coto de Caza El Angolo is located is complete. (P.22)	Age	.014	51 to 80 – 18 to 30	.014
			51 to 80 – 31 to 50	.005

Note: Non-parametric data, which have been significant, have a P (test value) of less than 5%, RE means the relevant ranges and Sig refers to the level of significance.

Regarding the non-parametric Mann-Whitney U tests (Table 7) and Kruskal-Wallis (Table 8), associativity was carried out with the questions (Likert scale) based on age, marital status and origin. For the Mann-Whitney U test, the following was obtained:

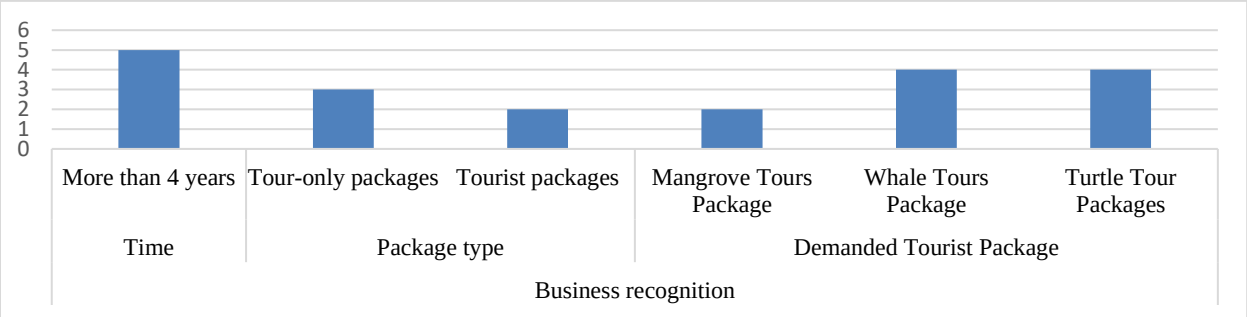
Based on gender, for question 11 with *p* of .017, it was determined that there are significant differences, so it is inferred that the majority of women have a negative perception about the existence of advertising and announcements in the ANP CCEA.

By associating question 2 and question 18 (p = .03), it was shown that there is a difference between people who have gone and those who have not visited the ANP, because the majority of people who visited the place thought that they agreed that the Travel agencies have been a means by which the development of tourism in the ANP is generated, in the same way those that have not gone; However, to a lesser extent, those who did not visit the ANP also chose to disagree with the question. It is worth mentioning that there were 12 people out of the total (100 people) who visited the ANP CCEA, so there is also a difference.

In question 10 (p = .027) and question 22 (p = .014) there were significant differences depending on age; observing for the first question the difference between 18 to 30 and 31 to 50 years (.009); For the second question there is a relevance of 51 to 80-18 to 30 and 51 to 80-31 to 50. Therefore, it is inferred that respondents aged 18 to 50 agree that the influencer affects the choice of the ANP, likewise, that all the ages presented disagree that the information on the ANP's tourist resources is complete.

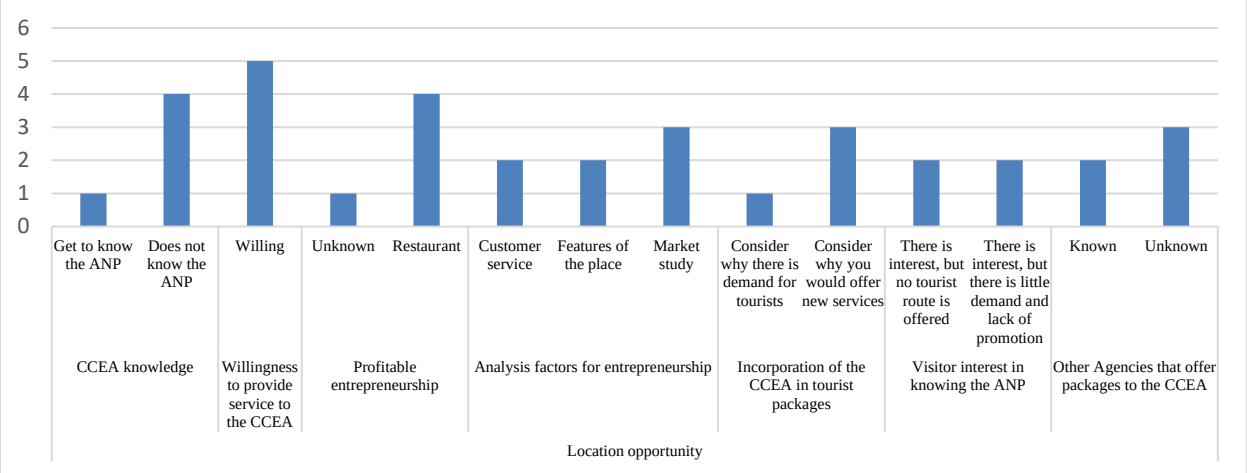
For question 15 (p = .026) based on origin, it showed that there is a discrepancy, since respondents from the north associated with central Peru and the north with international turned out to be more significant. It follows that the price of transportation to get to the ANP is accessible for some people depending on their finances.

In Figure 2 it can be seen that, in the business recognition category, the 5 travel agencies have been working in the city of Máncora for more than 4 years. In addition, it is shown that 3 travel agencies offer tour-only packages, which consists of a full day, while 2 agencies offer tourist packages, which incorporate lodging, transportation and tours. Finally, 4 tourist agencies mentioned that the most requested tourist package is the Whale and Turtle Tours.



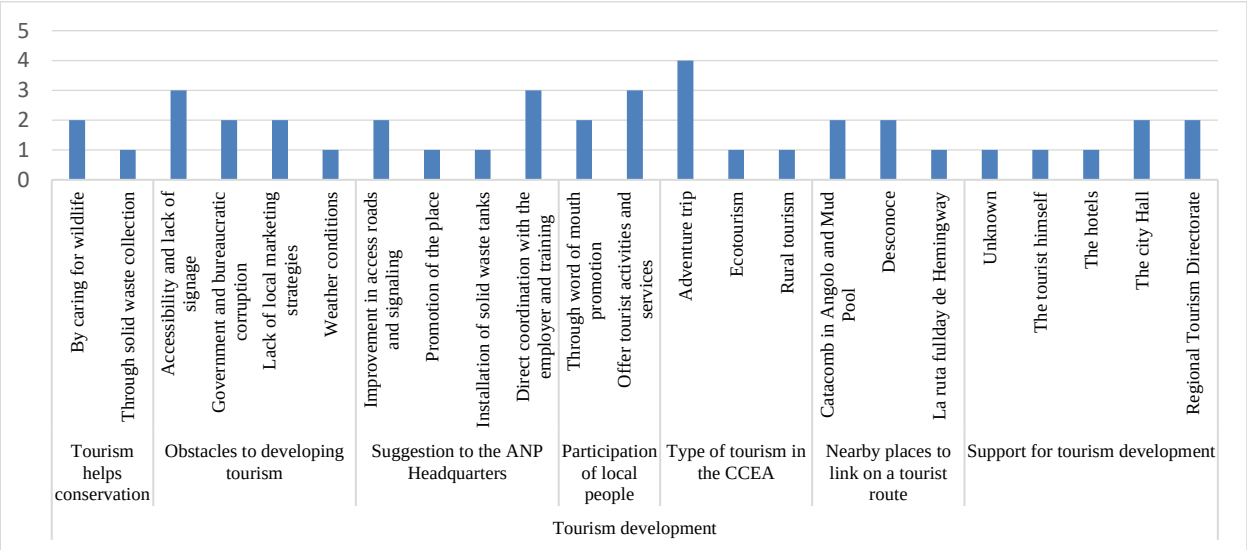
Source. Data collected from interviews with Máncora travel agencies.

Figure 2. Business recognition.



Source. Data collected from interviews with Máncora travel agencies.

Figure 3. Location opportunity.



Source. Data collected from interviews with Máncora travel agencies.

Figure 4. Tourism development.

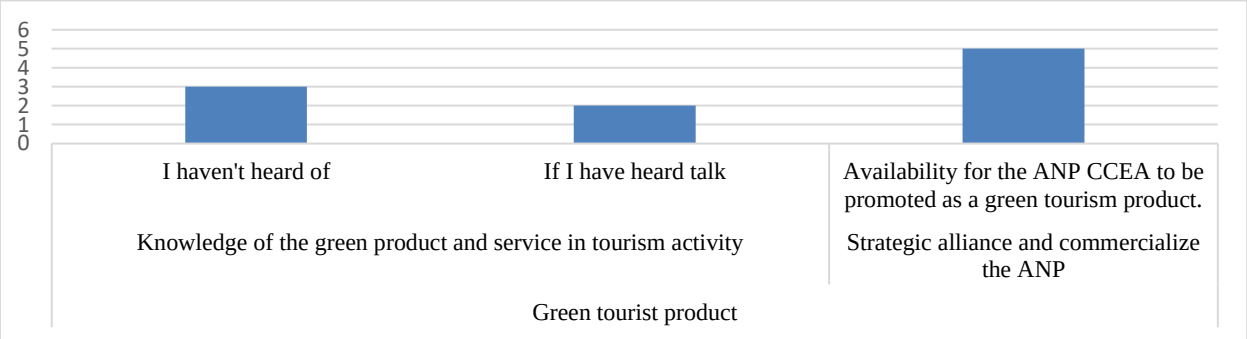
Figure 3 shows the Place Opportunity category of the ANP CCEA, demonstrating that, of the 5 travel agencies interviewed, only 1 knows the ANP CCEA, but 2 do know of travel agencies that provide packages to that ANP, being A very important factor, however, is that all agencies would be willing to offer tourist services to the ANP, taking into account that a profitable venture that could be offered would be a restaurant, as expressed by 4 travel agencies; In addition, to develop a business in the ANP, various factors must be analysed, the most notable being the market study to know the profitability that would be generated by considering a business in the ANP, as stated by 3 travel agencies. Likewise, 3 interviewees considered offering tourist packages where the ANP is incorporated, because it is a new service that would be presented to potential visitors and there is also visitor interest in getting to know the area, however, there is little demand, lack of promotion and They still do not offer it within their tourist route.

Figure 4 presents the category of Tourism Development in the ANP CCEA, of which 2 travel agencies expressed that tourism helps the conservation of nature through the care of fauna in the CCEA. Likewise, 3 agencies mentioned that the obstacles to developing tourism in the ANP have been accessibility and lack of signage, 2 expressed that government corruption and bureaucracy, as well as the absence of marketing strategies for the place.

On the other hand, based on the suggestions made to the area headquarters for the development of tourism in the CCEA, the majority of 3 agencies stated that there should be direct coordination with businessmen and that, in addition, training on the ANP CCEA, both to residents and service providers.

Likewise, 2 of the agencies interviewed mentioned that the greatest support for the development of tourism in the ANP CCEA has been from the Municipality and the Regional Directorate of Foreign Trade and Tourism. However, the local population has participated through word-of-mouth promotion, as expressed by 3 travel agencies and 2 indicate that they are involved in offering tourist activities and services to potential visitors.

Finally, the type of tourism most meaningful to those interviewed was adventure tourism, as stated by 4 travel agencies. Among the nearby places that can be linked for a tourist route with the ANP CCEA, 2 agencies indicated that it has been the Catacumba del Angolo and the mud pool.



Source. Data collected from interviews with Máncora travel agencies.

Figure 5. Green tourist product.

Figure 5 displays the Green Tourism Product category, demonstrating that, of the 5 travel agencies interviewed, 3 agencies mentioned that they had not heard about the green product and service in tourism activity, while 2 of them expressed that yes they heard those terms. However, all the agencies stated that they would be willing to be part of a strategic alliance to promote the ANP CCEA, as a green tourism product.

DISCUSSION

According to the results of the research, it was determined that, from the population sample of visitors to the city of Máncora, 12 potential tourists visited the ANP CCEA, according to their perspective the area has an image of an ecological and resting place, where You can do activities such as trekking, bird watching, cycling and photography. In addition, they would recommend visiting the destination because you enjoyed the experience. Similarly, in Martínez's research, the research visitors recommended going to the place visited and considered the place a profile of a cultural destination (Martínez, 2017). In addition, potential tourists received information about the tourist destination through advertising in the mass media and the Internet; in addition, they would like the content of the advertising to have messages and promotions, since there is little advertising of the tourist services offered by travel agencies. trips on the ANP and opt for affordable prices regarding tourist services and transportation because their average expense is S/100 to S/200, but that does not mean that the services or products have low quality compared to the price. For Muñoz's study, the tourist services to the Galapagos and Sumaco reserve that the residents offer have low quality standards, their target audience being tourists who have a more economical budget.(Muñoz, 2017).

On the other hand, the second specific objective of the research is to know the perception of travel agencies regarding the ANP CCEA as a tourist destination. It was evident that, of the 5 travel agencies interviewed, only 1 knew about the ANP, however, the 5 agencies mentioned that they would be willing to provide tourist services in the ANP CCEA and integrate it into their tourist packages, because in this way they would offer new services to potential visitors, since there is interest among tourists in knowing this area, however, they have not yet They provide it on a tourist route, due to the low demand. Therefore, the sites and activities must be oriented according to the needs of the tourist.(Sánchez-Mojica et al., 2022).

Among the places that can be taken into account to establish a tourist route in the ANP CCEA, they indicated that it is the Catacumba del Angolo and mud pool. On the other hand, attractions such as: the glacial Sollipulli volcano, Araucaria and the Hualalafquén lagoon complement the development of tourism in the tourist destination of Pucón, since they are located in a strategic area (Garin & Quinteros, 2020). On the other hand, the elements that can be considered within the "*The soul of Don Vasco*" circuit, Pátzcuaro, Mexico, are the viewpoints, the lakes, the gastronomy and the heritage festivals. (García & Mercado, 2023).

Likewise, the profitable venture that they could incorporate into their tourist packages has been a restaurant in the ANP CCEA as a business opportunity, as indicated by 4 travel agencies. Furthermore, in their opinion, various factors should be analysed, which were the good customer service, knowing the characteristics of the place and carrying out a market study, the latter being the most relevant among those interviewed. According to the perception of the interviewees, the majority mentioned that the biggest obstacle that exists to developing tourism in the ANP CCEA has been accessibility and lack of signage. On the other hand, the study by Mazo and Cortes aimed to develop an explanatory format to develop competence in tourist destinations for seniors, according to the interpretation of the concepts and tourism managers, in the case of Tabasco, Mexico, which is why it was obtained as a result, the managers suggest to the State that adequate infrastructure for each target audience be established in all tourist sites and commercial sectors. In addition, other factors that would contribute to the development of tourism in Tabasco have been having roads and appropriate public transportation (Mazo Quevedo & Cortés Puya, 2020).

Consequently, they mention that the local population has become involved through word of mouth promotion and also by offering activities and services to the ANP CCEA. According to Mazo y Cortes, in their results, they stated that the tourist promotion of Tabasco as a tourist destination does not reach the entire public,

especially the elderly groups, which is why it is necessary that they be carried out through TV, radio or newspapers, to be able to reach that segment of visitors, since social networks are not an appropriate medium (Mazo & Cortés, 2020).

Regarding whether the agencies know the term green product, they state that they do not know about it, but there is a predisposition on the part of the agencies to be part of a strategic alliance, to promote and market the ANP CCEA as a green tourism product. Likewise, the agencies believe that tourism has helped conserve the ANP CCEA through the care of the fauna. Furthermore, thanks to tourist activity, the development of tourism helps to preserve culture and have a more sustainable use of nature (Garin & Quinteros, 2020). Likewise, they expressed that the type of tourism they would offer in said fight is adventure tourism. Otherwise, Merkez and Yilmaz in their study mention that residents and farmers have a positive perspective on rural tourism, making it a key economic factor for the local population.(Merkez & Yilmaz, 2022).

In this way, they suggested to the area headquarters to coordinate with businessmen, training both residents and service providers and improve access roads and signage so that there is better development of tourism in the CCEA. Therefore, according to the perspective of the interviewees, they express that the municipality and the regional tourism management support the development of tourism in the ANP CCEA. However, Mazo and Cortés in their study obtained the results that tourism managers perceive slow the development of tourism in Tabasco, due to the little investment interest in the tourism sector on the part of the authorities (Mazo & Cortés, 2020). Likewise, for Garin and Quinteros, the interviewees stated that municipal management has not supported the development of tourism, with respect to the promotion and improvement of tourist conditions, which prevents having a relationship between the private and public sectors.(Garin & Quinteros, 2020).

CONCLUSIONS

The perception of both potential visitors and travel agencies has been significant for this research, because it was determined that 12 people had previously visited the ANP CCEA, of whom they thought that the area had an image of an ecological and resting place. , in this place you could carry out tourist activities such as: trekking, bird watching, cycling, hiking and taking photographs, in addition, they recommended visiting the destination to family, friends or acquaintances who were informed about the ANP. It is worth mentioning that two sources from which they received information about the ANP have been through advertising in mass media (press, radio, television) and the Internet (website, social networks, etc.). However, there is little dissemination of the ANP's tourist resources offered by travel agencies that is at the same time complete, because it lacks extensive information. On the other hand, the prices of tourist services and transportation to visit the ANP are not accessible, since they consider that on average they should spend from S/100 to S/200, with a good quality of service, so Prices offered by tourism managers are high.

Equally important, the representatives of the travel agencies in Máncora are unaware of the ANP Coto de Caza El Angolo, however, they show interest in offering it within their tourist packages, given that it is a new service that is shown to potential visitors, and In addition, there is interest among them to know, but they still do not offer it on their tourist route, because there is little promotion and demand. In addition, they say that the type of tourism that could be offered in the ANP CCEA is adventure tourism. Considering the places that could be taken into account to establish a tourist route, the Catacumba del Angolo and the Poza de Barro. However, the restaurant has been the venture that they considered locating within the ANP, but a market study must be carried out to know the profitability, expenses and budget obtained by positioning it.

On the other hand, they show a willingness to be part of a strategic alliance that promotes and markets the ANP CCEA as a green tourism product, having more ecological tourism and also improving conditions such as accessibility and signage to visit the area.

AUTHOR CONTRIBUTIONS

Apaza-Panca, Watanabe, and Mamani conceived and designed the study; Tavara, Ortiz, Girón and Olaguivel collected, processed and analysed the data. All authors wrote the article and approved the final submission.

SUPPORTING AGENCIES

No funding agencies were reported by the authors.

DISCLOSURE STATEMENT

No potential conflict of interest were reported by the authors.

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ORIGINAL ARTICLE

Combined futsal training: The combination of rotation play training with the HIIT protocol affects anaerobic endurance abilities

AYYALA HAQQI THORIQ AS-SAFA, I DEWA MADE ARYANANDA WIJAYA KUSUMA, IMAM SYAFII, DAVID AGUS PRIANTO, YANUAR ALFAN TRIARDHANA , BAYU AGUNG PRAMONO

Department of Sport Coaching Education. Faculty of Sports and Health Sciences. State University of Surabaya. Indonesia.

ABSTRACT

A training model that combines physicality and tactics is really needed in futsal. This study aims to analyse the effect of rotation play training with HIIT Protocol on the anaerobic abilities of amateur futsal players. This research uses an experimental method with a two-group pre-test and post-test design. The sample in this study consisted of 30 amateur futsal players with an age of 19.23 ± 0.57 years, height of 165.60 ± 5.63 cm, body mass of 59.17 ± 5.24 kg, and BMI of 21.60 ± 1.93. Samples were divided randomly into an experimental group (EG) and a control group (CG). Data analysis used a Paired Sample T-test and an Independent T-test with a significance level of .05 and used Cohen's ES to measure the magnitude of differences between groups. This study used the running anaerobic sprint test (RAST). The variables in RAST that will be analysed are Peak Power (W); Mean Power (W); Peak Power per Weight ($W.kg^{-1}$); Mean Power per Weight ($W.kg^{-1}$); Fatigue Index (%); Total effort time (s). The paired sample t-test resulted in a significant difference in EG with significance values of Peak Power p = .010, Mean Power p = .007, Peak Power per Weight p = .011, Mean Power per Weight p = .008, Fatigue Index p = .045, and total effort time p = .011, while in CG all variables do not have significant differences. The Independent T-test found that there was a significant difference between EG and CG with a significance value of p < .05. This research concludes that the rotation play training model with HIIT Protocol has a positive effect on the anaerobic endurance of amateur futsal players.

Keywords: Performance analysis, Rotation play, High-intensity interval training, Anaerobic, RAST.

Cite this article as:
As-Safa, A. H. T., Kusuma, I. D. M. A. W., Syafii, I., Syafii, D. A., Triardhana, Y. A., & Pramono, B. A. (2024). Combined futsal training: The combination of rotation play training with the HIIT protocol affects anaerobic endurance abilities. *Journal of Human Sport and Exercise, 19*(2), 600-607. https://doi.org/10.55860/0m4zm966

Corresponding author. *Department of Sport Coaching Education. Faculty of Sports and Health Sciences. Universitas Negeri Surabaya. Indonesia.*
E-mail: yanuartriardhana@unesa.ac.id
Submitted for publication December 31, 2023.
Accepted for publication January 30, 2024.
Published April 01, 2024 *(in press* March 04, 2024).
JOURNAL OF HUMAN SPORT & EXERCISE ISSN 1988-5202.

doi: https://doi.org/10.55860/0m4zm966

INTRODUCTION

Rotation play is one of the important things in the game of futsal. Futsal is an intermittent and dynamic sport that involves fast actions and precise movements based on physical parameters, techniques and tactics (Castagna et al., 2009; Mendes et al., 2022; Naser et al., 2017). Rotation play is used to describe the performance of tactics indicated by variables, space, time or tasks that most determine team cooperation and effectiveness in controlling the ball in the sport of futsal (Garganta, 2009). According to Da Cruz et al. (2020); Ohmuro et al. (2020), futsal is a high-intensity game with a short recovery time and requires sound technical and tactical abilities. For this reason, each player must have good skills to carry out tactics and strategies during the match. Specifically, futsal is characterized by players who are constantly moving and rotating positions because by rotating, the players can damage the opponent's defence and create much space to be utilized to score goals.

Anaerobic endurance is a very important physical component to help players perform rotation play quickly and precisely in futsal games because futsal is a sport that involves high-intensity locomotor activity which requires aerobic and anaerobic fitness in matches (Claus et al., 2017; Ribeiro et al., 2020; Rico-González et al., 2022). There have been several previous studies on futsal physical training, but it has not been combined holistically with technical and tactical training Campos et al. (2021); Soares-Caldeira et al. (2014); training focuses only on the physical Paz-Franco et al. (2017); Teixeira et al. (2019). It cannot be denied that the results of this research have had a positive impact on improving the performance of futsal players. However, if reviewed at tactical needs, where futsal requires structured rotation play. It seems necessary to develop training in a holistic direction, namely combining tactical and physical training in one training model. This is supported by previous research, which found that futsal games have certain organizational patterns Zagatto et al. (2009), both attacking and defending, depending on the match situation (Bueno et al., 2018).

In sports coaching, High-intensity interval training (HIIT) is very popularly used to improve physical abilities, especially anaerobic endurance. Previous research has proven that HIIT has a positive effect on players' anaerobic endurance (Kunz et al., 2019; Yan et al., 2022). If we look at the very high physical demands when doing rotation play, combining rotation play with HIIT is crucial, so it is necessary to scientifically review the impact of combining these exercises so that specific futsal training needs can be achieved. The results of this research can help coaches and players create more targeted training programs that combine the tactical and physical elements required in the game of futsal. This research can also provide valuable insight into how the game of futsal at the amateur level can improve.

MATERIAL AND METHODS

Study participants

A total of 30 male futsal players at amateur futsal clubs participated in this research. He is 19.23 ± 0.57 years old, with a height of 165.60 ± 5.63 cm, a body mass of 59.17 ± 5.24 kg, and a BMI of 21.60 ± 1.93. All samples involved have experience playing in amateur leagues. Then, all samples were divided randomly into an experimental group (EG) and a control group (CG).

Study protocol

The treatment and control groups were given a pre-test to determine their initial anaerobic endurance abilities. Next, the treatment group was given rotation play exercises with HIIT protocol for six weeks with a frequency of three times a week. The control group was not given special treatment but continued to undergo exercise with the same duration and frequency as the treatment group. After six weeks of carrying out the research,

in the final week, the treatment and control groups were given a post-test to determine the difference in anaerobic endurance ability with rotation play training with HIIT protocol. This study used RAST. The variables in RAST that will be analysed are Peak Power (W), Mean Power (W), Peak Power per Weight ($W.kg^{-1}$), Mean Power per Weight ($W.kg^{-1}$), Fatigue Index (FI) (peak power – minimum power/peak power) x 100), Total effort time (s) (Zagatto et al., 2009).

Treatment protocol

The treatment group is divided into three groups, which will then take turns carrying out rotation play with HIIT Protocol. Group 1 does rotation play with a predetermined movement pattern with an intensity of 90-95% of the maximum heart rate, while groups two and three wait their turn while passing with moderate intensity. Polar verity sense is used to monitor HR_{max} at a predetermined intensity. The interval used in this treatment is 1:3. Each group does rotation play at high intensity for 2 minutes before taking turns with the next group. In the first and second weeks, each group did eight sets of rotation play, ten sets in the third and fourth weeks, and twelve sets in the fifth and sixth weeks.

Data analysis

The data in this study are presented in the form of mean and standard deviation. The prerequisite tests in this study used the normality test and homogeneity test. The normality test uses the Shapiro-Wilk test, and the homogeneity test uses the Levene test. The percentage change (Δ%) between the results before (Pre) and after (Post) during the training period was calculated using the following formula: Δ% = ((Post-Pre)/Pre)*100. Next, the paired sample test was used to see the differences in the averages of each group and the independent sample test was used to compare the differences in the averages of the experimental group and the control group. Statistical significance was set at $p < .05$. The magnitude of the differences between groups, this study used Cohen's ES. An ES above 0.8 is considered large, between 0.8 and 0.5 is considered moderate, between 0.5 and 0.2 is considered small, and less than 0.2 is considered insignificant (Cohen, 2013).

RESULTS

Table 1 above describes the characteristics of the two research sample groups. Furthermore, the normality test carried out using the Shapiro-Wilk test showed that all variables in the EG group and CG group had a normal distribution with a significance value of Sig > .05. The same thing was also found in the homogeneity test using the Levene test, showing a significance result of > .05.

Table 1. Characteristic of group.

Group	Age (year)	Height (cm)	Body Mass (kg)	BMI
EG	19.00 ± 0.53	163.47 ± 5.38	60.47 ± 4.16	22.65 ± 1.60
CG	19.47 ± 0.52	167.73 ± 5.19	57.87 ± 6.00	20.55 ± 1.67

Note. Data are presented as mean ± SD.

Table 2. The above shows the differences between the EG and CG pre-test and post-test. In the EG group there were significant differences in Peak Power ($p = .010$, ES = 0.73), Mean Power ($p = .007$, ES = 0.79), Peak Power per Weight ($p = .011$, ES = 0.72), Mean Power per Weight ($p = .008$, ES = 0.77), Fatigue Index ($p = .045$, ES = 0.55), and Total effort time ($p = .011$, ES = 0.73). In CG, all variables do not have significant differences.

Table 2. Results of RAST pre and post-test in both groups.

Variable	Group	Pre	Post	Δ%	*p*	ES
Peak Power (W)	EG	543.35 ± 75.52	588.10 ± 113.16	7.61	.010*	0.73
	CG	538.64 ± 66.65	536.76 ± 99.33	0.35	.699	-0.10
Mean Power (W)	EG	418.66 ± 60.93	457.59 ± 73.67	8.51	.007*	0.79
	CG	436.68 ± 54.63	429.36 ± 88.75	1.71	.633	-0.12
Peak Power per Weight (W.kg^{-1})	EG	9.02 ± 1.37	9.74 ± 1.84	7.36	.011*	0.72
	CG	9.31 ± 0.62	9.28 ± 1.41	0.31	.714	-0.09
Mean Power per Weight (W.kg^{-1})	EG	6.95 ± 1.07	7.58 ± 1.18	8.26	.008*	0.77
	CG	7.55 ± 0.56	7.41 ± 1.27	1.84	.602	-0.13
Fatigue Index (%)	EG	43.41 ± 7.16	38.36 ± 6.75	13.16	.045*	0.55
	CG	40.10 ± 6.64	41.89 ± 3.20	4.29	.863	-0.04
Total effort time (s)	EG	34.14 ± 1.87	33.11 ± 1.81	3.11	.011*	0.73
	CG	33.01 ± 0.89	33.42 ± 1.92	1.22	.298	-0.27

*Note. Data are presented as mean ± SD; Δ (%): percentage of change between pre and post-training performance; p: level of significance; ES: effect size; * Significant difference, p < .05.*

Table 3. The above shows significant differences between EG and CG. All variables have a significance value of $p < .05$; this shows that there are significant differences between EG and CG. If viewed from the ES value, Peak Power has a medium effect, Mean Power has a large effect, Peak Power per Weight has a medium effect, Mean Power per Weight has a large effect, Fatigue Index has a large effect, and Total effort time has a large effect.

Table 3. Comparison RAST in both groups.

Variable	EG	CG	*p*	ES
Peak Power (W)	44.75 ± 63.79	-1.88 ± 54.87	.041*	0.78
Mean Power (W)	38.93 ± 50.92	-7.33 ± 48.27	.016*	0.93
Peak Power per Weight (W.kg^{-1})	0.72 ± 1.04	-0.03 ± 0.93	.046*	0.76
Mean Power per Weight (W.kg^{-1})	0.63 ± 0.83	-0.14 ± 0.84	.018*	0.92
Fatigue Index (%)	-5.05 ± 7.65	1.80 ± 7.79	.022*	0.89
Total effort time (s	-1.03 ± 1.46	0.41 ± 1.27	.008*	1.05

*Note. Data are presented as mean ± SD; p: level of significance; ES: effect size; * Significant difference, p < .05.*

DISCUSSION

Rotation play training with HIIT Protocol has a positive influence on increasing anaerobic endurance. Increasing anaerobic endurance is influenced by controlling the contribution of anaerobic energy during training sessions; this is crucial in planning training programs, adjusting training loads, session duration, and its relationship with lactic acid production in muscles, especially after undergoing high-intensity intermittent training (Buchheit & Laursen, 2013). Futsal is a sport that requires good physical condition, especially endurance, because it uses high intensity, so the players need intense training. In the sport of futsal, the intensity used in matches is 75% of playing action, while more than 83% of the rest interval is with a work-to-rest ratio of approximately 1:1, where half of the work is at high intensity, 83% of playing time has been spent above 85% maximum heart rate (HR_{max}) Amani-Shalamzari et al. (2019); Kunz et al. (2019); Therapy et al. (2011). The findings of this study are in line with research Avar et al. (2019), which states that high-intensity interval training (HIIT) is a time-saving strategy to increase anaerobic capacity. Therefore, HIIT has become a suitable resistance training method for anaerobically dominant sports such as futsal.

Intensive training is a routine that is usually carried out by elite athletes in order to improve their physical condition. HIIT may be useful for restoring body composition and quality of physical fitness. However, to optimize performance, intensive training and proper recovery are needed (Gómez et al., 2023). The effort required by each player depends on several factors, such as physical and individual performance, because every futsal sports training program involves aerobic and anaerobic training (Borges et al., 2022). By using 90%-95% intensity for six weeks, players can experience significant improvements in their anaerobic endurance. Intermittent exercise that achieves ≥90% of maximum heart rate and maximum oxygen uptake (VO_{2max}), separated by recovery or rest periods, is an exercise model that is trending towards improving physical condition and fitness (Atakan et al., 2020; Engel & Sperlich, 2014; Faude et al., 2013). High-intensity interval training (HIIT) is defined as a 'near maximal' effort generally performed at an intensity that produces ≥80% (but often 85-95%) of maximal heart rate (Macinnis & Gibala, 2016). The frequency of three times a week is important in this study. It is in line with previous research, which reports that HIIT is effective when performed for three sessions per week for at least six weeks to reduce the phenomenon of negative reactions caused by glycogen depletion, metabolite accumulation in muscles, and neuromuscular tension and so on increasing endurance and athlete performance (Yan et al., 2022).

Anaerobic endurance is continuous with the level of fatigue with a good anaerobic level, it influences the small risk of injury due to fatigue, which results in a decrease in an athlete's performance Güler et al. (2020); Lopes et al. (2019), in line with a significant reduction in the fatigue index of the experimental group who received rotation play training with HIIT Protocol. High-intensity interval training (HIIT) is an effective exercise regimen for improving several physiological parameters important for performance, including cardiometabolic function, oxygen uptake kinetics, strength and anaerobic capacity, ion transport capacity, and muscle fatigue resistance (Hostrup & Bangsbo, 2023).

CONCLUSION

Based on the results of research and discussions about rotation play training with HIIT Protocol, it was concluded that this training method had a positive effect on increasing Peak Power, Mean Power, Peak Power per Weight, Mean Power per Weight, as well as reducing Fatigue Index and Total effort time. Rotation play training with HIIT Protocol can be an alternative physical exercise without eliminating the characteristics of playing futsal.

AUTHOR CONTRIBUTIONS

As-Safa, Kusuma, Pramono conceived and designed the experiments. Syafii, Prianto and Triardhana performed the data collection and analysis. All the authors wrote the paper and approve the final submission.

SUPPORTING AGENCIES

No funding agencies were reported by the authors.

DISCLOSURE STATEMENT

No potential conflict of interest were reported by the authors.

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ORIGINAL ARTICLE

Effect of conditioning activity absolute intensity on seated shot put performance

DIEGO DE ALCANTARA BORBA, LAURA RIBEIRO, YAN LÉO DE MELO VIEIRA, CAMILA FERNANDA COSTA E CUNHA MORAES BRANDÃO, LUCAS RIOS DRUMMOND, LUCAS TÚLIO DE LACERDA

Department of Physical Education. University of the State of Minas Gerais-Divinópolis Unit. Brazil.

ABSTRACT

Conditioning activities are widely used in sports for improving performance in a subsequent main activity. Therefore, understanding the organization of these exercises is important for athletes. Therefore, the objective this study was to evaluate whether the conditioning activity absolute intensity affects the seated shot put performance. Twenty-four physically active male adults were subjected, every 24 hours apart and in a randomized manner, to the following situations: control (no conditioning activity), seat shot 2 kg ball; seated shot 4 kg ball and; seated shot 6 kg ball. Three minutes after these shots, participants performed the seat shot put main activity (4kg). To record the seat shot put performance, the greatest distance of the six attempts was considered. The shot put distance was greater in conditioning activity compared to the control situation ($p < .05$). There was no difference in shot put distance among conditioning activity situations ($p > .05$). In addition, individual analysis using typical error showed that 63% of the participants responded positively to the conditioning activities. In conclusion, despite the beneficial effect of the conditioning activity in relation to the control situation, there was no effect of the absolute intensity of the conditioning activity on shot put performance.

Keywords: Performance analysis, Training, Post-Activation potentiation.

Cite this article as:
Borba, D. D., Ribeiro, L., De Melo Vieira, Y. L., Costa E Cunha Moraes Brandão, C. F., Rios Drummond, L., & Túlio De Lacerda, L. (2024). Effect of conditioning activity absolute intensity on seated shot put performance. *Journal of Human Sport and Exercise, 19*(2), 608-616. https://doi.org/10.55860/wzc9m179

Corresponding author. *Department of Physical Education. University of the State of Minas Gerais-Divinópolis Unit. Brazil.*
https://orcid.org/0000-0001-7982-3517
E-mail: diegoalcantaraborba1@gmail.com
Submitted for publication December 23, 2023.
Accepted for publication January 26, 2024.
Published April 01, 2024 *(in press* March 04, 2024).
JOURNAL OF HUMAN SPORT & EXERCISE ISSN 1988-5202.

doi: https://doi.org/10.55860/wzc9m179

INTRODUCTION

Throwing objects of different shapes and masses is a common task in several sports, such as basketball, handball, American football, athletics, among others. In athletics. shot put is a sport in which the athlete throws a 4 kg or 7 kg iron ball, in the female and male categories, respectively, the greatest horizontal distance possible (World Athletics, 2023).

Performance in a sport or motor task is normally measured by physical values such as speed, in a sprint; duration, as in a Marathon; the height or distance of a jump or even the distance reached by an implement, as in throwing modalities in athletics. Throwing activities are characterized by a combined demand on muscular strength and power capabilities (Terzis et al., 2012). Strength is defined as the greatest capacity to generate tension by one or more muscle groups and power as the product of strength and speed, which is manifested by the ability to perform rapid movements in the face of external resistance (Turner & Comfort, 2022).

The conditioning contraction or conditioning activity (CA) are strength and power exercises, performed before the main activity (MA), used to improve the performance of the latter after a period of interval between them (Zimmermann et al., 2019; Evetovich, Conley and McCawley, 2015). CA can trigger a series of mechanisms of acute and temporary increase in physical performance, known as post-activation potentiation (PAP) (Sale, 2002; Evetovich, Conley and McCawley 2015). The mechanisms related to CA-induced PAP will generate greater excitability in the motoneuron group, resulting in greater recruitment of type IIx motor units, decreased pre-synaptic inhibitions and increased nerve impulse conduction speed (Zimmermann et al., 2019; Rodriguez-Falces et al., 2015; Docherty, Robbins, Hodgson, 2004).

In relation to muscular mechanisms, the increase in the activation of the myosin light chain and the increase in calcium (Ca^{++}) activity are mentioned. According to Rassier (2000), phosphorylation of regulatory myosin light chain (RCL) alters the conformation of the cross-bridges, placing the globular myosin heads in a position closer to the thin actin filaments. The second mechanism is associated with calcium (Ca^{++}) which, according to Batista et al. (2010), there is greater release of calcium by the sarcoplasmic reticulum, increasing its concentration in the sarcoplasm. The increase in sarcoplasmic Ca^{++} can lead to greater interaction with troponin, causing greater release of actin sites for connection of myosin cross-bridges. These two mechanisms may result in an increased capacity to generate muscle tension after a brief period of rest before of the MA (Zimmermann et al., 2019; Terzis et al., 2009; 2012, Wilson et al., 2013).

Various exercises, such as squats, jumps, and sprints, as well as their load configurations have been investigated as triggering PAP and acute improvement in physical performance (2013; Evetovich, Conley & McCawley, 2015; Hancock, Sparks & Kulman, 2015; Turner et al., 2015; Sarramian, Turner & Greenhalgh, 2015; Borba, Lopez & D'al Ferro, 2019). However, it seems that the effects of intensity through the manipulation of different values of CA external resistance (absolute intensity) have been little investigated. Thus, the present study aimed to evaluate how the conditioning activity absolute intensity affects performance in the main activity of seat shot put. As indicated in the literature (Borba et al. 2017), CA is expected to improve performance in seat shot put.

The results of the present study may contribute to a better understanding of the effects of AC intensity on the performance of physical exercises aimed at health, as well as sports performance before training and competition. Understanding the effects of CA can contribute to more effective prescription of physical exercise.

MATERIALS AND METHODS

Ethical procedures and sample

Twenty-four male volunteers participated in the research (Age: 25 ± 7 years; Body mass: 73 ± 13 kg; Height: 1.8 ± 0.1 m; Frequency of physical exercise: 4 ± 2 times a week; Duration: 90 ± 64 min.), after signing the Free and Informed Consent Form delivered by the responsible researcher. The procedures respected the standards of resolution 466/12 for research with human. The present study was approved by the University of Minas Gerais Stat (UEMG) Research Ethics Committee (no: 6.548.895).

For the sample calculation, the Gpower 3.1.9.2 software was used a priori, using the following parameters: effect size = 0.25 (based in Borba et al., 2018; 2019); significance level = .05 and power (1-β) = 0.8; F-test family for repeated measures. The inclusion criteria were: 1) individuals between 18 and 40 years old; 2) physically active individuals. Subjects who did not complete all experimental situations and/or presented any illness or injury that interfered with the exception activities during the stipulated experimental period were excluded from the sample.

Experimental design

This is an experimental and cross-sectional study with repeated measures, in which the subjects participated in four experimental situations, in addition to familiarization with the procedures, in a randomized manner and with a 24-hour interval between them:

a) Control (main activity only - official 4 kg shot put implement).
b) 2 kg ball throw followed by official shot put implement (2kg+4kg).
c) 4 kg shot put implement followed by the official shot put implement (4kg+4kg).
d) 6 kg ball throw followed by official shot put implement (6kg+4kg).

The first exercise is the CA and the second the MA. The greatest distance in six attempts was recorded as the seat shot put performance (meters).

Procedures

1st) On the first visit, the subject answered the readiness questionnaire to practice physical exercise. If the subject was in the habit, he was subjected to anthropometric measurements. Such measurements were carried out in the Physiology and Metabolism Laboratory located at the UEMG. Next, the subject was familiarized with the CA and MA.

2nd) In the second and other visits, the subject underwent experimental interventions in a randomized manner. The interval between the CA and MA was three (3) minutes. In the control situation, there was no CA, only the MA. The experimental situations took place in a flat, grassy area measuring approximately 100 m^2 located at the UEMG. Both CA and MA consisted of six throws. To record the seat shot put performance, the greatest distance of the six MA attempts was considered.

CA familiarization session

Two series of three throws were performed with each overload of CA (2kg, 4kg or 6 kg) in this order. Every three throws were given a 30-second interval. In the seat shot put, the volunteers remained seated in a chair with their back resting against the backrest; feet fixed on the ground holding the implement with both hands at chest height, touching the thumbs to the sternum; elbows open (away from the midline of the trunk) as suggested by Borba et al. (2019). Without losing contact with the back of the chair and feet with the ground, the participant threw the ball (or shot put 4kg implement) with both hands, extending the elbows. The throwing

angle was established using a goniometer (Universal, CARCI®, Brazil) positioned with the centre at the midpoint of the shoulder, so that the side of the trunk and the arm form an angle of 20º. Furthermore, a horizontal ruler was placed and adjusted in front of the participant to guide the angle and direction of the throw. This form of throwing was chosen in order to minimize the participation of the lower limbs. Furthermore, the seat shot put technique is an easy for beginners to assimilate and learn (Jayaraman, 2015). All procedures were carried out between 2:00 pm and 4:00 pm, Monday to Friday.

Measurements

To describe the characteristics of the participants, height and body mass were measured using a digital scale with a stadiometer (Welmy®, Brazil) on the first day of the visit. Both body mass (kg) and height (m) were measured, with the volunteer wearing light clothing and barefoot. When stepping on the scale, the participant stood with their eyes facing the horizon. The researcher then recorded body mass and then positioned the stadiometer over their head to measure height. The participants' age, sex, weekly frequency, duration and type of physical exercise were also recorded. The estimated time for these measurements was 10 to 15 minutes and carried out by the same evaluator.

The seat shot put distance (MA performance), was measured with a tape measure to the nearest meter and centimetre. The zero point of the tape measure was positioned on the edge of the seat. The measuring tape was then stretched to the edge of the mark made by the implement on the ground closest to the zero point.

As control variables, rating of perceived exertion (RPE), total quality of recovery (TQR) and ambient dry temperature were collected. RPE was measured using the Borg scale from 0 to 10 adapted by Foster (2001), in which 0 means rest or not at all tiring and 10 means maximum effort. It would be applied five minutes after each experimental session. The TQR, in a similar sense, is a scale that starts at number 6, not recovered at all, and progresses to number 20, fully recovered, being applied at the beginning of the experimental sessions (Kenttä & Hassmén, 1998). The ambient temperature was checked at the during of each experimental session using a mercury thermometer.

Statistical analysis

Data were presented as mean ± standard deviation. Repeated measures ANOVA was used to compare performance between situations. The Mauchly and Shapiro-Wilk tests were used to analyse the sphericity and normality of the data. To determine the location of differences, Scheffe post hoc was used. The significance level for statistical difference adopted was less than 5%. The effect size of differences between situations in a pairwise manner was estimated using Cohen's d calculation for paired samples. Data were analysed using JAMOVI software version 2.3.28.

Furthermore, the volunteers' individual response to the intervention was assessed using typical error (Healy and Comyns, 2017). The mean and standard deviation (SD) of the control situation shot put distance for each participant were calculated. The positive effect of CA was considered when the high try shot put distance was 1.5 x SD greater than the average in the control situation. When the high try subject's performance was 1.5 x SD lower than the average in the control situation, the effect of CA was considered negative. Finally, if shot put performance was within ± 1.5 x SD of the mean, it was considered non-responsive to CA.

RESULTS

The repeated measures ANOVA indicated that the shot put distance was greater in situations with CA compared to control ($F = 7.03$; $p = < .001$; $\eta^2p = 0.023$). There was no statistical difference between the other

comparisons ($p > .05$). In addition, there was no statistical difference for the variable TQR ($F = 1.78$; $p = .16$), RPE ($F = 2.29$; $p = .08$) and ambient temperature ($F = 1.03$; $p = .38$) among situations.

Table 1. Comparison of the seat shot put distance among experimental situations.

Situations	Mean	Standard deviation (m)
Control	3.88	0.510
2KG*	4.05	0.557
4KG*	4.06	0.568
6KG*	4.08	0.609

*Note. *Higher than control (p < .05). Cohen effect size: Control x 2kg = 0.7; Control x 4kg = 0.75; Control x 6kg = 0.71.*

Individual analysis using typical error indicated that the majority of participants responded positively to the CA, especially the 2kg situation. There was no negative response to the effects of CA (Table 2).

Table 2. Individual response to conditioning activity protocols.

Participant	Control mean	Control standard deviation	Inferior limit	Superior limit	2kg	4kg	6kg
P1	4.04	0.36	3.51	4.58	Positive	Positive	Neutral
P2	4.06	0.18	3.79	4.33	Positive	Neutral	Neutral
P3	4.59	0.14	4.37	4.80	Positive	Positive	Positive
P4	3.93	0.20	3.62	4.23	Neutral	Positive	Neutral
P5	3.81	0.10	3.66	3.96	Positive	Neutral	Positive
P6	3.67	0.21	3.35	3.99	Neutral	Neutral	Positive
P7	3.44	0.19	3.15	3.72	Neutral	Neutral	Neutral
P8	3.41	0.27	3.00	3.81	Neutral	Neutral	Positive
P9	3.58	0.18	3.30	3.85	Neutral	Positive	Positive
P10	3.37	0.07	3.25	3.48	Positive	Positive	Positive
P11	3.18	0.11	3.01	3.35	Positive	Positive	Neutral
P12	2.95	0.09	3.51	4.58	Positive	Neutral	Neutral
P13	2.93	0.36	2.38	3.47	Positive	Positive	Positive
P14	3.05	0.07	2.94	3.15	Positive	Positive	Positive
P15	3.85	0.32	3.36	4.33	Neutral	Neutral	Neutral
P16	4.05	0.29	3.61	4.49	Positive	Positive	Positive
P17	3.23	0.12	3.06	3.41	Positive	Positive	Positive
P18	4.33	0.36	3.79	4.87	Neutral	Neutral	Neutral
P19	4.03	0.15	3.80	4.26	Positive	Positive	Positive
P20	3.13	0.07	3.03	3.23	Positive	Positive	Positive
P21	4.67	0.54	3.86	5.47	Positive	Positive	Positive
P22	3.20	0.28	2.78	3.62	Neutral	Positive	Neutral
P23	3.61	0.19	3.33	3.89	Neutral	Positive	Neutral
P24	3.88	0.25	3.50	4.26	Positive	Neutral	Positive
Positive responses to conditioning activity					66%	62%	58%

DISCUSSION

The objective of the present study was to evaluate whether the absolute intensity of the conditioning activity (CA) would affect shot put performance. The results indicated that the CA seat shot put distance situations

were greater compared to the control situation, which indicates the presence of post-activation potentiating (PAP) phenomenon. However, the CA absolute intensity did not interfere int the seat shot put performance.

Previous studies have also found improvement in shot put performance following CA protocols. Terzis et al. (2012) evaluated the effect of three counter-movement jumps and, at another time, a 20 m sprint on the shot put distance in subjects trained. The shot put distance was greater after the jumps (15.85 ± 2.41 m vs. 15.45 ± 2.36 m, p = .0003) and the sprint (15.90 ± 2.46 m vs. 15.34 ± 6 2.41 m, p = .0007) compared to the control situation. The authors attribute the results to PAP caused by the CAs performed.

In the same sense, Borba et al. (2018) would evaluate the effect of two sets of five maximum repetitions on the bench press on the shot put distance in untrained male subjects. The shot put distance was greater in the bench press CA in the compared to the control situation (8.2 ± 1.2 m vs. 7.8 ± 0.8 m; p = .009). Once again, the authors attribute the acute improvement in performance to PAP mechanisms triggered by CA.

Still on this topic, Evetovich, Conley and McCawley (2015) investigated the effect of three maximum repetitions in the bench press and three maximum repetitions in the squat on shot put performance in university athletes of both sexes. Contrary to previous studies, there was no effect of CA squats on shot put distance. However, the shot put distance increased after performing the bench press CA compared to the control situation (11.91 ± 1.81 m vs. 11.77 ± 1.81; $p \leq .05$). The authors attribute the result to the specificity of the muscle group involved in CA of the upper limbs (bench press) compared to CA performed on the lower limbs (squat). Furthermore, despite probably having increased central activation, it can be thought that the lack of CA effect on the lower muscles is due to the non-activation of the local muscular mechanisms involved in throwing. Therefore, it can be imagined that central and muscular mechanisms have different importance in PAP, at least for the main throwing activity.

In general, the mechanisms related to PAP are related to the increase in the conduction speed of nerve impulses to the muscle and greater activation of type IIx motor units (Rodriguez-Falces et al., 2015). CA generates greater excitability in the set of motoneurons, resulting in greater recruitment of motor units, decreased pre-synaptic inhibitions and increased nerve impulse conduction speed (Docherty, Robbins, Hodgson, 2004),. At the muscular level, studies indicate that CA improves the positioning of contractile filaments and greater availability of ion calcium (Ca^{++}) from the sarcoplasmic reticulum (Rodriguez-Falces et al., 2015; Docherty, Robbins, Hodgson, 2004). Thus, all these adjustments increase the muscle's ability to generate tension and speed movements.

Adding, Zhi et al. (2005) reports that greater manifestations of PAP occur in trained individuals, due to the fact that this group has greater ease in recruiting type IIx motor units compared to untrained individuals. Kristiansen et al. (2016), explain that this fact occurs because this motor unit has a greater capacity for phosphorylation of myosin light chains, along with a CA. However, untrained individuals may also experience a PAP improved performance after performing CA (Borba et al., 2018; 2019), which corroborates the results of the current study.

The present study obtained results similar to those in the literature, showing an improvement in seat shot put performance after the CA protocols, which probably activated one or more PAP mechanisms. However, differently from the literature, the present study sought to evaluate different degrees of absolute CA intensity on strength/power performance. However, the results did not indicate a different effect between absolute intensities in triggering PAP in a throwing activity. It was expected that greater CA intensities would result in greater distances, due to the greater probability of greater recruitment of type IIx motor units, for example.

Perhaps the best explanation for the lack of difference in performance between CA situations is due to the impossibility of identifying the value of the relative intensity imposed on each participant. For example, Fukutani et al. (2014) showed, in plantar flexion, the extent of PAP was significantly larger as the conditioning contraction intensity increased up to 80% maximal voluntary contraction (MVC). In contrast, the extent of PAP in thumb adduction increased significantly only up to 60% MVC ($p < .05$), but not at higher intensities. Thus, these results indicate that the effects of CA intensity depend on the group or muscle action evaluated.

Still on this topic, the difficulty in throwing probably varied among participants due to differences in strength capacity among them. In other words, the relative muscular tension during the throwing of the 2 kg ball in a weaker subject could be similar to the tension generated by a stronger subject when throwing the heavier ball, which would equalize the situations among the participants. Therefore, the relative intensities used would be similar in terms of the magnitude of the PAP mechanisms. Finally, the results of the present study also do not rule out the hypothesis that greater differences between the intensities of CAs are necessary. The values used in the present study were in the range of 100 to 200% difference between the CA loads. It may be that greater intensities are necessary to find differences among situations used.

Regarding individual analysis (typical error), the present study showed that the majority (63%) of participants responded positively to the intervention with CA. This type of analysis is mainly justified in the sporting world. It is important as some athletes may respond, be indifferent, or even reduce performance after a CA (Zimmermann et al., 20219). For example, on a track and field relay race team, it is possible that two of the best athletes of the four members present negative responses to CA. However, the coach assumes that CA is beneficial for the group. Thus, the decision could harm its best athletes and compromise the team's results. Therefore, it is suggested that in addition to the average CA results, analysing individual responses is relevant in the sporting context.

The present study is not free from limitations. As described, the physiological mechanisms associated with PAP were not measured. Therefore, it is suggested that new studies add measures to the physiological variables related to PAP. Furthermore, the present study was not able to identify the relative intensity applied by the volunteers. Therefore, it was not possible to guarantee similar tensions between participants in each situation.

CONCLUSION

The results of the present study indicated that the conditioning activity absolute intensity does not affect seat shot put performance. However, the conditioning activities were able to trigger post-activation potentiating, since the seat shot put distance was greater compared to the control situation. Overall, participants responded positively to the conditioning activity effects. Future studies with higher the conditioning activity intensities, prescription based on relative intensity, as well as measurements of the physiological mechanisms that trigger post-activation potentiating are indicated to improve the understanding of the conditioning activities effects on physical and sports performance.

AUTHOR CONTRIBUTIONS

Borba, D. A.: Design of the study question; construction of the study design; data analysis; article writing; review of the article final text. Ribeiro, L. Construction of the study design; data analysis; data collection; article writing; review of the article final text. Lacerda, L. T. Construction of the study design; data analysis; article writing; review of the article final text. Brandão, C. F. C. M.: Article writing; review of the article final

text. Vieira, Y. L. M.: Data collection; review of the article final text. Drummond, L. R.: Article writing; review of the article final text.

SUPPORTING AGENCIES

No funding agencies were reported by the authors.

DISCLOSURE STATEMENT

No potential conflict of interest were reported by the authors.

ACKNOWLEDGMENT

The authors would like to thank the Pró-Reitoria de Pesquisa e Pós-Graduação from Universidade do Estado de Minas Gerais for their support.

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ORIGINAL ARTICLE

Analysis of the effectiveness of different play types in the end of game possessions of close EuroLeague matches

PANAGIOTIS FOTEINAKIS[1], STEFANIA PAVLIDOU[1], NIKOLAOS STAVROPOULOS[2]

[1]*Department of Physical Education and Sport Science. Democritus University of Thrace. Komotini, Greece.*

[2]*Laboratory of Biological Evaluation of Human Performance. School of Physical Education and Sport Sciences. Aristotle University of Thessaloniki. Thessaloniki, Greece.*

ABSTRACT

End-of-game possessions during the final minutes of a game often have a significant impact on the final result of the match. The purpose of the present study was to analyse the structure and efficacy of possession play types in the last two minutes of the fourth quarter and overtime of EuroLeague close matches and relate them to the result of the game. The offensive play types of 90 EuroLeague games were analysed. 955 end-of-game possessions were analysed and categorized into 11 predefined play types. Sport Scout STA software was used as the observation instrument. The results indicated that the isolation (ISO) play type (23.6%) had the highest frequency, while Hand-Off (0.63%) was the least frequent play type. Cut (CUT) play type was the most effective (82.4%), producing 1.58 Points Per Possession (PPP), followed by PB (69%), and 1.33 PPP. Post Up, ISO, and Spot Up play types were the least effective, producing 0.78–0.98 PPP. Winning teams had longer-lasting possessions compared to defeated teams. Longer-lasting possessions were less effective than possessions that lasted less than 6 seconds. More cooperative play types increased the efficacy of possessions at the end of the game.

Keywords: Performance analysis, Sports performance, Basketball, Offensive actions, Crunch-time, Efficacy, EuroLeague.

Cite this article as:
Foteinakis, P., Pavlidou, S., & Stavropoulos, N. (2024). Analysis of the effectiveness of different play types in the end of game possessions of close EuroLeague matches. *Journal of Human Sport and Exercise, 19*(2), 617-630. https://doi.org/10.55860/rj38hm02

Corresponding author. *Department of Physical Education and Sport Science. Democritus University of Thrace. Komotini, Greece.*
E-mail: pfotinak@phyed.duth.gr
Submitted for publication January 16, 2024.
Accepted for publication January 19, 2024.
Published April 01, 2024 *(in press* March 04, 2024).
JOURNAL OF HUMAN SPORT & EXERCISE ISSN 1988-5202.

doi: https://doi.org/10.55860/rj38hm02

INTRODUCTION

End-of-game possessions in basketball have become more and more important in the last few seasons. According to EuroLeague, 42% of the regular season games were decided by two possessions or fewer in season 2022-2023 (Euroleague.net). The offense is arguably one of the major components of the game, especially at the end, where a single shot can determine the result of the game. Game management from the coach and the selection of a certain play type may be critical to the team's win or loss (Christmann et., 2018). Knowing the time and score and how to handle the end-of-game possessions in close games will usually determine the outcome of the game, changing the impact of the fan's perceptions regarding how a team played (Bashuk, 2012).

Once the clock hits the last two minutes of the fourth quarter, the offensive demeanour changes. Coaches, along with the players, organize their offensive actions to maximize the offensive chances for scoring points (Peraica, 2022). Identifying these offensive play types can become a determining factor in improving decision-making and tactical performance during the match, as it will create the best opportunities to find the most efficient and repeatable ways of scoring with the least opposition, thus creating uncontested shots or reasonably high percentage shots (Christmann et., 2018, Matulaitis and Bietkis, 2021, Skinner, 2012). These offensive strategies usually involve planned or improvised technical and tactical manoeuvres that are trying to disrupt the defensive setup (Peraica, 2022).

Previous research has evaluated offensive performance through statistical and observational analysis. Besides studies observing parameters that distinguish winning and losing teams (Csataljay et al., 2012, Sampaio and Janeira, 2003, Çene, 2018, Stavropoulos et al., 2021, Karipidis et al., 2001, Fotinakis et al., 2000), other studies analysed the efficacy of offensive actions and their effect on the outcome of the game, such as transition (TR) (Christmann et al., 2018, Matulaitis and Bietkis, 2021, Fotinakis et al., 2002, Tsamourtzis et al., 2005), Pick and Roll (PnR) ball-handler (PnRBH) and screener (PnRSC) actions (Gómez et al., 2015, Marmarinos et al., 2016, Vaquera et al., 2016, Koutsouridis et al., 2018, Polykratis et al., 2010), isolation (ISO) actions (Christmann et al., 2018, Matulaitis and Bietkis, 2021, Zukolo et al., 2019, Garefis et al., 2006), off-ball screen (OBS) actions (Matulaitis and Bietkis, 2021, Gómez et al., 2015, Stavropoulos et al., 2021), hand-off (HO), cuts (CUT), spot-up (SUP) plays and post up (PUP) actions (Christmann et al., 2018, Zukolo et al., 2019), and inbound (IN) plays (Christmann et al., 2018).

Through the categorization of the play types, we can better understand the interactions of the players during the games and the contribution of each play type to the result of the offense. These patterns or actions are designed by the coaches, heavily practiced by the players, and then repeated in the game (Chen et al., 2023). Understanding how teams generate successful scoring throughout the play types is practically and theoretically pivotal (Christmann et al., 2018).

Situations in the end phase of the game are evaluated as highly critical, and the decision-making behaviour of the players is of lower quality compared with situations that are characterized as low-critical situations (Bar-Eli and Tractinsky, 2000). According to Christmann et al (2018), "*The crunch time is not only spectacular and thrilling; it is also particularly competitive and ensures, perhaps unlike some 'blowout' games, the full effort of all players on the floor*". Combined also, with the increased criticality of the end-of-game possessions in games with a balanced score (close games), since they are decisive for the outcome, it is crucial to gain knowledge of the successful play types at the end of the game. Understanding how these play types contribute to offensive success provides a framework for refining strategies, optimizing player strengths, and addressing weaknesses, serving as a powerful tool for dissecting basketball dynamics, enhancing decision-

making, and ultimately influencing the positive outcome of offensive sequences (Lamas et al., 2015, Remmert, 2003).

Despite the increased interest in providing insights regarding the play types that are used during the game, there is a lack of research regarding what is effective or problematic in the last possessions of the game. Studies specifically examining end-of-game situations within close games are rare (Christmann et al., 2018, Prieto-Lage et al., 2022). The purpose of the present study was to analyse the structure and efficacy of the possession play types that the teams are using in the last two minutes of the fourth quarter and overtime of EuroLeague close games, relate types of play to scoring outcomes, and classify their effectiveness regarding the result of the game.

MATERIAL AND METHODS

Participants and data collection

The sample consisted of 90 close games from the 2022-2023 (n = 45) and 2023-2024 (n = 45) regular seasons of the EuroLeague. The games were recorded from the publicly acceded EuroLeague TV (https://tv.euroleague.net/). The selected games were up to a 5-point score differential at the end of the game (close games). All the possessions (n = 1138) that finished within the last 2 minutes of the fourth quarter and overtime (crunch time) of the games were recorded. 183 possessions were categorized as Miscellaneous play types, involved possessions stopped by defenders' intentional fouls or errant passes before the initiation of a play type, or involved possessions with no identifiable play type, which were omitted from play type analyses. The remaining 955 possessions were analysed.

The sample involved all EuroLeague teams. As this study did not involve experimentation of any kind, it was an observational study in a natural environment, and the collected data were publicly accessible, it was not necessary to obtain the informed consent of the competitors (American Psychological Association Ethical principles of psychologists and code of conduct, 2002).

Measures

The categorization of every offensive possession by play type and the variables examined are presented in Table 1. Those play types are actions that are considered standardized and cover all the possible scoring attempts in the game, while they can translate the team's tactical decisions into accountable data (Christmann et al., 2018, Chen et al., 2023, Božović, 2021, McBasketball, 2017).

For the evaluation of the efficacy of the play types, the following variables were analysed during the observation of each end-of-game possession of the games: The result of the game (win-loss), the duration of the different play types possessions (1-24 seconds), the status at the moment of the possession (win, lose, deuce), and the outcome of the possession (made or missed 2-point & 3-point, foul without free throws bonus (FO), foul with bonus free throws (FT), goal fouls (2PF, 3PF) and turnovers (including offensive fouls).

A possession according to the outcome was considered successful in the case that the team scored for two (2p) or three (3p) points, a basket and foul for 2p or 3p (2pF, 3pF), and when the offense received a foul with no bonus free throws (FO) or a foul with bonus free throws (FT1, FT2, FT3). A possession was considered unsuccessful in case the team made a missed shot (-3p, -2p), made a turnover of any kind (TU), and had a blocked shot (BL).

Table 1. Definition and description of the examined play types, the game status at the onset of the crunch time, and the offensive outcome of the possession.

Variables	Definition and description
Offensive Outcome	
Successful	Possession ending event finished with a made Field Goal for 2 or 3 points (2P, 3P), a basket and foul for 2-p or 3p (2PF, 3PF), and when the offense received a foul with no bonus Free Throws (FO) or a foul with bonus Free Throws (FT1, FT2, FT3).
Unsuccessful	Possession ending event finished with a missed shot (-3P, -2P), made a turnover of any kind (TU, including offensive fouls), and had a blocked shot (BL).
Game status at the onset of the crunch time (120 seconds before the end of the game)	
Win	The team is leading in the score.
Lose	The team is behind in the score.
Deuce	Teams are tie in the score.
Offensive Play Types	
Pick and Roll Ball-Handler (PnRBH)	Possession ending event finished by the ball-handler in the pick-and-roll. Includes off dribble shots or direct shots before dribbling off the screen, pull-ups and floaters, by that player. Includes also possessions where the ball handler rejects the screen (dribbles away from the screen).
Pick and Roll Screener (PnRSC)	Possession ending event where the screener receives the ball. These are the slips, rolls, and pops from screeners in the pick-and-roll.
Transition (TR)	Transition possession ending event before the defense is being set within 5-8 seconds.
Spot Up (SUP)	Possession ending event finished with a catch and shot or catch and drive. They can be catching and shooting, attacking a close out by dribbling into a pull-up, dribbling into a floater, or driving to the rim.
Isolation (ISO)	Possession ending event where the player is in 1vs1 situation trying to size up and create space from his defender.
Hand-Offs (HO)	Possession ending event where the screener with or without dribbling hands over the ball to a player cutting towards him, acting as an immediate screener creating space for his teammate.
Cuts (CUT)	Possession ending event where the player without a screen cuts out or toward the ball to receive it. Includes backdoor cuts and flash cuts and spacing when a player is getting open near the basket.
Putbacks (PB)	Possession ending event where a tip in or quick shot happens after offensive rebound.
Post Ups (PUP)	Possession ending event with the player receiving the ball with his back to the basket in proximity or inside the paint area.
Off Ball Screen (OBS)	Possession ending event generated by a player running off a screen, whether it be a pin-down, flare screen, elevator screens, or any other of the plethora of screen variations before they receive the ball. This includes curls and fades.
Miscellaneous (M)	Possession ending event that does not fit in the above categories. Includes but not limited to possessions such as: Players being fouled in the backcourt, errant passes out of bounds, possessions where the player dribbles into a pull up 3-point shot in the halfcourt, inbounds passes that go directly out of bounds, technical fouls etc.
Inbound Play (IN)	Possession ending event that is generated from the sideline or the baseline and creates a spatial advantage for the player. For this study the inbound play types were recorded only when it was concluded within 4 seconds after the inbound pass.

Procedure

The games were analysed through systematic observation using video analysis software (Sport Scout STA Ver. 3.2). The software was used to play all games on a laptop, pausing and replaying the games when possession was observed, and the results during the monitoring of the games were registered on a Microsoft Excel spreadsheet (Microsoft Inc., Washington USA).

The analysis of the games was carried out by a high-level professional basketball coach and Sports Sciences graduate with more than 20 years of experience. To ensure that the data were correctly observed and registered, each game was observed twice. To examine how stable the registration from the observer was and to ensure the validity of the data, in five randomly selected games, the observation was repeated by the

observer after one month. The weighted Cohen's Kappa correlation coefficients were used to assess intra-observer reliability. The obtained results were 0.83 to 0.98, indicating high to perfect agreement (Altman, 1991).

Statistical analysis

The SPSS 29 package software for statistical analysis was used in this study. Contingency table analysis was used for the group comparisons between the categorical variables (play type and offense outcome) with a chi-square (x^2) distribution. Post hoc and planned comparison procedures for interpreting chi-square contingency-table test results were used (Beasley and Schumacker, 1995, Garcia-Perez and Nunez-Anton, 2003). The post hoc methods supplement the analysis of standardized residuals by reporting the percentage contribution of each cell to the overall chi-square statistic (relative contribution) and the percentage of variance shared by the two factors (absolute contribution). One-way analysis of Variance (ANOVA) with Tamhane's T2 multiple comparison post hoc test for unequal variance (Shingala and Rajyaguru, 2015) was used to determine if there are significant differences in the play type of possession associated with Points Per Possession (PPP) and the duration of the offense. A value of $p < .05$ was considered statistically significant.

RESULTS

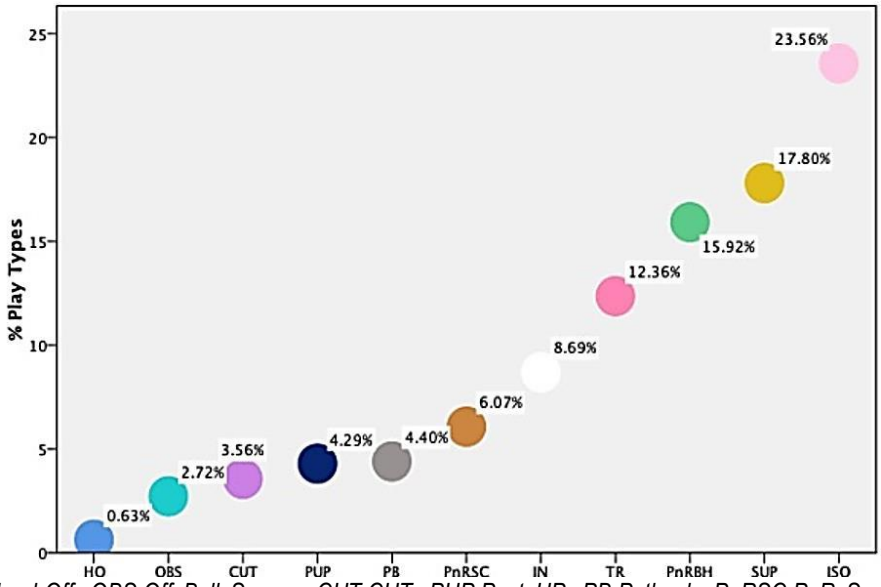
The mean difference in the score at the end of the matches was 3.18 ± 1.41 points (mean ± SD), while the score line (points difference) at the onset of the possession was 3.21 ± 2.3 points, ranging from 0 to 13 points. The home team won 57.6% of the games. The preliminary comparison between the winning and the defeated teams regarding the game status (win, lose, or deuce), revealed that the teams that had the score lead at the onset of the first possessions during the crunch time (120 seconds before the end of the match), won the match in 70.2% of the games ($x^2 = 25.214$, $p < .001$).

The structure and frequency distribution of the possession play types as depicted in Figure 1 indicate that the predominant play type in the EuroLeague during the last 2 minutes of the 4th quarter and overtime was ISO (23.56%), followed by SUP (17.8%) and PnRBH (15.92%) possessions. TR (12.36%) and IN (8.69%) play type possessions were following. There were no statistically significant differences between the winning and defeated teams ($x^2 = 14.293$, $p = .161$).

The comparison between the winning and defeated teams in the coefficient of possession's play types showed that in 6 out of 11 possession-ending events, the winning team performed greater success (Figure 2). Winning teams succeed more in IN possessions (69% vs. 40%, $x^2 = 6.812$, $p < .05$), OBS (57% vs. 42%), PUP (55% vs. 42%), ISO (54% vs. 42%), TR (69% vs. 59%), and SUP possession play types (36% vs. 35%). The defeated teams performed better in CUT possessions (93% vs. 72%), PB (79% vs. 56%), PnRSC (65% vs. 48%), and HO (82% vs. 50%). PnRBH possession play type was equally successful between winning and defeated teams (51%).

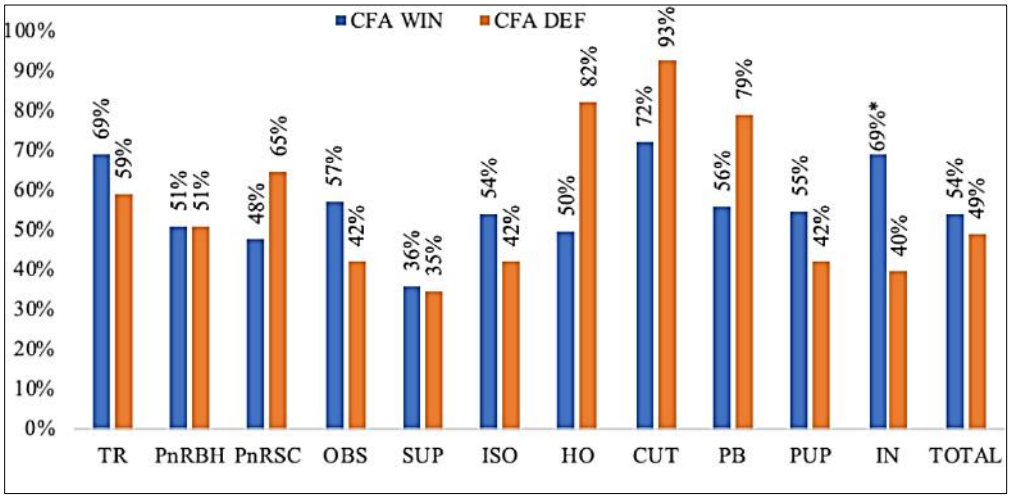
Regarding the efficacy (successful or unsuccessful) between the different possessions ending event play types (Table 2), CUT appeared to be the most effective play type, producing at 82.4% a successful outcome ($p < .001$), followed by PB with 69% of the possessions finishing with a successful outcome ($p < .001$). Furthermore, TR with 62.7% ($p < .001$), and PnRSC with 56.9% ($p < .001$) successful outcomes, were following in terms of effectiveness. HO play-type possessions were highly effective (HO, 66.7%), but with no statistical significance due to the limited number of possessions. On the other hand, possession play types

from SUP (p < .001), ISO (p < .001), PUP, and OBS more often ended up unsuccessful rather than successful.



Play Types: HO:Nand-Off, OBS:Off Ball Screen, CUT:CUT, PUP:Post UP, PB:Putback, PnRSC:PnR Screener, IN:Inbound, TR:Transition, PnRBH:PnR Ball-Handler, SUP:Spot Up, ISO:Isolation.

Figure 1. Frequency of possessions play types.



*Play Types: TR:Transition, PnRBH:PnR Ball-Handler, PnRSC:PnR Screener, OBS:Off Ball Screen, SUP:Spot Up, ISO:Isolation, HO:Nand-Off, CUT:CUT, PB:Putback, PUP:Post UP, IN:Inbound. (*p < .05).*

Figure 2. Efficiency of possessions ending event play types between the winning and defeated teams.

The comparisons in Points Per Possession (PPP) between winning (PPP = 1.09) and defeated (PPP = 1.04) teams revealed no statistically significant differences (F = .361, p = .548). As depicted in Table 2, significant differences were determined using the One-Way Analysis of Variance (ANOVA) by comparing all the end-of-event play types with the PPP (F = 1.965, p < .05). Tamhane's T2 multiple comparison post hoc test revealed

that CUT producing 1.58 PPP was statistically more efficient than PUP possessions (0.78 PPP, $p < .05$), ISO possessions (0.98 PPP, $p < .05$), and SUP possessions (0.93 PPP, $p < .05$).

Table 2. Description of the possession play types regarding their outcome and Points Per Possession (PPP).

Play Types	Outcome of the Offense		
	Successful	Unsuccessful	Points Per Possession (PPP)
TR	62.7**	37.3%**	1.28
PnRBH	51.3%	48.7%	1.03
PnRSC	56.9%**	43.1%**	1.02
ISO	47.6%**	52.4%**	0.98*
SUP	35.3%**	64.7%**	0.93*
PUP	48.8%	51.2%	0.78*
PB	69%**	31%**	1.33
HO	66.7%	33.3%	1.5
OBS	46.2%	53.8%	1.0
IN	51.8%	48.2%	1.06
CUT	82.4%**	17.6%**	1.58*
TOTAL	51.1%	48.9%	1.06

*Play Types: TR:Transition, PnRBH:PnR Ball-Handler, PnRSC:PnR Screener, ISO:Isolation, SUP:Spot Up, PUP:Post UP, PB:Putback, HO:Nand-Off, OBS:Off Ball Screen, IN:Inbound, CUT:CUT. *p < .05, **p < .001.*

Table 3. Description of the possession play types regarding the duration of the possession.

Play Types	Duration of the possession (sec)					
	Total		Winning Teams		Defeated Teams	
	M	*SD*	*M*	*SD*	*M*	*SD*
TR	5.6**	2.3	5.7	2.3	5.6	2.3
PnRBH	14.0*	4.5	15.28*	4.3	12.8*	4.5
PnRSC	14.8*	4.9	17.22*	4.14	12.65*	4.7
ISO	14.7**	5.9	16.8*	5.3	12.8*	5.8
SUP	13.7**	6.7	17.04**	5.79	11.4*	6.48
PUP	15.7**	5.7	14.8	5.7	16.6	5.86
PB	1.43**	0.5	1.39	0.50	1.46	0.58
HO	10.3	5.2	17.0	5.8	9	4.6
OBS	9.1*	5.0	10.7	5.9	8.58	4.76
IN	2.3**	1.5	2.14	1.37	2.52	1.62
CUT	14.1**	5.8	15.78*	5.5	12.3*	5.88
TOTAL	11.49	6.9	13.31*	7.17	10.03*	6.35

*Play Types: TR:Transition, PnRBH:PnR Ball-Handler, PnRSC:PnR Screener, ISO:Isolation, SUP:Spot Up, PUP:Post UP, PB:Putback, HO:Nand-Off, OBS:Off Ball Screen, IN:Inbound, CUT:CUT. *p < .05. **p < .001.*

Table 3 also compares the different play types regarding their duration. The results showed that there was a statistically significant difference between the different play types in the duration of the offense ($F = 315.411$, $p < .001$). Tamhane's T2 multiple comparison post hoc test revealed that PB, IN, and TR play type possessions had a statistically shorter-lasted duration compared with SUP, PUP, PnRSC, ISO, PnRBH, and CUT ($p < .001$) possessions, where the duration of the play types was longer-lasted. PB and IN possessions were also statistically significantly shorter-lasting compared to OBS possessions ($p < .001$). OBS possessions were statistically shorter-lasting compared with PnRBH, CUT, and SUP possessions ($p < .05$)

and also with PnRSC, ISO, and PUP possessions ($p < .001$). Regarding the comparison between winning and defeated teams, statistically significant differences in the duration of the play types were found in PnRBH and PnRSC possessions ($p < .05$), in SUP possessions ($p < .001$), and in possessions finishing with a CUT ($p < .05$). Totally, winning teams had statistically significant longer-lasting duration in their possessions ($F = 80.560$, $p < .001$).

DISCUSSION

The present study is, to the best of our knowledge, the first study to analyse the possessions play type at the end of a close EuroLeague game. A similar study analysed the possession play types in NBA close games (Christmann et al., 2018). The objective of this research was to analyse the effectiveness of the different possession play types in the last two minutes of the last quarters and overtime in games with a final score equal to or less than 5 points in EuroLeague games and identify differences between the winning and defeated teams.

The results indicated that there were no significant differences between the winning and defeated teams in the comparison of the frequency and the structure of the possession play types. Hence, we can conclude that the winning and defeated teams applied almost identical structures and frequencies of finishing actions to score. The most frequent play type was ISO possessions (23.5%). These results are similar to those acquired by other studies (Zukolo et al., 2019, Christmann et al., 2018, Karipidis et al., 2010). Regarding the Pick and Roll (PnR), PnRBH (15.9%) and PnRSC play types (6.07%) combined for 22% of the total possessions. The researchers specify that ball screens are the most frequently performed play type (Lamas et al., 2011, Gomez et al., 2015, Marmarinos et al., 2016, Remmert, 2003, Vaquera et al. 2013, Vaquera et al. 2016). Although PnR actions were not the most frequent play type in this study, the findings correspond to Nunes et al. (2016) argument that 25.3% of total possessions end with a PnR. On the other hand, Christmann et al. (2018) findings indicated that PnR play type represented 29.1% of the total possessions in the last two minutes of NBA close games, a percentage that is significantly higher in NBA games.

SUP (17.8%) possessions were also frequently performed at the end of the game. In modern basketball, the most common finishing offensive actions without screens are SUP (Zukolo et al., 2019, Selmanovic et al., 2015) and the results of this study confirm this argument. The share of TR offense play type followed with 12.36% of the total possessions. This result is similar to other studies (Christmann et al., 2018, Selmanovic et al., 2015, Fotinakis et al., 2002).

Regarding the efficacy of each play type, CUT appeared to be the most effective way to score (1.58 PPP, 82.4% of the possessions' successful outcome). The results of this study confirm the findings of previous studies (Zukolo et al., 2019, Matulaitis and Bietkis, 2021, Vaquera et al., 2016). CUT in basketball involves players making quick and tactical movements without the ball on the strong or weak side of the defence, creating scoring opportunities close to the basket or in open areas on the court that can lead to high-percentage scoring. Especially, backdoor cuts involve offensive players moving behind defenders toward the basket, catching the defence off guard, and creating easy scoring opportunities. Incorporating CUT into offensive tactical patterns requires communication, teamwork, and a good knowledge of the fundamentals. Coaches often emphasize the importance of off-ball movement to create dynamic and effective ways to score.

PB play type possessions, also known as offensive rebounds, followed by a quick shot, were, as expected, very efficient in this research, producing 1.33 PPP and a successful outcome at 69% of the possessions. Teams that excel at PB can significantly impact the game by converting missed shots into second-chance

points, and besides that, they significantly reduce the opponent's chance to create a quick and favourable transition (Zukolo et al., 2019). The importance of offensive rebounds is well documented in previous studies (Matulaitis and Bietkis, 2021, Dežman et al., 2002, Kubatko et al., 2007, Suáres-Cadenas & Courel- Ibáñez, 2017, Tsamourtzis et al., 2005), producing high-percentage scoring opportunities because offensive players are often in proximity to the basket.

TR play type was particularly effective, producing 1.28 PPP (67.2% successful possessions). The TR offense in basketball targets exploiting defensive vulnerabilities and creating scoring opportunities before the opposing defence sets up. The results of this study are in agreement with previous studies establishing TR play type as particularly effective in scoring (Christmann et al., 2018, Matulaitis and Bietkis, 2021). IN play type is not often examined in the literature and involves tactical movements designed to inbound the ball successfully and create scoring opportunities. IN possessions produced 1.06 PPP (51.8% successful possessions) in this study, which is lower than the 1.5 PPP from IN possessions during the last two minutes of NBA games (Christmann et al., 2018). Regarding the comparison between winning and defeated teams, IN possessions were the only statistically significant different play type (69% for winning vs. 42% for defeated, successful possessions). Effective IN plays, tailored to the strengths of the players and adjusted to the specific game situations, play a crucial role in a team's overall offensive strategy, especially during the last minutes of the game, and the results of this study support this argument.

The results of this study showed that PnRBH possessions produced 1.03 PPP (51.3% possessions with a successful outcome), while PnRSC 1.01 PPP (56.9% possessions with a successful outcome). Elite men's basketball teams more often use PnRBH as the end-of-possession play type but with lower efficacy compared with PnRSC play type possessions (Zukolo et al., 2019). Christmann et al. (2018) explained that the efficacy of the Pick and Roll in the last two minutes of NBA games reached 1.1 PPP, and in 52.8% of the possessions the teams scored, results that are very close to our findings. On the other hand, Zukolo et al. (2019) observed in their study that Pick and Roll effectiveness was 36% and Pick and PoP 35%, while Nunes et al. (2016) revealed that the efficiency of Pick and Roll reached 36.3% in direct score. Marmarinos et al. (2016) stated in their study that PnRBH produced 0.81 PPP, while PnRSC produced 1.25 PPP when the Roll man cut inside the basket and 0.95 PPP when they popped out. These findings are lower than the results of this study, showing that the pick-and-roll offensive play type is more effective at the end of the game. This can be explained for several reasons. In clutch moments, teams rely on the Pick and Roll for its versatility and ability to exploit defensive weaknesses, putting a lot of pressure on the defence and requiring quick decision-making. Late in the games, when every possession matters, the Pick and Roll can manage the shot clock effectively, and even if the initial play breaks down, the ball handler can still create a shot, preventing losing balls and possessions and going to the foul line more frequently than other play type possessions (Matulaitis and Bietkis, 2021). Additionally, at the end of the game, the ball goes to the most skilled players, the stars of the team, who can create dynamic offensive opportunities and exploit defensive vulnerabilities, making this play type a go-to option when teams need reliable scoring opportunities.

Concerning the result of the game, it was found that the teams that were defeated had higher efficacy in PnRSC possessions (65%) compared with the winning teams (48%), while PnRBH possessions were equally successful (51%). This finding coincides with the study of Nunes et al. (2022) and Prieto-Lage et al. (2022), showing that the teams that were defeated or were behind in the score at the time of possession were more effective compared to the winning teams. This might be explained by the fact that the defeated teams played more aggressively due to the score, aiming to generate defensive mismatches (Prieto-Lage et al., 2022). Çene (2018), also stated in his study that the teams compete more aggressively when the score is close.

OBS was found to produce 1.0 PPP with 46.2% successful possessions. These results are in agreement with other studies (Matulaitis and Bietkis, 2021, Zukolo et al., 2019). A study by Stavropoulos et al. (2021), aiming to evaluate the efficiency of off-ball screens on the weak side that positively affect the finishing move and the outcome, concluded that the outcome of every OBS action in the basketball context depends on several factors, such as the type of defence, the characteristics of the players involved, the scoreboard, the finishing moves and the screen types on the strong and weak side. Regarding the result of the game, winning teams were more effective than the defeated (57% vs. 42% successful possessions, respectively). These findings are very similar to the results of Zukolo et al. (2019), where winning teams had 51% successful actions while defeated teams had 39%.

ISO actions turned out to be a less effective play type (0.98 PPP, 47.6% of possessions with a successful outcome). Although players who can play efficiently in ISO situations usually have a distinct role in the team's plays (Uhlmann et al., 2014) it seems that it is not effective at the end of the EuroLeague games. Christmann et al. (2018) found similar results in the last 2 minutes of close NBA games (0.9 PPP, 42.4% of the possessions offense scored). ISO actions are characterized by a decreased number of cooperative actions, making it difficult for the offensive player to score. The low effectiveness of the ISO play type possessions was observed in other studies (Zukolo et al., 2019, Matulaitis et al., 2021). Concerning the comparison between the winning and defeated teams, the winning teams were more efficient than the defeated (54 vs. 42% successful possessions).

Possessions that ended with a SUP action were also less effective compared to other play types. SUP actions produced 0.93 PPP and were successful only at 35.3%. The findings of this study are very close to those of Zukolo et al. (2019), who found that the efficiency of SUP actions was 37% in the 2013 European Championship of Slovenia. Matulaitis and Bietkis (2021) stated also that the ends of the ball possession from SUP more often ended up inefficiently rather than efficiently. PUP end-of-game possessions were also characterized by low efficacy (48.8% successful possessions, 0.78 PPP).

The average efficacy of the different play types in this study was 51.1%, slightly above the findings recorded by Lehto et al. (2010) in the Olympic Games of Beijing (49%), and significantly higher than the efficiency of finishing actions studied by Zukolo et al. (2019), which was 42.6%. Regarding the PPP, the average of the different play types in this study was 1.06 PPP, slightly below Christmann et al. (2018) findings for NBA games (1.2 PPP).

Regarding the duration of the play types, the results of the study showed that the quicker play types (TR, IN, and PB, mean duration <6 seconds) produced 1.22 PPP combined with 61.1% of the possessions ending with a successful outcome, while longer-lasting possession play types (ISO, PUP, mean duration >14.5 seconds) produced 0.88 PPP as an average, with 48.2% of the possessions ending successfully. Pick-and-roll possessions had a mean duration of 14.4 seconds, while CUT, which requires more players to cooperate, had a duration of 14 seconds. Prieto-Lage et al. (2022) observed in their study that Pick and Roll was more effective when executed between 9–16 seconds of possession. Therefore, it seems that the duration of the possession affects the efficacy of the end-of-possession play type, with the most efficient possessions being the ones that last no more than 6 seconds. Winning teams, as expected, kept the ball more in their hands, finishing an average of 3 seconds later than the defeated teams in possession. Similar results were found in another study (Matulaitis and Bietkis, 2021), where the authors concluded that the most efficient ball possessions are those that last no more than 10 seconds.

CONCLUSIONS

Winning teams employed longer-lasting possessions in the last two minutes of the game and overtime because they were protecting the end-of-game lead, trying to freeze and delay the game and use as much of the game clock as possible, particularly if they held a narrow lead. Coaches may choose to run longer plays that exploit matchups, create open shots, or involve key players who excel in clutch situations. On the other hand, trailing teams may opt for a quick scoring attempt to preserve time for potential defensive stops or fouls. In situations where a team is trailing and needs multiple scores to catch up, the duration of end-of-game possessions becomes critical. Teams may aim for quick scores to maximize the number of possessions in the remaining time. The duration of end-of-game possessions in basketball is influenced by a combination of strategic decisions, time management, shot clock considerations, clock stoppages, and the specific game situation. Teams target to balance the need for efficient scoring opportunities with the constraints imposed by the remaining time on the game clock. The ability to execute under pressure and make effective use of limited time is crucial in these late-game scenarios.

The findings suggest that coordinated actions and teamwork among players produce a more effective outcome at the end of the game. Teams that can underscore the importance of teamwork, communication, and understanding the strengths and tendencies of the game, related to the score line and the remaining time, often find success in their actions. The play types that involved less cooperative actions, such as ISO and PUP possessions, were less effective compared with play types that involved the cooperation and movement of two, three, or even four players, such as PnRBH and PnRSC, OBS, and especially CUT. According to Christmann et al. (2018), the ISO play type exhibits fewer dynamics, is more static, and employs a lower action frequency, thus being more foreseeable, providing the defence with better possibilities to adapt. Additionally, Uhlmann and Barnes (2014), noted that solo scoring negatively influenced the team's performance. Thus, coaches should advise their players to attempt a TR offense whenever possible, use more cooperative play types that involve more actions, and reduce the individual or less cooperative play types that proved less effective. Further research is required regarding the play types that are more or less effective at the end of the game, scrutinizing more details regarding the offense and the defence, the profile of the players that finish the last possessions, and the criticality of the possession.

AUTHOR CONTRIBUTIONS

Conceptualization, P.F. and S.P; methodology, P.F and N.S.; software, N.S and P.F.; validation, P.F. and N.S., investigation, P.F.; resources, P.F. and S.P.; data curation, P.F. and S.P.; writing—original draft preparation, P.F. and S.P.; supervision, N.S.; All authors have read and agreed to the published version of the manuscript.

SUPPORTING AGENCIES

No funding agencies were reported by the authors.

DISCLOSURE STATEMENT

No potential conflict of interest were reported by the authors.

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REVIEW ARTICLE

Main characteristics of preventive postural hygiene training programs in the educational field

CARLOS GARCIA-ALEN LORES[1], JULIA MARIA CRESPO COMESAÑA[2], MARGARITA ROSA PINO JUSTE[3]

[1]*Faculty of Education Sciences. University of Santiago de Compostela. Santiago de Compostela, Spain.*

[2]*Department of Pedagogy and Didactics. Faculty of Education Sciences. University of Santiago de Compostela. Santiago de Compostela, Spain.*

[3]*Department of Didactics, Educational Organization and Research Methods. Faculty of Education Sciences and Sport. University of Vigo. Pontevedra, Spain.*

ABSTRACT

Objective: To determine the state of the art regarding preventive training programs on postural hygiene and back health in an educational context. Introduction: The prevalence of non-specific back pain in population reaches alarming figures and its causes are largely preventable. Adequate training in postural education is necessary along students' academic career. Method: Retrospective descriptive study, using the PRISMA method. Results: 61 original articles published from 2017 to 2021 have been analysed. Discussion: Postural education programs have demonstrated their effectiveness and have provided benefits for the participating students.

Keywords: Review, Health literacy, Postural education, Educational intervention, Back pain.

Cite this article as:
Garcia-Alen Lores, C., Crespo Comesaña, J. M., & Pino Juste, M. R. (2024). Main characteristics of preventive postural hygiene training programs in the educational field. *Journal of Human Sport and Exercise, 19*(2), 631-653. https://doi.org/10.55860/hzjr0h70

Corresponding author. *Department of Pedagogy and Didactics. Faculty of Education Sciences. University of Santiago de Compostela (Vida Campus). Rúa Prof. Vicente Fráiz Andón, s/n, 15782, Santiago de Compostela. Spain.*
E-mail: juliamaria.crespo@usc.es
Submitted for publication January 15, 2024.
Accepted for publication February 19, 2024.
Published April 01, 2024 *(in press* March 04, 2024).
JOURNAL OF HUMAN SPORT & EXERCISE ISSN 1988-5202.

doi: https://doi.org/10.55860/hzjr0h70

INTRODUCTION

Students in schools frequently adopt inadequate and/or maintained postures for long periods of time, in class and in everyday life, which can have important consequences on their development. One of these most common consequences is back pain, mainly low back pain (Maher et al., 2017), which some studies link directly to the adoption of inappropriate postures (Da Rosa et al., 2017; Maher et al., 2017; Dullien et al., 2018; Minghelli, 2020a) and are mostly not pathological in origin (Illeez et al., 2020).

The high prevalence of this condition makes it a real public health problem (Maher et al., 2017; Subbarayalu and Ameer 2017; Amyra-Natasha et al., 2018; Clark et al., 2018; Dullien et al., 2018; Jonsdottir et al., 2019) with important implications for health services (Minghelli, 2020a; Garvick et al., 2019). It also carries future implications in adulthood (Coenen et al., 2017; Assiri et al., 2020), including being the leading cause of disability globally (Hartvigsen et al., 2018). This problem is not only prevalent among the adult population, but increasingly affects adolescent and child learners (Dianat et al., 2017; Maher et al., 2017; Dullien et al., 2018; Rodríguez-Oviedo et al., 2018).

Given that postures performed during everyday life are modifiable elements of lifestyle, interventions can be used to improve the posture of children and adolescents (Mantilla et al., 2021).

In Spain, according to data from the Annual Report of the National Health System (Ministry of Health, 2018), 18.5% of the Spanish adult population suffers from back pain, being more frequent in women than in men. This problem affects people of all ages (Hartvigsen et al., 2018; Vlaeyen et al., 2018). Amado-Merchán (2020) estimates that around 80% of the population will suffer from back pain at some point in their lives. But other studies put the prevalence as high as 95% (Kalki et al., 2020). Without adequate care, it will have repercussions in the personal, occupational and social spheres, and can become highly limiting for people's daily lives and increase healthcare costs (Amado-Merchán, 2020).

International studies reveal a worldwide situation very similar to the Spanish situation and it is predicted that the problem will increase globally in the coming decades (Hartvigsen et al., 2018). Back pain and specifically low back pain is considered a major public health problem (Maher et al., 2017; Subbarayalu and Ameer 2017; Amyra-Natasha et al., 2018; Clark et al., 2018; Dullien et al., 2018; Jonsdottir et al., 2019) that directly affects the respective national health services (Minghelli, 2020a; Garvick et al., 2019).

Furthermore, back problems that arise in late adolescence have a high probability of persisting into adulthood (Santos et al., 2021; Assiri et al., 2020; Illeez et al., 2020; Paranjape and Ingole, 2018; Dugan, 2018; Coenen et al., 2017; de-Oliveira-Saes and Flores-Soares, 2017).

Based on these approaches and considering that education is one of the cornerstones for intervening in back pain (O'Sullivan et al., 2019), the inclusion of postural education as a content of Health Education is fully justified in the training process of students (Mata-Bazán and Campos-Cornejo, 2018; Chacón-Borrego et al., 2018).

The period corresponding to the compulsory school age is a sensitive phase for working on health-related contents (Wawrzyniak et al., 2017) that contribute to the development of competences that accompany the individual throughout his or her life (Amado-Merchán, 2020; Chacón-Borrego et al., 2018; Mata-Bazán and Campos-Cornejo, 2018). Health promotion plays a fundamental role in the development of personal skills that favour health-oriented behavioural changes and the promotion of healthy lifestyles (Kabasakal et al.,

2020; Pinto and Silva, 2020). Furthermore, children and adolescents suffer from back problems from an early age, coinciding with their entry into the educational system, and the prevalence figures increase from adolescence onwards (MacDonald et al., 2017).

With regard to the promotion of healthy habits, the area of Physical Education plays a leading role in the education of students (Morrish and Neesam, 2021; Amado-Merchán, 2020; Mata-Bazán and Campos-Cornejo, 2018). Authors such as Morrish and Neesam (2021) recommend promoting the interdisciplinary treatment of health together with the rest of the areas, so that such learning is as meaningful as possible and lasts into adulthood (Ghobadi et al., 2018; Mata-Bazán and Campos-Cornejo, 2018). This requires a coordinated approach from the teaching team, where the role of teachers is vital, both as promoters of healthy habits in the classroom and as facilitators of the participation of the entire educational community (Chacón-Borrego et al., 2018).

Postural education programs have positive results, both in the acquisition of knowledge and in the improvement of behaviours related to back health. However, we know that the effects diminish with the passage of time, so it would be interesting to maintain these programs throughout the students' educational process, in order to acquire healthy habits that last over time (Amado-Merchán, 2020).

METHOD

Study design

This systematic review responds to a retrospective descriptive design, for which the PRISMA method - Preferred Reporting Items for Systematic Reviews and Meta-Analysis- (Page et al., 2021) was used.

Search strategy

A systematic search of recent literature was carried out in the following databases: Scopus and Web Of Science (WOS). The search range was from 2017 to 2021 in both databases. This search was conducted between January and May 2022 and aimed to find publications related to the treatment of postural hygiene in the educational setting, specifically, in children and young people in schools. The search formula used was the following: (TITLE ("*postur* educat**" OR "*postur* hygiene*" OR "*postur* habits*" OR "*back care*" OR "*back health*" OR "*back pain*" OR "*LBP*" OR "*ergonom**" OR "*postur* health**" OR "*postur* habit**" OR "*postur* behavior**" OR "*back postur**" OR "*back educat**") AND ABS (school* OR children OR student* OR schoolchildren OR adolescent* OR teenager*)).

Data selection and extraction

The bibliometric analysis process took place in two phases. In the first phase, the results obtained in the initial search were screened. Only original research articles published in scientific journals were included and case studies, systematic reviews, books, conferences, etc. were excluded. The search result returned 468 and 428 articles from Scopus and WOS, respectively, to be filtered. Of this initial number, 317 articles were eliminated before screening, because of being duplicated. The records identified and selected for screening (n = 579) were then dumped into the RefWorks bibliography management tool. From this application, a first screening of non-relevant articles was carried out, according to their title and abstract. 482 records were excluded at this stage of the process. Thus, a total of 97 records were evaluated for eligibility. In the second phase of the screening, the full texts of the articles were obtained and the data and information relating to the categories and subcategories of analysis shown in Table 1 below were extracted.

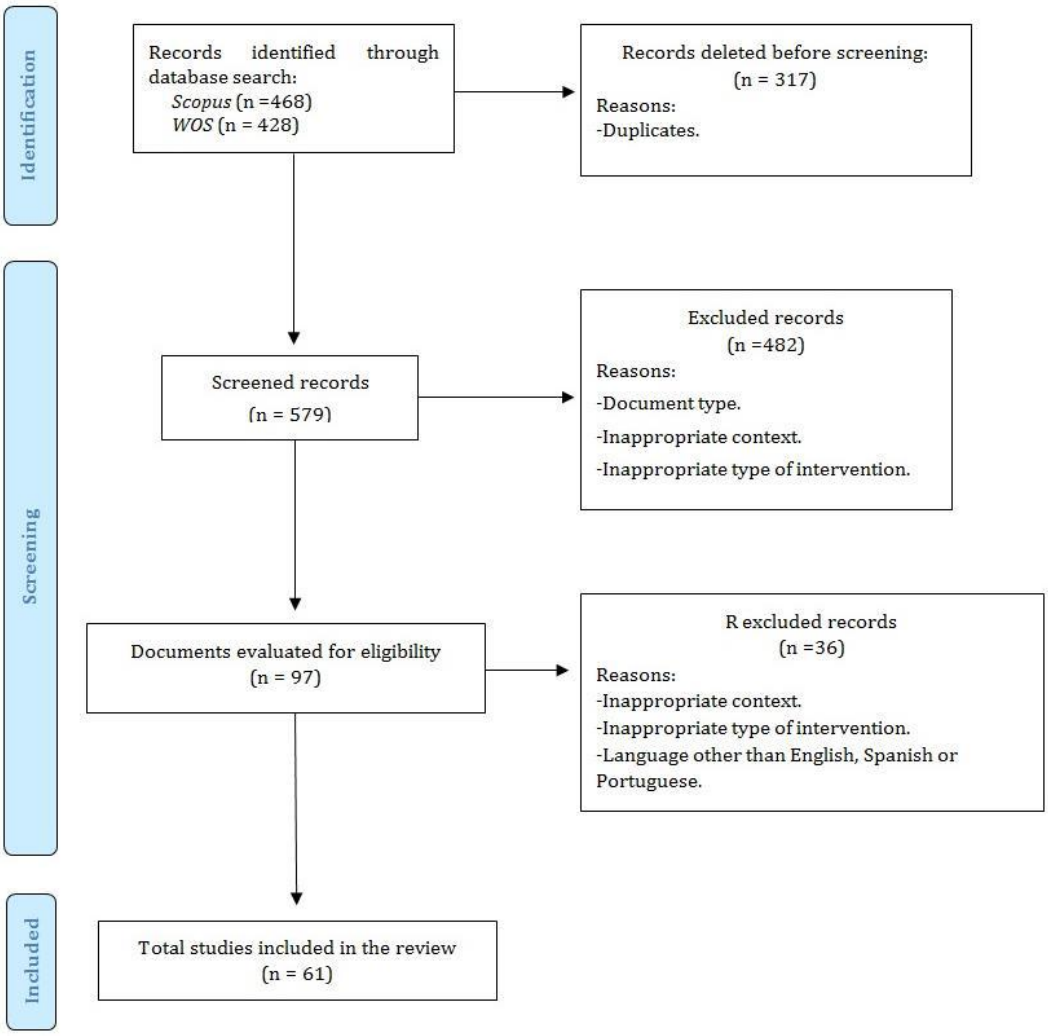

Figure 1. Flowchart of the studies analysed during the review process.

Table 1. Categories and subcategories of analysis.

Categories	Subcategories
Object of study	Intervention programs in postural education. Validation of research instruments. Use of electronic devices for posture analysis. Prevalence of back pain in children, adolescents, and young adults.
General description	Year of publication. Magazines of publication and number of articles in each one. Authors: number of authors in each article and main authors. Countries and continents of publication.
Research method	Type of design. Type of methodology. Sample characteristics: size, age and educational stage.
Content analysis	Contents, instruments and results of intervention programs. Instruments and results of instrument validation studies. Device for posture analysis: description of the instrument. Instruments and results of back pain prevalence studies.

In this second screening phase, 36 records were excluded. The remaining 61 records were finally included in the review and the information corresponding to the categories described above was analysed, classified and recorded in a Microsoft Excel spreadsheet. This procedure is summarized and represented in the PRISMA flow chart in Figure 1.

RESULTS

The analysis of the records found was carried out according to the selected categories and subcategories of analysis.

Subject matter of the research studies

According to the type of research carried out, 11 studies (18%) were interventions in the educational setting (primary and/or secondary level) consisting of the implementation of postural education intervention programs in the school population (school-age students and young adults). Another 4 studies (7%) consisted of validations or cultural adaptations of instruments (health questionnaires). We also found 1 study (2%) describing the applicability of an electronic device in posture analysis. Finally, 45 studies (74%) analysed the incidence of back pain in school populations and the causes and risk factors associated with it.

Year of publication

Of the 61 records analysed, 7 studies (11%) were published in 2017, 8 studies (13%) in 2018, 10 studies (16%) in 2019, 20 studies (33%) in 2020 and 16 studies (26%) in 2021.

Type of design

Following the classification of Dankhe (1986): 12 studies (19.7%) are of the explanatory type, 45 studies (73.8%) are of the correlational type and 4 studies (6.5%) are of the descriptive type.

Methodology

Regarding the type of methodology used in the research: 60 studies (98%) are quantitative and 1 study (2%) is qualitative.

Journals and number of articles published in them

According to the journals and the number of articles published in them, we find: 5 articles (8%) published in the *International Journal of Environmental Research and Public Health*, 3 articles (5%) in the *Journal of Back and Musculoskeletal Rehabilitation*, 2 articles (3%) in *BMC Musculoskeletal Disorders*, *BMC Public Health*, *British Journal of Pain*, *Spine, Sportis. Revista Técnico-Científica del Deporte Escolar, Educación Física y Psicomotricidad*, *Sustainability* and *Work*. In the remaining journals (n = 39), 1 article (2%) was published in each journal.

Authors

According to the number of contributing authors and co-authors, we found: 3 articles (5%) were written by 1 author, 6 articles (10%) by 2 authors, 9 articles (15%) by 3 authors and 43 articles (70%) by 4 or more authors.

As for the authors listed as principal investigators (single author or first author of the research team): Minghelli and Miñana-Signes appear most frequently, with 3 articles (5%) each. Akbari-Chehrehbargh, Sainz de Baranda, González-Gálvez and Kedra appear as principal investigators in 2 articles (3%) each. The rest of the first authors (n = 47) appear in only 1 article (2%) each.

Literature production by country and continent

The countries where most studies have been carried out are Spain, with 15 articles (25%), Brazil, with 10 articles (16%) and Iran, with 6 articles (10%). India, Italy, Poland and Portugal have 3 articles (5%) each. In the USA, Malaysia and Indonesia, 2 studies (3%) were conducted in each country. In the remaining countries (n = 12), 1 study (2%) took place in each.

Grouping the countries by continent, Europe covers the most research with 29 articles (48%), followed by Asia with 16 (26%), South America with 11 (18%), Africa with 3 (5%) and North America with 2 (3%).

Characteristics of the sample analysed

The sample size used in the studies varies in a range between 18 and 11619 persons. We found: 15 studies (25%) with samples larger than 1000 persons; 11 studies (18%) with samples between 500 and 999 persons; 22 studies (36%) with samples between 100 and 499; 5 studies (8%) with samples between 50 and 99 persons; 6 studies (10%) with samples between 18 and 49 persons and 2 studies (3%) which, due to their characteristics, were not implemented in any population group.

Regarding the sample size according to the object of study of the research: 5 articles (45.5%) of postural education intervention programmes were implemented in groups of 18-49 people, 1 article (9%) in groups of 50-99 people and 5 articles (45.5%) in groups of 100-499 people.

In the research on instrument validations: 3 studies (75%) were conducted with samples of 100-499 persons; 1 study (25%) was conducted in a group of 500-999 persons.

The only study found on the use of an electronic device for posture analysis did not require any population sample.

Finally, according to the studies on the prevalence of back pain: 1 investigation (2.2%) did not include any population sample; 2 articles (4.4%) were implemented in groups of 18-49 people; 3 studies (6.7%) in groups of 50-99 people; 14 studies (31.1%) were implemented in groups of 50-99 people; 14 studies (31.1%) were implemented in groups of 100-499 people; 1 study (25%) was implemented in a group of 500-999 people; 1 study (25%) was implemented in a group of 500-999 people; 15 studies (33.3%) in groups of more than 1000 people.

The registered studies included students from public, private and charter schools and they were 6-20 years old.

Content analysis

a) Intervention programs in postural education

These studies have been carried out in experimental groups made up of pupils in educational centres and the results (post-test) were analysed in comparison with the previous data (pre-test).

a.1) Program content

The main contents covered by the educational programs analysed are:

- Anatomical and functional concepts of the back (Minghelli et al., 2021; Mantilla et al., 2021; Serrano-Durá et al., 2021; Akbari-Chehrehbargh et al., 2020a; Cabrera-González et al., 2020; Miñana-Signes et al., 2019; Dullien et al., 2018; Dos-Santos et al., 2017).
- Analysis of postures in classroom and daily life activities:

- Posture while sitting (Minghelli et al., 2021; Mantilla et al., 2021; Serrano-Durá et al., 2021; Blanco-Morales et al., 2020; Akbari-Chehrehbargh et al., 2020a; Cabrera-González et al., 2020; Miñana-Signes et al., 2019; Dullien et al., 2018).
- Posture while writing while seated (Minghelli et al., 2021; Minghelli, 2020b; Miñana-Signes et al., 2019; Dos-Santos et al., 2017).
- Posture while using the computer while seated (Serrano-Durá et al., 2021; Blanco-Morales et al., 2020; Cabrera-González et al., 2020; Miñana-Signes et al., 2019; Sellschop et al., 2018; Dos-Santos et al., 2017).
- Transport of the school bag (Minghelli et al., 2021; Mantilla et al., 2021; Serrano-Durá et al., 2021; Blanco-Morales et al., 2020; Akbari-Chehrehbargh et al., 2020a; Minghelli, 2020b; Cabrera-González et al., 2020; Miñana-Signes et al., 2019; Dos-Santos et al., 2017).
- Weight distribution inside the school bag (Minghelli et al., 2021; Mantilla et al., 2021; Serrano-Durá et al., 2021; Akbari-Chehrehbargh et al., 2020a; Minghelli, 2020b; Cabrera-González et al., 2020; Miñana-Signes et al., 2019).
- Maximum school bag weight (Minghelli et al., 2021; Serrano-Durá et al., 2021; Akbari-Chehrehbargh et al., 2020a; Minghelli, 2020b; Cabrera-González et al., 2020; Miñana-Signes et al., 2019; Dullien et al., 2018).
- Decubitus posture (Minghelli et al., 2021; Mantilla et al., 2021; Serrano-Durá et al., 2021; Cabrera-González et al., 2020; Miñana-Signes et al., 2019; Dos-Santos et al., 2017).
- Posture while watching TV or playing games (Minghelli et al., 2021; Serrano-Durá et al., 2021; Cabrera-González et al., 2020; Miñana-Signes et al., 2019).
- Posture while typing messages on a mobile phone (Minghelli et al., 2021; Minghelli, 2020b; Miñana-Signes et al., 2019).
- Standing posture (Minghelli et al., 2021; Mantilla et al., 2021; Serrano-Durá et al., 2021; Akbari-Chehrehbargh et al., 2020a; Cabrera-González et al., 2020; Miñana-Signes et al., 2019).
- Posture when reaching for an overhead object (Serrano-Durá et al., 2021; Cabrera-González et al., 2020; Miñana-Signes et al., 2019).
- Posture when lifting a heavy object from the ground (Minghelli et al., 2021; Mantilla et al., 2021; Serrano-Durá et al., 2021; Akbari-Chehrehbargh et al., 2020a; Minghelli, 2020b; Cabrera-González et al., 2020; Miñana-Signes et al., 2019; Dullien et al., 2018; Dos-Santos et al., 2017).
- Posture when lifting a light object from the ground (Minghelli et al., 2021; Mantilla et al., 2021; Akbari-Chehrehbargh et al., 2020a; Minghelli, 2020b).
- Posture when transporting from one place to another:
    - Shopping bags (Minghelli et al., 2021; Mantilla et al., 2021; Serrano-Durá et al., 2021; Cabrera-González et al., 2020; Miñana-Signes et al., 2019; Dos-Santos et al., 2017).
    - A heavy object (Minghelli et al., 2021; Serrano-Durá et al., 2021; Akbari-Chehrehbargh et al., 2020a; Cabrera-González et al., 2020; Miñana-Signes et al., 2019; Dullien et al., 2018; Dos-Santos et al., 2017).

– Consequences of incorrect and/or prolonged postures (Minghelli et al., 2021; Serrano-Durá et al., 2021; Cabrera-González et al., 2020; Miñana-Signes et al., 2019).
– Muscle strengthening exercises (Serrano-Durá et al., 2021; Akbari-Chehrehbargh et al., 2020a; Cabrera-González et al., 2020; Miñana-Signes et al., 2019; Dullien et al., 2018).

- Flexibility exercises (Blanco-Morales et al., 2020; Akbari-Chehrehbargh et al., 2020a; Cabrera-González et al., 2020; Miñana-Signes et al., 2019).

Other contents analysed in the intervention programs recorded were:

- Analysis of postures in classroom and daily life activities:
  - Sitting in a seat without a backrest (Dos-Santos et al., 2017).
  - Posture when getting out of bed (Minghelli et al., 2021).
  - Posture while putting on shoes (Akbari-Chehrehbargh et al., 2020a).
  - Posture while sweeping the floor (Miñana-Signes et al., 2019).
  - Posture while brushing teeth (Miñana-Signes et al., 2019).
  - Proper jaw posture when chewing (Dos-Santos et al., 2017).
- Analysis of posture during exercise and physical activities (Cabrera-González et al., 2020; Miñana-Signes et al., 2019).
- Breaks during prolonged postures (Minghelli et al., 2021).
- Exercises for rest intervals (Minghelli et al., 2021; Mantilla et al., 2021).
- Massage application (Blanco-Morales et al., 2020).
- Relaxation exercises (Cabrera-González et al., 2020; Miñana-Signes et al., 2019).
- Balance exercises (Cabrera-González et al., 2020; Dullien et al., 2018).
- Examples of back-healthy sports (Dullien et al., 2018).
- Levels of motivation and perception of effort (Serrano-Durá et al., 2021).
- Level of daily physical activity (Akbari-Chehrehbargh et al., 2020a).

a.2) Instruments used

The instruments most commonly used to obtain the results were:

- A theoretical test of postural awareness (Minghelli et al., 2021; Mantilla et al., 2021; Serrano-Durá et al., 2021; Miñana-Signes et al., 2019; Dullien et al., 2018; Sellschop et al., 2018; Dos-Santos et al., 2017).
- A practical performance test (Minghelli et al., 2021; Minghelli, 2020b; Dullien et al., 2018; Dos-Santos et al., 2017).
- A questionnaire on the presence of back pain (Minghelli et al., 2021; Akbari-Chehrehbargh et al., 2020a; Cabrera-González et al., 2020; Miñana-Signes et al., 2019; Dullien et al., 2018).
- Socio-demographic data recording (Blanco-Morales et al., 2020; Akbari-Chehrehbargh et al. 2020a).
- Physical muscular endurance tests (Serrano-Durá et al., 2021; Cabrera-González et al., 2020; Dullien et al., 2018).
- Other methods:
  - o Motivation and effort rating scales (Serrano-Durá et al., 2021).
  - o Self-perception scales of efficacy in postural behaviour (Akbari-Chehrehbargh et al., 2020a).
  - o Focus groups, field notes, diaries and interviews (Blanco-Morales et al., 2020).
  - o Clinical examination (Dullien et al., 2018; Sellschop et al., 2018).
  - o Anthropometric data (Dullien et al., 2018).

a.3) Analysis of the records on postural education intervention programs found

A comparative study of 2 intervention models based on the Back School (Minghelli et al., 2021) showed that the programme with longer duration, weekly frequency and practice obtained better results in increasing ergonomic knowledge of posture, as well as reducing back pain. On the other hand, the intervention based on the Back Care Education Programme (Mantilla et al., 2021) also obtained better results in the theoretical-practical questionnaires of the intervention groups compared to the control group.

The intervention carried out through a teaching methodology based on gamification (Serrano-Durá et al., 2021) obtained significant improvements in terms of content assimilation, compared to the traditional methodology, although only in female students. The results in terms of motivation and self-perception of effort were satisfactory in the whole sample.

Interventions based on school physiotherapy programs (Blanco-Morales et al., 2020; Minghelli, 2020b) contributed to: theoretical-practical training on the adoption of correct posture, reduction of back pain in all adolescents involved, greater awareness of the consequences of not adopting proper posture and increased motivation to make changes in their daily postural habits (Blanco-Morales et al., 2020).

On the other hand, it was also found that most adolescents adopt an inadequate posture when performing activities at school or in everyday life, which can lead to musculoskeletal disorders. These results point to the need for health promotion at school to encourage postural literacy to prevent posture-related back problems and pain (Minghelli, 2020b).

The theory-based back care intervention (T-Bak) showed positive results in terms of increasing the back care knowledge of Primary School pupils. For this reason, the implementation of intervention programs is recommended in educational institutions at this school stage (Akbari-Chehrehbargh et al., 2020a).

The intervention based on a lesson plan of postural education content (Cabrera-González et al., 2020) is, according to its authors, easy to apply as it is specifically designed for inclusion in formal education. In it, the results show significant improvements in knowledge of back health and a high prevalence of students with low back pain was found. Low back pain is a public health problem and adolescence is a stage characterized by the appearance of this ailment. Therefore, the benefits of this study could have positive consequences in the prevention of back pain, as well as other health problems. On the other hand, this study also showed that there is little knowledge about postural attitudes and habits that can be dangerous for health. In any case, didactic interventions of a curricular nature mean that teachers assume the responsibility of contributing to the promotion of healthy habits that have significant consequences in the lives of students.

In another postural education intervention, framed within the Postural Education Program for Schoolchildren (Dos-Santos et al., 2017), students improved their theoretical knowledge of back care and postural attitudes in most of the activities of daily living analysed, with respect to the values recorded in the pretest.

An educational intervention program in back health (Miñana-Signes et al., 2019) contributed to improving both knowledge and the acquisition of postural habits in activities of daily living. According to the authors of the study, Physical Education classes are the ideal environment for carrying out educational programs on back health. It is necessary to carry out more studies with validated instruments in order to continue improving intervention programs.

A specific intervention on computer use (Sellschop et al., 2018) obtained positive results in terms of the adoption of ergonomic sitting postures, working in front of the screen. This study showed the importance of early intervention in the school environment to increase efficient postural behaviour and thus contribute to a positive impact on the health system.

Other studies (Dullien et al., 2018) despite improving the postural habits of the participants did not obtain satisfactory results in improving back pain, as the prevalence could not be reduced below 30%. Long duration

physical activity, excessive weight of backpacks and sitting for long periods of time were evidenced as the 3 main causes of back pain.

b) Validation of research instruments

In the records analysed during the systematic search, 4 recent studies on validation of new research instruments related to the implementation of postural education programs were found. These articles were separated into a different subcategory.

The first of the studies (Szilagyi et al., 2021) aims to develop and validate a back care knowledge questionnaire for use with children aged 6-10 years. The current literature makes validated questionnaires available to researchers for pupils from 14 years of age, but there is a shortage of validated instruments for younger ages, despite the fact that postural education intervention programs are recommended from the age of 4 years. The result was satisfactory and validation showed the instrument to be valid and reliable.

The second study (Miñana-Signes et al., 2021b) aims to make a cultural adaptation of an instrument already validated in the original country and language. The Back Pain and Body Posture Evaluation Instrument - BackPEI (Back Pain and Body Posture Evaluation Instrument). For this purpose, the authors of the study carried out a translation into Spanish and a reliability test of the instrument. The results were satisfactory and similar to those obtained with the original Brazilian version.

In the third article (Akbari-Chehrehbargh et al., 2020b) the aim of the researchers is to develop and validate a questionnaire to measure healthy spine-related behaviours in school populations. The lack of assessment instruments that measure postural learning based on Social Cognitive Theory has led them to design the Back-care Behavior Assessment Questionnaire (BABAQ). The results of its development and validation were positive and make the BABAQ a valid instrument.

The last article (Monfort-Pañego and Miñana-Signes, 2020) aims to develop and validate a Questionnaire to Evaluate the Back-hEalth related postural Habits in dAiLy actiVitiES (BEHALVES) of adolescents. The results confirmed that the questionnaire is a valid and reliable instrument for assessing the postural habits of students during activities of daily living.

c) Use of electronic device for postural analysis

Among all the recent studies recorded, only Lubkowska (2018) described the applicability of an electronic device as an aid for the assessment of body posture. The Wiva sensor is placed on the joint to be analysed and uses Bluetooth technology to send precise information on the movement of the joint, allowing the ranges of movement considered healthy or optimal for the objective of the intervention to be controlled.

d) Prevalence of back pain in the school population and its causes and risk factors

The last of the subcategories is also the one on which most studies have been carried out. The scientific literature contains a large number of studies on the prevalence and risk factors for back pain in children, adolescents and young adults in the formal educational system.

d.1) Instruments used

The most commonly used instrument for obtaining results was the self-administered questionnaire, although the personal interview was used in 4 of the articles consulted (Iacovelli et al., 2021; Minghelli, 2020a; Akbar et al., 2019; Spiteri et al., 2017) and the observation sheet in 4 studies (Vidal-Conti et al., 2021; Illeez et al.,

2020; Sukartini et al., 2020, Paranjape and Ingole, 2018). The majority of the researches opted for the combined use of several instruments. Regarding the type of questionnaire, there is diversity in its use. Several authors implemented standardized instruments (Miñana-Signes et al., 2021a ; Noll et al., 2021; Vitta et al., 2021; Bento et al., 2020; González-Gálvez et al., 2020; Schwertner et al., 2020; Galozzi et al, 2019; Aparicio-Sarmiento et al., 2019; de-Oliveira-Saes and Flores-Soares, 2017; Da Rosa et al., 2017; Meziat-Filho et al., 2017), while others opted for adaptations of standardized questionnaires (Iacovelli et al., 2021; Kedra et al., 2021; Masiero et al., 2021; Muñoz-Serrano et al., 2021; Layuk et al., 2020; Ayed et al., 2019, Khalil and Alrubaey, 2019) and, in other studies, ad-hoc designed instruments were applied (Iacovelli et al., 2021; Kedra et al., 2021; Muñoz-Serrano et al., 2021; Galozzi et al., 2019; Aparicio-Sarmiento et al., 2019; Rodríguez-Oviedo et al., 2018; Mohammadi et al., 2017).

d.2) Analysis of the records found on the prevalence of back pain in schoolchildren

Low back pain is the most common musculoskeletal complaint related to the back and spine (González-Gálvez et al., 2021). Kalki et al. (2020) estimate that up to 95% of the population will suffer back pain at some point in their lives.

In the articles analysed, the authors recorded a wide range of figures for the prevalence of back pain: 33-90% of those surveyed suffered pain at some time in their lives (Vidal-Conti et al., 2021; Miñana-Signes et al., 2021a; Masiero et al, 2021; Kalki et al., 2020; Schwertner et al., 2020; Galozzi et al., 2019; Noormohammadpour et al., 2019; Akbar et al., 2019; Kiat et al., 2018; Paranjape and Ingole, 2018); 19-74% in the last year (Kedra et al., 2021; Vitta et al., 2021; Miñana-Signes et al., 2021a; Bento et al, 2020; Minghelli, 2020a; Fabricant et al., 2020; Sainz de Baranda et al., 2020a and 2020b; Kedra et al., 2019; Rodriguez-Oviedo et al., 2018; Meucci et al., 2018); 27-80% in the last month (Santos et al., 2021; Ayed et al., 2019; Oka et al., 2019; Khalil y Alrubaey, 2019; Noormohammadpour et al., 2019; Akbar et al., 2019; Hadziomerovic et al., 2018; Spiteri et al., 2017; Dianat et al., 2017); 11-45% in the last 7 days (Miñana-Signes et al., 2021a; Vidal-Conti et al., 2021; Sainz de Baranda et al, 2020a and 2020b; de-Oliveira-Saes and Flores-Soares, 2017); 9-32% point prevalence at the time of answering the questionnaire (Vidal-Conti et al., 2021; Miñana-Signes et al., 2021a; Minghelli, 2020a, Schwertner et al., 2020; Shuhaimi and Rahman, 2020).

The presence of pain is not only more common in women, but also appears with greater intensity (Iacovelli et al., 2021). However, other studies (Miñana-Signes et al., 2021a; González-Gálvez et al., 2021; Assiri et al., 2020) found no relationship between gender and the higher prevalence of back pain.

According to most of the studies consulted, the prevalence increases in parallel with the age of the students (Kedra et al., 2021; Miñana-Signes et al., 2021a; Noll et al., 2021; González-Gálvez et al., 2020; Minghelli, 2020a; Fabricant et al., 2020; Ayed et al., 2019; Aparicio-Sarmiento et al., 2019; Kedra et al., 2019; Meucci et al., 2018; de-Oliveira-Saes y Flores-Soares, 2017). However, Assiri et al. (2020) did not find this correlation.

The scientific literature states that the prevalence of back pain in adolescents is very high, with important consequences on their quality of life (Iacovelli et al., 2021; Santos et al., 2021; Masiero et al., 2021; González-Gálvez et al., 2020; Ayed et al., 2019; Galozzi et al., 2019). Masiero et al. (2021) recorded 14% of students reporting non-specific disabling low back pain at some point in their lives. The first manifestations of this condition are detected from the age of 10 years (Miñana-Signes et al., 2021a) and there is a high probability that it will persist into adulthood (Santos et al., 2021; Assiri et al., 2020; Illeez et al., 2020; Paranjape e Ingole, 2018; de-Oliveira-Saes y Flores-Soares, 2017).

Several studies highlight the burden this problem places on the health care system (Minghelli, 2020a; Garvick et al., 2019). Hence, there are authors, such as Kalki et al. (2020), who consider back pain to be one of the most underestimated public health problems.

The causes of back pain in childhood and youth are as diverse as in adults, with those of mechanical origin being the most frequent and not those caused by disease (Illeez et al., 2020).

Back pain was associated with prolonged sitting (Kemta et al., 2021; Masiero et al., 2021) and incorrect sitting posture (Minghelli, 2020a; Meziat-Filho et al., 2017). Minghelli (2020a) highlights the importance of this aspect, given the high number of hours' students spend sitting in schools. However, Sainz de Baranda et al. (2020a) found no correlation between the way of sitting and the appearance of back pain, despite finding that most students sat inappropriately in class.

Other risk factors pointed out by the scientific literature are: incorrect adjustments of school furniture (Ayed et al., 2019; Dianat et al., 2017); posture during the handling of electronic devices and the time spent using them(Vitta et al., 2021; Masiero et al., 2021; Bento et al., 2020; Minghelli, 2020a; Ayed et al., 2019); time spent watching television (Santos et al., 2021; Noll et al., 2021; Bento et al., 2020; Ayed et al., 2019; Oka et al., 2019; Paranjape e Ingole, 2018; Meziat-Filho et al., 2017); lack of adequate rest (Masiero et al., 2021; Muñoz-Serrano et al., 2021); high BMI (González-Gálvez et al., 2020; Spiteri et al., 2017); presence of lumbar hyperlordosis (Sainz de Baranda et al., 2020b); family history of back pain (Kemta et al., 2021; Noll et al., 2021; Masiero et al., 2021; Oka et al., 2019; Noormohammadpour et al., 2019; Dianat et al., 2017); passive smoking (Noormohammadpour et al., 2019).

Low physical activity was associated with the development of back pain (González-Gálvez et al., 2021; Masiero et al., 2021; González-Gálvez et al., 2020; Schwertner et al., 2020). Sedentary lifestyles affect key aspects of postural control, such as core toning and hamstring flexibility (González-Gálvez et al., 2021). This is why authors such as Schwertner et al., (2020), relate the practice of Physical Education at school to a protective factor against back pain.

Other studies found no direct relationship between back pain and the following risk factors: lack of rest (Schwertner et al., 2020); use of electronic screens (Schwertner et al., 2020; Dianat et al., 2017); time spent in sedentary activities (González-Gálvez et al., 2021; Dianat et al., 2017); student BMI (González-Gálvez et al., 2021; Masiero et al., 2021; Schwertner et al., 2020).

The incidence of back pain is directly linked to the prolonged use of school bags (Ayed et al., 2019; Khalil y Alrubaey, 2019; Dianat et al., 2017) and to the weight of school bags (Santos et al., 2021; Kedra et al., 2021; Layuk et al., 2020; Kalki et al., 2020; Shuhaimi y Rahman, 2020; Ayed et al., 2019; Noll et al., 2021; Assiri et al., 2020; Akbar et al., 2019; Rodríguez-Oviedo et al., 2018; Kiat et al., 2018; Hadziomerovic et al., 2018; Paranjape e Ingole, 2018; Spiteri et al., 2017). Although there are studies that found no relationship with school bag weight (Kemta et al., 2021; Oka et al., 2019; Dianat et al., 2017).

The way the backpack is carried also influences the incidence of back pain for some authors (Noll et al., 2021; Assiri et al., 2020; Khalil y Alrubaey, 2019; Rodríguez-Oviedo et al., 2018). However, for other researchers there is no such relationship (González-Gálvez et al., 2021) and there is even a study (Khalil and Alrubaey, 2019) that points out that the simple fact of using a school bag is already a risk factor in itself.

There are studies that have shown a low level of knowledge about back health on the part of the participating students (Aparicio-Sarmiento et al., 2019; Kedra et al., 2019). This finding justifies the need to carry out educational interventions in schools themselves, as proposed by numerous authors (Vidal-Conti et al., 2021; Alami et al., 2020; Minghelli, 2020; Schwertner et al., 2020; Assiri et al., 2020; Ayed et al., 2019; Kedra et al., 2019; Kiat et al., 2018; Paranjape e Ingole, 2018; Mohammadi et al., 2017; de-Oliveira-Saes y Flores-Soares, 2017).

DISCUSSION

Scientific production is considerably higher in the last two years and has been mainly developed by European scientists, especially Spanish scientists. On the other hand, Africa's low scientific production stands out, which could be attributed to lower investment in research, fewer researchers and/or limited international collaboration (Venkata et al., 2021), and the reduced contribution of North American studies. It is worth highlighting the case of Oceania, which despite having well-established economies, has zero research output on the subject.

With regard to the type of design (Dankhe, 1986), all the studies corresponding to intervention programmes in postural education, due to their experimental nature, are of an explanatory type. While the studies of validation of instruments and the great majority of those on the prevalence of back pain are of the correlational type. Lastly, the only study related to the use of an electronic device for the evaluation of posture is descriptive, since it does not include any type of intervention or analysis between variables. It is limited to describing the functioning and usefulness of the device as a tool for assessing body posture.

On the other hand, quantitative methodology is the preferred option in the studies found in this review. Only one article (Blanco-Morales et al., 2020) mentions qualitative methodology.

Regarding the publication medium, most of the studies were included in specialised journals of public health, health promotion and Physical Education and Sport, and elaborated by a team of 4 or more authors. Among the main authors who appear most frequently, we highlight Minghelli and Miñana-Signes, from Italy and Spain, respectively, who are authors of 3 articles each. In the case of Minghelli, 2 of them as sole author.

Most of the studies highlight the very high prevalence of back pain in the school population in formal education and the effects on their quality of life. One study (Masiero et al., 2021) even highlights that the number of students who claimed to suffer or have suffered disabling back pain at some point in their lives was 14%. This is a very high figure, given that we are talking about back pain that is disabling for everyday life and non-specific, i.e. back pain that cannot be attributed to a specific cause (Maher et al., 2017).

Although the percentage range is wide and varies between studies, the worst figures found determine the incidence of back pain at some point in life in 90% (Kalki et al., 2020) of students surveyed, 74% (Kedra et al., 2019) suffered pain in the last year, 80% (Hadziomerovic et al., 2018) in the last month, 45% (de-Oliveira-Saes and Flores-Soares, 2017) in the last week and 32% (Shuhaimi and Rahman, 2020) at the time of the study. In line with these data, there are authors (Kalki et al., 2020) who estimate that up to 95% of the population will suffer from this ailment at some point in their lives and that the origin of this ailment is not attributable to pathologies in most cases (Illeez et al., 2020), so prevention strategies are recommended, from an early age and from the educational centres themselves, to promote lifestyle habits related to back health.

In the literature consulted, there is no clear consensus on the relationship between back problems and the possible causes that give rise to them. Some authors (Vlaeyen et al., 2018) describe this problem as a real challenge for researchers and health professionals, due to the enormous variety of manifestations, possible causes, risk factors and consequences for quality of life. Although several studies establish incorrect sitting posture, sitting for long periods of time, incorrectly adjusted school furniture, school bags, lack of rest, a high Body Mass Index and time spent using electronic devices as risk factors for the appearance of back pain, other studies have found no relationship between these factors and back pain. One of the latter studies (Sainz de Baranda et al., 2020a), despite not relating the appearance of back pain to an inadequate sitting posture, does warn about the high number of students who do not sit properly in class and the possible harmful effects for a still developing spine which spends a large part of the day in the same position (Sainz de Baranda et al., 2020a; Minghelli, 2020a). Recall that, although adult height is reached between 15-17 years for girls and 17-19 years for boys (Carrascosa and Mesa, 2018), full bone maturity does not end until around 25 years of age (Cech and Martin, 1995).

Most of the articles analysed highlight that back ailments are more frequent as students get older and especially affects the female population. The moment of appearance is at very early ages, around 10 years of age (Miñana-Signes et al., 2021a), becoming more acute from 11-12 years of age (Sukartini et al., 2020) and several studies agree that that the probability that this condition persists into adulthood is very high (Dugan, 2018; Coenen et al., 2017). But it is not necessary to reach adulthood to assess the consequences of this problem. Back pain in school-age children is a growing public health problem, consuming health service resources and overloading the health system (Minghelli, 2020a; Garvick et al., 2019).

For all these reasons, prevention training programs should accompany the student throughout their academic life and not be limited to the temporal range corresponding only to their compulsory schooling. Even more so when a study (Jonsdottir et al., 2019) relates academic adherence as a risk factor for back pain. That is, the longer the time spent in the educational system, the greater the probability of suffering from back pain.

The large percentage of studies dedicated to the prevalence and causes of back pain in children, adolescents and young adults is striking, compared to the subject of study in the rest of the publications. Likewise, it is paradoxical that, in view of the devastating results on the incidence of back problems in the population analysed, the majority of these studies recommend the educational intervention of postural education content in the school environment, but there are very few articles. focused on this type of interventions.

On the other hand, several studies highlight the protective factor of physical activity, especially school Physical Education, against the problems caused by low back pain (González-Gálvez et al., 2021; Masiero et al., 2021; González-Gálvez et al., 2020; Schwertner et al., 2020; O'Sullivan et al., 2019; Hartvigsen et al., 2018). This fact shows the need to enhance the useful practice time in this area, as well as provide a greater weekly workload for this subject at all educational stages (Uddin et al., 2020), as recommended by the European Commission in the Eurydice Report (EACEA, 2013).

To the scarce literature on the implementation of postural education programs in the field of formal education, an additional limitation must be added: the characteristics of the samples analysed. Of the 11 articles found, 5 (45%) are studies based on samples of less than 50 students, which requires taking the data with caution before extrapolating the results, especially in those cases whose samples are made up of groups. -class already predefined by the educational centre and not random (Morales-Vallejo, 2009).

Regarding the size of the samples used, it should be noted that back pain prevalence studies were implemented in larger population groups. Most of the articles of this type include samples of more than 500 people and, within these, the majority were carried out in groups of over 1000 people, a figure not found in any of the other three types of research. On the opposite end are studies on intervention programs in postural education, with a much smaller sample size. In this case, most of the studies found were carried out with samples of less than 100 people. This fact can be explained by the characteristics of the research itself. Prevalence studies require larger samples to be representative. The cross-sectional nature and the use of an effective instrument, such as the self-administered questionnaire, in the majority of back pain incidence studies provides agility to the process and facilitates the management of larger samples that provide significance to the investigation.

On the other hand, the studies found on educational interventions in school environments, due to their mostly longitudinal nature, require maintaining groups under control throughout the duration of the study (weeks, months or years), before, during and after the intervention. In several of these studies, a combination of various research instruments (questionnaires, field tests, teaching materials, interviews, electronic devices, etc.). Smaller samples facilitate the management of this task without diminishing the significance of the results obtained.

Even so, the results of the intervention programs in postural education demonstrate the effectiveness and benefits obtained through the implementation of education programs for back health in the field of formal education. Improvement increases in programs of longer duration, weekly frequency, and practice time (Minghelli et al., 2021). Several studies have highlighted the low level of knowledge about back care that students have at the beginning of the intervention (Miñana-Signes, 2017; Miñana-Signes et al., 2019; Cabrera-González et al., 2020). This finding has been confirmed by other prevalence studies that obtained very low levels of general knowledge about back health (Kedra et al., 2019; Aparicio-Sarmiento et al., 2019).

Regarding the contents of the intervention programs in postural education, most of the analysed studies focused on both theoretical and practical aspects. The theory focused on anatomical and functional concepts of the back. Practice focused on learning correct postures in daily life situations (including the school environment) and the consequences of inappropriate postures. The postures included were both static and dynamic and those that most frequently appeared in these studies were: sitting (sitting alone on a chair/bench, at a desk/table, writing, working with a computer, watching TV, playing video games...); carrying a backpack (placing the backpack on the back, proper distribution of objects inside, maximum weight of the backpack...); lying down (lying, sleeping...); mobile phone use (writing a message); standing (static); managing objects (reaching for an elevated object, lifting a heavy or light object from the ground, carrying heavy objects and shopping bags...). Some studies also included physical exercises for strength and flexibility to improve student's physical condition and mitigated possible physical limitations when adopting the correct position.

The instruments used in this type of interventions were varied: mainly written questionnaires, practical performance tests and physical condition tests. The questionnaires were used to measure the level of knowledge about back health care, the prevalence of back pain and to record personal and sociodemographic data; The practical performance tests measured the ability/skill of each student implement proper postures in different situations of daily life; and the physical tests measured the student's level of physical condition, especially the strength, endurance and flexibility of the muscles involved in the posture.

The studies of research instruments' validation aimed to measure the reliability and applicability of 4 instruments that recorded information about back health knowledge. The instruments used in the 4 investigations were also questionnaires.

CONCLUSIONS

Scientific literature on postural education programs shows the effectiveness of interventions in the educational field, but the literature is scarce compared to the numerous studies about prevalence of postural problems.

Scientific production is concentrated mainly in the last 2 years and comes mostly from European researchers. Spain and Brazil are the countries with the greatest scientific contribution to the topic of study.

The most common type of study is correlational and the predominant methodology is quantitative.

The scientific journals that contributed the most literature are those whose themes are directly linked to health.

Most of the articles were published by 4 or more authors and the researchers who most frequently appear as first authors are the Italian Beatriz Minghelli and the Spanish Vicente Miñana-Signes.

The sample size is considerably larger in studies on the prevalence of postural problems than in educational intervention programs in schools.

The contents of the postural education intervention programs focus on addressing postures present in daily life (and school) situations, which are summarized in sitting, standing, lying down, carrying a backpack, using the phone and moving objects.

The most commonly used instrument in the analysed articles is the questionnaire. The main variables to be measured were knowledge of back health, the presence of pain and personal data of the student evaluated.

Many articles warn about the high prevalence of back pain, especially low back pain and emphasize the preventive factor of physical activity and Physical Education in school, so giving this subject a greater curricular weight and reinforcing the contents of postural education would yield important health benefits.

The prevalence of back pain in children, adolescents and young adults, especially in women, is very high in all the analysed countries. This problem causes serious harm to the population. The onset age is before adolescence. It affects the female gender to a greater extent and there is a high probability that this condition will persist into adulthood, which makes it one of the most underestimated health problems.

For all these reasons, it is necessary to promote preventive and literacy training programs on back health care in formal education that involve the entire educational community.

AUTHOR CONTRIBUTIONS

All authors have contributed significantly to the design of the project, selection of documents, reading and analysis of texts, as well as to the final writing of the manuscript.

SUPPORTING AGENCIES

No funding agencies were reported by the authors.

DISCLOSURE STATEMENT

No potential conflict of interest were reported by the authors.

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ORIGINAL ARTICLE

Comparing physical, technical and tactical performances in the World Cup Qatar 2022

LUÍS BRANQUINHO[1,2,3], ELIAS FRANÇA[4], JOSÉ TEIXEIRA[2,5,6], NELSON VALENTE[1], TIAGO REIS[7], RONALDO VAGNER THOMATIELI-SANTOS[4,8], PEDRO FORTE[2,3,6,7],RICARDO FERRAZ[2,9]

[1]*Agrarian School of Elvas. Polytechnic Institute of Portalegre. Portalegre, Portugal.*
[2]*Research Center in Sports Sciences, Health Sciences and Human Development (CIDESD). Covilhã, Portugal.*
[3]*CI-ISCE – ISCE Douro. Penafiel, Portugal.*
[4]*Interdisciplinary Graduate Program in Health Sciences. Federal University of São Paulo. São Paulo, Brazil.*
[5]*Department of Sport Sciences. Polytechnic Institute of Guarda (IPG). Guarda, Portugal.*
[6]*Department of Sport Sciences. Polytechnic Institute of Bragança (IPB). Bragança, Portugal.*
[7]*Higher Institute of Educational Sciences of the Douro (ISCE Douro). Penafiel, Portugal.*
[8]*Graduate Program in Psychobiology. Federal University of São Paulo. São Paulo, Brazil.*
[9]*Department of Sports Sciences. University of Beira Interior (UBI). Covilhã, Portugal.*

ABSTRACT

The main objective of this study was to compare the physical, technical, and tactical performances of the 32 teams that participated in the FIFA World Cup Qatar 2022™ concerning the confederation to which they belong and the FIFA ranking. Key statistics from the 64 matches played during the FIFA World Cup Qatar 2022™ were analysed. The data from these matches were encoded and calculated by a multi-camera optical tracking system (TRACAB Gen5, ChyronHego). Significant differences were identified between Rank 1-15th vs. Rank 16-35th and Rank 1-15th vs. Rank 36-61st for possession, total attempts at goal, total attempts on target, total passes, total complete passes, passes completion possession, completed line breaks, defensive line breaks, receptions in the final third, and ball progressions. However, defensive line breaks were different only between Rank 1-15th vs. Rank 36-61st, and ball progressions was only different between Rank 1-15th vs. Rank 16-35th. Africa and Europe national confederation showed significant differences (all $p < .05$) for possession, total attempts on target, total passes, total complete passes, passes completion, completed line breaks, and receptions in the final third, except for total attempts on target, whose differences are between Asian and South American confederation ($p < .05$). When considering the FIFA ranking and the confederations, there are significant differences key performance indicator of the teams.
Keywords: Performance analysis, Soccer, National teams, Key statistics, Match running, Analysis.

Cite this article as:
Branquinho, L., França, E., Teixeira, J., Valente, N., Reis, T., Thomatieli-Santos, R. V., Forte, P., & Ferraz, R. (2024). Comparing physical, technical and tactical performances in the World Cup Qatar 2022. *Journal of Human Sport and Exercise, 19*(2), 654-666. https://doi.org/10.55860/t8ybtk14

Corresponding author. *Agrarian School of Elvas, Polytechnic Institute of Portalegre, Av. 14 de Janeiro 13, 7350-092 Elvas. Portugal.* *https://orcid.org/0000-0001-9000-5419*
E-mail: luis_branquinho@outlook.pt
Submitted for publication December 20, 2023.
Accepted for publication January 26, 2024.
Published April 01, 2024 *(in press* March 04, 2024).
JOURNAL OF HUMAN SPORT & EXERCISE ISSN 1988-5202.

doi: https://doi.org/10.55860/t8ybtk14

INTRODUCTION

The FIFA World Cup (WC) is the most popular sporting event in the world (Chadwick et al., 2022). This competition is organized by FIFA and takes place every four years in a different part of the globe (Andersson et al., 2021), where the best teams from each continent try to win the title of world champion. Nowadays, there are six football confederations (Csató, 2023), each with a few specific places for participation. The South American Football Confederation (CONMEBOL) has three to four teams, 13 teams come from the Union of European Football Associations (UEFA), four or five from the Asian Football Confederation (AFC), five teams from the African Football Confederation (CAF), three or four teams from the Football Confederation of North, Central America and the Caribbean (CONCACAF), and zero or one from the Football Confederation of Oceania (OFC), in addition to the host country that has a direct entry (Durán et al., 2017; Kessouri, 2023; Kubayi & Toriola, 2020).

For the first time in history, the FIFA Qatar 2022™ (2022-WC) took place in the middle of the competitive season and there is a growing curiosity to clarify the impact that these changes had on the performance of the teams (Kessouri, 2023). For this reason, it seems essential to carefully analyse variables associated with the physical, technical, and tactical components that occurred during the competition. In recent years, one of the most used performance determinants in soccer has been physical variables (Branquinho et al., 2021; Durán et al., 2017; Lago-Peñas, 2012; Pino-Ortega et al., 2021). However, numerous investigations have reported on technical performance (Arslan et al., 2020; Modric et al., 2019), tactical behaviour (Goes et al., 2021; Musa et al., 2019), and the interdependence between them (Aquino et al., 2016; Filetti et al., 2017). Previous evidence reported that physical performance standards seemed to vary between athletes from different continents (Alves et al., 2019; Tuo et al., 2019), and these issues may be particularly important when comparing performance across different national teams. Despite the constant growth of football worldwide, and the evolution of infrastructures and constant technological advances, there are still differences between clubs from different continents that can influence performance in the national team context (Goslin & Mosola, 2020), mainly in confederations with less competitive championships (Gasparetto & Barajas, 2020; Razmjooy et al., 2016). The importance of ball possession and its influence on the result of matches is a topic of current discussion (da Mota et al., 2016; Kubayi & Toriola, 2019; Maneiro et al., 2020). Previous investigations reported that teams that achieved greater ball possession times achieved better rankings in championships (Alves et al., 2019; Lago-Peñas & Dellal, 2010). Regarding the technical component, a previous investigation reported that there seemed to be a positive relationship between the number of blocks, pass accuracy, finishing ability, counterattacks, and the probability of winning (Fernandez-Navarro et al., 2019; Lepschy et al., 2018).

Thus, based on the undeniable importance of these variables on performance, it seems important to verify the existing differences regarding the physical, technical, and tactical performances of the teams that participated in the 2022-WC as previous identified (Kubayi & Toriola, 2020). Changes in the competition schedule may negatively or positively affect the performances of national teams from different confederations. In addition, it seems interesting to verify whether the performances obtained by the teams are related to the FIFA Ranking since this directly influences the draw for the group stage of the competition.

Thus, the main objective of this study was to compare the physical, technical, and tactical performances of the 32 teams that participated in the 2022-WC concerning the confederation to which they belong and the FIFA ranking.

MATERIAL AND METHODS

Participants

Key statistics from the 64 matches played during the 2022-WC were analysed. The data from these matches were encoded and calculated by a tracking system (multi-camera optical tracking system: TRACAB Gen5, ChyronHego), available free of charge at the FIFA website (https://www.fifatrainingcentre.com/en/game/tournaments/fifa-womens-world-cup/2023/match-report-hub/post-match-summary-reports.php). The validity and accuracy of data collection by TRACAB Gen5 were previews provided (Linke et al., 2020).

Procedures

To analyse the game's variables, the teams were divided according to the FIFA Ranking in which they were at the beginning of the competition (October 2022) and the confederation to which they belonged. Thus, the teams were grouped as follows: a) UEFA (13 teams); b) CONMEBOL (4 teams); c) CONCACAF (4 teams); d) CAF (4 teams); e) AFC + Australia (6 teams). In total, 18 variables were analysed that were classified as key indicators (i.e., physical, technical, and tactical). As the 32 teams played 3 to 7 matches (a total of 128 games), we calculated the average of the 18 variables for each team, thus producing 32 data sets. Eight data from matches that had extra time (i.e., 120 minutes) were excluded. Table 1 shows the variables that were analysed and how they were calculated.

Statistical analysis

For descriptive statistics, the Kolmogorov–Smirnov and Levene's tests were used to test the normality and homogeneity, where a normal distribution was observed. Data are presented as the mean ± SD. National teams were encoded according to FIFA conference (i.e., AFC, CAF, UEFA, CONMEBOL, and CONCACAF) and ranking (i.e., 1-15th vs. 15-35th vs. 36-61st). To compare groups, we use one-way analysis of variance (ANOVA) and when a significant difference occurred, Tukey post-hoc tests were used to identify localized effects in mean differences in key indicators performance (KPI) for each condition. The effect size index (eta square: η^2) was computed and interpreted as: (i) without effect if $0 \geq \eta^2 \leq 0.04$; (ii) minimum if $0.04 > \eta^2 \leq 0.25$; (iii) moderate if $0.25 > \eta^2 \leq 0.64$; and (iv) strong if $\eta^2 > 0.64$ (Ferguson, 2009; Hopkins et al., 2009). Statistical significance was set at $p < .05$. All statistical analyses were conducted using IBM SPSS Statistics for Windows (Version 27.0., IBM Corp, Armonk, NY, USA). ES calculations were performed with G*Power (Version 3.1.5.1 Institut für Experimentelle Psychologie, Düsseldorf, Germany). Data visualization was produced using GraphPad Prism (GraphPad Software, Inc., San Diego, CA, USA).

RESULTS

Table 1 presents FIFA ranking group mean differences for each key performance indicator (KPI). Significant differences were found between Rank 1-15th *vs.* Rank 15-35th and Rank 1-15th *vs.* Rank 36-61st for possession, total attempts at goal, total attempts on target, total passes, total complete passes, pass completion, completed line breaks, defensive line breaks, receptions in the final third, and ball progressions (all $p < .05$), except in defensive line breaks, ball progressions, and total defensive pressures applied (see Table 1 and Figure 1).

Table 2 presents the mean differences between FIFA confederations for each KPI. Significant differences between confederations CAF and UEFA national teams showed significant differences were found for possession, total attempts on target, total passes, total complete passes, passes completion, completed line

Table 1. Mean differences in key performance indicator (KPI) for each FIFA ranking group.

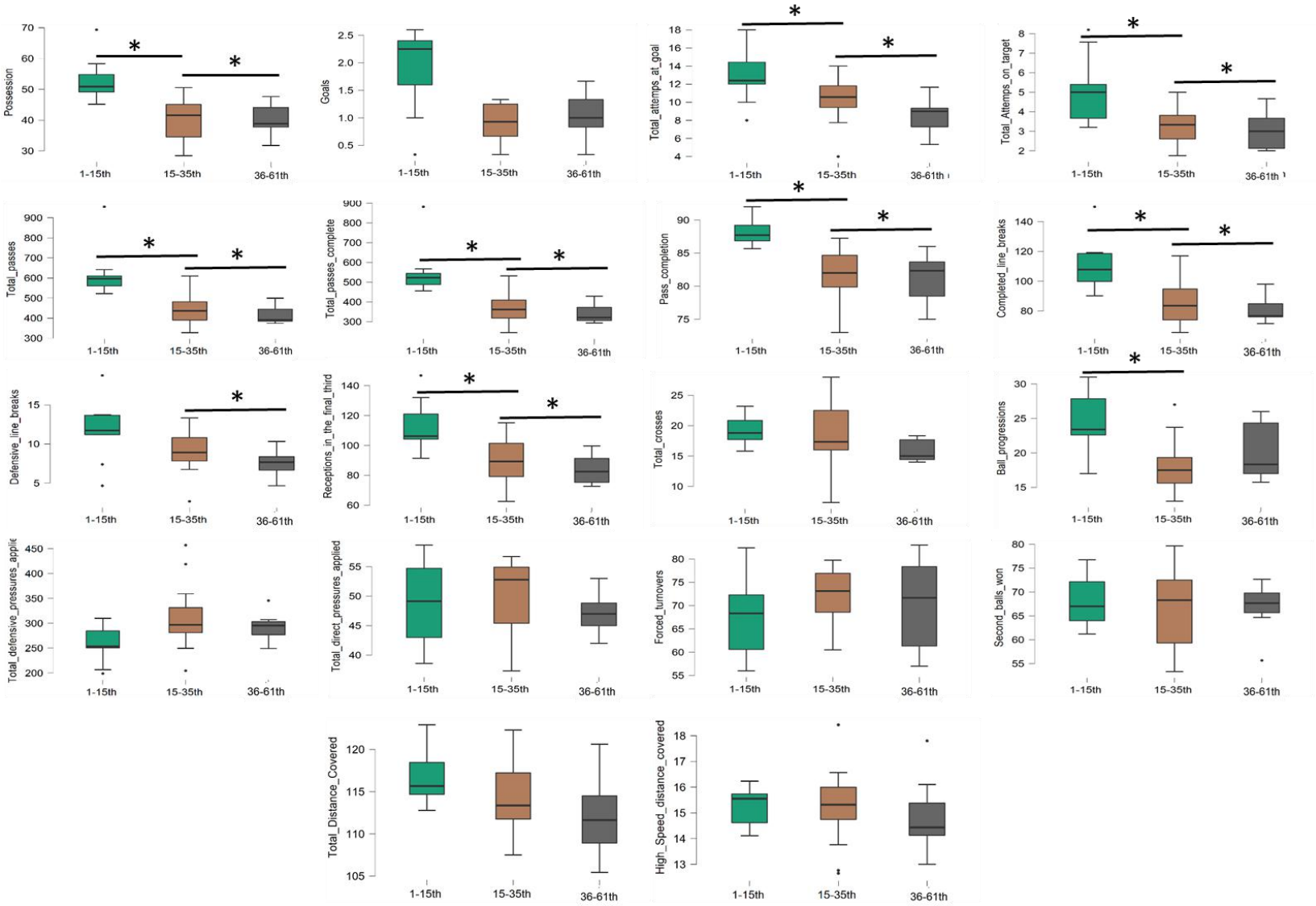
Variables	***FIFA Ranking***			***ANOVA***			***Post-Hoc***
	Rank 1-15th (n = 14)	*Rank 16-35th (n = 11)*	*Rank 36-61st (n = 7)*	*F*	*p*	η^2	*Tukey*
Possession (%)	49.86 ± 7.32	38.44 ± 7.38	40.29 ± 5.60	9.31	< .001	0.39	a,b
Goals (N)	1.54 ± 0.81	0.95 ± 0.38	1.05 ± 0.45	3.17	.057	0.18	-
Total attempts at goal (N)	12.57 ± 2.89	9.92 ± 2.47	8.46 ± 2.12	6.66	.004	0.35	a,b
Total attempts on target (N)	4.69 ± 1.55	3.02 ± 0.80	3.04 ± 1.04	7.22	.003	0.33	a,b
Total passes for (N)	575.85 ± 128.14	416.13 ± 67.25	417.91 ± 46.26	10.64	< .001	0.42	a,b
Total complete passes (N)	504.39 ± 128.04	341.99 ± 68.01	343.12 ± 49.77	10.92	< .001	0.43	a,b
Passes completion (%)	86.71 ± 2.71	81.15 ± 3.89	81.10 ± 4.00	10.39	< .001	0.42	a,b
Completed line breaks (N)	104.60 ± 18.17	83.00 ± 15.93	81.12 ± 8.97	7.82	.002	0.35	a,b
Defensive line breaks (N)	11.20 ± 3.36	8.68 ± 2.91	7.54 ± 1.83	4.31	.023	0.23	b
Receptions in the final third (N)	107.54 ± 16.91	85.51 ± 14.13	84.02 ± 10.86	8.66	.001	0.37	a,b
Total crosses (N)	19.62 ±3.69	17.46 ± 5.10	15.93 ± 1.88	2.21	.128	0.13	-
Ball progressions	22.61 ± 4.77	17.49 ± 4.18	20.39 ± 4.43	4.00	.029	0.22	a
Total defensive pressures (N) applied (N)	269.39 ± 4.43	320.12 ± 71.82	293.06 ± 30.61	3.16	.057	0.18	-
Total direct pressures applied (N)	46.76 ± 6.43	49.88 ± 6.92	47.10 ± 3.59	0.54	.591	0.04	-
Forced turnovers (N)	69.95 ± 7.78	71.99 ± 5.77	70.16 ± 10.30	0.23	.793	0.02	-
Second balls won (N)	68.34 ± 5.43	66.39 ± 9.08	66.70 ± 5.51	0.28	.760	0.02	-
Total distance covered (Km)	115. 65 ± 4.14	115.15 ± 4.09	112.08 ± 5.13	1.69	.206	0.10	-
High speed distance covered (km)	15.25 ± 1.01	15.29 ± 1.48	14.90 ± 1.58	0.22	.801	0.02	-

Letters in Turkey post-hoc: a, differences between Rank 1-15th vs. Rank 15-35th; b, differences between Rank 1-15th vs. Rank 35-61st.

Table 2. Mean differences in key performance indicator (KPI) for each between FIFA Confederations.

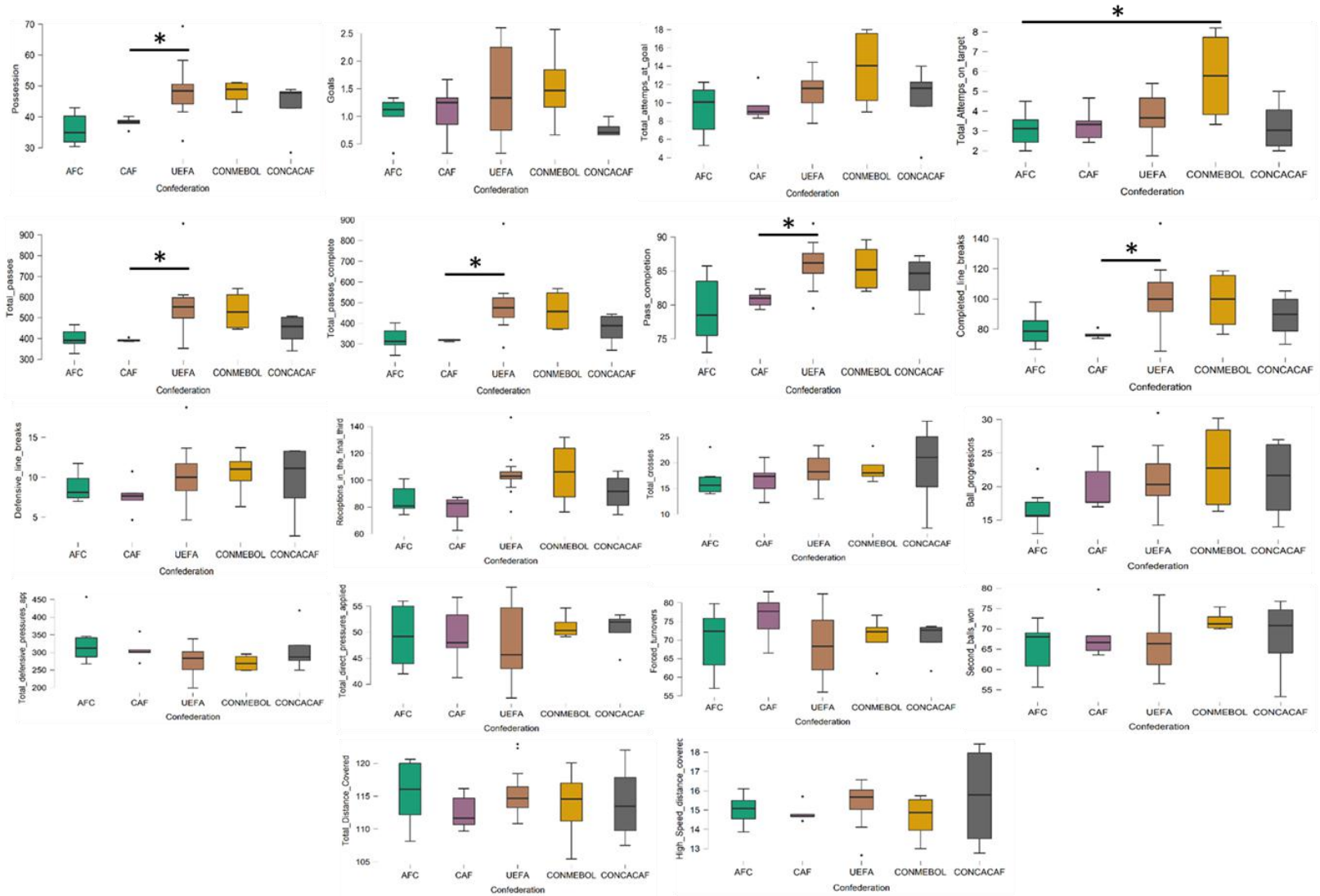
Variables	*FIFA Confederations*					*ANOVA*			*Post-Hoc*
	AFC (n = 5)	*CAF (n = 5)*	*UEFA (n = 13)*	*CONMEBOL (n = 4)*	*CONCACAF (n = 4)*	*F*	*p*	η^2	*Tukey*
Possession (%)	36.02 ± 5.31	38.14 ± 1.77	48.67 ± 8.89	47.64 ± 4.47	43.23 ± 9.85	4.14	.010	0.15	b
Goals (N)	1.03 ± 0.37	1.09 ± 0.51	1.42 ± 0.81	1.54 ± 0.79	1.77 ± 0.16	1.20	.333	0.20	-
Total attempts at goal (N)	9.28 ± 2.86	9.69 ± 1.78	11.07 ± 2.15	13.77 ± 4.61	10.29 ± 4.35	1.69	.182	0.31	-
Total attempts on target (N)	3.11 ± 0.92	3.32 ± 0.88	3.74 ± 1.08	5.78 ± 2.46	3.27 ± 1.38	3.09	.032	0.38	c
Total passes for (N)	399.19 ± 50.04	392.47 ± 7.49	561.34 ± 137.99	535.96 ± 100.47	441.48 ± 78.60	4.20	.009	0.38	b
Total complete passes (N)	323.69 ± 57.30	317.93 ± 4.08	488.49 ± 137.90	462.78 ± 105.30	372.98± 80.56	4.16	.009	0.41	b
Passes completion (%)	79.23 ± 5.18	80.82 ± 1.18	85.96 ± 3.21	85.50 ± 3.74	83.81 ± 3.80	4.64	.006	0.33	b
Completed line breaks (N)	79.97 ± 11.50	76.57 ± 2.68	102,50 ± 19.96	98,79 ± 20.91	88.73 ± 15.91	3.33	.024	0.10	b
Defensive line breaks (N)	8.78 ± 1.88	7.65 ± 2.17	10.29 ± 3.57	10.53 ± 3.08	9.56 ± 5.02	0.75	.567	0.35	-
Receptions in the final third (N)	85.57 ± 10.91	78.10 ± 10.34	104.34 ± 15.86	105.17 ± 25.78	91.10 ± 14.77	3.60	.018	0.06	b
Total crosses (N)	16.65 ± 3.40	16.72 ± 3.28	18.59 ± 3.21	18.90 ± 2.99	19.33 ± 8.99	0.46	.763	0.15	-
Ball progressions	16.82 ± 3.33	20.12 ± 3.90	21.06 ± 4.56	23.01 ± 7.03	21.08 ± 6.41	1.19	.339	0.22	-
Total defensive pressures (N) applied (N)	329.96 ± 68.67	307.34 ± 32.65	269.30 ± 44.04	270.45 ± 23.88	310.71 ± 74.32	1.92	.135	0.03	-
Total direct pressures applied (N)	49.25 ± 6.35	49.26 ±5.98	48.21 ± 7.58	51.12 ± 2.49	50.48 ± 3.94	0.21	.932	0.10	-
Forced turnovers (N)	69.78 ± 9.07	76.04 ± 6.46	69.28 ± 8.16	70.54 ± 6.69	70.15 ± 5.70	0.74	.576	0.10	-
Second balls won (N)	65.36 ± 6.69	68.56 ± 6.46	66.11 ± 6.71	71.97 ± 2.47	67.94 ± 10.45	0.73	.580	0.07	-
Total distance covered (Km)	115.52 ± 5.28	112.57 ± 2.74	115.63 ± 3.64	113.66 ± 6.18	114.12 ± 6.45	0.52	.725	0.07	-
High speed distance covered (km)	15.01 ± 0.81	14.85 ± 0.49	15.42 ± 1.10	14.62 ± 1.25	15.69 ± 2.84	0.53	.715	0.15	-

Letters in Turkey post-hoc: b, significant differences between CAF and UEFA; c differences between AFC and CONMEBOL. Significant differences are verified as: (a) Asia/AFC vs Africa/CAF; (b) Asia/AFC vs Europe/UEFA; (c) Asia/AFC vs South America/CONMEBOL; (d) Asia/AFC vs Nort and Center America/CONCAF; (e) Africa/CAF vs Europe/UEFA; (f) Africa/CAF vs South America/Conmebol; (g) Africa/CAF vs Nort and Center America/CONCAF (h) Europe/UEFA vs South America/Conmebol; (i) Europe/UEFA vs Nort and Center America/CONCAF; (j) Nort and Center America/CONCAF vs South America/Conmebol. Abbreviations: AFC –Asian Football Confederation; CAF – Confédération Africaine de Football; UEFA – Union Européenne de Football Association; CONMEBOL – Confederación Sudamericana de Fútbol; CONCACAF – Confederation of North, Central American and Caribbean Association Football; F – F statistics; p – p value; η2 – eta squad.



*Note. * Denote statistical difference at p < .05. Abbreviations: FIFA – Fédération Internationale Football Association.*

Figure 1. Key performance indicator (KPI) for each FIFA ranking group.



*Note. * Denote statistical difference at p < .05. Abbreviations: AFC –Asian Football Confederation; CAF – African Football Confederation; UEFA – Union of European Football Associations; CONMEBOL – The Organization for Football in South America; CONCACAF – Confederation of North, Central American and Caribbean Association Football.*

Figure 2. Key performance indicator (KPI) according to confederations.

breaks, and receptions in the final third, except for total attempts on target, whose differences are between AFC and CONMEBOL teams (see Table 2 and Figure 2).

Table 2 presents the mean differences between FIFA confederations for each KPI. Significant differences between confederations were found for possession, total attempts on target, total passes, total complete passes, passes completion, completed line breaks, and receptions in the final third. According to post hoc analysis, CAF and UEFA national teams showed significant differences on all mentioned variables, except for total attempts on target, whose differences are between AFC and CONMEBOL teams (see Table 2 and Figure 2).

DISCUSSION

The aim of this study was to compare the physical, technical, and tactical performances of the 32 teams that participated in the 2022-WC concerning the confederation to which they belong and the FIFA ranking. This study confirmed differences between national teams from Rank 1-15th *vs.* Rank 15-35th and Rank 1-15th *vs.* Rank 36-61st for possession, total attempts at goal, total attempts on target, total passes, total complete passes, pass completion, completed line breaks, defensive line breaks, receptions in the final third, and ball progressions (all $p < .05$), except in defensive line breaks, ball progressions, and total defensive pressures applied. Relating FIFA confederations, significant differences were found between CAF and UEFA national teams for possession, total attempts on target, total passes, total complete passes, pass completion, completed line, and receptions in the final third.

The FIFA ranking and confederations are two separate international football factors that are not directly related to each other. Thus, the present study aimed to understand how each factor can affect the KPI during the 2022-WC (Cea et al., 2020). The FIFA Ranking determines the relative strength and performance of national teams, being calculated based on a variety of factors, including match results, the importance of matches, and the strength of opponents (Kubayi, 2020). The FIFA ranking provides an indication of a team's performance and standing in international football but does not have a direct impact on the WC itself. It is more of a reference point to assess a team's strength and potential (Kessouri, 2023). This study confirmed the effect of FIFA Ranking in all KPI's variables, except in defensive line breaks, ball progressions, and total defensive pressures applied.

However, once the WC begins, the FIFA ranking does not directly affect a team's performance or KPIs. The teams compete against each other on an equal footing, and their performance in the tournament determines their success (Kubayi, 2020). Tuo et al. (Tuo et al., 2019) showed significant differences in the match running performance between national players from UEFA and CONMEBOL. Also, Tuo et al. (Tuo et al., 2019) reported that football players from AFC, CAF, and CONCACAF conferences covered less total distance, spent less playing time, and covered less distance in jogging and low-speed running. In contrast, they spent more time walking than players from UEFA and CONMEBOL. Our study only reported significant differences between UEFA and CAF players in 2022-WC, corroborating with study from 2018 which show differences in offensive variables (Kubayi & Toriola, 2020). On the other hand, in 2018 was also reported a similarity in top speed achieved, number of sprints made, and time spent and distance covered in the moderate- and high-speed running (HSR) intensity zones by players from all confederations (Tuo et al., 2019). According to Tuo's study, the HSR distance covered by CONCACAF players was less than that by CAF players. In our study, the match running performance does not present significant differences, unlike the technical performance variables where there are differences between CAF and UEFA national players (i.e., possession, total

passes, total complete passes, passes completion, completed line breaks, and receptions in the final third). Only total passes showed significant differences between Asian and South American players.

As well, the FIFA ranking provides an overall assessment of a team's performance and standing in international football, while the WC tournament structure involves group stages and knockout rounds. These factors, along with a team's preparation, squad quality, tactical approach, and individual performances, play significant roles in determining a team's performance and KPIs during the 2022-WC. In fact, that this ranking is updated monthly makes it more unstable, and there is no consensus on its application in practical terms. Instead, the tournament is structured with group stages, followed by knockout rounds leading to the final, something that can influence during the group phase and especially in the knockout phase. Previous, Cea et al. (2020) analysed the FIFA ranking impact on WC finals, reporting a series of small adjustments to that technique, using a prediction model calibrated to generate a reference ranking. A qualitative and statistical examination of the FIFA ranking informs these recommended changes. Our research confirmed differences between national teams from Rank 1-15th *vs.* Rank 16-35th and Rank 1-15th *vs.* Rank 36-61st in all KPI's variables, except in defensive line breaks, ball progressions, and total defensive pressures applied. About technical issues, previously Kubayi (2020) reported that the highest number of goals was yielded from the final third (35%) when compared to the first and middle thirds. Also, most goals were preceded by short passes (69.9%), while 13.6% of goals came from long passes and 16.5% from mixed passes. Our study only recorded differences between the CAF and UEFA national teams, all of which were offensive possession variables, specifically: possession, total shot attempts, total passes, total passes completed, passes completed, line breaks completed, and receptions in the final third. Yi et al. (Yi et al., 2019) showed that possession-play outperformed direct-play-characterized teams in all variables relating to goal-scoring, attacking, and passing and covered more distance in sprints and high-intensity running. Both possession- and direct-play teams scored greater values in passing, pass accuracy, and delivery into the offensive third while playing against direct-play teams than when playing against possession-play teams.

The differences between UEFA and CAF teams may be associated with the styles of play implemented in each continuum. Culturally, the African teams tend to potentiate speed and fast attacking/attacking, while the European teams tend to be more tactically solid and with a more possession-oriented game (Clemente et al., 2015). Kessouri (2023) determined the match performance difference between the Top Five African national teams in the group stage of the 2022-WC, concluding that total shots, shots on target, shooting from open play, possession, total passes, passing accuracy, short passes, long ball accuracy, and key passes. In contrast, the African teams played more long balls, committed many fouls, made more clearances and saves by goalkeepers, and received more yellow cards than there. This style of play also tends to be present in European teams (Castellano & Pic, 2019; Hewitt et al., 2016). Indeed, most of what distinguishes these teams are cultural impact, with particular playing style of developed throughout time. They also included strategic and tactical considerations, player qualities, and the coach's philosophy (Castellano & Pic, 2019; Sarmento et al., 2013). Although there are already many African players in the main European leagues, many of them central figures in their teams, these players tend to play tactical roles associated with progression and mobility (Baloyi & Bekker, 2011). Previous network-based studies reported a small positive correlation with total connections, network density and clustering coefficient. High levels of goals scored were associated with high levels of total connections, net density, and clustering coefficient (Clemente, 2018). That is, these activity profiles tend to be influenced by the type of activity and/or match running performance, being highly dependent on contextual factors, the tactical system, and the competition phase itself (Clemente et al., 2020). Also, there is an optional influence in the match running performance among winger players vs. exterior defenders. Central forwards had significant drops in degree prestige when compared to exterior defenders and central defenders, defensive midfielders, and midfielders. When passing network centrality levels were

compared across won and lost matches, there were minor gains in degree prestige among midfielders and small increases among strikers among the winners (Clemente et al., 2015).

Current research can help coaches, analysts, and sports scientists with performance construction profiles for teams with diverse tactical approaches, as well as the development of training routines, to optimize playing style. As a limitation, it can be pointed out the fact that the analysis only reports average values for the teams of each confederation and classification, making it necessary to individualize the data for each player and/or team (Aquino et al., 2019; Teixeira et al., 2022). Future research should influence how playing styles and advancing competition influence differences in physical, technical, and tactical performances of the 32 teams that participated in the 2022-WC. Likewise, future studies should compare the results obtained in the final phase with the training and qualification phases in order to identify patterns and similarities that may predict the physical, technical, and tactical performances (Teixeira et al., 2021).

CONCLUSIONS

This current research confirmed differences between national teams when capering by FIFA ranking in several KPI's variables (such as possession, total attempts at goal, total attempts on target, total passes, total complete passes, pass completion, completed line breaks, defensive line breaks, receptions in the final third, and ball progressions.). Relating FIFA confederations, significant differences were found CAF and UEFA national teams for possession, total attempts on target, total passes, total complete passes, pass completion, completed line, and receptions in the final third, showing an explicit difference between confederation in KPI. Future research should investigate how playing styles and advancing competition influence the differences in physical, technical, and tactical performances of the 32 teams that participated in the 2022-WC.

AUTHOR CONTRIBUTIONS

LB: conceptualization, formal analysis, funding acquisition, investigation, methodology, project administration, resources, software, supervision, validation, visualization, writing–original draft, writing–review and editing. EF: conceptualization, data curation, formal analysis, funding acquisition, investigation, methodology, resources, software, supervision, visualization, writing–original draft, writing–review and editing. JT: investigation, writing–original draft, writing–review and editing. NV: writing–original draft, writing–review and editing. TR: writing–original draft, writing–review and editing. RT: conceptualization, data curation, funding acquisition, project administration, supervision, validation, visualization, writing–original draft, writing–review and editing. PF: investigation, writing–original draft, writing–review and editing. RF: conceptualization, data curation, funding acquisition, project administration, supervision, validation, writing–original draft, writing–review and editing, resources.

SUPPORTING AGENCIES

This project was supported by the National Funds through the FCT—Portuguese Foundation for Science and Technology (project UIDB04045/2020) and by Fundação de Amparo à Pesquisa do Estado de São Paulo (FAPESP—Grant number: 2021/03601-1).

DISCLOSURE STATEMENT

No potential conflict of interest were reported by the authors.

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ORIGINAL ARTICLE

Patterns of collective organization associated with positive and negative momentum experiences in football: An expert coach description-based analysis

HERVÉ GAUTIER[1], OLIVIER CAVAILLES[2], CHRISTOPHE GERNIGON[1]

[1]*EuroMov Digital Health in Motion. University of Montpellier. IMT Mines Alès, France.*
[2]*Faculty of Sport and Exercise Sciences. University of Montpellier. France.*

ABSTRACT

Purpose: Momentum experiences in sport competition are known to be associated with performance-related behavioural changes. In addition to effort exertion, interpersonal synchronization in small team sports has been identified as a behavioural correlate of momentum experiences. However, there is a lack of research on collective organization related to momentum in larger team sports. The present study aimed to identify and compare patterns of collective organization in football according to positive and negative momentum experiences in the form of gradual and significant score variations. Method(s): We analysed expert coaches' video-based descriptions of the collective organization of high level football teams that experienced positive and negative momentum phases during international matches. Results: The main results show that positive momentum phases were associated with forward-located and compact team block, as well as with players' runs more often directed towards the opposing goal. Negative momentum phases were associated with backward-located and stretched team block, as well as with frequent backward runs and block-disconnected individual actions. Conclusion(s): These initial findings regarding the relationships between momentum experiences and collective organization in team sports pave the way for the training of skills for early detection of momentum phases and skills for reacting appropriately to their onset.

Keywords: Performance analysis, Allo-confrontation, Frequency analyses, Qualitative analyses, Soccer, Team sports.

Cite this article as:
Gautier, H., Cavailles, O., & Gernigon, C. (2024). Patterns of collective organization associated with positive and negative momentum experiences in football: An expert coach description-based analysis. *Journal of Human Sport and Exercise, 19*(2), 667-678. https://doi.org/10.55860/mtfbn157

Corresponding author. *EuroMov Digital Health in Motion. University of Montpellier. IMT Mines Alès, France.* *https://orcid.org/0000-0003-2226-6021*
E-mail: herve.gautier@umontpellier.fr
Submitted for publication January 04, 2024.
Accepted for publication January 26, 2024.
Published April 01, 2024 *(in press* March 04, 2024).
JOURNAL OF HUMAN SPORT & EXERCISE ISSN 1988-5202.

doi: https://doi.org/10.55860/mtfbn157

INTRODUCTION

Since Adler's (1981) adaptation of the physical concept of momentum to human behaviours in terms of a "*dynamic state of intensity marked by an increase or decrease in speed of movement, grace and success*" (p. 29), this topic has received increasing attention from sport scientists. Research has mainly focused on the identification of the antecedents, processes, and consequences of the phenomenon of momentum (e.g., Briki et al., 2013; Den Hartigh et al., 2014 Gernigon et al., 2010; Markman & Guenther, 2007; Perreault et al., 1998; Taylor & Demick, 1994). Thus, it has been shown that, in a context of achievement, the precipitation of events or series of events (Taylor & Demick, 1994) can influence the perception of an individual to approach or move away from the goal to be achieved (Gernigon et al., 2010; Markman & Guenther, 2007; Vallerand et al., 1988). Such a perception then leads to positive or negative changes in the perceptual (Den Hartigh et al., 2018), cognitive, affective, motivational, physiological and behavioural spheres (e.g., Briki et al., 2013; Den Hartigh et al., 2014 ; Den Hartigh et al., 2016; Gernigon et al., 2010; Taylor & Demick, 1994; Vallerand et al., 1988). These changes which, according to Adler (1981), can be gradual (placid momentum) or brutal (explosive momentum) are likely to influence performance (Briki et al., 2013; Den Hartigh et al., 2014; Den Hartigh et al., 2016; Perreault et al., 1998; Taylor & Demick, 1994; Vallerand et al., 1988). As a result of these characteristics, the momentum experience can be considered to be a complex and highly dynamic phenomenon (Gernigon et al., 2010).

Among the precipitation of events identified as momentum triggers in sport, one of the most often cited by athletes or coaches is how rapidly or decisively the score evolves—in point- or goal-counting sports—or more generally the increase or decrease of distance from victory (Briki et al., 2012; Jones & Harwood, 2008; Taylor & Demick, 1994). Such is the case in team sports, where qualitative (Jones & Harwood, 2008) or experimental (Den Hartigh et al., 2020) research has identified scoring as a major determinant of the development of psychological momentum. Especially, dramatic changes in the score, which are sometimes observed in football, are often associated with the most beneficial consequences for the team that is catching up from behind and the most catastrophic for the team that is losing the lead (see for example https://en.wikipedia.org/wiki/Last-minute_goal).

The behavioural consequences of the momentum experience that have been examined mainly concern energy expenditure in the form of exerted effort (Briki et al., 2013; Den Hartigh et al., 2014; Den Hartigh et al., 2016; Perreault et al., 1998). Vallerand and his colleagues (Perreault et al., 1998; Vallerand et al., 1988) also refer to synchronism as a perceived behavioural characteristic of momentum. Unfortunately, these authors do not define what they mean by synchronism nor do they specify whether the notion of synchronism can also be applied at the inter-individual level, as in team sports. In addition, there is a lack of research focusing on the role of momentum experiences in synchronization, especially at the inter-individual level corresponding to the collective organization of sport teams.

Some studies have shown qualitative evidence of deterioration of intra-team interactions and a collective collapse associated with experiences of momentum caused by unfavourable score changes (Apitzsch, 2009; Wergin et al., 2018). Positive momentum experiences, on the other hand, have been rated by team sport players as conducive to team cohesion (Redwood-Brown et al., 2018). The only study (Den Hartigh et al., 2014) that has examined the effects of momentum experiences on interpersonal synchronization in sport focused on rowing dyads experimentally placed in competition—on ergometers—against virtual opponent dyads. Race scenarios, displayed on a video screen, were manipulated to have participants believe that they were catching up with and then overtaking their opponent (positive momentum) or that they were being caught up with and then overtaken by their opponent (negative momentum). The positive momentum

condition was associated with an increase in rowers' perceived cohesion, while the negative momentum condition was associated with a decrease in perceived cohesion. This decrease was more pronounced than was the increase observed for the positive momentum condition. Behaviourally, the level of synchronization between dyad partners was found to be lower and less stable in the negative momentum condition than in the positive momentum condition. In addition, synchronization stability tended to degrade during the negative momentum experience, whereas it tended to improve during the positive momentum experience. While these results shed some light on the effects of momentum experiences induced by reversals of competitive advantage on interpersonal synchronization, their limitation to teams of dyads invites examination of their possible extension to collective organization of team sports teams formed of more than two partners.

While the quality of intra-team interactions (Apitzsch, 2009; Redwood-Brown et al., 2018; Wergin et al., 2018) or interpersonal synchronization (Den Hartigh et al., 2014) have been found to be related to performance-dependent experiences of momentum, how patterns of collective organization are associated with such experiences in team sports remains to be identified. Therefore, the purpose of the present study was to identify and then compare patterns of collective organization in football according to positive and negative momentum experiences considered in terms of gradual and significant score variations. To this end, expert coaches' video-based descriptions of the collective organization of teams experiencing positive and negative momentum phases during international matches have been qualitatively and quantitatively analysed.

MATERIALS AND METHODS

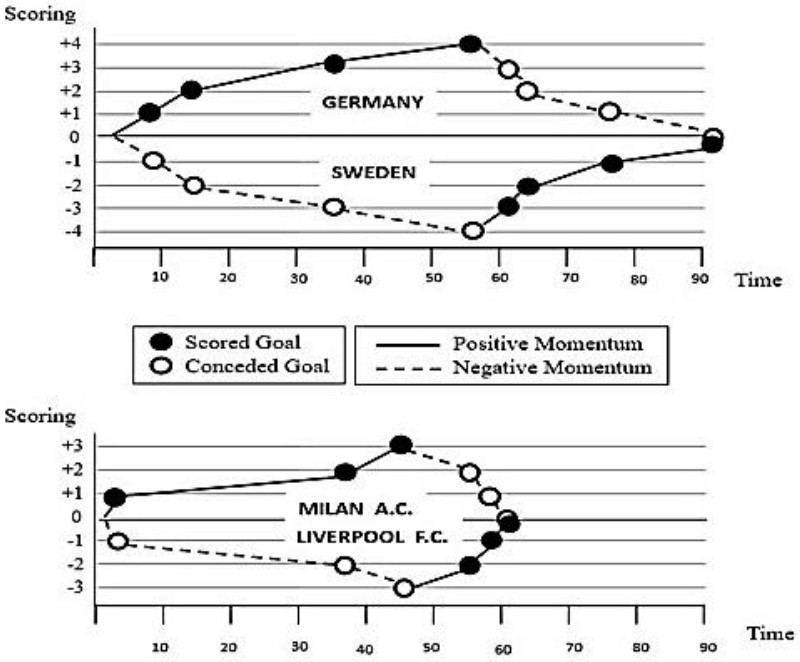
Participants

By means of individual allo-confrontation interviews (Mollo & Falzon, 2004), four expert football coaches were asked to watch videos of two international football matches and describe the collective organization of the teams involved (one expert per team) while these teams were experiencing positive and negative momentum phases, as defined by significant upward and downward score changes, respectively. According to Mollo and Falzon (2004), allo-confrontation interviews consists of confronting experts in an activity with traces (e.g., video) of that activity performed by others, in their absence. The data provided by the experts were processed according to the three steps recommended by Poizat et al. (2012) for third-person data analysis. First, a video-based field study was carried out to describe in detail the activity's features under study, namely, for the present study, collective organization patterns. Second, the players' behaviours were transcribed in terms of interactional organization of their activities. Third, the observed patterns were grouped into broader categories using an inductive method (e.g., Patton, 1980). In addition to this qualitative analysis, the observed patterns were finally quantified for comparison between momentum types.

Measures

Two high-stake international football matches, each presenting a sequence of two phases of momentum with opposite valences (positive-negative or negative-positive), served as support for the study. Although the agreement of the actors whose activity is studied by allo-confrontation is usually required (Mollo & Falzon, 2004), this was not the case for the present study, since the videos of the matches viewed are public, widely broadcasted, and open to examination by many people (e.g., opponents, scouts, recruiters, instructors, journalists). One match was a qualification match for the 2014 World Cup between Germany and Sweden on October 16, 2012. The final score of this match was 4-4 after Germany had led 4-0. The other match was the final of the Champions League of the Union of European Football Associations (UEFA), A.C., Milan vs. Liverpool F.C. on May 25, 2005. Liverpool won the match in a penalty shootout after trailing 0-3 and then making a comeback to 3-3. These two matches were chosen because in each of them, (a) a team gained an advantage and then saw that advantage grow rapidly (+2, +3, and/or +4) before being caught up and

overtaken, and (b) the other team's comeback and equalizer took place well before the end of the match. This choice of a comeback far from the end of the match was made to avoid introducing a second type of momentum specific to the end-of-match context (Den Hartigh et al., 2020). A positive or negative momentum phase corresponded to a series of consecutive goals scored or conceded, respectively (see Figure 1).



Note. Scores are represented in terms of the score difference between two teams.

Figure 1. Phases of positive momentum and negative momentum according to score changes during the Germany vs. Sweden match (top) and A.C. Milan vs. Liverpool F.C. (bottom).

Procedures

Allo-confrontation interviews were conducted with expert football coaches who voluntarily participated in the study and gave their consent for their statements to be recorded and transcribed. They were four French male (ages: 40, 49, 59, and 63) who were chosen for their experience in football coaching. They were UEFA Pro or UEFA A diploma holders, professional or national team coaches, federation technical staff or coaches of teams at the highest regional level. In addition to their high level and highly reputed diplomas, their long experience (between 15 and 35 years) of football coaching at the national level constituted a tangible criterion for identifying them as expert coaches (Côté & Salmela, 1993).

The interviews were conducted by the first author of this article in a semi-structured format, while the expert coaches were watching the video footage of the matches. The periods concerned by the interviews began 5 min before the change in the score marking the start of a momentum phase, so that the expert being interviewed could identify the general pre-momentum organization of the team. The interviews lasted 60 to 100 minutes and were recorded using a Dictaphone. Each interview began with a reminder of the research objectives and the method used during the interview. For a given momentum period, each expert coach was asked to freely comment on the organizational aspects of one of the two teams in the match being viewed. He was free to choose events that he felt were indicative of the collective organization of the team being examined. At all times, he had control over the video's progress (i.e., freeze frame, slow motion, rewind) to support his commentary. The researcher only intervened to ask the expert to clarify certain points or to

refocus on observable facts, avoiding any interpretations or judgment. For example, when an expert declared "*Maybe Milan aren't made to defend like that*", he was then asked, "*What do you mean, based on what you are seeing?*", which prompted the following clarification: "*Being very low*". As another example, when an expert said, "as soon as they lose the ball they are a little less passive", the researcher asked, "*How can you say they're less passive?*", which prompted the following answer "*I already think about the fact of having raised their block by 20 m*".

Analysis

Each expert coach's verbalizations were transcribed in their entirety. Inductive coding and categorization procedures were first carried out by the first two authors of this article. They themselves have extensive experience in the analysis of competitive football. The first author has a 10-year experience as a player at the French national level and performed as a professional player outside France for two years. He holds the UEFA A diploma and is a football teacher at the Faculty of Sports Sciences of the University of Montpellier. The second author is also a football teacher at the same faculty, and also holds the UEFA A diploma. He was a staff member of African national selections for international competitions for 4 years.

These two researchers independently coded and categorized the verbatim data from the positive and negative momentum phases of all teams. First, they coded data in terms of meaningful units of collective organization. A unit of meaning is the smallest unit of action that makes sense for an interviewee, according to the continuous flow of the activity he describes (Theureau, 1992). These meaningful units of collective organization were grouped into categories, which could in turn be grouped into higher-level categories, and so forth (e.g., Gernigon et al., 2004). Several precautions were taken to ensure the trustworthiness of the analyses. First, the two researchers in charge of the analyses reviewed the interview transcripts for any questions that might have been too general or that might have influenced interviewees' comments. This verification thus led to the deletion of 5 unreliable action units. Second, these researchers coded the data independently, then compared and discussed the codes until consensus labels were adopted. This operation led to modifying 54 labels. Only what was verifiable and observable in support of the video was kept.

The identified units of meaning were quantified according to their different levels of description and then subjected to chi-square tests (χ^2) to test for possible significant differences in the distributions of their frequencies according to the type (positive vs. negative) of momentum.

RESULTS

The two researchers in charge of coding and classifying the data agreed on 515 units of meaning concerning teams' collective organization during the selected momentum phases. These units of meaning, associated either with experiences of positive momentum or with experiences of negative momentum, were grouped into 14 first-order categories called themes, which could in turn be grouped into 6 second-order categories called dimensions, which could then be classified according to 3 third-order categories ranging from the macroscopic to the microscopic levels of collective organization (see Table 1).

Macroscopic organization

The macroscopic level includes descriptions of the collective organization concerning all the outfield players on a team. A number of descriptions concerned the team block, which is defined, according to the Senior Trainee Booklet (French Football Federation, 2015), as being made up of "*all the lines of the same team (3 lines: defence, midfield, attack) engaged in an offensive action (offensive block) or defensive action (defensive block)*". Thus, the block reflects the arrangement of all the players on the playing space along the

longitudinal axis of the playing field (i.e., the defended goal/ attacked goal axis). More specifically, a forward block corresponds to the players' location in the opposing camp and a backward block corresponds to the players' location close to their own goal. A total of 67 units of meaning concerned the longitudinal position of the team block. This position was found to vary according to the period of the type of momentum ($\chi^2_{(1)} = 37.3$; $p < .001$). The forward block (e.g., "*So, the Swedish block is having fun; it is moving more forward.*") was found more frequently in the positive momentum phase ($n = 21$) than in the negative momentum phase ($n = 5$). Conversely, the backward block (e.g., "*Their block is visibly much backward and much less aggressive than it was earlier on the ball carrier*") appeared more often in negative momentum phases ($n = 38$) than in positive momentum phases ($n = 2$).

Table 1. Patterns of collective organization identified and categorized according to football teams' positive and negative momentum experiences.

Levels of Collective Organization *Dimensions* Themes	**Positive Momentum (n)**	**Negative Momentum (n)**
Macroscopic Level		
Longitudinal position of the team block	*26*	*41*
Forward Block	21	3
Backward Block	5	38
Mesoscopic Level		
Team Block Compactness	*23*	*46*
Compact Block	23	6
Stretched Block	0	40
Team Block Connectivity	*12*	*88*
Connected Actions	9	1
Disconnected Actions	3	87
Microscopic Level		
Ball Carrier – Nearest Opponent Distance	*23*	*69*
Ball Carrier Close to Direct Opponent	23	0
Ball Carrier Far from Direct Opponent	0	69
Without-ball Offensive Runs	*38*	*30*
Toward Attacked Goal	37	4
Non-goal-oriented Runs	0	25
Toward Defended Goal	1	1
Without-ball Defensive Runs	*59*	*60*
Toward Attacked Goal	56	5
Non-goal-oriented Runs	0	33
Toward Defended Goal	3	22

Mesoscopic organization

The mesoscopic level includes descriptions of collective organization concerning actions between lines of players. Some mesoscopic descriptions referred to the compactness of the team block, namely, the distance between the lines of players (defenders, midfielders, and attackers) on the longitudinal axis of the pitch. A compact block corresponds to short distances between the lines of the team block, whereas a stretched block corresponds to long distances between these lines. A total of 69 units of meaning relating to team block compactness were recorded. Their distribution reveals that they significantly depend on the type of momentum ($\chi^2_{(1)} = 47.57$; $p < .001$). The team block was found to be more often compact (e.g., "There pam!

it has just tightened, it has just tightened, here, there yes, again! And the ball is recovered of course.") during phases of positive momentum (n = 23) than during phases of negative momentum (n = 6). Conversely, the team block was often stretched (e.g., "*The reds are far away; we can't see them; they're in their half-court; the team is cut in half, look, great! See?*") during phases of negative momentum (n = 40), but never during phases of positive momentum (n = 0).

Other mesoscopic descriptions referred to connectivity, which is the coherence of individual actions with the ongoing collective organization of one's team. A total of 100 units of meaning relating to connectivity to the team block were identified. Connectivity showed significant differences depending on the type of momentum ($\chi^2_{(1)}$ = 64.02; p < .001). Connected actions (e.g., "*Yeah, there're four of them in the (German) box, they're there anyway. There pam! there.*") were found more frequently during positive momentum phases (n = 9) than during negative momentum phases (n = 1). Conversely, disconnected actions (e.g., "*Look, how can we walk like this, they're in the 14th minute, you've got guys walking; look!*") were much more frequent during negative momentum phases (n = 87) than during positive momentum phases (n = 3).

Microscopic organization

The microscopic level includes descriptions of players' individual actions in relation to the group. First, the experts' attention was aroused by several notable cases of distance between the ball carrier and the first defender to come up on him. A total of 92 units of meaning relating to this distance were counted, the distribution of which varied greatly depending on the type of momentum ($\chi^2_{(1)}$ = 92.00; p < .001). Typical cases of short ball carrier – nearest opponent distances (e.g., "*we have completely reversed the trend, we have Swedes who are close.*") were observed during the defending team's phases of positive momentum (n = 23), but not during its phases of negative momentum (n = 0). Conversely, instances of long distances (e.g., "*He's there; he's not going to get any closer and.... the Swedish defender is far from the German ball carrier.*") were frequent during the defending team's phases of negative momentum (n = 69) but absent from its phases of positive momentum (n = 0).

The experts' attention was also drawn by the direction of certain runs without the ball made towards one's own goal, towards the opponent's goal, or not directed towards one of the two goals (i.e., non-goal-oriented runs) during either the offensive phases (i.e., when the team is in possession of the ball) or defensive phases (i.e., when the team is not in possession of the ball) of the game.

For offensive phases, 68 meaning units relating to typical runs without the ball were identified, with a significant difference in frequency depending on the type of momentum ($\chi^2_{(2)}$ = 51.33; p < .001). Offensive runs without the ball in the direction of the goal to attack (e.g., "*They're already in the forward movement and therefore automatically they create, as we can see, that they have created a greater possibility of forward play.*") were found to be more frequent in positive momentum phases (n = 37) than in negative momentum phases (n = 4). Non-goal-oriented offensive runs without the ball (e.g., "*First action where I tell you there is no one moving; there is no projection.*") were observed in negative momentum phases (n = 25), but not in positive momentum phases (n = 0). Finally, offensive runs without the ball in the direction of one's own goal (e.g., "*It's difficult to advance, eh. There they are forced to retreat.*") were extremely rare, in both positive (n = 1) and negative (n = 1) momentum phases.

For defensive phases, 119 meaning units relating to runs without the ball were recorded, with different frequencies depending on the type of momentum ($\chi^2_{(2)}$ = 90.08; p < .001). Defensive runs without the ball in the direction of the opposing goal (e.g., "*You have the guys who are there to defend like demons and there behind there are some moves; look at the impact; he was over there; then he finds himself there [a much*

more advanced place].") were found to be more frequent in positive momentum phases (*n* = 56) than in negative momentum phases (*n* = 5). Non-goal-oriented defensive runs without the ball (e.g., "*on the block, they are quite passive*") were observed in negative momentum phases (*n* = 33), but not in positive momentum phases (*n* = 0). Finally, defensive runs without the ball in the direction of one's own goal (e.g., "*There is no harassment from the carrier so it is a defensive withdrawal.*") were found to be more frequent in phases of negative momentum (*n* = 22) than in phases of positive momentum (*n* = 3).

DISCUSSION

The aim of this study was to qualitatively identify, and quantify for comparative purposes, patterns of collective organization in football according to momentum experiences, defined here by gradual and significant variations in score. To this end, interviews were carried out with expert football coaches who were shown videos of positive momentum and negative momentum sequences from high-stakes international matches. Based on an inductive approach, the qualitative data collected for the phases of positive and negative momentum were classified into themes, themselves grouped into dimensions ranging from the macroscopic to the microscopic level of description of the teams' collective organization.

At the macroscopic level, the team block appeared to be more frequently located towards the front of the field and less frequently towards the rear of the field in phases of positive momentum than in phases of negative momentum. These forward or backward positions of the team block had been identified by Gréhaigne et al. (1997) as manifestations of offensive and defensive intentions, respectively. It should be noted that offensive intentions, in the form of performance-approach goals (i.e., beating the other) have already been found to be associated with positive momentum (Briki et al., 2012; Gernigon et al., 2010), while defensive intentions, in the form of performance-avoidance goals (i.e., to avoid being beaten by the other) have been found to be associated with negative momentum. (Briki et al., 2012).

At the mesoscopic level, the team block appeared more often compact in the positive momentum phase than in the negative momentum phase. According to Gréhaigne et al. (2011), an extended team block is typical of a disorder within the team, particularly during defensive phases for which the team block is normally and wisely more contracted (Gréhaigne & Godbout, 2013). Consequently, the accentuated stretching of players' lines that is observed during negative momentum phases reflects a greater heterogeneity of behaviours and shows that negative momentum is the corollary of deterioration in collective organization. As regards the block's connectivity, disconnected individual behaviours were much more frequent in negative momentum phases than in positive momentum phases. This disconnection associated with negative momentum adds to the list of task-irrelevant behavioural responses identified by Apitzsch (2009) when a team collapses (e.g., focus on the referee).

At the microscopic level, the distance between the ball carriers and their direct opponents were shorter during the defending team's phases of positive momentum and longer during their phases of negative momentum. These findings reflect a greater combativeness to recover the ball during positive momentum phases than during negative momentum phases. Since a team in possession of the ball is by definition in an offensive situation, these behaviours of quick ball recovery can be interpreted as another behavioural manifestation of the offensive intentions (i.e., performance-approach goals) classically associated with positive momentum.

As regards the direction of runs without the ball, the number of runs towards the goal to attack is significantly higher in positive momentum than in negative momentum, regardless of whether the players' team is in an attacking or defending role. This rush forward during positive momentum phases is consistent with the

findings of Jones and Harwood (2008) who observed that a positive momentum experience leads teams to want to increase their advantage by scoring more goals These forward runs are consistent with forward positions of the team block, observed at the macroscopic level, as well as with offensive intentions that are usually associated with positive momentum in the form of performance-approach goals (Briki et al., 2012; Gernigon et al., 2010). Runs without the ball towards the defended goal or not directed towards a goal are more frequent in negative momentum phases than in positive momentum phases, whether the team is in attack or in defence, with the exception, however, of runs towards the defended goal which are always rare in attacking situations. While the need to protect its goal is not salient for an attacking team, it is not surprising that it becomes so as soon as this team is no longer in possession of the ball, especially when it is experiencing a difficult negative momentum pass (Silva et al., 2014). Runs towards the goal to be defended then constitute behavioural responses to the emergence of this need. These withdrawal runs are consistent with the retreat of the team block observed at the macroscopic level, as well as with defensive intentions that are usually associated with negative momentum in the form of performance-avoidance goals (Briki et al., 2012). Positive momentum or negative momentum phases might have been expected to be characterized by more attack situations or more defence situations, respectively, consistent with the observation that most of the time spent in the opposing 30 meters reflects positive momentum (Higham et al., 2005). However, it is not the number of offensive or defensive runs that differ according to the momentum phases, but much more the forward or backward direction of these runs.

CONCLUSIONS

This study constitutes a first attempt to characterize the relationships between momentum experiences generated by significant changes in score and certain patterns of collective organization in football. Based on the analyses carried out by expert coaches of videos of high-level football matches, this research has identified specific collective indicators of positive and negative momentum experiences. Nevertheless, the results of this research should be considered with caution due to the small number of matches on which it is based (n = 2). Matches with spectacular score increases are rare, and the available videos of these matches are often of too poor a quality to support accurate analysis. The present results based on a very small sample of matches should therefore be considered with caution, particularly with regard to their generalizability to other football matches and other levels of practice.

Another limitation relates to the impossibility of verifying that the momentum phases chosen objectively on the basis of score changes corresponded to momentum phases subjectively experienced by the players. Yet, the behavioural effects of momentum are widely recognized as resulting from perceptual, cognitive, affective and motivational processes (e.g., Taylor & Demick, 1994) and the literature on momentum is mainly based on concepts such as psychological momentum (e.g., Gernigon et al., 2010; Markman & Guenther, 2007; Taylor & Demick, 1994; Vallerand et al., 1988) or the momentum experience (e.g., Hubbard, 2015). The present study deserves to be replicated with the players themselves as interviewees, which would require that elite players be available to take part, which is often not the case.

In terms of practical applications, coaches' knowledge of prototypical collective organization patterns of momentum phases is valuable. For Higham et al. (2005), any football match includes, to varying degrees, three phases of momentum: neutral, with one's team, and against one's own team. It is important for every coach to be able to recognize the early warning signals of the collective configurations associated with these different types of momentum to be able to provide the players very quickly with the necessary instructions to implement appropriate behavioural responses. These instructions can be given during stoppages in play, such as throw-ins, set-pieces, injuries, etc. The coach's ability to anticipate and the players' ability to react

appropriately require specific training based on the characteristics and consequences of momentum. Therefore, players, too, would gain responsiveness by accessing this kind of knowledge: "*If players know what they have to do in the match and, when psychological momentum is against their team, and what they have to change to give themselves a chance, then they will feel in control of events.*" (Higham et al., 2005).

AUTHOR CONTRIBUTIONS

Gautier, Cavailles and Gernigon wrote the paper and collected the data. All authors approved the final submission.

SUPPORTING AGENCIES

No funding agencies were reported by the authors.

DISCLOSURE STATEMENT

No potential conflict of interest were reported by the authors.

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ORIGINAL ARTICLE

Facial fingerprint analysis using artificial intelligence techniques and its ability to respond quickly during karate (kumite)

MOHAMMED ASIM GHAZI[1,2], MAYASA ABD ALI KADHIM[3], LAMYAA HASAN ALDEWAN[4], SANAA JAWAD KADHIM ALMAYAH[4]

[1]*Faculty Physical Education. Alexandria University. Alexandria, Egypt.*

[2]*Faculty of Physical Education and Science Sport. Al-Mustaqbal University. Babylon, Iraq.*

[3]*College of Education and Sports Sciences. University of Kufa. Iraq.*

[4]*College of Physical Education and Sports Sciences. University of Basra. Iraq.*

ABSTRACT

The document discusses the use of facial fingerprint analysis using artificial intelligence (AI) techniques to quickly respond during karate matches. The integration of AI with sports technical analysis has the potential to improve the technical and tactical level of athletes. Traditional methods for tactical intelligence analysis in competitive sports have limitations such as high cost, data loss, delay, and low accuracy, but the use of convolutional neural networks and graph convolution models has shown promising results in the automatic, intelligent analysis of karate athletes' technical action recognition, action frequency statistics, and trajectory tracking. Eye-tracking technology is also used to analyse various aspects of performance and help identify visual strategies employed by athletes. By analysing video footage of facial biometrics during karate competition performances, performance criteria can be measured based on relevant skills in karate, and an objective scoring rubric can be developed for each criterion. Then, the scores can be compared between performers to see individual strengths and weaknesses and to optimize training, technique, and performance. Ultimately, the study seeks to investigate how to improve performance and decision-making in kumite by using AI techniques to analyse the eye print during an exhibition performance.

Keywords: Performance analysis, Facial fingerprint, Artificial intelligence techniques, High-Performance sports organizations, Gap-Size.

Cite this article as:
Ghazi, M. A., Kadhim, M. A. A., Aldewan, L. H., & Almayah, S. J. K. (2024). Facial fingerprint analysis using artificial intelligence techniques and its ability to respond quickly during karate (kumite). *Journal of Human Sport and Exercise, 19*(2), 679-689. https://doi.org/10.55860/r05vhj78

Corresponding author. *Faculty Physical Education. Alexandria University. Alexandria, Egypt.* https://orcid.org/0000-0003-1311-6400
E-mail: mohammed.asim.ghazi@uomus.edu.iq
Submitted for publication January 01, 2024.
Accepted for publication January 26, 2024.
Published April 01, 2024 *(in press* March 04, 2024).
JOURNAL OF HUMAN SPORT & EXERCISE ISSN 1988-5202.

doi: https://doi.org/10.55860/r05vhj78

INTRODUCTION

Analysing the eye print using artificial intelligence techniques can improve the recognition of technical actions and tactics in karate matches. The integration of artificial intelligence technology with sports technical and tactical analysis can enhance the technical and tactical level of athletes (Katharina, 2019) Traditional methods of tactical intelligence analysis in competitive sports have limitations such as high labour cost, data loss, delay, and low accuracy.

However, the use of graph convolution models based on deep learning, combined with attention mechanisms and weight coefficients assigned to joints, has shown significant improvements in the accuracy of technical action recognition. In addition , gaze tracking sequences can provide insights into the decision-making process of karateka during attacks.(Jun-Yao, 2022). Fixation sequences around the body and head of the opponent are associated with different types of attacks and counters, with shorter fixation sequences leading to faster punching responses and longer sequences associated with evading lunges and kicks to disrupt the opponent and maintain distance ; (Williams, 1999) and (Dicks, 2010)showed that expert boxers adopted a more efficient search pattern compared to non-experts and tended to maintain foveal fixation as a visual pivot on central regions of the opponent's body while using their peripheral vision to acquire information from the hands and feet regarding the initiation of an attack.(Jianping, 2021),Currently, few studies have examined visual search behaviours in combat sports such as boxing, kung fu, karate, and judo (al., 1995) Williams and Elliott (1999) also reported that expert karate fighters exhibited superior anticipation compared with non-experts when experiencing varying levels of anxiety and that they anchored their fovea on the central regions of their visual display while using their peripheral vision to monitor their opponent's limb movements. Thus, these studies suggest a correlation between the level of expertise and the fighter's visual search strategy.

Milazzo et al. (2016b) reported that expert karate fighters spent more time fixating on their opponent's head and torso with a low search rate, as opposed to novices, who spent more time fixating on the pelvis and the front hand Â their opponent with a high search rate. Similarly, expert judo fighters used a search strategy involving fewer fixations of longer duration and spent more time fixating on the lapel and face than to their novice counterparts (Piras et al., 2014). Expert kung fu fighters (like Tae Kwon Do fighters) attack mostly with their legs anchored and their gaze focused at the lower region of their opponent to monitor the relevant cues for kicking attacks (Hausegger et al., 2019).

Present a problem in this way

Facial Fingerprint Analysis: Enhancing Kumite Matches with Artificial Intelligence In the world of karate, the ability to react quickly and accurately is crucial. Kumite matches require athletes to make split-second decisions, relying on their instincts and training. However, what if there was a way to enhance these matches even further? Enter facial fingerprint analysis using artificial intelligence techniques. Facial fingerprint analysis is a cutting-edge technology that utilizes AI algorithms to analyse and identify unique facial features. By capturing and analysing the facial expressions and movements of karate athletes during humite matches, AI can provide valuable insights and feedback in real-time. One of the key advantages of facial fingerprint analysis is its ability to respond quickly. AI algorithms can process vast amounts of data in milliseconds, allowing for immediate feedback and analysis.

This real-time analysis can help athletes identify their strengths and weaknesses, enabling them to make adjustments on the fly and improve their performance. Furthermore, facial fingerprint analysis can also be used to enhance coaching and training. By analysing the facial expressions and movements of athletes during practice sessions, AI can provide personalized feedback and guidance. Coaches can use this

information to tailor training programs and techniques to individual athletes, thus maximizing their potential. In conclusion, facial fingerprint analysis using artificial intelligence techniques has the potential to revolutionize kumite matches in karate. Its ability to respond quickly and provide real-time analysis can enhance athletes' performances and training. By harnessing the power of AI, karate athletes can take their skills to new heights, pushing the boundaries of what is possible in the world of martial arts.

Background study

Eye-tracking technology involves the use of specialized equipment to monitor and record eye movements. It has been widely used in various fields, including psychology, marketing, user experience research, and sports performance analysis. By tracking eye movements, researchers can gain insights into attentional focus, visual perception, decision-making processes, and other cognitive aspects related to performance., In the context of sports, including martial arts such as karate, eye-tracking technology can be used to analyse various aspects of performance.

For example, it can help identify visual strategies employed by athletes, assess their situational awareness, and evaluate their reaction times to specific stimuli. This information can be valuable for coaches, trainers, and athletes themselves to optimize training, technique, and performance. Although I do not have specific references related to the use of eye-tracking technology in karate matches, you may consider exploring the research literature on eye-tracking in sports performance analysis or sports vision science.

In addition , advancements in artificial intelligence and computer vision techniques can further enhance the analysis of eye movements and provide valuable insights into sports performance. It is worth noting that research is continuously evolving, and new studies may have been published since my last update. Therefore, I recommend consulting academic databases, research publications, and sports science journals for the most recent studies on eye-tracking and specifically in martial arts or karate specifically Therefore, the researcher, in pursuit of this study, seeks to investigate how to use artificial intelligence techniques in analysing the eye print in the ability to quickly respond during an exhibition performance.

MATERIAL AND METHODS

Study procedures

The descriptive and survey method was used, then the experimental method was used for that study to apply it to the study sample, which is (5) karate players who obtained the black belt in Dan (1) through the use of high-quality video clips from the World Championship for Adults in Hungary in the period of 10/10/2023 to 10/30/2023 by following the following: Using artificial intelligence techniques in eye print analysis, through eye print analysis procedures in karate matches, then collecting eye print data during the kumite match, pre-processing techniques for eye print data, applying intelligence algorithms Artificial analysis, interactive eye print analysis during karate matches, real-time monitoring of eye print data, immediate reaction to eye print changes, enhancing performance and decision-making in kumite.

Facial fingerprint analysis using artificial intelligence techniques has been applied in various fields, including competitive sports such as karate. The integration of artificial intelligence technology and sports technical and tactical analysis can improve the technical and tactical skills of athletes. In the field of karate, the study of athletes' training and competition videos is an important means of technical and tactical analysis. Traditional methods for tactical intelligence analysis have limitations such as high labour costs , data loss, and low accuracy. However, the use of convolutional neural networks and graph convolution models has

shown promising results in automatic intelligent analysis of karate athletes' technical action recognition, action frequency statistics, and trajectory tracking (Katharina P. P., 2019).

This technology effectively addresses the shortcomings of traditional methods and lays a foundation for technical and tactical analysis in karate (Jianping, 2021). Face recognition technology has been applied in various sport. One study used face recognition for sportsman check-in at the National Intercollegiate Athletic Games, resulting in high user satisfaction and interest in future use of the technology (Yan, 2014).

Another study proposed user identification using face recognition in sports simulator applications, aiming to provide customized services to users (Andr, 2017) Additionally, motion capture technology, such as Kinect, has been used in sports training to analyse and study real-time movements (Quan, 2014) (Hyungkwan, 2012). These studies highlight the potential of face recognition and motion capture technologies in enhancing sports training and performance.

Analysing video footage of facial biometrics during karate competition performances

Define the performance criteria you want to measure based on relevant skills in karate. Examples could include eye contact, facial expressions, body language, focus, confidence levels, emotional control, communication skills, stance/positioning, technique execution, etc., Develop an objective scoring rubric for each criterion, such as a scale from 1-10. Clearly define each point on the scale. Use facial recognition software to extract still frames from the video at regular intervals, such as every 2 seconds. The frames should clearly show the performer's face., For each frame, independently score the performer's facial expressions and body language based on the rubric criteria. Average the scores over time to gauge consistency., Note any correlations between criteria - for example, higher confidence associated with better eye contact. This could provide insights into drivers of performance. Analyse changes in scores over the performance duration. Are some parts stronger? Does control fluctuate with the intensity of routines/moves?

Compare scores between performers to see individual strengths and weaknesses. High-level performers could serve as a benchmark. Interview performers afterwards to get their perspective on mental state, challenges, lessons learned and how they can improve. This provides a more holistic view. The goal is to use objective data to spark discussion on developing performers' mental game and full potential. Performance reflects both physical and psychological factors working together.

Scientific steps to create a facial fingerprint through neural networks and during competition performance?

First, take a facial fingerprint before the measurement process using the electronic device designed to measure reaction speed for skills in karate (punches, kicks) and registered in the Patent and Inventions Office, (705/2017) Egypt. Storing data through a database designed to store data issued by the electronic device and processing the data through a neural network and through quantitative and qualitative analysis through the reference code and using the (OPEN CV) program. The players perform the match within (3) mins of the actual time of the karate (kumite) match. Placing cameras on all sides of the field so that shots and face shots can be taken during matches.

Taking cards and snapshots, processing them, and comparing them with the first fingerprint placed on the electronic device. import cv2Work on deriving expressions and making comparisons with body language. Through this, athletic performance is improved and predicted. Note: We used illustrative images from the Google search engine to express and link the theoretical content and the practical part of the study. Figure 1.

Figure 1. Scientific steps to create a facial fingerprint through neural networks and during competition performance.

Standards upon which facial fingerprint analysis is based during competitive performance
Looking into the opponent's eyes

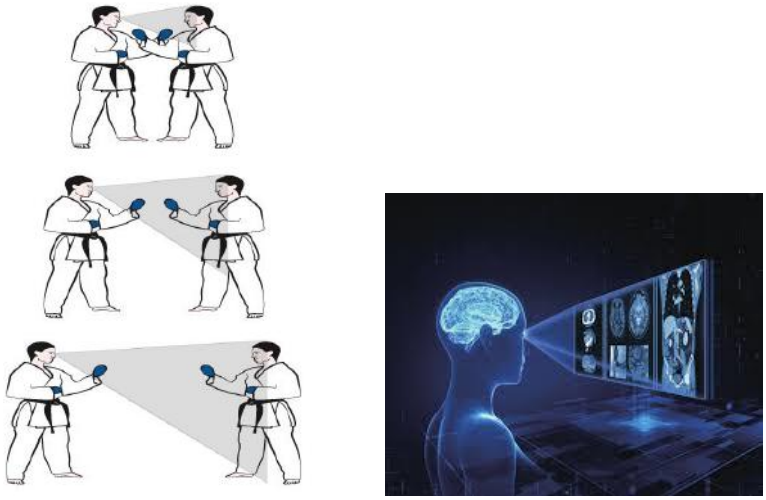

Figure 2. Photos of the eye's vision level during performance.

"*Enzan no Metsuke*" is an important technique used in Kendo that involves looking into the opponent's eyes with a gaze towards the far mountain. This technique allows expert Kendo fighters to take in not only the opponent's face but also their whole body, enabling them to react instantaneously and find openings or opportunities for attack. Studies have shown that visual search strategies differ between experts, novices, and a Kendo master (Shihan). The Shihan and experts primarily fixate on their opponent's eyes or head region, using a visual search strategy involving fewer fixations of longer duration. Novices, on the other hand, focus mainly on the opponent's sword. The Shihan consistently looks at the opponent's eyes, even during preparation and defence sessions. This suggests that the Shihan and experts absorb information from their opponent's entire body using peripheral vision, while novices rely on focal vision and search for detailed information about their opponent (Takaaki, 2020).

By analysing video clips of the five players in the study, under a program to analyse facial expressions and facial expressions during match performance, the researcher reached the following criteria.

Table 1. Analyse facial expressions and facial expressions during match.

Criteria	Number of attempts	Player					Time (m/s)	M	SD	Effect size
		Pl.1	PL.2	PL.3	PL.4	PL.5				
Eye contact	10	4	3	2	2	2	2.34	2.43	1.0	1.8
Facial expressions	10	2	4	1	3	4	3.24	3.23	2.0	0.5
Body language	10	5	5	4	1	2	3.21	3.21	0.0	0.1
Focus	10	6	2	5	4	4	4.12	4.12	1.1	1.1
Confidence:	10	5	4	2	5	3	5.23	5.23	1.0	1.0
Emotional control:	10	3	5	4	2	4	6.32	6.23	1.0	2.0
Communication	10	5	2	3	4	2	5.32	5.23	1.1	0.91
Average results	10	40%	30%	20%	20%	20%	4.25	4.23	1.23	1.1

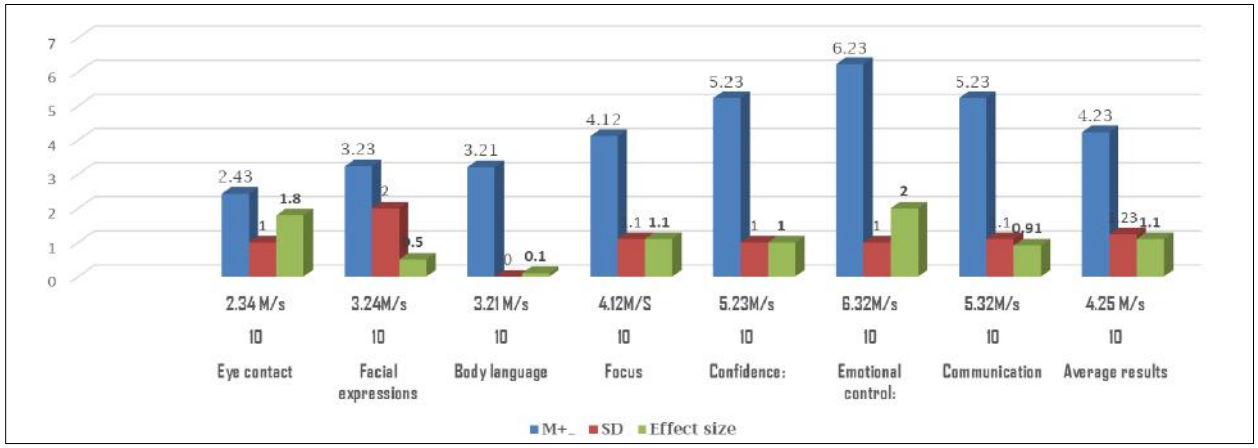

Figure 3. A diagram to convey views during the performance.

The results are shown in Table 1. Based on the average results provided in the table, the players' performance in the different criteria can be evaluated. The average results column shows the average score for each criterion across all players. In terms of eye contact, the average score is 2.43 out of 10. This suggests that overall, the players had low eye contact during the attempts. The effect size of 1.8 indicates a relatively large effect. For facial expressions, the average score is 3.23 out of 10. This indicates a moderate level of facial expressions displayed by the players. The effect size of 0.5 suggests a small effect. In terms of body language, the average score is 3.21 out of 10. This suggests that the players had a moderate level of body language during the attempts. The effect size of 0.1 indicates a very small effect. For focus, the average score is 4.12 out of 10. This suggests that overall, the players had a relatively high level of focus during the attempts. The effect size of 1.1 indicates a moderate effect. In terms of confidence, the average score is 5.23 out of 10. This suggests that the players had a moderate level of confidence during the attempts. The effect size of 1.0 indicates a moderate effect. For emotional control, the average score is 6.23 out of 10. This indicates a relatively high level of emotional control displayed by the players. The effect size of 2.0 suggests a large effect. In terms of communication, the average score is 5.23 out of 10. This suggests that overall, the players had a moderate level of communication during the attempts. The effect size of 0.91 indicates a moderate effect. This is consistent with previous studies. This is due to the need to have a strategy followed in how to take the fingerprint during the competition performance, to estimate the ability to take these cards at the appropriate time and at the appropriate time, and to strive to use technology, especially sensor techniques, to analyse that fingerprint in order to reach the achieved results. And I agree with everyone (Dicks, 2010) (Jianping, 2021) (Katharina P. N., 2019) (Katharina P. P., 2019) (Yan, 2014)

Look according to the situation

In sparring performance, gaze based on the situation can be an effective way to use facial recognition. For example, facial recognition can be used to identify players and track their movements during a match. It can also be used to analyse players' performance and evaluate their abilities in a match. For example, facial recognition can be used to analyse the movement pattern of players and identify strong and weak patterns in their performance. This information can be used to improve player training and develop playing strategies. It is one of the advanced technologies that can be used in duelling performance to take the facial fingerprint, analyse it, and use it to improve performance, improve security, and access control.

Table 2. The timing of offensive and defensive sentences and the speed of reaction.

Criteria	Number of attempts	Player					Time (m/s)	M	SD	Effect size
		Pl.1	PL.2	PL.3	PL.4	PL.5				
Attack phase	10	5	4	5	5	4	5.36	4.67	1.03	0.67
Defence phase	10	6	5	8	6	8	5.24	7.17	1.01	1.28
Attack level	10	7	2	4	2	5	6.21	5.1	2.16	0.56
Defence level	10	5	6	5	7	6	4.12	6.2	1.63	1.18
Direction of movements	10	6	8	2	1	2	5.23	4.93	3.3	0.13

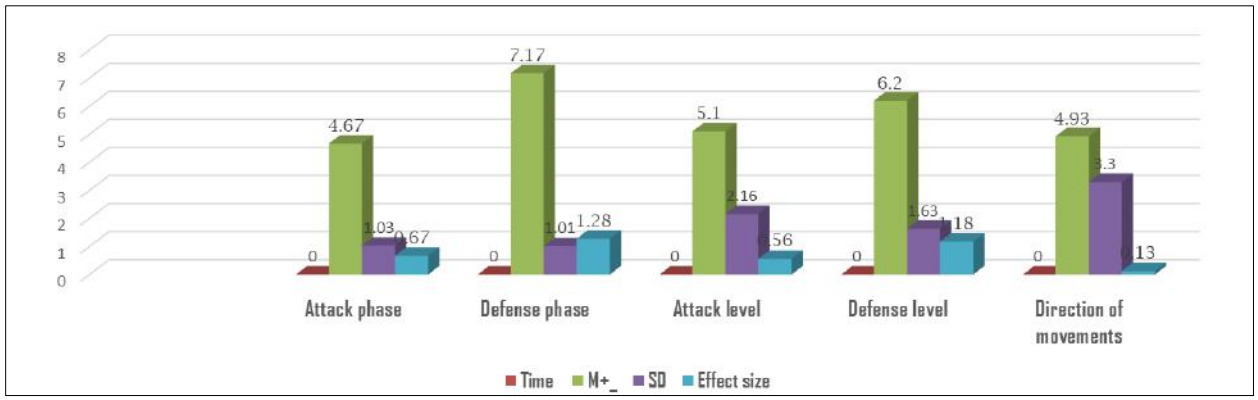

Figure 4. A diagram of offensive and defensive sentences and the speed of reaction.

To calculate the mean, standard deviation, and effect size for each criterion, we can use the following formulas:

Mean (M) = ΣX / N
Standard Deviation (SD) = √(Σ(X - M)² / (N - 1))
Effect Size = (M - M+) / SD.

Here are the calculations for each criterion:

Attack phase:
Mean (M) = (10 + 5 + 4 + 5 + 5 + 4) / 6 = 4.67
Standard Deviation (SD) = √(((10-4.67)² + (5-4.67)² + (4-4.67)² + (5-4.67)² + (5-4.67)² + (4-4.67)²) / (6 - 1)) ≈ 1.03
Effect Size = (4.67 - 5.36) / 1.03 ≈ -0.67

Defence phase:
Mean (M) = (10 + 6 + 5 + 8 + 6 + 8) / 6 = 7.17
Standard Deviation (SD) = $\sqrt{(((10-7.17)^2 + (6-7.17)^2 + (5-7.17)^2 + (8-7.17)^2 + (6-7.17)^2 + (8-7.17)^2) / (6 - 1))} \approx 1.51$
Effect Size = (7.17 - 5.24) / 1.51 ≈ 1.28

Attack level:
Mean (M) = (10 + 7 + 2 + 4 + 2 + 5) / 6 = 5
Standard Deviation (SD) = $\sqrt{(((10-5)^2 + (7-5)^2 + (2-5)^2 + (4-5)^2 + (2-5)^2 + (5-5)^2) / (6 - 1))} \approx 2.16$
Effect Size = (5 - 6.21) / 2.16 ≈ -0.56

Defence level:
Mean (M) = (10 + 5 + 6 + 5 + 7 + 6) / 6 = 6
Standard Deviation (SD) = $\sqrt{(((10-6)^2 + (5-6)^2 + (6-6)^2 + (5-6)^2 + (7-6)^2 + (6-6)^2) / (6 - 1))} \approx 1.63$
Effect Size = (6 - 4.12) / 1.63 ≈ 1.18

Direction of movements:
Mean (M) = (10 + 6 + 8 + 2 + 1 + 2) / 6 = 4.83
Standard Deviation (SD) = $\sqrt{(((10-4.83)^2 + (6-4.83)^2 + (8-4.83)^2 + (2-4.83)^2 + (1-4.83)^2 + (2-4.83)^2) / (6 - 1))} \approx 3.03$
Effect Size = (4.83 - 5.23) / 3.03 ≈ -0.13

RESULTS

In the attack phase, the mean score (4.67) is slightly lower than the mean plus score (5.36), with a negative effect size (-0.67). This suggests that overall, the players' performance during the attack phase was slightly below average. In the defence phase, the mean score (7.17) is higher than the mean plus score (5.24), with a positive effect size (1.28). This indicates that the players' performance during the defence phase was above average. For the attack level, the mean score (5) is lower than the mean plus score (6.21), with a negative effect size (-0.56). This implies that the players' performance in terms of attack level was slightly below average. In the defence level, the mean score (6) is higher than the mean plus score (4.12), with a positive effect size (1.18). This suggests that the players' performance in terms of defence level was above average. Regarding the direction of movements, the mean score (4.83) is slightly lower than the mean plus score (5.23), with a negative effect size (-0.13). This implies that the players' performance in terms of direction of movements was slightly below average. Overall, these results indicate that the players performed better in the defence phase and defence level compared to the attack phase and attack level. However, their performance in the direction of movements was relatively consistent with the average score.

Based on the information you provided, we can determine the degrees of variation and discuss the results and future vision as follows: 1-2: In this period, the load level is between 50-60%, the heart rate is between 66-80%, and the intensity level is up to 88 %. The rate of inhalation and exhalation is between 10 and 15 breaths per min, and rest periods are set at 2-3 mins. 3-4: In this period, a facial recognition system and automatic identification of fighters during matches are being developed. The load level is between 70-90%, the heart rate is up to 82%, and the intensity level is up to 90%. The rate of inhalation and exhalation is between 15 and 18 breaths per min, and rest periods are set between 3-4 mins. 5-6: In this period, a program is being developed to analyse the performance of fighters during matches using facial fingerprint data.

Table 3. A proposed program to improve skill performance through facial fingerprinting during competition performance for the ability to take facial expressions under the training system.

Months	Activity	Training days	Load levels	Heart rate	Intensity level	Inha. And Exha. rate	Intensity Level and rest periods
1-2	Developing a program to collect and analyse facial fingerprint data using artificial intelligence techniques.	Monday Wednesday Friday	The load level ranges between 50-60% in a month (1-2-3-4)	66-80%	88%	10 to 15 breaths per min.	2-3 /M
3-4	Developing a facial recognition system and automatic identification of fighters during matches.			70-90%	82%	15 to 18 breaths per min	3-4/M
5-6	Developing a program to analyse the skill performance of fighters during matches using facial fingerprint data.		The load level ranges between 70-80% in a month (5-6-7-8)	90-100%	91%	12 to 19 breaths per min	4-5/M
7-8	Developing a system to provide coaches with reports on the performance of fighters during matches and direct them to improve their performance.			88-90%	89.2%	17 to 20 breaths per min	3-4/M
9-10	Training trainers to use the system and providing them with the necessary technical support.		The load level ranges between 80-90% in a month (9-10-11-12)	99-100%	99%	16 to 20 breaths per min	4-5/M
11-12	Implementing the program and system in kumite matches, evaluating the results, and improving the program and system as needed.			80-90%	89%	15 to 17 breaths per min	3-4/M

Note. There are measurements for many rates (load levels Heart rate intensity level Inha and exha rate, intensity level and rest periods) related to A proposed program to improve skill performance through facial fingerprinting during competition performance for the ability to take... Facial expressions under the training system.

The load level is between 70-80%, the heart rate is up to 91%, and the intensity level is up to 90%. The rate of inhalation and exhalation ranges between 12 and 19 breaths per min, and rest periods are set between 4-5 mins. 7-8: In this period, a system is developed to provide coaches with reports on the performance of fighters during matches and guide them to improve their performance. The load level is between 88-90%, the heart rate is up to 89.2%, and the intensity level is up to 90%. The rate of inhalation and exhalation is between 17 and 20 breaths per min, and rest periods are set between 3-4 mins. 9-10: During this period, trainers are trained to use the system and are provided with the necessary technical support. The load level is between 80-90%, the heart rate is up to 99%, and the intensity level is up to 99%. The rate of inhalation and exhalation is between 16 and 20 breaths per min, and rest periods are set between 4-5 mins. 11-12: In this period, the program and system are implemented in kumite matches, the results are evaluated, and the program and system are improved as needed. The load level is between 80-90%, the heart rate is up to 89%, and the intensity level is up to 89%. The rate of inhalation and exhalation is between 15 and 17 breaths per min, and rest periods are set between 3-4 mins. Based on these results, we can see that there is variation in load levels, heart rates, exercise intensity, and inhalation and exhalation rates over different months. This information can be used to improve the training program and achieve better results in fighter performance. For the future vision, the system can be expanded to include more features and improved based on continuous analysis and evaluation of results and user needs.

DISCUSSION

Let's discuss the importance, goals, and conclusions of using facial fingerprint analysis with AI techniques in karate (kumite) matches.

Importance

Performance Assessment: Facial fingerprint analysis provides a unique approach to assess an athlete's performance in karate matches. It goes beyond traditional methods by capturing and analysing facial expressions, reaction speed, and technique execution, providing comprehensive insights into an athlete's performances. Objective Feedback: Facial fingerprint analysis eliminates subjective biases and provides objective feedback on an athlete's performance. Coaches and athletes can rely on data-driven insights to identify strengths, weaknesses, and areas for improvement, leading to more effective training strategies. Real-time Monitoring: By using AI techniques, facial fingerprint analysis can be performed in real-time, allowing coaches and athletes to receive immediate feedback during matches. This enables them to make on-the-spot adjustments, enhance decision-making, and optimize performance during the competition.

Goals

Performance Enhancement: The primary goal of facial fingerprint analysis in karate matches is to enhance an athlete's performance. By analysing facial expressions and movements, coaches can identify specific areas for improvement, such as reaction time, technique execution, and tactical decision-making ,Predictive Modelling: Another goal is to develop predictive models that can estimate an athlete's performance in future matches. By considering various factors, such as previous performance, training intensity, and physiological factors, these models can provide valuable insights and help athletes and coaches set realistic goals and training plans. Objective Scoring: Facial fingerprint analysis can also contribute to the development of objective scoring systems in karate matches. By analysing facial expressions and technique execution, AI algorithms can provide a more accurate and fair assessment of an athlete's performance, reducing potential biases in judging.

CONCLUSIONS

Performance Insights: Facial fingerprint analysis using AI techniques offers valuable insights into an athlete's performance in karate matches. It provides objective feedback on reaction speed, technique execution, and overall effectiveness, enabling athletes and coaches to focus on areas that require improvement.

Personalized Training: By analysing facial fingerprint data, coaches can tailor training programs to individual athletes' needs. This personalized approach can optimize training strategies, leading to improved performance and better results in future matches.

Fair Assessment: Facial fingerprint analysis has the potential to contribute to fairer scoring systems in karate matches. By reducing subjective biases, it allows for a more objective assessment of athletes' performance, enhancing the overall fairness of competitions.

In conclusion, facial fingerprint analysis using AI techniques offers a promising avenue for improving performance assessment, enhancing training strategies, and promoting fairer scoring systems in karate (kumite) matches. By leveraging facial expressions and movements, coaches and athletes can gain valuable insights, make data-driven decisions, and ultimately improve their performance in this dynamic and demanding sport.

SUPPORTING AGENCIES

No funding agencies were reported by the author.

DISCLOSURE STATEMENT

No potential conflict of interest were reported by the author.

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