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ORIGINAL ARTICLE

Physical performance, haematological and behavioural parameters of five mineral water in rats

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ABSTRACT

The objective of this study was to compare the effect of five mineral water mostly consumed in Cameroun on performance, haematological and behavioural parameters in the rats. Twenty-four rats (140 g) were used for this study. Among the groups, there are a control group which received deionized water and five experimental groups which received different mineral water (*Tangui, Supermont, Opur, Aquabelle and Semme*) during 21 days. Rats were allowed for swimming exercise every alternate day between 11h and 17h. On the day 21, rats from each group were subjected to the forced swimming test with tail load. One hour after the forced swimming test, the open field test was carried out to evaluate their behaviour. Water and food consumption, body weight, relative organ weight and haematological parameters were evaluated. Results showed that all the mineral water used during this experimentation did not have any effect on water intake, food consumption, body weight and relative organ weight ($p > .05$). However, significant increase ($p < .01 – p < .001$) in swimming time of rats consuming *Tangui* (445.00 ± 43.60 seconds) and *Opur* (450.80 ± 51.03 seconds) were observed as compared to the control group (325.50 ± 24.37 seconds). In the same way, results of behavioural and haematological parameters showed significant modifications in the same groups in comparison with control group ($p < .01 – p < .001$). Differences of swimming time, hematologic and behavioural parameters observed in rats having consumed *Tangui* and *Opur* could be due to the quantity of some minerals (calcium and magnesium) present in those drinks.
Keywords: Sport medicine, Physical activity, Anxiety, Sports health, Sports nutrition.

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INTRODUCTION

Heat resulting during practice of physical exercise is mainly dissipated by evaporation and perspiration. The dehydration which follows block the dissipation of heat, leading to the increase of body temperature, the losses of electrolytic and the reduction of physical performance (Walsh et al., 1994). To prevent these effects, athletes must hydrate themselves as soon as possible. It is thus recommended to the athletes to absorb at least 500 ml of liquid (mineral water, fruit juice, sport drinks) two hours before the beginning of physical activity (Shi, 2004). However, recent studies proved that pure water is not the best solution to be consumed after exercise to replace the sweat water lost (Bigard, 2007).

Recent studies showed that practicing physical activity for more than one hour could cause minerals losses and have a negative effect on athlete's health (IFN, 2010; Gibson et al., 2010; Lazarte et al., 2015). In addition, consumption of 4 litters water and more, practically without sodium to compensate sweat losses, could lead to symptomatic hyponatremia, cerebral oedema, neurological signs, coma and death (Hsieh et al., 2002). In order to replace water and electrolytic losses caused by the practice of physical activity, athletes can consume mineral water. The use of those mineral water was justified by their particular property. Indeed, according to their composition, these drinks are recognized as having a benefit for athlete's health (IFN, 2010).

In Cameroun, several mineral water marks used in training sessions and during competitions exists on the market. However, the choice of these mineral water by athletes does not depend on scientific criteria and there is limited data confirming their efficacy for improving performance. The objective of this study was to evaluate the effect of five mineral water mostly consumed in Cameroun on performance, haematological and behavioural parameters in rats subjected to a training program.

MATERIALS AND METHODS

Mineral waters

Five most consumed mineral waters (*Tangui, Supermont, Opur, Aquabelle and Semme*) were bought in the local market (Yaoundé) and used for this study. The choice of these mineral water is justified by fact that they were mostly consumed in Cameroon. The mineralogical composition of those mineral water was obtained from the labels present on each bottle.

Animals

Male albino rats of Wistar strain weighing 140 g were obtained from the Animal house of the National Institute of Youth and Sports in Yaoundé. They were placed in plastic cages in a room under standard Laboratory conditions (temperature 20 to 30°C, relative air humidity 45 to 55%, and 12/12 h light/dark cycle). The rats were fed with a basal diet and water *ad libitum*. The feed was a standard rat chow (National Veterinary Laboratory (LANAVET), Cameroon) composed of carbohydrates (52%), protein (22%), fat (6.5%), water (12%), ash (6%), and fibre (4.5%). The authorization for the use of laboratory animals in this study was obtained from the Cameroun National Ethics committee (Reg. No FWA-IRB00001954). The use, handling and care of animals were done in adherence to the European Convention (Strasbourg, 18.III.1986) for the protection of vertebrate animals used for experimental and other purposes (ETS-123), with particular attention to Part III, articles 7, 8 and 9. The animals were transferred to the laboratory at least 1 hour before the start of the experiment. The experiments were performed during the day (11:00-17:00hr).

Animal grouping

After two weeks of acclimatization, thirty rats (six groups of five rats) were used for this study. Among the groups, there are a control group which received deionized water and five experimental groups which received five different mineral drinks (*Tangui, Supermont, Opur, Aqua-Belle and Semme*) during 21 days. The quantity of food and water consumed by each group of rats, as well as body weights were measured every two days during 21 days, between 11:00 AM and 12:00 AM.

Swimming training program

Swimming training program was performed as describe previously (Lamou et al., 2016) but with some modifications. The rats of the experimental and control groups were allowed for swimming exercise every alternate day for a period of 21 days. Each animal was placed individually in a swimming pool (90cm × 45cm × 45cm), filled with water to a depth of 35 cm (Matsumoto et al., 1996; Kamakura et al., 2001) and maintained at 25 ± 1°C (Qi et al., 2014). The initial swimming time of the rats was 15 minutes, then 5 additional minutes were added every two days. The rats were then removed from the pool, dried with a paper towel, and returned to their original cages. The pool water was replaced after each session. After the last training session, the rats were prepared for the open field test.

Open field test

Following 12 hour of food and water deprivation, animals of all groups were submitted to open field test as described by Belzung (1999). The rats were individually placed at the centre of a clean open field apparatus (40×40×15 cm, divided into 25 squares), and the activity of each was video recorded for 5 minutes and analysed later. The latency period (time in the centre square), defecation, crossing (number of squares crossed indicating spontaneous locomotor activity), grooming and rearing (exploratory activity) for individual rat were scored. The arena was cleaned after each test using a 70% v/v ethanol.

Weight loaded force swimming test

The weight loaded force swimming test was performed as described previously (Lamou et al., 2016) but with some modifications. Briefly, one hour after open field test, rats taken from each group were subjected to the force swimming exercise. Each animal was supplied with a constant load (corresponding to 10% of the body weight) tagged to the tail and placed individually in a swimming pool (90 cm × 45 cm × 45 cm), filled with water to a depth of 35 cm and maintained at 30 ± 1°C (Qi et al., 2014). Exhaustion was determined by observing loss of coordinated movements and failure to return to the surface within 10 seconds (Qi et al., 2014) and swimming time was recorded immediately. The rats were then removed from the pool and dried with a paper towel. At the end of the swim, the rats were rested for an hour and then sacrificed (under ether anaesthesia) by cutting through the jugular vein, blood samples were taken into bottles containing EDTA as anticoagulant was used to determine blood cell count.

Statistical analysis

Except mineralogical composition results of each drink, other results are expressed as mean ± standard error of mean (SEM). Statistical analysis was done by one-way analysis of variance (ANOVA) followed by Dunnett's test for multiple comparisons and p-values less than .05 were considered significant.

RESULTS

Mineralogical composition of mineral water

Mineralogical composition of mineral water obtained from the labels present on each bottle was presented in Table 1. Observation of those results indicated that all mineral water used in this study have not the same mineralogical composition. Calcium and magnesium were most found in *Tangui* (32.00 mg/l and 21.00 mg/l for calcium and magnesium respectively) and *Opur* (45.00 mg/l and 16.00 mg/l for calcium and magnesium respectively). Potassium were most found in *Tangui* (10.00 mg/l), while chlorides, sodium and bicarbonate were most found in *Aquabelle* (4.00 mg/l) *Semme* (12.00 mg/l) and *Opur* (268.40 mg/l).

Table 1. Mineralogical composition of mineral water.

Minerals (mg/l)	Mineral water				
	Tangui	*Supermont*	*Opur*	*Aquabelle*	*Semme*
Calcium	32.00	30.00	45.00	20.00	13.00
Magnesium	21.00	5.90	16.10	9.00	12.00
Potassium	10.00	3.80	0.58	1.50	5.00
Chlorites	1.00	1.30	00	4.00	00
Sodium	1.00	00	2.02	2.00	12.00
Bicarbonate	217.00	134.00	268.40	96.00	161.00

Source. Labels obtained from each bottle.

Body weight, food and water intake

Consumption of different mineral water has no significant effect on body weight (Table 2) and food and water intake (Table 3) as compared to control group (p > .05).

Table 2. Body weight change of the rats during experimentation.

Body weight (g)	Week 1	Week 2	Week 3
Control group	140.00 ± 17.94	160.50 ± 15.69	168.75 ± 15.65
Tangui group	139.50 ± 19.12	159.50 ± 8.70	165.00 ± 5.29
Supermont group	139.75 ± 20.29	156.50 ± 20.17	163.25 ± 17.17
Opur group	141.00 ± 20.48	155.25 ± 13.96	168.75 ± 18.71
Aqua-Belle group	141.50 ± 20.09	157.50 ± 20.73	161.25 ± 13.00
Semme group	141.75 ± 19.70	161.25 ± 18.01	165.75 ± 14.20

Note. Each value represents the mean ± SEM, n = 5.

Table 3. Food (g/group/week) and water (ml/group/week) intake in rats.

Food intake (ml/group/week)	Week 1	Week 2	Week 3
Control group	207.75 ± 24.66	190.25 ± 41.04	197.00 ± 44.65
Tangui group	231.75 ± 18.84	192.50 ± 60.23	197.25 ± 44.75
Supermont group	204.75 ± 19.72	201.25 ± 62.36	186.00 ± 49.81
Opur group	206.00 ± 16.35	178.25 ± 55.31	184.75 ± 21.70
Aqua-Belle group	207.75 ± 32.49	191.00 ± 73.03	188.75 ± 22.19
Semme group	216.00 ± 21.60	196.00 ± 40.11	164.75 ± 13.43
Water intake (ml/group/week)	**Week 1**	**Week 2**	**Week 3**
Control group	145.76 ± 20.24	140.76 ± 18.86	238.51 ± 73.78
Tangui group	105.86 ± 20.37	127.86 ± 10.63	244.61 ± 82.86
Supermont group	144.97 ± 34.65	133.22 ± 6.34	270.22 ± 96.09
Opur group	132.42 ± 25.37	121.92 ± 17.47	267.42 ± 69.84
Aqua-Belle group	122.16 ± 16.75	106.66 ± 10.60	265.16 ± 83.17
Semme group	121.06 ± 25.49	128.31 ± 31.16	257.29 ± 92.45

Note. Each value represents the mean ± SEM.

Behaviours scored

Results of behavioural parameters (latency period, defecation, crossing, grooming and rearing) were shown in Table 4. Significant decrease of defecation and latency period were observed in Tangui, Opur and Semme groups as compared to control group ($p < .05 – p < .001$). In the same way, significant decrease of grooming was observed in *Tangui, Supermont, Opur* and *Aqua-Belle* groups as compared to control group ($p < .05 – p < .001$). However, number of squares crossed and exploratory activity (rearing) increased significantly in *Tangui* and *Opur* groups as compared to control group ($p < .01 – p < .001$).

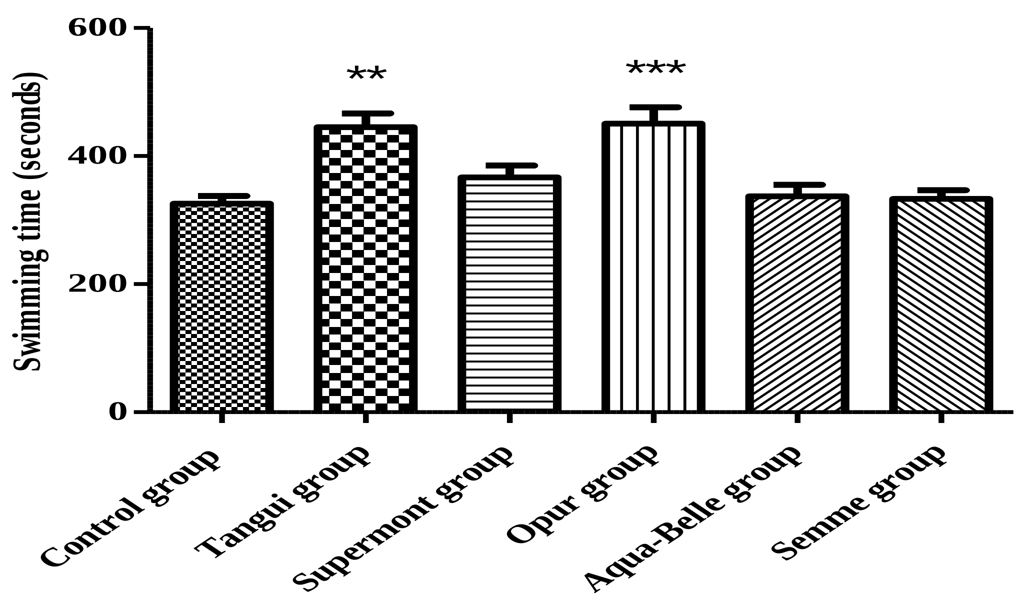
Table 4. Behaviours scored of rats during experimentation.

Treatment	Defecation (g)	Latency period (sec)	Crossing	Grooming	Rearing
Control group	0.32 ± 0.19	11.00 ± 3.56	19.00 ± 3.16	6.75 ± 1.71	3.00 ± 1.41
Tangui group	0.12 ± 0.07*	5.00 ± 1.41**	34.50 ± 10.02**	2.50 ± 1.29***	8.00 ± 2.58***
Supermont group	0.25 ± 0.07	7.00 ± 2.16	24.50 ± 5.32	4.50 ± 1.29*	4.75 ± 1.50
Opur group	0.06 ± 0.04**	6.00 ± 2.94*	37.75 ± 8.73***	2.00 ± 0.82***	7.50 ± 1.29**
Aqua-Belle group	0.21 ± 0.10	9.75 ± 2.22	25.00 ± 5.48	3.75 ± 1.26**	5.50 ± 1.29
Semme group	0.25 ± 0.10	6.00 ± 2.16*	20.25 ± 2.06	5.50 ± 1.29	5.50 ± 2.08

*Note. Each value represents the mean ± SEM, $n = 5$. *p < .05, **p < .01 and ***p < .001 compared with control group.*

Swimming time to exhaustion

Swimming time to exhaustion of rats were presented in Figure 1. Results showed that swimming time of Tangui and Opur groups were significantly higher than that recorded for the control group ($p < .01 – p < .001$). Maximum swimming time was recorded in Opur group (450.80 ± 51.03 seconds) with a rate of increase of 38.49% as compared to control group (325.50 ± 24.37 seconds).



*Note. Data are presented as mean ± SEM, $n = 5$. **p < .01 and *** p < .001 compared with control group.*

Figure 1. Swimming time of rats subjected to FSET.

Haematological parameters

As shown in Table 4, no significant difference of number lymphocytes, red blood cells, haematocrit and haemoglobin between the control group and the test groups was observed (p > .05). While a significant increase in the white blood cells number of *Tangui group* was observed as compared to control group (p < .01 – p < .001). The rate of granulocyte (in the *Tangui group*) and the percentages of lymphocyte and monocyte (*in Opur group*) increased significantly (p < .05; p < .001) in comparison to control group. However, significant decrease (p < .01 – p < .001) of the rate of monocyte in four test groups (*Tangui, Supermont, Aqua-Beautiful and Semme groups*) and percentage of granulocyte in two test groups (*Tangui and Supermont groups*) were observed as compared to reference group.

Table 4. Haematological parameters of rats

Haematological parameters	Control group	Tangui group	Supermont group	Opur group	Aqua Belle group	Semme group
WBC (10^3/µl)	7.11 ± 1.33	11.45 ± 3.30*	9.89 ± 2.43	9.70 ± 2.65	8.50 ± 2.33	8.15 ± 2.22
LYM (10^3/mm^3)	3.17 ± 0.57	2.24 ± 0.20	3.43 ± 0.79	2.88 ± 0.63	3.38 ± 1.02	3.26 ± 0.20
MON (10^3/mm^3)	1.65 ± 0.50	0.47 ± 0.17***	0.70 ± 0.21***	1.30 ± 0.07	1.03 ± 0.12**	0.84 ± 0.07***
GRA (10^3/mm^3)	3.79 ± 0.61	9.45 ± 5.91*	6.20 ± 2.83	7.05 ± 1.64	4.53 ± 0.91	4.77 ± 0.66
LYM (%)	34.35 ± 9.57	37.95 ± 6.85	41.07 ± 10.59	58.10 ± 17.18*	36.65 ± 5.12	37.57 ± 6.02
MON (%)	16.62 ± 2.97	8.827 ± 4.44	16.12 ± 4.39	34.60 ± 9.47***	16.60 ± 2.65	12.30 ± 1.41
GRA (%)	72.95 ± 10.72	43.45 ± 9.11**	38.70 ± 7.14***	62.95 ± 13.82	80.45 ± 3.40	57.70 ± 8.35
RBC (10^6/mm^3)	4.52 ± 0.55	5.12 ± 0.34	4.42 ± 0.51	4.61 ± 0.44	4.35 ± 0.48	4.40 ± 0.30
HTC (%)	45.05 ± 7.63	41.32 ± 3.92	38.02 ± 2.67	48.05 ± 5.44	37.95 ± 7.82	40.65 ± 3.95
HGB (g/dL)	13.54 ± 1.86	14.20 ± 1.29	12.45 ± 0.62	12.57 ± 0.40	12.32 ± 2.03	13.64 ± 0.76
PLA (10^3/mm^3)	395.00 ± 78.74	406.75 ± 54.83	395.00 ± 78.74	417.75 ± 62.82	313.00 ± 46.08	378.00 ±61.74

*Note. Each value represents the mean ± SEM, n = 5. *p < .05, **p < .01 and ***p < .001 compared with control group. WBC: White Blood Cells, LYM: Lymphocytes, MON: Monocytes, GRA: Granulocytes, RBC: Red Blood Cells, HTC: Haematocrits, HGB: haemoglobin, PLA: platelets.*

DISCUSSION

The present study was undertaken to compare the effect of five mineral drinks mostly consumed in Cameroun on performance, hematologic and behaviour parameters in the rats subjected to a training program. Results showed that all the mineral drinks used during this experimentation did not have any effect on water and food consumption (p > .05). Moreover, body weight and relative organ weight did not present any significant difference between tests groups and control group (p > .05). However, significant increase in swimming time of rats consuming Tangui (p < .01) and Opur (p < .001) were observed as compared to the control group. Values of swimming time are 445.00 ± 43.60, 450.00 ± 51.03 and 325.50 ± 24.36 seconds respectively for Tangui, Opur and control group. In the same way, results of behavioural and haematological parameters showed significant modifications in the same groups in comparison with control group (p < .05 – p < .001). Those results can be explained by the fact that all mineral drinks used in this study have not the same mineralogical composition. In fact, potassium was most found in Tangui (10.00 mg/l), while sodium was found in sufficient quantity in Opur (2.02 mg/l) (Table 1). Moreover, calcium and magnesium were most found in Tangui (32.00 mg/l and 21.00 mg/l for calcium and magnesium respectively) and Opur (45.00 mg/l and 16.00 mg/l for calcium and magnesium respectively) (Table 1). Similar results have been reported by Misner (2006) and Bigard et al. (2007), who shown that pure water can't be the best solution to replace water lost in sweat. Minerals are involved in hundreds of biological processes relevant to exercise and athletic performance, such as energy storage/utilization, protein metabolism, inflammation, oxygen transport, cardiac rhythms, bone metabolism and immune function (Kerksick et al., 2018; Heffernan et al., 2019). They were essential to prevent water lost, decrease in muscular and nervous functions and to facilitate recovery. Recent studies showed that practicing physical activity for more than one hour could cause sodium, calcium, magnesium, potassium loss and could have a negative effect on athlete's performance and health, leading to fatigue, cerebral oedema, neurological signs, coma and death (IFN, 2010).

CONCLUSION

Our data suggest that rats consuming Tangui and mostly Opur have benefit effects on endurance capacity, behavioural and haematological parameters. Those effects could be due to the presence, in sufficient quantities, of electrolytes in these mineral drinks. However, further investigations are necessary to elucidate the molecular mechanisms.

AUTHOR CONTRIBUTIONS

Conceptualization, methodology and writing original draft were made by Drs Bonoy Lamou, Mbame Jean-Pierre and André Hamadou. Formal analysis was made by Mr Ngarsou Pierre. Editing were made by Dr Bonoy Lamou.Dr Jean-Pierre Mbame, Dr André Hamadou ans Ms Doukoya Joséphine have been involved in data collection and curation. All authors have read and agreed to the published version of the manuscript.

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No potential conflict of interest was reported by the authors.

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ORIGINAL ARTICLE

Relationship between swimming speed and physiological and perceptual responses in skins race

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ABSTRACT

Purpose: This study investigated the relationships between swimming speed and physiological and perceptual responses in a skins race, in which a maximum of three races are repeated with a rest in between each round. Methods: The study measured the physiological responses in terms of the heart rate, maximal oxygen uptake ($\dot{V}O_2$ max), and oxygen debt (O_2 debt) and examined the perceived exertion to determine the perceptual response. Specifically, it measured the swimming speed and blood lactate (Bla) levels of seven male collegiate swimmers in three rounds of 50 m freestyle, which simulated skins race. It also conducted a bicycle ergometer test to measure their $\dot{V}O_2$ max and O_2 debt. Results: The results showed a significant association between swimming speed and Bla. In other words, the study found a significant association between swimming speed and glycolysis during the skins race. However, it did not find a significant association between swimming speed and $\dot{V}O_2$ max or/and O_2 debt. Conclusion: Hence, it concluded that a swimmer's skill level is related to the swimmer's speed in the skins race. These findings provide an understanding of the physiological parameters that effect performance in high-intensity sports.
Keywords: Performance analysis of sport, Physical conditioning, Skins race, Swimminig Speed, Blood lactate, Maximal oxygen uptake, Oxygen debt.

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INTRODUCTION

Established in 2019, the International Swimming League (ISL) was a new initiative in the domain of professional swimming. This competition has two formats—team competition and skins race. In the team competition, teams compete for points to win. The team competition comprises 10 teams, 11 preliminary league matches, 6 playoff matches, and a final match. Four teams compete in each match, and two representatives are selected from each team for each race. Teams receive points for each race, which determines the winner of the team competition. The points are distributed in descending order from the first-place finisher to the eighth-place finisher. However, there are several rules for earning points, and the points awarded are not always earned. One of these rules is referred to as the jackpot time rule. This rule applies to the first-place finishers players of a race who outdo their opponents by a time margin exceeding the jackpot time. The points distributed to the competitors of the race in question are awarded to the first-place finisher. Conversely, the cutoff time rule applies to players who fail to finish the race within the minimum cutoff time. These athletes lose their points and subject their team to penalty. These unique rules make it important for swimmers to consider tactics at ISL.

Concerning the skins race, it is a relatively new event. It consists of eight swimmers from four teams, each having two representatives. It differs from the team competition in that it involves winning three 50 m races. Half of the swimmers are eliminated after each 50 m round, and the winner is decided after the third round. The interval between each round is set to 3 min. For the first time in the history of competitive swimming, the winner-takes-all system of the ISL allows players to take all the points accumulated in each of the three rounds. This is different from the conventional swimming competitions where the points can be collected once per race. However, in the ISL's skins race, swimmers can swim a maximum of three rounds and earn points at the end of each round. As a result, the ISL skins race swimmers can earn points thrice more than the swimmers at other events and have a greater impact on the team competition. Given this, the swimmers can contribute to the team competition by earning high points in the skins race competition. However, a swimmer should possess both endurance and speed to earn high points, and thereby realize the winner-takes-all benefit of the skins race.

There are several studies on swimming speed and endurance. Kurokawa et al. (1985) reported that maximal oxygen uptake ($\dot{V}O_2$ max) and maximal oxygen debt (O_2 debt) influence performance outcomes. However, this is based on the assumption that the winner is determined by a single swim. Under such circumstances, $\dot{V}O_2$ max and O_2 debt have been found to be related to swimming speed, but the effects of these parameters have been unclear in competitions such as skin races, in which multiple races are repeated within a short span of time. In this context, this study investigates the relationships between swimming speed and physiological and perceptual responses in the skins race. In this race, a maximum of three races are repeated with a rest in between each round.

METHOD

Subjects

The study sampled seven healthy male collegiate swimmers (age: 19.6 ± 1.4 years; height: 170.1 ± 4.6 cm; and weight: 62.0 ± 7.3 kg), who held their best record in 50 m freestyle (26.9 ± 1.8 sec). They trained in the water and on land about thrice/week and twice/week, respectively. The subjects' $\dot{V}O_2$ max, $\dot{V}O_2$ max/wt, O_2 debt, and O_2 debt/wt were 3355.7 ± 378.4 ml/min, 54.5 ± 6.2 ml/min/kg, 5715.7 ± 4100 ml, and 91.9 ± 62.8 ml/kg, respectively.

Procedure

Skins race, $\dot{V}O_2$ max, and O_2 debt were measured on separate days. Skins races were conducted in a long-distance swimming pool. Subjects completed three rounds of 50 m crawl in accordance with the skins race competition. Using a stopwatch, the study manually measured the swim time for each round. After a 50 m cool-down period of 3 min, the swimmers proceeded to the next round.

The study conducted a bicycle ergometer (i.e., Power Max-VII, Combi) test to measure $\dot{V}O_2$ max and O_2 debt (Aerobike 330, Combi). The ergometer works as an exercise load device. Concerning $\dot{V}O_2$ max, after 30 min of seated rest, the subjects performed at 60 rpm and 0 W for 3 min; the load was increased by 50 W every 3 min until the subjects were exhausted. Concerning the O_2 debt, after 30 min of seated rest, the subjects performed full power pedaling work at a load equal to 7.5% of their body weight for 30 s. The study measured the oxygen uptake during the recovery period, after pedaling.

Measurement items

At the start phase of the skins race, the subjects positioned themselves on a starting block with a back plate (Seiko). The interval between the starts was 3 min. The study measured the swimming speed, heart rate (HR) (A300, polar), and blood lactate concentration (lactate pro2, Arkray) at rest, after the warming-up, and 1 min after each round for 5 times during the skins race. It also measured the post-race subjective exercise intensity (ratings of perceived exertion: RPE).

The study used a wearable exhaled gas measurement device to measure $\dot{V}O_2$ max (Pnoe, Endo Medical, Inc.). Specifically, the study continuously measured $\dot{V}O_2$, $\dot{V}CO_2$, RER, VE, VT, BF, FEO_2, and $FECO_2$; $\dot{V}O_2$ max was the maximum value of the average values per min. The subjects were asked to indicate their HR during exercise and RPE from a table, which was shown to the subjects 1 min before the load change.

The study used a wearable exhaled gas analyzer to measure the O_2 debt (Pnoe, Endo Medical, Inc.). The study obtained the O_2 debt by subtracting the subjects' resting $\dot{V}O_2$ from the sum of $\dot{V}O_2$ at 40 min, immediately after full strength pedaling work for 30 s at a load of 7.5% of the body weight. Resting $\dot{V}O_2$ denoted the sum of the last 10 min of the 40 min of the $\dot{V}O_2$ work, after the exercise.

Statistical treatment

The study expressed the results as mean ± standard deviation and adopted a significance level of less than 5%. It calculated the Pearson's product-rate correlation coefficient for correlations.

RESULTS

Table 1 shows swimming speed, HRmax, RPE, and Bla for the three rounds of the skins race. Swimming speed was highest in round one, which decreased progressively with each round; however, HRmax, RPE, and Bla increased with rounds.

Table 2 shows the correlation matrix between swimming speed and Bla, for each round. Swimming speed in each round was significantly related to swimming speed and Bla in the next round.

Table 1. Swimming speed, HRmax, RPE, and Bla for the three rounds of skins race.

Indices		1R	2R	3R
Speed (m/s)	Mean ± SD	1.7 ± 0.1	1.7 ± 0.1	1.6 ± 0.2
HRmax (beats/min)	Mean ± SD	170.3 ± 8.0	174.3 ± 8.7	175.0 ± 7.4
RPE	Mean ± SD	14.0 ± 1.3	15.7 ± 1.0	17.4 ± 0.9
Bla (mmol)	Mean ± SD	7.4 ± 2.7	12.9 ± 4.7	15.7 ± 4.2

Table 2. Correlation matrix between swimming speed and Bla for each round.

	1	2	3	4	5
1. Swimming speed for round 1					
2. Swimming speed for round 2	.981**				
3. Swimming speed for round 3	.971**	.993**			
4. Bla for round 1	.695	.641	.626		
5. Bla for round 2	.836*	.857*	.830*	.593	
6. Bla for round 3	.905**	.863*	.838*	.625	.923**

*Note. **: p < .01, *: p < .05.*

Table 3 shows the relationship matrix between swimming speed, $\dot{V}O_2$ max ($\dot{V}O_2$ max/wt), O_2 debt (O_2 debt/wt), and $\dot{V}O_2$ max+O_2 debt ($\dot{V}O_2$ max/wt+O_2 debt/wt). $\dot{V}O_2$ max was significantly associated with O_2 debt (O_2 debt/wt) and $\dot{V}O_2$ max+O_2 debt ($\dot{V}O_2$ max/wt+O_2 debt/wt). O_2 debt (O_2 debt/wt) was significantly associated with $\dot{V}O_2$ max/wt+O_2 debt/wt ($\dot{V}O_2$ max/wt+O_2 debt/wt).

Table 3. Relationship matrix between $\dot{V}O_2$ max, $\dot{V}O_2$ max/wt, O_2 debt, O_2 debt/wt, $\dot{V}O_2$ max+O_2 debt, $\dot{V}O_2$ max/wt+O_2 debt/wt and Swimming Speed.

	1	2	3	4	5	6	7	8
1. $\dot{V}O_2$max								
2. $\dot{V}O_2$max/wt	.473							
3. O_2debt	.812*	.607						
4. O_2debt/wt	.776*	.675	.994**					
5. $\dot{V}O_2$max+O_2debt	.840*	.604	.999**	.990**				
6. $\dot{V}O_2$max/wt+O_2debt/wt	.771*	.724	.986**	.998**	.982**			
7. Swimming speed for round 1	.165	-.580	.096	.033	.104	-.025		
8. Swimming speed for round 2	.272	-.443	.174	.119	.185	.068	.981**	
9. Swimming speed for round 3	.309	-.382	.268	.216	.276	.164	.971**	.993**

*Note. **: p < .01, *: p < .05.*

DISCUSSION

This study examined the relationships between swimming speed and physiological and perceptual responses during skin races. To this end, the study sampled male collegiate swimmers, whose best record in 50 m freestyle varied widely. Specifically, the study found a difference of 5.4 s between the fastest and slowest swimmers. This implies a large difference in the swimming technique of the subjects.

Concerning their anaerobic capacity, the O_2 debt (5.72 l and 91.9 ml/kg, respectively) of the subjects were 11–34% lower than those of the leading male swimmers in Europe and the United States (8.69 l and 118 ml/kg) (Cureton 1951), male university swimmers in Europe and the United States (7.75 1 and 103 ml/kg (Shephard et al. 1974), Japanese male university group (8.67 l and 131.1 ml/kg) (Kurokawa et al. 1985), and male elite swimmers (8.05 l and 118.6 ml/kg) (Kurokawa et al. 1985).

Concerning their anaerobic capacity, $\dot{V}O_2$ max were 3.36 l and 54.5 ml/kg/min, which were 19–33% lower than those of the top male swimmers (4.14–5.051/min) (Holmer 1972; Holmer et al. 1974; Magel and Faulkner 1967). These values were 0–21% lower than those of the male university swimmers (3.36–4.261/min) (Dixon and Faulknerm 1971; Holmer 1972; McArdle, et al. 1971), 6–17% lower than those of the Japanese male elite swimmers (4.04 l/min, 58.2 ml/kg/min) (Kurokawa et al. 1985), and almost equal (1–6%) to those of the male university students (3.63 l/min, 54.8 ml/kg) (Kurokawa et al. 1985). In terms of $\dot{V}O_2$ max/wt, the subjects were almost equal to their counterparts in universities and elite groups. Thus, although the subjects had a lower anaerobic energy supply capacity than that of the high-level swimmers, their aerobic energy supply capacity was approximately at the same level.

This study found a significantly high correlation coefficient between swimming speed and Bla in skins race. This relationship strengthened as the players progressed to the subsequent rounds. In this regard, Sakai et al. (1999) showed that, among the indices of the aerobic energy-producing capacity, submaximal work capacity had a higher correlation with intermittent high-power exercise than that of $\dot{V}O_2$ max. It must be noted that the submaximal work capacity does not increase the Bla of individuals exercising under constant load conditions. However, the energy-producing capacity of the lactic acid system did not have a significant correlation with an intermittent high-power exercise. This also implies that the former does not share a significant relationship with the ability to maintain swimming speed in a high-intensity intermittent exercise such as the skins race. However, Sakai et al. (1999) examined a high-intensity exercise as a 7-second full-power exercise, which is shorter than the skins race. Skins race is a short-duration, high-intensity, intermittent exercise that takes approximately 30 s to complete. In this regard, Hatta (2009) pointed out that glucose breakdown can contribute toward high lactate levels during exercise. Studies show that glucose breakdown is key to energy supply during high-intensity and short-duration exercises. Given that Bla is an index of energy supply capacity in glycolysis, an increase in Bla in the skins race indicates that the subjects' ability to maintain swimming speed in the skins race (high-intensity intermittent exercise of about 30 s performed every 3 min) is related to the lactate energy production capacity. Thus, the results suggest that the ability to maintain swimming speed during the skins race is mainly related to the ability to produce lactate energy. This ability becomes more pronounced with every subsequent round.

Concerning the aerobic energy-producing capacity, the results showed that swimming speed in the skins race does not share a significant correlation with the aerobic energy-producing capacity ($\dot{V}O2$ max, $\dot{V}O_2$ max/wt) or anaerobic energy-producing capacity (O_2 debt, O_2 debt/wt). However, the results showed a significant association between the body mass index (BMI) and swimming speed in each round. In this regard, in 100–400 m swimming, studies have reported a significant association between swimming speed and the absolute and relative values of $\dot{V}O_2$ max, especially the absolute values (Kurokawa et al. 1995). This can be attributed to the fact that, since buoyancy plays a role in swimming, there is little need to support body weight against gravity (Kurokawa et al. 1985). Moreover, the body surface area (which is closely related to body weight) does not affect individual differences in body water resistance (Miyashita, 1970). Since skins racing is an underwater exercise, body weight is not considered a disadvantage, but an advantage, in this competition The subjects had a relatively large muscle mass because of their regular training regimen. This muscle mass increased their BMI, thereby significantly influencing their swimming speed.

Regarding $\dot{V}O_2$ max, Yamamoto and Kanehisa (1990) showed that the relationship with $\dot{V}O_2$ max was stronger during intermittent and sustained full-strength exercise performed for short periods of time. This is because prolonged exercise stimulates the supply of both anaerobic and aerobic energy. In other words, the energy expended during exercise is repeatedly recovered by the aerobic activity during rest and used for the next exercise. The same might be true for high-intensity, intermittent exercise such as the skins race. However, this study did not find significant differences in the aerobic or anaerobic energy supply capacity of the subjects. The effect of the aerobic energy supply capacity on recovery during the interval was also not found significant. Hence, the study deduced that the differences in the subjects' swimming skills (as captured by subjects' best records of 50 m freestyle) affected the swimming speed of the subjects in the first round of the skins race. This finding suggests that the swimming speed in the first round was significantly associated with the swimming speed in the second round, and the swimming speed in the second round was significantly associated with the swimming speed in the third round.

Given that the skins race is a high-intensity, short-duration intermittent exercise, both the lactic- and aerobic energy supply capacities were expected to play role in the skins race as a. However, this study did not find significant differences in the aerobic energy supply capacity or anaerobic energy supply capacity. Bla was also significantly associated with swimming speed in the skins race. Hence, this study concluded that there is a significant relationship between the resulting differences in skill level and the swimming speed in the skins race.

AUTHOR CONTRIBUTIONS

Conceptualization: Y. Tsukahara and T. Ueda. Data curation: Y. Tsukahara. Formal analysis: Y. Tsukahara and T. Ueda. Investigation: Y. Tsukahara. Methodology: Y. Tsukahara and T. Ueda. Project administration: T. Ueda. Resources: T. Ueda. Supervision: T. Ueda. Validation: T. Ueda. Visualization: T. Ueda. Writing – original draft: Y. Tsukahara. Writing – review & editing: T. Ueda.

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DISCLOSURE STATEMENT

We communicated the intent and methods of this study to the subjects. We also obtained informed consent. This research was also approved by the research ethics committee of the Graduate School of Education, Hiroshima University. The committee gave a reference number HR-ES-000338.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

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Anthropometric characteristics of elite male taekwondo athletes according to weight category and performance level

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ABSTRACT

The aim of this study was to: 1) compare the anthropometric characteristics of elite male taekwondo athletes between selected weight categories using the 'full' International Society for Advancement of Kinanthropometry (ISAK) profile; and 2) compare the index of sitting height/stature ratio, and lower-limb segment lengths between standards of competitors. Thirty-two elite male taekwondo athletes volunteered to take part and they were categorised according to five competition weight categories (<58, <63, <68, <74, and <87kg). Anthropometric measurements were performed according to the ISAK profile protocol (42 measures), and the data were compared between the weight categories. Athletes were also divided into two groups based upon their previous success and selected variables were compared between the groups. Significant differences were identified in a range of anthropometric variables between athletes' weight categories, including percentage of body fat [%BF], skinfold thickness, measurement girths, lengths and widths, and somatotype components. Such differences were generally more notable between the lighter (<58kg) and heavier (<63, <68, <74, and <87kg) weight categories, with lighter weight categories tending to exhibit lower %BF, skinfold thickness, smaller/shorter specific limb girths, breadths, and lengths, and lower endomorphy when compared with their heavier weight counterparts. International level athletes displayed significantly lower sitting height/ stature ratio, and greater iliospinale and tibiale laterale height than their national level counterparts ($p < .05$). The findings of this study provide focused reference values to assist preparations for selected weight categories within the sport, and they offer a framework to support talent identification programmes.

Keywords: Performance analysis of sport, Physical Conditioning, Anthropometry, Taekwondo, Weight categories, Somatotype, Combat sports, Body composition.

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INTRODUCTION

Taekwondo is an Olympic combat sport practiced by an estimated >80 million people worldwide (World Taekwondo Federation 2022). Senior male World Taekwondo (WT) competitions are held according to weight categories designated as <54, <58, <63, <68, <74, <80, <87, >87 kg (World Taekwondo Federation, 2020). Taekwondo contests feature full-contact combat between two opponents, with a prominent emphasis on kicking techniques to the torso and head. In this sport, a range of physical, technical, tactical, physiological, and psychological characteristics can determine athletes' success (Falco et al., 2009; Heller et al., 1998; Sadowski et al. 2012). Several anthropometric characteristics have also been linked with performance in taekwondo. These include height, body mass index (BMI), body fat percentage (%BF), and limb length (Kazemi et al., 2006; Markovic et al., 2015; Scamardella et al., 2020; Mirali et al., 2021). As such, anthropometric variables are routinely collected alongside other physical components of fitness to assist athletes' preparations for competition (Bridge et al., 2014). These variables may also serve as a valuable composite of talent identification (Norjali et al., 2019).

Body composition is an important anthropometric variable that might contribute to success in taekwondo competition. Elite international level taekwondo athletes tend to exhibit relatively low levels of %BF, albeit marked variation in %BF has been observed between competitor standards, genders, and age groups (Bridge et al., 2014; Pieter & Taaffe, 1990; Pieter & Bercades, 2009). Mirali et al. (2021) have recently identified differences in %BF between WT weight categories in elite male competitors. The lighter weight divisions (<54 and <58kg) tended to display lower %BF and skin fold thickness when compared with their heavy weight (<80 and >87kg) counterparts (Mirali et al. 2021). Whilst these novel findings are valuable to support athletes' competition preparations (e.g., weight-making practices), existing data are confined to the total sum of 8 skinfolds and concomitant estimates of %BF. More comprehensive evaluation of the skinfold thickness at each discrete measurement site might advance our understanding of regional fat distribution, and thereby offer more specific reference values for specific weight categories within the sport (Franchini et al., 2014).

Somatotype is another important a variable collected during routine testing in taekwondo, and it may be used for talent identification. Research has identified that 'ectomorphic mesomorph' is the archetypal somatotype exhibited by male taekwondo competitors (Bridge et al., 2014); but more recently it has been discovered that these characteristics may be modulated by competitors' weight category. For instance, athletes in lighter taekwondo weight divisions (<54 and <58kg) were categorised as 'mesomorphic ectomorph', whereas heavier weights (<68, <74 and 80kg) displayed 'ectomorphic mesomorph' character (Mirali et al., 2021). This novel observation is, however, currently confined to a single study, and hence it remains unclear whether this trend extends to other taekwondo populations and/or if it can be replicated (Halperin et al., 2018). Importantly, existing research into the somatotype and anthropometric variables of taekwondo athletes between weight categories has been performed using 'restricted' International Society for Advancement of Kinanthropometry (ISAK) profiles (Mirali et al., 2021). Research evaluating the 'full' ISAK profile (42 measures) between weight categories in taekwondo is needed to offer more comprehensive understanding and provide more focused reference values for specific variables, such as limb girths, widths, and lengths.

There has been considerable debate surrounding the importance of stature and limb length in achieving success in taekwondo (Bridge et al., 2014; Heller et al., 1998; Scamardella et al., 2020). Whilst it has been assumed that stature and the length of the lower extremities may be conducive to achieving success, existing evidence remains inconclusive (Kazemi et al., 2013; Markovic et al., 2005; Sadowski et al., 2012). Recently, however, sitting height/stature ratio has been identified as a promising alternative measure capable of discerning differences in the stature of the head and trunk, and legs between standards of competitors in taekwondo (Mirali et al., 2021). This ratio was found to be lower in international compared with national level competitors (Mirali et al., 2021). Nevertheless, this novel observation is founded on a single recent investigation. As such, it would be valuable to determine if this trend extends to other taekwondo populations and whether it is reproducible to enhance validity of this construct (Halperin et al., 2018). Likewise, more detailed evaluation of specific lower limb segments (e.g. iliospinale and tibiale-laterale length) would conceivably offer more thorough understanding and more specialised reference values.

The aims of this study were to: 1) compare the anthropometric characteristics of elite male taekwondo athletes between selected weight categories using a 'full' ISAK profile; and 2) compare the index of sitting height/stature ratio, and specific lower limb segments between standards of competitors. It was hypothesized that the anthropometric characteristics would vary between weight categories in taekwondo, and that international level athletes would exhibit lower sitting height/stature ratio, and longer iliospinale and tibiale-laterale lengths than national level counterparts.

METHOD

Participants

Thirty-two elite WT senior male taekwondo athletes (mean age: 20 ± 3.5 years with 4-10 years of training experience, and actively training 4-6 days/week and 1.5-2 hours/day) agreed to participate. The study was approved by Ege University Scientific Research Ethics Committee in the Faculty of Medicine (Approval No:16-3/1) in accordance with the Declaration of Helsinki Ethical Principles for Medical Research Involving Human Subjects. Written informed consent was obtained from all the participants prior to data collection.

Experimental approach

Participants were divided into five groups according to their competition weight categories (<58, <63, <68, <74, and <87kg). Variables attained from the 'full' ISAK profile (42 measures) were compared between weight categories. Athletes were also divided into two groups based upon their previous success; 'international' (World Championships or International medallists) or 'national' taekwondo athletes (national medallists) (Mirali et al., 2021). The sitting height/ stature ratio, and iliospinale and tibiale-laterale lengths were compared between the national and international (international n = 25 and national n = 7) athletes to determine whether this variable might be able to discriminate between athletes' success.

Procedures

Anthropometric measurements were taken according to the 'Full' ISAK profile protocol (Stewart et al., 2011) by an accredited ISAK Level III anthropometrist in the Kinesiology Laboratory of Ege University, Faculty of Sport Sciences at the beginning of the season - in the morning. The technical error of measurement (TEM) was lower than 7.5 % for each skinfold area and lower than 1.5 % for the other measurements (Marfell-Jones et al., 2022). Body mass, stature, sitting height, and arm span were measured with a precision of 0.1 kg and 0.1 cm (Seca 769, Germany).

Skinfold thicknesses of the triceps, subscapular, biceps, iliac crest, supraspinale, abdominal, front thigh, and medial calf regions were measured with a calibrated skinfold calliper (nearest 0.2 mm, Holtain Ltd., UK.). Skinfold thickness was calculated using both the Σ6 (Triceps + subscapular + supraspinal + abdominal + front thigh + medial calf), and Σ8 skin fold measures. Percentage of body fat (BF%) was determined using the following formula: (0,1051 (Triceps + subscapular + supraspinal + abdominal + front thigh + medial calf) + 2,585) (Yuhasz, 1974).

Body Mass Index = [(BMI (kg) / Stature (m^2)], Waist/Hip Ratio = Waist girth (cm) / Hip girth (cm) and Sitting height ratio (cm) / stature (cm) were calculated. Girths of head, neck, arm (relaxed), arm (flexed and tensed), forearm (maximum), wrist (distal styloids), chest (mesosternal), waist (minimum), gluteal (hips), thigh (1 cm gluteal), thigh (mid-troch-tib. lat), calf (maximum) and ankle (minimum) regions were measured with a steel measuring tape (Cescorf Brasil, 0.1 cm distinction) (Perini et al., 2005). Length measurements of acromiale-radiale, radiale-stylion, midstylion-dactylion, iliospinal height, trochanterion height, trochanterion-tibiale laterale, tibiale laterale height and tibiale mediale-sphyrion tibiale regions were performed with a segmometer (Cescorf Brasil, 0.1 cm distinction). Breadth measurements of biacromial, A-P abdominal depth, biiliocristal, foot length, transverse chest, A-P chest depth, humerus, bi-styloid and femur regions were measured with large and small sliding callipers (Holtain Ltd., UK).

Somatotype components of athletes were determined and classified according to the 13-somatotype category method (Carter & Heath, 1990). Measurements were taken on the right side of the body during the off-season. By using Microsoft Office Excel 2007 program, data recording and consistency between measurements were ensured.

Statistical analysis

The statistical software IBM Statistical Package for the Social Sciences (SPSS) v.15.0 (SPSS, Chicago, IL, USA) was used to analyse all statistical data. According to weight categories, all data are presented as mean and standard deviation. After confirming that the data were normally distributed by the Shapiro-Wilk test, a repeated one-way ANOVA was implemented to identify differences in the dependent variables and partial eta squared (η^2) were used to calculate the effect size for ANOVA. Subsequent comparisons between weight categories were performed using the post hoc Tukey test. An independent *t* test was used to compare the physical characteristics between national and international athletes. The level of significance was set at $p <$ .05.

RESULTS

Descriptive anthropometric and somatotype variables between weight categories are presented in Table 1. One-way ANOVA identified significant differences in several demographic, anthropometric and somatotype variables between weight categories.

Demographic variables

Body mass increased significantly across each of the weight categories (Table 1). BMI was significantly lower in the <58kg weight category when compared with the <74, and <87kg categories. BMI was lower in the <63kg compared with the <58kg category. Sitting height and arm span was significantly lower in the <58 and 63kg categories compared with the <74kg category. Arm span was significantly lower in <74kg compared with the <68kg category, but significantly higher in the <74kg compared with <58 and <63kg categories. There were no significant differences in age and stature between the weight categories.

Skinfolds

The lightest weight category (<58 kg) exhibited significantly lower sum of six skinfolds and BF% than heavier weight divisions (<68, <74, and <87 kg), and lower sum of eight skinfolds compared with <63, <68, <74, and <87 kg divisions (Table 1). Skinfold thickness of subscapular, iliac crest and supraspinale were also significantly lower in <58kg compared with <63, <68, <74, and <87kg categories. The <58kg category also displayed significantly lower abdominal skinfolds compared with <68, <74, and <87 kg categories, and significant lower triceps skinfold compared with <74 and <87 kg categories. No significant differences were observed in the remaining skinfold variables between weight categories (Table 1).

Table 1. Descriptive Anthropometric Characteristics for Male Taekwondo Athletes According to Weight Categories (means ± SD).

Variables (n=32)	Weight Categories						
	<58 kg (n=5)	<63 kg (n=4)	<68 kg (n=11)	<74 kg (n=6)	<87 kg (n=6)	*p*-value	η^2
Demographic Characteristics							
Age (years)	19.9±1.0	19.3±1.4	20.5±2.5	20.4±3.2	20.6±0.8	.866	.04
Body mass (kg)	57.7±3.6	63.1±0.6	68.0±2.4	74.4±4.4	87.9± 6.9	.001*	.87
Stature (cm)	171.6±5.6	173.9±3.9	179.4±4	184.0±5.5	186.0±7.1	.216	.18
Sitting height (cm)	91.1±0.7	89.1±3.2	92.0±3.6	96.0±2.3 ^{þ}	96.3±3.4	.002*	.46
Arm span (cm)	176.4±4.5	169.6±7.4	188.2±4.1	181.1±7.4 ^{ß}	186.1±6.6	.001*	.50
BMI (kg/m^2)	21.1±0.8^{y}	19.6±1.2	21.1±1.2	22.0±1.2	25.5±2.6	.001*	.63
Skinfolds (mm)							
Σ6	35.7±3.6$^{\Delta}$	39.5±8.5	46.4±15.8	44.2±12.4	68.1±17.0	.005*	.41
Σ8	46.6±5.9^{y}	52.6±11.5	60.6±21.5	56.9±15.6	91.5±21.6	.003*	.43
Body fat (%)	6.3±0.4$^{\Delta}$	6.7±0.9	7.5±1.6	7.2±1.3	9.7±1.8	.005*	.41
Triceps	4.9±0.8†	5.3±0.8	6.9±2.3	6.3±2.0	9.9±4.1	.018*	.34
Subscapular	6.7±0.4^{y}	6.8±1.3	7.8±1.3	7.4±0.7	11.0±2.1	.001*	.58
Biceps	2.9±0.5	2.8±0.1	3.5±1.4	2.9±0.4	4.3±0.9	.081	.25
Iliac Crest	8.1±2.2^{y}	10.0±3.5	10.7±4.8	9.8±3.6	18.9±4.2	.001*	.47
Supraspinale	4.2±0.5^{y}	5.1±0.7	5.5±1.3	5.2±1.2	9.7±2.2	.001*	.68
Abdominal	8.3±2.4$^{\Delta}$	8.4±4.1	10.5±4.6	10.8±4.2	18.7±6.7	.006*	.40
Front thigh	7.9±2.7	6.6±0.9	9.4±4.7	8.8±4.0	11.7±2.7	.279	.16
Medial calf	5.9±1.7	5.0±1.0	6.2±2.8	5.6±1.6	7.1±2.6	.651	.08
Girths (cm)							
Head	54.7±0.7	55.1±1.2	55.7±2.3	56.3±0.8	56.9±1.4	.216	.15
Neck	36.0±1.0^{y}	34.4±1.0$^{\eta}$	36.1±1.4	36.7±1.0	39.1±1.0	.001*	.63
Arm (relaxed)	27.0±0.8^{y}	25.6±2.2	27.8±1.4	28.5±0.5	31.5±2.4	.001*	.60
Arm (flexed and tensed)	29.6±2.0$^{\Delta}$	27.2±2.7	30.2±1.2	31.2±0.6$^{\theta}$	33.4±1.5	.001*	.61
Forearm (maximum)	25.0±1.1$^{\Delta}$	24.1±1.4	25.4±1.0	26.0±0.4	29.4±4.3	.002*	.46
Wrist (distal styloids)	16.1±1.1	16.3±0.5	15.9±1.1	17.0±0.3	19.5±4.4	.088	.25
Chest (mesosternale)	85.9±4.9	91.8±4.5	88.1±14.4	95.1±4.1	98.7±6.1	.145	.21
Waist (minimum)	72.2±2.9$^{\varepsilon}$	70.2±3.2	71.4±11.5	76.2±4.1	85.5±4.5	.010*	.37
Gluteal (hips)	88.4±1.8	92.5±2.2	89.1±14.1	96.6±1.7	101.6±5.6	.071	.26
Thigh (1cm gluteal)	52.3±1.6$^{\eta}$	50.2±0.8	52.5±8.8	56.6±1.9	60.8±4.2	.029*	.32
Thigh (mid-troch-tib. Lat.)	46.8±1.0	49.2±2.3	48.1±8.1	51.7±1.6	55.5±4.7	.071	.26
Calf (maximum)	35.2±0.6$^{\Delta}$	32.0±4.5	36.8±1.0	37.5±0.8$^{\theta}$	40.6±2.4	.001*	.62
Ankle (minimum)	21.0±1.0	21.9±0.6	23.3±0.9	23.4±0.4	23.4±5.1	.301	.15
Lengths (cm)							
Acromiale-radiale	32.6±0.9†	33.1±1.6$^{\eta}$	35.0±1.7	34.9±1.9	36.8±1.5	.003*	.44
Radiale-stylion	25.9±1.7†	24.6±0.6	26.7±1.1	27.0±1.1	28.5±1.8	.001*	.49
Midstylion-dactylion	20.6±0.4$^{\eta}$	18.9±0.4	19.9±0.2	20.3±0.4	21.0±0.5	.007*	.39
Iliospinal height	97.0±2.2†	96.8 ± 6.3$^{\eta}$	101.3±2.5	105.2±6.1	107.3±4.3	.001*	.47
Trochanterion height	87.5±1.6§	88.2 ± 5.2	90.8±3.6	94.8±3.8	95.8±5.0	.007*	.39
Trochanter-tibiale laterale	41.7±1.3†	41.7 ± 2.6	43.2±2.3	43.4±1.6	46.2±2.5	.014*	.35
Tibiale lateral height	46.0±1.2$^{\eta}$	45.8 ± 2.8	48.3 ± 2.5	50.6±2.3	51.9±4.9	.009*	.38
Tibial mediale-sphyrion tibial	37.2±1.1†	37.8 ± 1.7	41.6 ± 2.7	41.6±1.6	43.9±3.4	.001*	.46

Breadths (cm)							
Biacromial	39.4±1.0	38.0 ± 1.5 $^{\eta}$	40.1 ± 1.8	41.9±1.7	40.4±1.6	.039*	.66
A-P abdominal depth	17.1±0.4	18.1±0.5	17.7±2.2	18.3±2.3	19.1±2.9	.597	.09
Biiliocristal	26.0±1.7 $^{\Delta}$	24.1 ± 0.5	26.6 ± 1.0	27.4±1.3 $^{\theta}$	29.0±1.1	.001*	.66
Foot length	26.4±1.1 $^{\eta}$	25.5 ± 2.1	26.6 ± 0.6	27.4±1.0	27.8±1.1	.021*	.33
Transverse chest	27.6±1.3	28.0±0.8	30.4±3.2	29.7±2.3	30.4±1.7	.165	.20
A-P chest depth	17.3±2.0	18.0±2.4	17.9±1.3	19.2±0.7	19.3±1.0	.145	.01
Humerus	6.6±0.3 ^{y}	6.7 ± 0.2	6.8 ± 0.2	6.8±0.2	7.3±0.4	.001*	.48
Bi-styloid	6.3±2.1	5.4±0.3	5.3±0.3	5.7±0.1	6.8±1.5	.263	.17
Femur	8.6±0.3	9.3±1.5	9.1±1.0	9.9±0.2	9.7±1.8	.421	.12
Somatotype							
Endomorphy	1.4±0.2 ^{y}	1.6 ± 0.4 $^{\varepsilon}$	1.8 ± 0.5	1.6±0.5	2.8±0.8	.001*	.48
Mesomorphy	3.0±1.5	4.2 ± 0.8	3.6 ± 0.9	3.9±0.8	4.3±1.3	.364	.14
Ectomorphy	3.2±0.6 $^{\varepsilon}$	4.0±0.9	3.6±0.8	3.5±0.8	2.1±1.3	.022*	.33

Note. ***kg:*** *kilogram,* ***cm:*** *centimetre,* ***mm:*** *millimetre,* ***BMI:*** *Body Mass Index* ***(****Body Weight (kg)/Height (m^2),* ***Σ6 :*** *The sum of six skinfolds (Triceps + subscapular + supraspinale + abdominal + front thigh + medial calf),* ***Σ8 :*** *The sum of eight skinfolds.*
ᵖ Significantly Different (p<.05) From weights <58 kg, <63 kg. ß Significantly Different (p<.05) From weights <58 kg, <63 kg, <68 kg. ʸ Significantly Different (p<.05) From weights, <63 kg, <68 kg, <74 kg, <87 kg. Δ Significantly Different (p<.05) From weights <68 kg, <74 kg, <87 kg.
ε Significantly Different (p<.05) From weights <68 kg, <74 kg. †Significantly Different (p<.05) From weights <74 kg, <87 kg. ŋ Significantly Different (p<.05) From weight <74 kg. θ Significantly Different (p<.05) From weights <63 kg, <68 kg. § Significantly Different (p<.05) From weight <87 kg.

Girth, breadth, and length measurements

Neck and relaxed arm girths were significantly smaller in the <58kg category compared with <68, <74, and <87kg categories (Table 1). Smaller neck girth was also evident in the <63 kg category compared with the <58 and <74kg category. The <58kg category displayed smaller arm (flexed and tensed), maximum forearm, and calf girths when compared with <68, <74, and <87kg categories. The <74kg category displayed significantly greater arm (flexed and tensed) and calf girths than <63 and <68 kg categories. The <58kg category also demonstrated significantly smaller waist (minimum) and thigh (1cm gluteal) girths compared with the <74kg category.

In terms of limb length, the <58kg category displayed significant shorter acromiale-radiale, radiale-stylion, iliospinal height, trochanter-tibiale laterale, and tibial mediale-sphyrion tibial lengths compared with <74 and <87kg categories (Table 1). The <63kg category displayed significantly shorter acromiale-radiale and iliospinal height than the <74kg category. The tibiale lateral and trochanterion height were also significantly shorter in the <58kg category when compared with the <74kg, and <87kg categories, respectively.

In terms of breath, the <58kg category demonstrated significantly smaller biiliocristal breath than the <68, <74, and <87kg categories, and smaller humerus breadth than the <63, <68, <74, and <87kg categories (Table 1). Biiliocristal breadth was significantly greater in the <74kg category than in the <63 and <68kg categories, and biacromial breadth significantly lower than in <63 compared with <74kg category. No other significant differences were identified between breadth measurements.

Somatotype

The lightest weight category (<58kg) displayed significantly lower endomorphy than the <63, <68, <74, and <87kg categories. The <63kg categories also exhibited significantly lower endomorphy than the heavier <68 and <74kg categories. Significantly higher ectomorphy was observed in the <68 and <74kg categories compared with the <58kg. No significant differences in mesomorphy were identified between the weight categories (Table 1). A 'mesomorph-ectomorph' and 'endomorphic mesomorph' somatotype feature was observed in the athletes.

Comparison between standards

International level athletes had significantly longer iliospinale height, tibiale laterale height and significantly lower sitting height/stature ratio than national athletes (*p* < .05; Table 2).

Table 2. Length of extremities and Sitting Height/Stature ratio between groups of success (means ± SD).

Variables	International (n=25)	National (n=7)	*p*-value
Iliospinale Height (cm)	103.2±2.0	97.1±3.7	.025
Tibiale Laterale Height (cm)	49.5±3.4	45.9±2.5	.010
Sitting Height/Stature Ratio (%)	0.51±1.1	0.52±0.9	.027

Note. cm: centimetre.

DISCUSSION

The aims of this study were to: 1) compare the anthropometric characteristics of elite male taekwondo athletes between selected weight categories using a 'full' ISAK profile; and 2) compare the index of sitting height/stature ratio, and lower limb segments between standards of competitors. In accord with the study hypothesis, a considerable number of anthropometric characteristics displayed marked variation between senior male WT weight categories. Such differences were most notable between the lighter (<58kg) and heavier weight categories (<63, <68, <74, and <87kg), albeit with some variation evident between specific variables. For the first time, the use of the full 'ISAK' profile provided more comprehensive information concerning the variation in specific anthropometric variables between weight categories (e.g. regional skinfold thickness, sitting height, and limb girths, widths, and breadths), and thereby offers more focused reference values for different weight categories within the sport. A further important finding was that measures of sitting height/ stature ratio and lengths of specific lower limb segments (iliospinale and tibiale-laterale lengths) were able to effectively discriminate between standards of taekwondo competitors. These findings have implications for both competition preparations and talent identification.

The estimated range of %BF from the sum of six skinfolds (~6-10%) in the current study is within the lower range of values reported in international male taekwondo athletes in previous studies (Olds & Kang, 2000; Heller et al., 1998; Rivera et al., 1998; Mirali et al., 2021), albeit there is some inherent variation in the measurement methods, predictive equations, and training phase (Bridge et al., 2014). Nevertheless, there was a trend for lower %BF and skinfold thickness in the lighter weight categories compared with heavy weight counterparts in the present study. More specifically, the %BF and sum of six skinfolds were significantly lower in the <58kg category when compared with the heavier <68, <74, and <87 kg categories, and the sum of eight skinfolds significantly lower than in the <63, <68, <74, and <87kg categories. Mirali et al. (2021), despite displaying higher overall %BF and sum of eight skinfolds than in the present study, also observed a trend for lower %BF and skinfold thickness in lighter weight categories. More specifically, they discovered significantly lower %BF and sum of eight skinfolds in the <54 and <58kg categories compared with their heavy weight (<80 and >87kg) counterparts. More precise comparison of the significant differences between the studies is, however, challenging due differences in the weight categories included for analysis. The observed differences in %BF between the weight categories may reflect variation in the requirements to 'make the weight' for competition and/or differences in the activity requirements of matches (Rydzik et al., 2021).

For the first time, we report the skinfold thickness for each measurement site between selected taekwondo weight categories. Differences in the sum of 8 skinfolds between weight categories seem to correspond more with differences in skinfold thickness of the trunk regions as opposed to distal areas. For instance, the subscapular, iliac crest, and supraspinale skinfold thickness were significantly lower in the <58kg category when compared with the <63, <68, <74, and <87kg categories, and the abdominal skinfolds were lower compared with the <68, <74, and <87kg categories. Apart from triceps skinfold, no significant differences were evident in the biceps, front thigh, and medial calf skinfold thickness between the weight categories. No comparative data exists between weight categories in taekwondo. Differences in specific site skinfold thickness have been observed in analogous combat sports such as karate and judo, but they do not appear generalisable and they contain divergent weight categories (Slankamenac et al., 2021; Franchini et al., 2014). The regional differences observed in skinfold thickness across measurement sites and between weight categories observed in the current study may therefore offer more specific reference values to assist competition preparations and 'weight making' practices exclusively in taekwondo. This seems particularly prudent given that the measurement of skinfolds is promoted as a more reliable and accurate outcome of body composition assessment when compared with the conversion of skinfolds to %BF (Kasper et al., 2021).

Body shape and limb length might conceivably influence technical execution in taekwondo (Falco et al., 2009), and girth measurements might reflect specific physiological adaptations (Friedl et al., 1994). Whilst some studies have measured limb girths, breadths, and lengths in taekwondo (Heller et al., 1998), the present study is the first to consider a comprehensive evaluation these variables using the 'full' ISAK profile between weight categories. There was a trend for increased/greater limb girths, breadths and lengths as the weight categories increased, but only selected variables reached statistical significance. Comparable trends have been observed across weight categories other combat sports (Slankamenac et al., 2021; Franchini et al., 2014), but the differences between specific categories do not appear generalisable between combat sports; nor are the weight classification boundaries wholly compatible.

In the present study, girths of several upper (neck, arm tense, arm relaxed, forearm) and lower body (calf) regions were significantly smaller in the <58kg category compared with the heavier <68, <74, and <87kg categories. There was also evidence of significant increases in arm (tensed) and calf girths as the weight categories increase between <68, <74 and <87kg. The thigh and waist girths were also smaller in the <58 compared with <74kg categories. These findings could reflect greater musculature and/or fat mass in the heavier weights, which may be a function of the divergent combat activity requirements, training regimes, and/or nutritional strategies (Bridge et al., 2011; Menescard et al., 2021). The <58kg also displayed significantly smaller biiliocristal and humerus breadths, than the <68, <74, and <78kg categories, and the <63, <68, <74, and <87kg categories, respectively. The <63 and 68kg category exhibited significantly smaller biacromial breadth than <74kg category. These data suggest greater upper body linearity in the lightweight categories. In terms of limb lengths, the lighter <58kg weight category displayed significant shorter upper (acromiale-radiale, radiale-stylion) and lower (iliospinal height, trochanter-tibiale laterale, and tibial mediale-sphyrion tibial) body limb lengths compared with the heavier <74 and <87kg categories. These differences could play a role in the technical and tactical strategies selected during matches (Falco et al., 2009; Santos et al. 2011; Menescard et al., 2021).

Previous studies demonstrate that elite male taekwondo athletes typically display 'ectomorphic mesomorph' character. In the present study, lighter <58, and <63kg weights displayed significantly lower endomorphy than the heavier <63, <68, <74, and <87kg; and <68, <74kg categories, respectively. There was also a tendency for higher mesomorphy in the heavy <87kg category compared with most lighter categories, although such differences did not reach statistical significance. There was a tendency for lower ectomorphy in the <87kg category compared with lighter categories, but again failing to reach statistical significance (Table 1). Ectomorphy was significantly higher in the <68 and <74kg compared with the <58kg category, but such data seemed somewhat variable between weight categories. Trends for higher endomorphy and mesomorphy compare favourably with recent research, but variable ectomorphy between weight categories is incongruent (Mirali et al., 2021). In the present study, the <58, <63, <68 and <74kg may be classified as 'mesomorph-ectomorph' suggesting more equal proportions muscular-skeletal tissue and linearity, with lower degree of fatness. Whereas <87kg category displayed 'endomorphic mesomorph' character, suggesting a predominance of muscular-skeletal tissue, with lower degree of fatness, and relative linearity. The <63kg category classification is similar to those reported in recent research, but the 'mesomorph-ectomorph' character displayed by <58, <68, and <74kg is slightly different to the 'mesomorphic ectomorphic' reported by Mirali et al., 2021. This variation seems to represent small differences between the ectomorphic and mesomorphic components (<0.5 units; Table 1). Further comparisons between studies are difficult due to differences in the weight categories included, but such differences might also reflect variation training and nutritional practices, or even populations/genetics (Peeters et al., 2007).

There has been considerable debate surrounding the importance of stature and limb length in achieving success in taekwondo (Bridge et al., 2014; Heller et al., 1998; Scamardella et al., 2020). Recently, sitting height/stature ratio has been identified as a promising measure capable of discerning differences in the stature of the head and trunk, and legs between standards of competitors in taekwondo (Mirali et al., 2021). In the present study, this ratio was significantly lower for international athletes compared with their national level counterparts. This is the first attempt to validate the construct via 'direct replication', a process regarded as essential to increase the confidence of novel methods in sports science research (Halperin et al., 2018). For the first time, the present study also identified significantly greater iliospinale and tibiale laterale height in the international compared with the national level athletes. This extends our understanding of specific differences in lower limb segments between these groups and hence may offer more precise reference values for talent identification programmes.

The present study has several strengths and limitations. This is the first study to examine the 'full' ISAK profile (42 measures) between weight categories in elite male competitors, hence it offers more precise reference points for several important variables within the sport. Nevertheless, several weight categories were omitted (<54, <80, >87kg) from the current study due to difficulties in recruiting enough elite level male athletes within each category. The attempt to include elite international male athletes also resulted in the inclusion of relatively low numbers within specific weight categories. Finally, the generalisability of the current findings to other taekwondo populations (e.g. females, and youth competitors) remains to be established.

CONCLUSION

This study demonstrates that several anthropometric characteristics displayed marked variation between weight categories in elite male competitors. For the first time, detailed information on the differences in anthropometric variables between weight categories using the 'full' ISAK profile is presented. These data provide more focused reference values to assist preparations (conditioning and 'weight-making' practices) for selected weight categories within the sport. A further key observation was that the sitting height/stature ratio, and the length of specific lower limb segments (iliospinale and tibiale laterale height) were capable of discriminating between athletes levels of success/standards. These data may collectively serve to support talent identification programmes with the sport.

AUTHOR CONTRIBUTIONS

Conception and design (Can, E. & Kutlay, E.). Implementation of exercise protocol and data collection (Can, E & Kutlay, E.). Formal analysis and interpretation of data (Can, E & Sillero Quintana, M.). Supervision

(Bridge, C.A., Kutlay, E. & Sillero Quintana, M.). Writing of original draft (Can, E.). Writing, review and final editing (Bridge, C.A.).

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SCIENTIFIC JOURNAL OF SPORT AND PERFORMANCE

ORIGINAL ARTICLE

Intra-articular hyaluronic acid plus sorbitol injections for the management of severe glenohumeral osteoarthritis in a former female volleyball player: A case report

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ABSTRACT

The glenohumeral joint is the third most common joint to be affected by osteoarthritis (OA). Practising volleyball can lead to shoulder arthritis due to repetitive mechanical stress on the shoulder joint. The first step of management of primary glenohumeral OA usually is the non-operative treatment, with intra-articular injections representing one of the most utilized treatments. The aim of this study is to report the outcomes of a series of three injections of hyaluronic acid (HA) plus sorbitol in a patient with severe glenohumeral OA. An 81-year-old female former volleyball player presented to our Rehabilitation Unit with more than 15 years history of shoulder pain and functional limitation. Since she refused to undergo surgery, we proposed her intra-articular injections of HA plus sorbitol. Outcome evaluation was made up to 12 months from the last injection by means of the Constant-Murley score and the Disability of the Arm, Shoulder and Hand questionnaire. Three injections of HA plus sorbitol for three weeks in a row in a patient with severe glenohumeral OA led to important improvements in pain reduction and better functionality at all follow-ups. Larger studies including more patients and with longer follow-ups are needed to confirm the consistency of these findings.
Keywords: Sport medicine, Glenohumeral osteoarthritis; Hyaluronic acid; Intra-articular injections; Osteoarthritis; Sorbitol.

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INTRODUCTION

Osteoarthritis (OA) is the most common joint disease worldwide, involving approximately the 15% of the worldwide population (Johnson and Hunter, 2014). The number of people affected by symptomatic OA is constantly rising due to the aging of the population and the global obesity epidemic (Neogi and Zhang, 2013). OA is a leading cause of disability and can affect people's physical and mental well-being. Healthcare resources and costs employed with managing the disease are considerable (Vina and Kwoh, 2018).

The glenohumeral joint is the third most common large joint to be affected by OA, following the knee and the hip (Ansok and Muh, 2018). Population-based studies showed that the 16.1%-20.1% of adults older than 65 years have radiographic evidence of glenohumeral OA (Oh et al., 2011). Glenohumeral OA is a multifactorial disease (Man and Mologhianu, 2014), with risk factors including ageing, female sex, obesity, rheumatic diseases, avascular necrosis, prior trauma or surgery, and participating in sports.

For example, shoulder arthritis is one of the most common injuries of professional volleyball players. It needs shoulder force to buckle, block, and bounce, which leads to frequent shoulder injuries (Cui, 2022).

Over time, glenohumeral OA results in worsening pain and stiffness, yielding functional limitations and decreased quality of life. Patients often complain of insomnia or difficult awaking due to the night pain, severely impacting the quality of life and the psychological health (Cho et al., 2017). Early glenohumeral degeneration is a difficult condition for the competing athlete who participate in overhead sports such as volleyball, and this may lead to impaired performance, and, ultimately, derailed careers (Reineck et al., 2008).

Patient's anamnesis, a careful clinical exam and radiographs are the keystone of a correct diagnosis and staging of glenohumeral OA. Radiographs usually show joint space narrowing and posterior glenoid wear. Subchondral sclerosis and osteophytes from the humeral head, often described as a "*goat's beard*", can also be present (Kircher et al., 2014).

The first step of management of primary glenohumeral OA usually is the non-operative treatment (Ansok and Muh, 2018). Drugs, such as paracetamol, nonsteroidal anti-inflammatory drugs (NSAIDs) and corticosteroids are commonly used (Ansok and Muh, 2018).

Intra-articular injections represent one of the most utilized non-operative treatments for glenohumeral OA, especially using corticosteroids and hyaluronic acid (HA), for which there are multiple formulations (Ansok and Muh, 2018). Several studies reported good outcomes in terms of pain and functionality with the use of HA at short-term and long-term follow-ups (Blaine et al., 2008; Brander et al., 2010; Colen et al., 2014; Di Giacomo and De Gasperis, 2015; Merolla et al., 2011).

Anyway, while the use of HA in the shoulder has been approved by the European Medicines Agency since 2007, the Federal Drug Administration has approved its use only in knees. For this reason, while the effects of HA injections are well studied for the treatment of knee OA, the effects on glenohumeral OA are still under discussion, even if several studies reported good outcomes in terms of pain and functionality at short-term and long-term follow-ups.

High affinity between HA and sorbitol stabilizes the complex through a very dense network of hydrogen bonds that do not modify the visco-elastic properties of HA (Conrozier, 2018). The strong ability of sorbitol to scavenge and neutralize oxygen free radicals has been demonstrated to delay degradation of the gel.

Moreover, neutralizing free radicals decreases migration of macrophages into the synovial membrane reducing inflammation, pain and oxidative stress-induced chondrocyte apoptosis (Migliore et al., 2014; Mongkhon et al., 2014). Furthermore, the penetration of the HA/sorbitol complex in the cartilage could represent a major mechanism explaining its long-term efficacy (Lavet et al., 2017).

Given these interesting *in vitro* findings related to the use of a combination of HA plus sorbitol and given the lack of clinical studies about the infiltrative treatment of shoulder OA using this kind of viscosupplement, in this study we wanted to report the outcomes of a series of three injections of HA plus sorbitol in a patient with severe glenohumeral OA who was not eligible for surgery.

MATERIAL AND METHODS

In December 2021, an 81-year-old former female volleyball player presented to the outpatient Clinic of the Rehabilitation Unit, Department of Public Health, University of Naples Federico II, Italy, with >15 years history of important right shoulder pain and functional limitation. She did not report neither systemic nor genetic disorders, nor history of allergies or intolerances. She did not experience any traumatic events or surgical interventions involving her right shoulder. She did not smoke. Her body mass index was 24. The patient underwent conservative treatments for years including relative rest, multiple rounds of NSAIDs and formal physical therapy, with some relief of her symptoms. Since her shoulder pain increased in severity and intensity over the last months, limiting her activities of daily living and keeping her awake at night causing significant sleep deprivation, she booked a medical appointment at our outpatient Clinic.

At the time of the medical consult, patient's VAS was 7/10, the Constant-Murley score (CMS) was 29/100, and the disability/symptom section' score of the Disability of the Arm, Shoulder and Hand (DASH) was 52%.

According to the Kellgren and Lawrence classification system, true antero-posterior radiograph showed a grade 4 (severe) glenohumeral OA with marked narrowing of the joint space, along with severe sclerosis, large osteophytes, and definite deformity of bone ends (Figure 1).

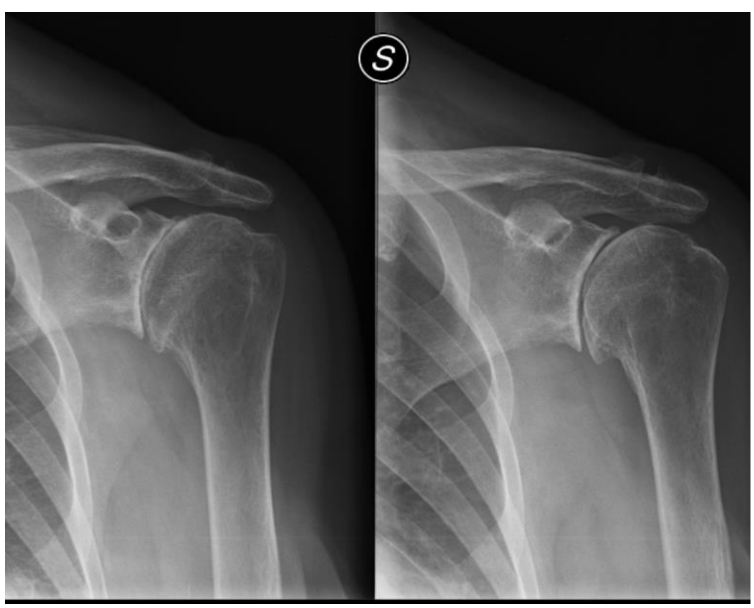

Figure 1. Radiograph obtained few days before the first medical appointment.

At physical examination, reduced ranges of movement and arm strength were found. According to the Management of Glenohumeral Joint Osteoarthritis Evidence-based Practice Guideline adopted by the American Academy of Orthopaedic Surgeons (AAOS) [18,19], the patient received indications for anatomic total shoulder arthroplasty. Then, to provide her some relief, we planned a series of three intra-articular injections of 2ml, high concentrated (20 mg/ml) 2 million Dalton (mDa) HA of non-animal origin, combined with high concentrated (40 mg/ml) sorbitol, once a week for three weeks in a row. After a full and clear description of the procedure, the patient was invited to sign the informed consent. Written informed consent for publication was also obtained prior to the intervention and data collection.

All injections were performed by a single doctor (B.C.) with >10 years of experience using an ultrasound-guided posterior approach with a 22-gauge needle. The patient was asked to rest her arm for 12 hours after each injection. No limitations on physical performance and daily activities were suggested for the rest of the time.

The patient was evaluated at the time of enrolment (T0) that was also the day of the first performed injection, at one month (T1), three months (T2) and 12 months (T3) after the last injection by means of the CMS and the DASH-disability/symptom section score.

The patient was totally compliant, following all the appointments given. No adverse events were described after HA injections.

RESULTS

Clinical data are reported in Table 1 and their trends are illustrated in Figure 2.

Table 1. CMS and DASH scores' trends on follow-ups.

	T0	T1	T2	T3
CMS	29 (13+16)	76 (30+46)	56 (24+32)	50 (18+32)
DASH (%)	52	12	10	13

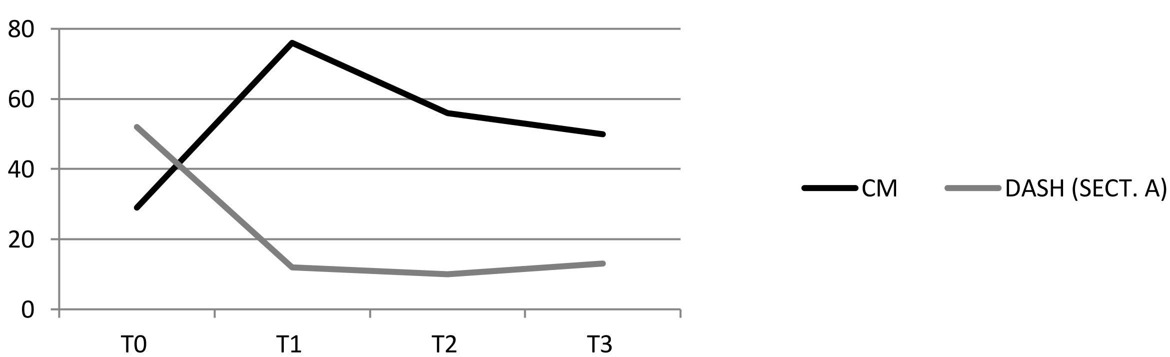

Figure 2. Graphical representation of CMS and DASH scores' trends on follow-ups.

At the time of enrolment (T0), the CMS was 29 (13+16), while the DASH score (referred to the disability/symptom section) was 52%.

One month after the last injection (T1), the CMS was 76 (30+46), while the DASH score (referred to the disability/symptom section) was 12%.

Three months after the last injection (T2), the CMS was 56 (24+32), while the DASH score (referred to the disability/symptom section) was 10%.

Twelve months after the last injection (T3), the CMS was 50 (18+32), while the DASH score (referred to the disability/symptom section) was 13%.

Regarding the CMS, the score increased from the baseline (T0) to T1 by 162%. After three months (T2), the score started to decrease, reporting a worsening of the 26% if compared to T1. From T2 to T3, the score further decreased, reporting a worsening of the 11%. Anyway, if compared to T0, the score at T3 increased by the 72%.

Regarding the DASH score (referred to the disability/symptom section), the score decreased from the baseline (T0) to T1 by 77%. After three months (T2), the score further decreased, reporting an improvement of the 17%. From T2 to T3, the score slightly increased, reporting a worsening of the 30%. Anyway, if compared to T0, the score at T3 decreased by the 75%.

DISCUSSION

Intra-articular injections of HA are one of the most used conservative treatments for OA. In this study, we wanted to investigate the effects of a series of three injections of HA plus sorbitol in a former female volleyball player with severe glenohumeral OA who was not eligible for surgery.

The results of our case-report showed noticeable improvements in shoulder pain reduction and improved functionality. These improvements were observed during the entire duration of follow-ups, with the higher improvement found at 1-month follow-up, with the CMS increasing from T0 to T1 by 162% and the DASH-disability/symptom section increasing from T0 to T1 by 77%.

Several studies in the available scientific literature evaluated the effects of intra-articular injections of HA in patients with glenohumeral OA.

A recent systematic review and meta-analysis by Zhang et al. (2019) analysed the efficacy of intra-articular HA administration on pain reduction in patients with glenohumeral OA. Fifteen studies, for a total of 1594 patients, were included in the review. The authors found significant reduction in pain at three and six months for patients receiving intra-articular HA injections for glenohumeral OA. Furthermore, improved functional outcomes at every follow-up time point were noticed across all the included studies. The authors concluded that HA injections for glenohumeral OA are safe and improve pain.

Few studies evaluated the effects of the association of HA and sorbitol, and almost all of them were conducted for knee OA.

A non-interventional study by Heisel and Kipshoven (2013) was conducted to assess the efficacy and tolerability of one, two or three intra-articular injections of a 2ml of high concentration (20 mg/ml) of a 2 mDa HA, combined with high concentration (40 mg/ml) of sorbitol for the treatment of OA. A total of 1147 patients were enrolled. The most treated joint was the knee (92.9%), followed by the hip (4.4%), and the shoulder (2.8%). Pain was assessed with Likert scale and went toward a reduction of 56.5% from baseline to six-month follow-up. Adverse reactions were rare, and no infections were reported.

Migliore et al. (2014) evaluated the efficacy of HA plus sorbitol injections for the treatment of symptomatic hip OA in a study prospective, non-controlled clinical trial. A total of 20 patients were enrolled in the study and received a single, ultrasound-guided injection of the hip with 4 ml of high concentration (20 mg/ml) of a 2 mDa HA, combined with high concentration (40 mg/ml) of sorbitol. Results were evaluated at three, six, nine and twelve months by means of several assessment tools. Mean scores of all clinical parameters were significantly different compared with the baseline mean value at each follow-up, and no systemic adverse effects were observed.

In a recent prospective cohort study by Cucurnia et al. (2021), a total of 77 patients with symptomatic knee OA were treated with a single intra-articular injection of a 4 ml of high concentration (20 mg/ml) of a 2 mDa HA, combined with high concentration (40 mg/ml) of sorbitol. Pain, stiffness, functional limitation, and total scores were significantly reduced at one, three and six months, but not at 12 months. Their results showed better outcomes in patients with a low-grade OA, but this finding was not in agreement with the one found also recently by Bruyère et al. (2021), who stated that that a more limited physical function at baseline was associated with more important function relief.

CONCLUSIONS

In our study, we decided to treat the patient using a HA plus sorbitol viscosupplement given the good outcomes reported by the above-mentioned studies, even if almost all studies were conducted for knee OA. Three injections of HA plus sorbitol for three weeks in a row in a patient with severe glenohumeral OA who was non-eligible for surgery led to important improvements in pain reduction and better functionality.

The clinical and functional improvements observed during the entire duration of follow-ups (with the higher improvement found at 1-month follow-up), together with the absence of side effects and the improvement of patient's quality of life, allow us to propose HA plus sorbitol viscosupplement as a safe and effective treatment for glenohumeral OA.

Larger studies including a consistent number of patient and with longer follow-ups are needed to confirm the consistency of these findings.

AUTHOR CONTRIBUTIONS

Domiziano Tarantino: methodology, investigation, writing, review and editing. Rossana Gnasso: data collection, investigation, review and editing. Felice Sirico: methodology, investigation, writing, review and editing. Bruno Corrado: data collection, methodology, investigation, writing, review and editing.

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DISCLOSURE STATEMENT

The Authors state that the methodology for this study is in accordance with the Declaration of Helsinki, and followed the guidelines given by the local ethics committee.

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SCIENTIFIC JOURNAL OF SPORT AND PERFORMANCE

REVIEW ARTICLE

Effects of high-intensity interval training on patients with type 2 diabetes mellitus: A narrative review

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ABSTRACT

Diabetes Mellitus (DM) which is characterized by pancreatic beta-cell dysfunction, peripheral insulin resistance, or both, is one of the most relevant cardiovascular risk factors worldwide. Its most prevalent and studied form is type 2 diabetes mellitus (DM2), a chronic multifunctional condition linked to physical inactivity and lifestyle. The purpose of this narrative review is to explore the implications of high intensity interval training on different hemodynamic, biochemical and anthropometric parameters of DM2 patients. Findings yielded that high-intensity interval training is a safe and recommended training method to improve functional capacity and certain parameters such as body weight and body mass index (BMI), systolic blood pressure (SBP), VO_2 maximum (peak) and Hb1Ac, compared to moderate and low intensity training, and passive controls. Moreover, the benefits of physical exercise are independent of weight loss and there is no nutritional protocol or drug to replace them.
Keywords: High intensity interval training; HIIT; Type 2 diabetes mellitus; Health.

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INTRODUCTION

Diabetes Mellitus (DM) is a metabolic disease characterized by inappropriate high levels of glucose in the bloodstream. Moreover, chronic DM has been linked to different complications as polyneuropathy, chronic kidney disease, cardiovascular disease, cerebrovascular disease, loss of vision and immunosuppression (Galicia-Garcia et al., 2020). The International Diabetes Federation estimates on 425 million the number of people affected worldwide by DM (Colberg et al., 2016; Khan et al., 2019). On the other hand, DM is originated by a pancreatic beta-cell dysfunction (DM1), peripheral insulin resistance (DM2), or both (Iglay et al., 2016). Between the different DM types, its most prevalent and studied form (approximately 90%) is DM2 (Khan et al., 2019; Lin et al., 2020), which will be explored in this review.

In the last years, a β-cell-centred model of DM has been proposed for a functional assessment of DM (Cerf, 2013). Accordingly, it is suggested that β-cell disfunction as well as its interactions with genetics, insulin resistance, environmental factors and inflammation are the key mechanisms of DM onset (Galicia-Garcia et al., 2020). The risk of developing DM2 follows a continuum through all abnormal blood glucose levels (Banday et al., 2020). However, the highest risk patients include those with altered basal blood glucose, impaired glucose tolerance, or a glycosylated haemoglobin (HbA1c) between 5.7- 6.4% (Galicia-Garcia et al., 2020). The progression towards DM2 is determined by a group of factors (Paulweber et al., 2010),of which some are "non-modifiable" and others are "modifiable”. Regarding non-modifiable risk factors, the most prevalent are (a) age, (b) race / ethnicity, (c) history of DM2 in first-degree relatives or with gestational diabetes, and (d) the presence of a polycystic ovary (Livadas et al., 2022; Wu et al., 2014). However, under a lifestyle approach, the most interesting factor are those defined as modifiable risk factors (Reddy, 2018). In addition, under this classification are included obesity, overweight and abdominal obesity, sedentary lifestyle, smoking, dietary patterns, as well as other disorders in glucose regulation which can be modulated under lifestyle interventions (Joseph et al., 2017). Thus, obesity and overweight increase the risk of impairment of glucose tolerance and DM2 at all ages, through an increment in insulin resistance (Cerf, 2013; Wondmkun, 2020). In addition, research confirms that more than 80% of DM2 cases can be attributed to obesity (Golay & Ybarra, 2005). Consequently, overweight reduction or conversion to normal weight also decrease DM2 onset risk, improving glycaemic control in patients with established diabetes (Wondmkun, 2020).

Moreover, a sedentary lifestyle entails a reduction in caloric expenditure, promotes weight gain, reduces aerobic capacity and muscle strength (Newton et al., 2013). Thus, sedentarism favours obesity and therefore increase the risk of DM2 (Langleite et al., 2016). Lifestyle modifications based on daily physical activity, avoiding tobacco and nutritional improvements, learning about health comorbidities according to obesity and DM2, as well as the study of these modifiable risk factors, are key interventions to reorient this prevalent pathology (Chester et al., 2018). Health education will be key for a successful treatment of this pathology (Chester et al., 2018). The establishment of pharmacological treatment in many occasions will be necessary but it will never replace the hygienic-dietary recommendations and physical activity (Raveendran, 2018). Certainly, physical activity improves insulin sensitivity, thus, it improves blood glucose levels to values in the normal range (Colberg et al., 2016; Hordern et al., 2012). To enhance glycaemic control, reduce or maintain body weight and/or reduce the risk of cardiovascular diseases, a plan of at least 150 minutes a week is recommended, developed in 3 to 5 weekly sessions of moderate to vigorous aerobic activity, at the 50-70% of your maximum heart rate with no more than 2 consecutive days of no activity (Colberg et al., 2016). However, shorter durations (minimum 75 min / week) of vigorous intensity or interval training (HIIT) may be sufficient for younger and more physically fit people (Colberg et al., 2010; Yang et al., 2014). However, previous research suggests that exercise programs may be designed according to specific modalities (Fritz et al., 2021). In this sense, Umpierre et al. (2011) concluded that aerobic exercise achieves a reduction in

HbA1c of 0.73% compared to 0.57% for strength training. However, when both training modalities were studied in combination, the total decrement of HbA1c was 0.51%.

Currently, medical guidelines have not well aggregated if new training methods as high-intensity interval training (HIIT) are an effective cost-benefit intervention in this patients (Paternina-de la Osa et al., 2017). Therefore, the objective of this review was to examine the effects of HIIT as part of the therapy of DM2. Specifically, it was intended to clarify whether the HITT causes an improvement in hemodynamic, analytical and anthropometric outcomes of DM2 patients, compared to other types of training, other physical activity or none at all.

SYSTEMATIC REVIEWS AND META-ANALYSIS ABOUT HIIT AND DM2

Regarding systematic reviews and/or meta-analysis, 5 articles have been published in the last five years (da Silva et al., 2019; De Nardi et al., 2018; Jiménez-Maldonado et al., 2020; Liu et al., 2019; Lora-Pozo et al., 2019; Picard et al., 2021):

In a recent systematic review with meta-analysis, (Picard et al., 2021), it was evaluated the effect of physical exercise on heart rate variability (HRV) in DM2 patients. Between the primary outcomes studied, it was found a usual comorbidity called cardiac autonomic neuropathy (CAN), which can trigger autonomous nervous system damage, coronary ischemia, arrhythmia, stroke, orthostatic hypotension and sudden death syndrome. Data included 21 interventions, where only 4 of the selected studies reported a HIIT protocol. Results, regarding HIIT elicit improvements in each exercise group, however, HIIT groups exerts more benefits in functional capacities than traditional resistance training, but not in VFC variables. Exercise enhanced essential biomarkers of DM2 including glycaemic control, insulin resistance, fat body mass, blood pressure, strength and lean body mass, despite of the insufficient number of non-resistance training protocols. Moreover, meta-analysis of the 4 HIIT studies reported benefits on HbA1c, BMI, total cholesterol, HDL, LDL, TGs and VO_2.

In other systematic review (Jiménez-Maldonado et al., 2020) found a primary role of glycemia in the prevention of comorbidities related to metabolic syndrome in DM2. HIIT alone or imbedded in a resistance training intervention exerts a positive impact on glycaemic in DM2 and non-dysmetabolic subjects comparable to aerobic training, which was fixed as the comparative reference.

Lora-Pozo et al. (2019) in a systematic review with meta-analysis of randomized control trials, explored the effects of HIIT compared to passive controls and other exercise interventions (e.g., aerobic exercise) in DM2 patients. Collected data reported anthropometric, cardio-pulmonary and metabolic measurements. After statistical analysis, obtained results favoured HIIT interventions, compared to passive controls: (Weight: standardized mean difference (SMD) = -2.09; 95% confidence interval (CI): (−3.41; −0.78); BMI: SMD = −3.73; 95% CI: (-5.53; -1.93); Systolic blood pressure: SMD = −4.55; 95% CI: (−8.44; −0.65); VO_{2max}: SMD = 12.20; 95%CI: (0.26; 24.14); HbA1c: SMD = -3.72; 95%CI: (−7.34; −0.10)]). Concerning HIIT effects compared to other interventions, this meta-analysis manifested positive improvements in weight loss, BMI, systolic blood pressure, VO_{2max} and HbA1c. This study also suggested better results in the moderate intensity exercise in contrast to lower intensities groups.

In a 5 RCTs systematic review (da Silva et al., 2019), authors examined the effects of a HIIT intervention in comparison to low or moderate interval training on blood glucose in DM2 patients. This review was characterized for being the first one analysing the impact of HIIT in DM2 with a RCT eligibility criteria. Most studies reported significant differences for weight and BMI in HIIT interventions. Metabolic profile measurements (SBP, DBP, cholesterol, TGs, fasting glucose and HbAC1) related to HIIT protocols were examined in only 1 study; significant differences were found for SBP and HDL cholesterol in 2 studies. Only 1 study reported data for medium intensity interval, showing improvements in LDL levels. Blood glucose was examined in 4 studies; all the selected interventions obtained significant differences for HIIT and moderate intensity training protocols.

Liu et al. (2019) developed a systematic review with meta-analysis of 13 studies (n = 345) exploring the effectiveness of HIIT on glycaemic control and cardio-pulmonary fitness. In this review HIIT was compared with moderate intensity interval training and a passive control in DM2 patients. HIIT protocols resulted in a positive reduction in fat body mass, HbA1c (SMD: - 0.37, 95% CI: - 0.55 ; - 0.19, p < .0001); VO_2 relative peak (SMD: 3.37 ml / kg / min, 95% CI: 1.88 ; 4.87, p < .0001); VO_2 absolute peak (SMD: 0.37/ min, 95% CI: 0.28 ; 0.45, p < .00001) fasting insulin, weight (SMD: - 1.22 kg, 95% CI: - 2.23 ; - 0.18, p = .02) and BMI (SMD: - 0.40 kg / m^2, 95% CI - 0.78 ; - 0.02, p = .04) compared to moderate intensity training.

In a meta-analysis of 7 low of risk bias studies (De Nardi et al., 2018), explored the impact of HIIT in comparison to continuum training in metabolic biomarkers of pre-DM2 and DM2 patients. HIIT increased significantly in 3.02 ml / kg / min (CI 95% 1.42-4.61) VO_{2max} in contrast to moderate intensity training. No differences were found between both training modalities for A1c, SBP, DPB, total cholesterol, LDL, HDL, BMI and waist to hip ratio (WHR).

Clinical guidelines concerning HIIT and DM2

Clinical practice guidelines targeting DM2 were also reviewed. HIIT was only mentioned in the Canadian Clinical Practice Guidelines (2018) and in the evidence summary of Dynamed (2018).

The Canadian Clinical Practice Guidelines (2018) discussed the benefits of HIIT within the chapter dedicated to physical activity and diabetes. It is known that HIIT induces greater cardiorespiratory functional adaptations but, when talking about patients with DM2, HIIT also seems to be more effective to improve glycaemic control compared to lower intensity continuous exercise. It is recommended for DM2 patients to perform interval trainings (short periods of vigorous exercise alternating with short recovery periods at low-to-moderate intensity or rest from 30 seconds to 3 minute each) aiming to improve their cardiorespiratory fitness (Grade B, Level 2).

In the evidence summary of Dynamed (2018) targeting alternative treatments for diabetes, HIIT is included as a plausible exercise protocol to reduce fasting glucose levels and HbA1c in patients with DM2 (Evidence level 3) based the findings reported by a randomized clinical trial.

Summary of the effects of HIIT on patients with DM2

Lingvay et al (2021) declared that obesity management should be the primary treatment for remission of DM2. In a recent study (Taheri et al., 2020), randomly assigned 158 patients with DM2 to an intervention (n = 79) and a control group (n = 79). The intervention group underwent lifestyle modifications with physical activity and nutrition interventions and was compared to another group based on general recommendations (passive control group). The intervention group lost 11.98 kg (95% IC: 9.72 a 14.23) while the control group lost 3.98 kg (95% IC: 2.78 a 5.18). Besides, the intervention group achieved a significantly greater remission of type 2 diabetes mellitus (61 vs. 12%).

High intensity training improves health parameters regardless of the induced weight loss (Gaesser & Angadi, 2021). In the latest guidelines for the management of heart failure by the European Society of Cardiology (McDonagh et al., 2021), it is recommended to perform 75-150 minutes of high intensity physical exercise per week aiming to reduce all causes of mortality, cardiovascular mortality and morbidity (IA evidence). In fact, Gaesser et al. (2020) state that the treatment of obesity (key for the treatment of type 2 DM) should focus on physical exercise due to its benefits regardless of weight loss: (1) The risk of mortality associated to obesity is attenuated or eliminated by moderate-high levels of cardiorespiratory fitness (measured by VO_{2max}) or high levels of physical activity (measured by number of steps per day, among others); (2) Most of the cardiometabolic risk markers associated to obesity can be improved with physical exercise independently of weight loss (Colberg et al., 2010). Improved cardiorespiratory fitness or elevated levels of physical activity are associated with greater reductions in mortality compared to weight loss alone (McDonagh et al., 2021).

At physiological and molecular levels, HIIT would regulate both lipid and glycaemic metabolism (Sabag et al., 2021). Focusing on glycaemic metabolism, HIIT would improve the quantity and quality of mitochondria organelles, which are key in the beta oxidation of fatty acids (Sabag et al., 2021). These effects would reduce the accumulation of ceramides and diacylglycerides, lipids that decrease insulin sensitivity by several mechanisms. In addition to the inhibition of protein kinase C resulting from physical exercise, it would induce an increase in the translocation of GLUT4 receptors at the muscle level, increasing peripheral glucose uptake and increasing the storage capacity of muscle glycogen (Banday et al., 2020; Sabag et al., 2021).

HIIT provides greater benefits to functional capacity compared to resistance training (Jiménez-Maldonado et al., 2020; Picard et al., 2021). Both, resistance training and HIIT improve glycaemic control, insulin resistance, fat mass, blood pressure, strength and lean body mass (Jiménez-Maldonado et al., 2020). Combining resistance training and HIIT improved only some results (Jiménez-Maldonado et al., 2020). On the other hand, HIIT and sprint interval training improve glycaemic control to a similar or greater degree than aerobic exercise in populations without metabolic syndrome or DM2 (Jiménez-Maldonado et al., 2020). HIIT improves body weight and significantly reduces BMI (da Silva et al., 2019; Lora-Pozo et al., 2019). Despite this, HIIT does not seem to induce greater effects compared to other exercise interventions. On the other hand, HIIT improves VO_{2max} absorption in DM2 patients, which indicates the maximum capacity of the cells of our body to absorb and use oxygen, also predicting glucose clearance by plasma insulin (De Nardi et al., 2018).

CONCLUSIONS

In conclusion, HIIT is a safe and recommended effective exercise for patients with DM2 to improve their functional capacities, body weight, BMI, blood pressure, VO_{2max} and Hb1Ac. There is no drug or nutritional intervention that could replace physical exercise benefits. Physical exercise is applicable to the entire population regardless of their financial resources. Further research is needed to clarify the most effective HIIT protocol depending on the targeted population.

AUTHOR CONTRIBUTIONS

All authors have worked in the development of this study. The study was conceived by AKR and APC, the literature search and reviewed was performed by AKR, PJM, APC and CAF, all authors participated in writing and the final critical revision of the manuscript.

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DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

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SCIENTIFIC JOURNAL OF SPORT AND PERFORMANCE

ORIGINAL ARTICLE

Evaluation of the effects of commercial Moringa Oleifera supplement on physical fitness of young fit adults: A pilot study

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ABSTRACT

Background. The Moringa oleifera (Moringa) nutritional supplement is often used for medicinal purposes due to its acclaimed healing abilities. Indeed, research indicates that Moringa possesses antioxidant and anti-inflammatory properties, and has the potential of being an ergogenic substance by enhancing energy metabolism. Yet, despite numerous manufacturers producing Moringa-based supplements, little scientific research has been conducted on humans. Aims. The aim of this pilot study was to evaluate the effects of Moringa as an ergogenic aid in improving aerobic and anaerobic exercise performance in healthy young fit subjects. Methods. A randomized, double-blind controlled study was performed to evaluate Moringa supplement compared to placebo. The study included 16 healthy young male and female, age 26.6 ± 3.0 years physical education college students. Participants were evaluated before and after six weeks of intervention of Moringa (310 mg x 2) or placebo capsules. Participants were measured for body composition, resting blood pressure (BP), resting heart rate (HR), graded cardiopulmonary test on a treadmill until reaching maximal oxygen consumption (VO_2max) and maximal anaerobic Wingate bicycle test. Results. There were no differences in physiological or physical performances between the two groups before and after the intervention. Conclusions. Despite promising indications of positive effects of Moringa plant on physiological processes, there was no effect on physical activity performance. As such, the administering of Moringa for improving athletic performance should be taken with caution. Further studies should be conducted to examine the effects of the Moringa plant on human performance in other populations.
Keywords: Sport medicine, VO_2max, Wingate test, Aerobic capacity, Anaerobic capacity, Body composition.

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INTRODUCTION

Plant-derived nutritional supplements are often used for their contribution to people's health or improved physical and mental performance and capabilities (Alidadi et al., 2020; Calabrese, 2021; Hussain et al., 2019; Poulsen et al., 2020). Yet these supplements are largely unregulated and understudied. One such example is the Moringa oleifera Lam (Moringa), a small native tree of the Himalayan regions of North-West India, often referred to as the *miracle plant*, thanks to its ability to prevent and treat many diseases. For centuries, this herbal plant has been used for medicinal purposes, with acclaimed healing properties that can assist and heal various chronic diseases (Abdull Razis et al., 2014; Essa et al., 2014). Indeed, Moringa is rich in proteins, vitamin A, minerals, essential amino acids, antioxidants, flavonoids, and isothiocyanates (Kou et al., 2018).

The literature indicates that Moringa has antioxidant and anti-inflammatory capabilities (Adedapo et al., 2015; Gupta et al., 2010; Jaafaru et al., 2018), and may even possess anti-fatigue properties and the ability to improve people's tissue antioxidant capacity (Lamou et al., 2016b). In vitro studies indicate that Moringa improves skeletal muscle metabolism by increasing oxidative energy metabolism and possibly even mitochondrial biogenesis (Duranti et al., 2021). Importantly, various studies in animals indicate a high degree of safety, with no adverse effects having been reported in human studies (Stohs & Hartman, 2015).

When examining the effects of Moringa in animal models, findings suggest a range of physiological pathways. First, Moringa increases calcium ATPase pump activity in skeletal muscle, which is important trait for maintaining healthy muscle cell functionality (Olayinka & O., 2017) Moreover, increased calcium ATPase activity may expedite the recovery phase of contracting muscle cells when exercising. Moreover, Moringa attenuates the effects of exercise on cardiac hypertrophy via scavenging reactive oxygen species (ROS) (Jasaputra et al., 2022). This reduction in ROS has the potential to enhance muscle recovery and adaptations after exercise, as ROS serve as an important mediator in such processes (Thirupathi & Pinho, 2018). Finally, Moringa has been found to stimulate mitochondrial biogenesis in skeletal muscles in rats (Ray et al., 2020), which in turn may increase exercise performance.

In humans, extracts of the Moringa leaves has been found to enhance metabolism of glucose and lipids, and exhibit antioxidant activity (Stohs & Hartman, 2015). A daily dosage of 7 grams of a Moringa powder supplement in postmenopausal women, over a three-month period, was found to decrease fasting blood glucose levels (by 13.5%) while increasing hemoglobin (by 17.5%) (Kushwaha et al., 2014). Interestingly, Moringa has also been shown to potentially be an ergogenic aid, by enhancing energy metabolism in adult skeletal muscles. This is achieved by increasing metabolic markers, including those involved in glycolysis, oxidative phosphorylation, mitochondrial biogenesis, and angiogenesis (Dissertations & Eze, 2020).

In animal studies, aqueous extract of Moringa over a 28-day period was found to increase maximum swimming time ability, blood hemoglobin, blood glucose, and hepatic and muscle glycogen reserves in male rats (Lamou et al., 2016a). Moreover, Moringa has been found to improve muscle function and treadmill endurance results in rats (Barodia et al., 2022). Indeed, many manufactures market Moringa supplements for improving exercise performance, yet to the best of our knowledge, no scientific evidence exists on the effect of Moringa on muscle performance or exercise performance in humans. The aim of this pilot study, therefore was to evaluate the effects of Moringa as a novel ergogenic aid for improving aerobic and anaerobic exercise performances in humans. More specifically, this study strives to evaluate the outcome of six weeks of treatment using Moringa leaf extract on aerobic and anaerobic exercise performances.

MATERIALS AND METHODS

The study has been approved by the institutional research ethics committee before experiment was started and that has been conducted in accordance with the principles set forth in the Helsinki Declaration (0197-18-WOMC).

Participants

This pilot study included 16 physical education college students. The students (seven men and nine women) were studying to become physical education teachers. Their average age was 26.6 ± 3.0 years, they were in good health (based on their self-reporting), and had not been administered any medication. Participants signed an informed consent approved by Helsinki board committee.

Procedures

For this randomized double blind control study, the participants were invited to our research lab a total of four times: *Time 1: Pre-Intervention Baseline session*, divided into two sessions, and *Time 2: Post-intervention session* six weeks later, also divided into two sessions. The participants were instructed to maintain their regular diet and exercise habits throughout the six-week intervention period. During the baseline session, the participants signed an informed written consent form after receiving a short explanation about the study. Next, they were measured for height, body composition (weight, body fat, BMR) resting blood pressure (BP), resting heart rate (HRrest), and VO_2max. Finally, the participants were asked to perform a graded cardiopulmonary test on a treadmill (explained in detail below). The participants were then asked to return to lab two-three days later to perform a Wingate bicycle Test (explained in detail below) – to prevent influence from the VO_2max. Six weeks later, the participant returned to the lab to perform the same tests.

Intervention

The participants were randomly divided into two groups, seven on the Moringa group and nine on the placebo group. The research group was administered two Moringa capsules a day (Moringa Arava, Israel). The control group was administered two placebo capsules a day. The Moringa and placebo capsules looked identical so that the participants could not tell them apart. Both groups were instructed to take one capsule at the morning and one at the evening after eating. Each Moringa capsule contained 310 mg of Moringa powder, consisting of 127 mg carbohydrates, 30 mg moisture, 91 mg protein, and 16 mg fat. This dosage was in line with the manufacturer's recommendations. The placebo capsule contained Dextrin.

Measures

Body composition [(weight, body fat and body mass index (BMI)] was measured using the Tanita MC 780-MAP Body Composition Analyzer (Japan); *resting BP* was measured using the Connex® ProBP™ 3400 Digital Blood Pressure Device (Welch Allyn®, USA); *HRrest* was measured using the *Polar Heart Rate Monitor* (USA). *Basal metabolic rate (BMR)* and *VO_2max* were measured based on a maximal graded exercise test that was performed on a treadmill (PPS MED; Woodway, Weil am Rhein, Germany) (Vehrs et al., 2007). Briefly, the starting velocity, which was 6 kph, was increased by 1 kph every minute. The slope was 1% throughout the test. Prior to each increase, *oxygen consumption (VO_2)*, *HR*, and *subjective sense of effort* (via the Rating of Perceived Exertion [RPE]) were measured. At the end of the test, when participants reached exhaustion, they were instructed to walk for an additional three minutest at 4 kph for active recovery. HR was measured at 1 minute after exercise termination (recovery-1).

The Wingate anaerobic test was performed on an ergometric bicycle (Monark, Ergomedic 894 Ea). The test started with a 3-minute warm up, pedaling with no load. Participants were asked to pedal as fast they could; when their maximum pedaling velocity was reached, a load was applied (pre-calculated as 8% of the participants' body mass). The participants were encouraged to maintain a 30-second maximal effort, after which they were instructed to continue pedaling with no load for an additional 3-minute active recovery period. Using the 30-sec all-out test, the following parameters were calculated: peak power (PP): the highest power obtained during first 5 s, mean power (MP): the average power exerted through the 30 s and fatigue index (FI): the percentage decrement between highest and lowest power output (Inbar et al., 1996).

Analysis

This study employed a quantitative methodology. To analyze the input received from the tests at the different time points of the study, two-way repeated-measures (group × before/after) analysis of variance was used. Data were analyzed with SPSS version 24, with significant set at $p < .05$.

RESULTS

Based on our findings, no differences were seen between the two groups at the baseline with regards to weight, body fat, BMI, BMR, resting HR, resting blood pressure, VO_2max, and the Wingate test. In addition, comparison were made between submaximal aerobic effort after 5 minutes in the VO_2max tests: (VO_2, RPE, HR minute 5). Moreover, for all variables measured, no differences were seen between the baseline and the post-intervention results, nor were any differences between the two groups (Table 1).

Table 1. The effects of Moringa vs placebo measured before and after intervention. Variables presented as means (SD).

	Moringa (N = 7)		**Placebo (N = 9)**	
	Pre-Intervention	**Post-Intervention**	**Pre-Intervention**	**Post-Intervention**
Weight (Kg)	62.8 (10.7)	63.0 (10.1)	65.5 (10.9)	65.5 (10.9)
BMI	23.3 (1.9)	23.3 (1.9)	23.4 (3.5)	23.3 (3.5)
Fat (%)	19.8 (6.8)	20.8 (6.0)	20.9 (8.9)	22.3 (9.2)
BMR (kcal)	1509.0 (294.7)	1497.1 (278.5)	1543.1 (246.4)	1379.5 (565.7)
SBP (mmHg)	111.3 (10.8)	113.6 (8.4)	119.2 (8.4)	115.8 (6.8)
DBP (mmHg)	65.7 (8.6)	65.3 (8.1)	66.7 (5.1)	65.2 (7.1)
HR rest (bpm)	61.0 (9.1)	68.7 (12.2)	69.0 (11.4)	68.7 (12.2)
RPE Minute 5	11.8 (4.9)	11.8 (4.8)	12.5 (2.2)	10.1 (3.7)
HR Minute 5	153.7 (19.3)	155.7 (18.8)	162.0 (19.2)	159.0 (18.5)
VO_2 Minute 5	32.6 (1.4)	33.5 (1.6)	32.5 (2.2)	33.0 (2.1)
VO_2max	44.7 (8.2)	41.6 (7.1)	41.0 (6.7)	41.0 (6.8)
RPE max	17.0 (3.9)	16.7 (3.7)	17.7 (1.5)	15.7 (3.7)
HR max	181.6 (9.6)	179.4 (7.5)	185.2 (9.9)	186.1 (8.9)
HR recovery 1 minute	176.1 (12.6)	172.6 (11.2)	181 (11.0)	181.0 (8.2)
VO_2 recovery 1 minute	40.6 (6.0)	38.1 (8.4)	37.7 (5.4)	36.6 (8.1)
Wingate MP (w/k)	7.1 (1.5)	6.3 (1.6)	7.1 (1.6)	6.6 (8.5)
Wingate PP (w/k)	10.0 (3.4)	8.5 (2.8)	9.7 (2.7)	9.1 (1.5)
Wingate FI (w/k)	52.2 (11.5)	47.7 (7.1)	50/6 (12.9)	53.2 (4.6)

DISCUSSION

The aim of this pilot study was to evaluate the influence of the Moringa nutritional supplement on physiological responses in aerobic and anaerobic exercise performances, following a six-week intervention program in healthy young active physical education college students. The Moringa treatment did not improve VO_2max test results or anaerobic Wingate test results. These findings different from Gopi (2017), who found a beneficial effect of a sport nutrient supplement that contained Moringa on aerobic performance (Gopi et al., 2017). This difference in findings could stem from differences in the nutritional supplement used in the two studies, especially as the supplement used in the comparative study included a number of ingredients. Moreover, the exercise test modality (time to exhaustion versus VO_2max) differed in the two studies, which may have also influenced the findings.

A recent literature review presents data supporting the positive effect of Moringa on body weight (Ali Redha et al., 2021) – a finding that was not seen in the current study. It is possible that six weeks of treatment were insufficient for achieving weight loss in young, fit physical education students. Moreover, the effect of Moringa on body weight could be related to its effect on blood glucose levels, as a recent review indicates that Moringa lowers blood glucose levels in diabetic humans (Owens et al., 2020). These effects of Moringa on blood glucose in healthy populations should therefore be further investigated.

Finally, the Moringa dosage used in this study, i.e., 620 mg per day, is the recommended dose stated by the manufacture. It is possible, however, that this dose in insufficient for having a meaningful effect on young healthy physically active participants. Indeed, different studies on humans apply different dosages of Moringa, as well as supplements that have been produce in different manners (leaf powder, extraction, cooked, etc.). Although studies using leaf powder such as in our study use higher dosages of Moringa (from 1-2 g and up to 8 g per day), limited effects can be seen (Monera-Penduka et al., 2017; Sissoko et al., 2020; Taweerutchana et al., 2017), except for aqueous leaf extracts of 2, 4, and 6 g yielded an effect on blood pressures in young healthy participants (George et al., 2018).

CONCLUSION

While some studies indicate a positive effect of the Moringa plant on physiological and pathological processes in animals, its effect on humans is unclear and should be further examined. In this study, no effects were seen of the powder extracted from the Moringa leaf on aerobic and anaerobic maximal capacity in young active healthy participants compared to a placebo.

AUTHOR CONTRIBUTIONS

S.T. responsible for the supervision and writing the first draft; S.T. and M.A. responsible for conceptualization; S.T., M.A. and A.E. responsible for methodology; T.O. responsible for performing the experiments, and data collection. All authors discussed the results and contributed to the final manuscript.

SUPPORTING AGENCIES

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DISCLOSURE STATEMENT

Availability of data and material

The datasets generated during the current study are available from the corresponding author on reasonable request.

Conflict of interest

The authors report there are no competing interests to declare and report no involvement in the research by the company that could have influenced the outcome of this work.

Ethical approval

Approval was obtained from the ethics committee of Wolfson medical centre. The procedures used in this study adhere to the tenets of the Declaration of Helsinki.

Consent to participate

Informed consent was obtained from all individual participants included in the study.

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SCIENTIFIC JOURNAL OF SPORT AND PERFORMANCE

ORIGINAL ARTICLE

Factors related to Sense of Coherence in Japanese university athletes: Cross-sectional studies based on demographic factors

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ABSTRACT

The main aim of the current study was to examine cross-sectionally the correlation between demographic factors and Sense of Coherence (SOC) in Japanese university athletes. The study's participants were 1,154 Japanese university athletes (771 males and 383 females, mean age 20.02 ± 1.13 years) that have enrolled in Japanese physical education universities. The survey items comprised sex, age, athletic events, years of an athletic career, regular position (regular or non-regular), competition level, and SOC. Binomial logistic regression analysis was then conducted to evaluate the correlation among demographic factors and SOC in universities athletes. The results of the study demonstrated that regular members of Japanese physical education universities were associated with higher SOC. Based on the above, the various life experiences that athletes experience when becoming a regular member could be associated with the establishment and development of SOC. The results of this study can lead to specific interventions toward the enhancement of SOC, not only in becoming regular members but also in SOC development and formation. Moreover, the presented results provide important information for psychological support and guidance to university athletes from a salutogenic perspective.
Keywords: Sport psychology, Demographic factors, Life experiences, University, Logistic regression.

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INTRODUCTION

During the 2020 Tokyo Olympics, several elite athletes complained repetitively regarding their mental health condition. The importance of mental health management is continuously increasing (Walker et al., 2022) and research indicates that depression and anxiety incidence in elite athletes is approximately 34%, higher when compared to the general population (Gouttebarge et al., 2019). University athletes have also reported mental health problems in depression and social anxiety (Storch et al., 2005). Research on Japanese university athletes implies that stressors in competitions and daily life can lead to mental health issues and burnout (Kimura et al., 2013). In addition, athletes that enrolled at a university via sports recruitment programs face difficulties in balancing sports life and academics that can lead to mental health issues (Arai et al., 2021). University athletes are required to cope with various stresses and preserve decent mental health.

In principle, stress research has focused predominantly on stress as a negative factor. Nevertheless, stress has also been considered a positive factor for personal growth. Sense of Coherence (SOC) is the theory suggesting that stress can be a positive force leading to improved health (Antonovsky, 1987). SOC is one of the core concepts of salutogenesis, it acts as a buffer for stressors and contributes in the maintenance of mental health (Höge & Büssing, 2004; Richardson & Ratner, 2005). A previous study evaluating the effects of SOC in university athletes discovered that athletes with a stronger SOC are under significantly lower stress and negative psychological symptoms (Skirka, 2000). The study indicated that competitive stress is perceived positively and stimulates good mental health.

Based on the above, SOC has contributed in the maintenance and improvement of university athletes' mental health. Nevertheless, not adequate research has been performed regarding specific factors inducing higher and lower SOC in university athletes. If solid factors are identified, they could contribute to specific interventions enhancing SOC during its development and formation.

The purpose of the current study was to cross-sectionally investigate the association among demographic factors and SOC in Japanese university athletes.

MATERIAL AND METHODS

Participants

The study included 1,154 university student-athletes (771 males and 383 females, mean age 20.02 ± 1.13 years) as participants that were enrolled in physical education in Japan, after completing a survey form.

Measures

Survey participants were questioned about sex, age, athletic events, years of an athletic career, regular position (regular or non-regular), and competition level (Regional tournament, National convention, or World championship).

The years of an athletic career were separated into four groups based on previous studies (Endo et al., 2012; Tokunaga et al., 1994).

SOC was measured based on the Japanese version of the SOC-13 scale (Antonovsky, 1987). SOC-13 consists of three factors: comprehensibility, manageability, and meaningfulness, while the total score of all 13 items was used as the SOC score. The higher score indicates the higher SOC rated. In addition, in a previous study, the reliability and validity of the Japanese version of the SOC-13 have also been verified

(Togari et al., 2008). The Cronbach's alpha coefficient in that study was 0.73, suggesting a commonly high internal consistency.

SOC was divided into low and high groups based on the median of 54 points obtained in this study.

Procedure

The survey was performed from June to September 2014 after acquiring the prior consent of the teacher in charge of the lecture, physical instructors, and club coaches. The subjects received explanations for the study's purpose before the survey.

This study was performed after approval from the Nippon Sport Science University research ethics review, with which the author was formerly affiliated.

Analysis

The qualitative data items were presented as the number of people (%), while quantitative data items were presented by the mean (±standard deviation). In order to assess the characteristics of the subjects, χ-square and t-tests were conducted. Binomial logistic regression analysis was then employed to evaluate the association among demographic factors and SOC in university athletes. SOC was employed as a dependent variable (low or high SOC) while the age group (18, 19, 20, 21, 22 years old), the years of an athletic career (0 – 2, 3 – 4, 5 – 9 and > 10 years), the regular position, and the competition level (Regional tournament, National convention or World championship) were selected as independent variants. The sex (male or female), the age, and the athletic events were applied as covariates. All data were analyzed using EZR (Kanda, 2013), and statistical significance was considered when less than 5%.

RESULTS

Athletic events of the participants (Table 1).

Table 1. Type of sport of the participant.

	n	*%*		*n*	*%*		*n*	*%*
Total	**1154**	**100**						
Track & Field	220	19.06	Kendo	15	1.30	Baton Twirling	3	0.26
Baseball	147	12.74	Soft Tennis	12	1.04	Fencing	3	0.26
Soccer	143	12.39	Badminton	11	0.95	Naginata	3	0.26
Basketball	77	6.67	Life Saving	10	0.87	Boxing	2	0.17
Handball	69	5.98	Lacrosse	9	0.78	Cheerleading	2	0.17
Softball	61	5.29	Ski	9	0.78	Inline Hockey	2	0.17
Rugby	52	4.51	Swimming	9	0.78	Rhythmic Gymnastics	2	0.17
Volleyball	43	3.73	Ultimate	9	0.78	Triathlon	2	0.17
Gymnastics	38	3.29	Dance	6	0.52	Ballet	1	0.09
American Football	34	2.95	Double Dutch	6	0.52	Figure Skate	1	0.09
Tennis	33	2.86	Futsal	6	0.52	Kyudo	1	0.09
Judo	30	2.60	Boat	5	0.43	Shorinjikenpo	1	0.09
Field Hockey	23	1.99	Canoe	5	0.43	Squash	1	0.09
Table Tennis	19	1.65	Ice Hockey	5	0.43	Taichi	1	0.09
Touch Rugby	17	1.47	Karate	5	0.43	Trampoline	1	0.09

The number of athletic events was 45. Track and field was the most common event.

Sociodemographic characteristics of the participants (Table 2).

Analysis revealed significant number of biases in the regular position ($\chi^2(1) = 18.93$, $p < .001$) and the competition level ($\chi^2(2) = 15.99$, $p < .001$).

Table 2. Sociodemographic characteristics of participants.

Factor	Group	Overall	Male	Female	*p*-value
n		1154	771	383	
Age group (%)	18 years old	120 (10.4)	78 (10.1)	42 (11.0)	.82
	19 years old	239 (20.7)	167 (21.7)	72 (18.8)	
	20 years old	412 (35.7)	271 (35.1)	141 (36.8)	
	21 years old	262 (22.7)	173 (22.4)	89 (23.2)	
	22 years old	121 (10.5)	82 (10.6)	39 (10.2)	
	Mean (±SD)	20.02 (1.13)	20.02 (1.13)	20.03 (1.13)	.88
Years of an athletic career (%)	0–2 years	62 (5.37)	47 (6.10)	15 (3.92)	.11
	3–4 years	116 (10.05)	73 (9.47)	43 (11.23)	
	5–9 years	448 (38.82)	286 (37.09)	162 (42.30)	
	> 10 years	528 (45.75)	365 (47.34)	163 (42.56)	
	Mean (±SD)	8.85 (3.97)	8.93 (4.06)	8.71 (3.79)	.38
Regular position (%)	Non regular	642 (55.63)	464 (60.18)	178 (46.48)	<.001[a]
	Regular	512 (44.37)	307 (39.82)	205 (53.52)	
Competition level (%)	Regional tournament	507 (43.93)	370 (47.99)	137 (35.77)	<.001[a]
	National convention	610 (52.86)	380 (49.29)	230 (60.05)	
	World championship	37 (3.21)	21 (2.72)	16 (4.18)	
SOC (%)	Low	549 (47.57)	355 (46.04)	194 (50.65)	.15
	High	605 (52.43)	416 (53.96)	189 (49.35)	

Note. Group compared by using the t-test or χ^2 test[a].

Table 3. Binomial logistic regression analysis of sociodemographic factors related to SOC.

		OR	95% CI	*p*-value
Age group	18 years old	1.00		
	19 years old	0.99	0.62 - 1.56	.95
	20 years old	1.07	0.70 - 1.64	.76
	21 years old	1.09	0.70 - 1.72	.70
	22 years old	1.64	0.96 - 2.79	.07
Years of an athletic career	0–2 years	1.00		
	3–4 years	1.20	0.57 - 2.56	.63
	5–9 years	1.00	0.47 - 2.13	.99
	> 10 years	0.92	0.42 - 1.99	.83
Regular position	Non regular	1.00		
	Regular	1.54	1.18 - 2.00	.00
Competition level	Regional tournament	1.00		
	National convention	0.82	0.63 1.07	.15
	World championship	1.34	0.60 3.00	.48

Note. OR: Odds Ratio, CI: Confidence Interval. Moderator variables were sex and type of sport.

SOC and binomial logistic regression analysis of sociodemographic factors (Table 3).

Binomial logistic regression analysis revealed that regular athletes (OR = 1.54, 95% CI = 1.18 – 2.00) were correlated with higher SOC than non-regular athletes.

DISCUSSION

In the present study, the correlation between demographic factors and SOC in Japanese university athletes was cross-sectionally assessed.

The binomial logistic regression analysis demonstrated that regular members were associated with higher SOC and the various experiences that athletes experience when becoming regulars could be associated with the formation and development of SOC.

Life experiences related to the establishment and development of SOC involve three factors: 1) Consistency, which is the experience of living within stable rules and norms, 2) Load balance, which is the experience of coping well under moderate stress and 3) Participating in shaping of outcomes which is the experience of participation in decision-making (Antonovsky, 1979; Sagy & Antonovsky, 2000).

In Consistency, many competitive sports contain rules and discipline in team activities. The rules and regulations affect consistent experiences and can contribute to stability in their competitive activities by providing a clear direction for their efforts. In addition, Consistency is an essential factor for the establishment of a continuous competitive experience and for being regular members.

In Load balancing, players experience higher stress in becoming regulars. When considering sports injuries for instance, a survey in athletic trainers demonstrated that all injured athletes suffer from psychological trauma (Larson et al., 1996). Furthermore, since athletes' injury layoffs have been correlated with lower SOC scores (Mayer & Thiel, 2014), high stress levels may interfere with SOC establishment. Although injury experiences can be significantly stressful, stress can become a balanced and the experience can be overcome with appropriate support from staff and professionals. Athletes are thus, expected to continue competing for earning a regular spot.

In Participating in shaping of outcomes, decision-making is significantly associated with the invention of training methods, performance enhancements and determination of team policy. In these cases, participation in team discussions initiatives can be critical while these experiences depend on the management by team coaches. A study has demonstrated that when team coaches unilaterally remove athletes' decision-making, distrust of the coach is generated, it interferes with athletes' identity and mental health and it leads to early withdrawal from competitions (Uematsu et al., 2021).

Based on the above, SOC is expected to be developed by a complex intertwining of three types of experiences: competitive experiences under stable rules and norms, successful coping experiences under moderate stress, and involvement in critical decision-making.

CONCLUSIONS

The outcomes of the present study contribute to the establishment of particular interventions to support the establishment and development of SOC and to eventually develop regular members. The presented results also provide an important resource for psychological support and guidance of universities athletes from a salutogenic perspective.

Nevertheless, the present study presented some limitations. Initially, world championship level participants accounted for only 3.2%, a significantly lower percentage of participants compared to other groups of the competition level. To this end, additional surveys for world championship level subjects should be pursued in the future. Moreover, a causal relationship is unknown as the current study was cross-sectional, and future studies should be focused on longitudinal studies.

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DISCLOSURE STATEMENT

No potential conflict of interest was reported by the author.

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ORIGINAL ARTICLE

Effects of increasing physical load and fatigue on the biomechanics of elite cyclists

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ABSTRACT

In this study, we propose to expand the research on the biomechanics of cycling, including changes caused by riding at different intensity levels and fatigue, similar to training or competition. Six well-trained, experienced male road cyclists (27.17 ± 3.89 years; 180.41 ± 5.31 cm; 75.23 ± 4.91 kg) with 8.3 ± 4.85 years of (professional) experience in road cycling underwent a lactate test, starting with 100 W and an increment of 20 W every 3 minutes until total exhaustion. Afterward, subjects drove an increment of 50 W every 3 minutes, starting again with 100 W and ending with 250 W (post-test). Changes in position were recorded via 2D video analysis. We found that with higher power output relative to the individual anaerobic threshold (IAT), the joint angles changed. No significant differences were present for the pre–post comparisons of the examined angles, which should map the influence of fatigue ($p > .05$). Future research should try to observe cycling movement in more realistic settings, such as cycling-specific fatigue or during an outdoor ride, as the biomechanics under these conditions are of particularly high relevance for the athletes. Overall, the results suggest performing bike fitting more individually and in more realistic situations or setting.
Keywords: Performance analysis of sport, Physical conditioning, Bike fitting, Movement analysis, Cycling, Joint overuse, Joint misloading, Biomechanics.

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INTRODUCTION

In road cycling, it is important to ride as economically as possible; over the course of a cycling stage, any energy saved might help to improve overall competition performance. Besides this, an optimal position on the bike plays a crucial role in both enhancing performance and reducing the risk of non-traumatic injuries (overuse) (Bini, Hume, Croft & Kilding, 2014; Dettori & Norvell, 2006).

Most research has focused on evaluating the efficiency of a seating position but with measurements at submaximal load perceived as habitually comfortable (Bini, Hume & Croft, 2014; Priego Quesada, Kerr, Bertucci & Carpes, 2018). However, it is unclear whether this procedure represents a realistic cycling situation in the field. If relevant angles of the lower body are dependent on different riding intensity levels and fatigue status, the determination of a position at a fixed submaximal load would underrepresent the real complexity. The transferability to high-intensity loads during a competition on the road or during sprints as they are ridden in track cycling seems substantially limited. There is only one prior study known to us that investigated the changes in sitting position during high-intensity 6s sprints (Bini, Daly & Kingsley, 2020). Such changes may lead to non-physiological positions and a potential increase in non-traumatic injury prevalence, which usually correlates with the level of fatigue. Fatigue leads to slower and less coordinated muscle activation, changing the activation pattern and, therefore, the movement (Abbiss & Laursen, 2005; Billaut, Basset & Falgairette, 2005), setting a risk for overuse injuries (Galindo-Martínez, López-Valenciano, Albaladejo-García, Vallés-González & Elvira, 2021). This injury prevalence is often linked to the knee (Bini & Bini, 2018; Clarsen, Krosshaug & Bahr, 2010) and lower back (Clarsen et al., 2010). Knee pain is often associated with a small knee angle, which leads to a medial rotation of the femur, lowering the contact point of the joint and thereby increasing the patellofemoral pressure (Bini et al., 2018). Proper bike fitting can prevent this misloading leading to overuse of the knee joint (Bini, Hume & Croft 2011) and can help to increase the efficiency of the movement (Bateman, 2014).

According to the above-mentioned aspects, there is a lack of research regarding the influence of different riding intensity levels and fatigue on lower-body biomechanics while riding. Therefore, we want to examine (1) whether different riding intensity levels relative to the individual anaerobic threshold (IAT) result in changes in the biomechanics of the lower body. Furthermore, we wish to evaluate (2) whether lower-body biomechanics while riding before (pre-test) and after an all-out treatment in a fatigued state (post-test) are different.

MATERIALS AND METHODS

Subjects and data acquisition

For this research, six well-trained, male road cyclists (27.17 ± 3.89 years; 180.41 ± 5.31 cm; 75.23 ± 4.91 kg) with 8.33 ± 4.85 years of (professional) experience in road cycling underwent body fat and body composition measurement using the InBody 770 (InBody Europe, Eschborn, Germany) system (body fat: 11.87 % ± 3.2; skeletal muscle mass: 37.75 ± 3.22 kg; lean leg mass: 20.57 ± 2.14 kg), a posture analysis (Balance 4D, Paromed, Neubeuern, Germany), and a dynamic 2D bike fitting. The sample size of this study was selected based on Bateman (2014).The subjects were recruited through contacting the team. The left and right body sides were both analysed to allow a comparison and additional validation of the results. Therefore, videos were recorded for both sides in the sagittal plane during the test. Prior to the study, the riders underwent a dynamic 2D analysis on the bike. For all subjects, the knee angle in the 90° crank position and the knee position in relation to the pedal axis met the selected reference values (knee angle: 110°–115° in the 90° position of the crank; axis of the knee vertically above the pedal axis (Bini et al., 2016)). The 90°

position (9 o'clock position) was selected for (pre-) evaluation, as there are greater forces present in the patellofemoral area than in the 180° position. Further, this position shows a higher reliability (Bini & Hume, 2016; Ericson & Nisell, 1987). The 180° position was additionally used for the following analysis, as it is most commonly used in bike fitting practice, as well as in other studies (Bini et al., 2011; Ferrer-Roca et al., 2011; Swart, & Holliday, 2019). After pre-evaluation of the position on the bike, subjects performed a lactate stepwise incremental test, starting at 100 W with an increment of 20 W every 3 minutes until total exhaustion (Wahl, Manunzio, Vogt, Strütt, Volmary, Bloch &Mester,2017). Post-treatment, it was controlled that every subject showed lactate values exceeding 8 mmol/l at the point of termination. Therefore, according to de Marées (2003), it can be assumed that a high fatigue status was present.

After the exhaustion, the cyclists had a short period of 5 minutes of active regeneration with low resistance selected as habitually comfortable. After this regeneration phase, the subjects drove an increment of 50 W every 3 minutes, starting again with 100 W and ending with 250 W.

Measuring method

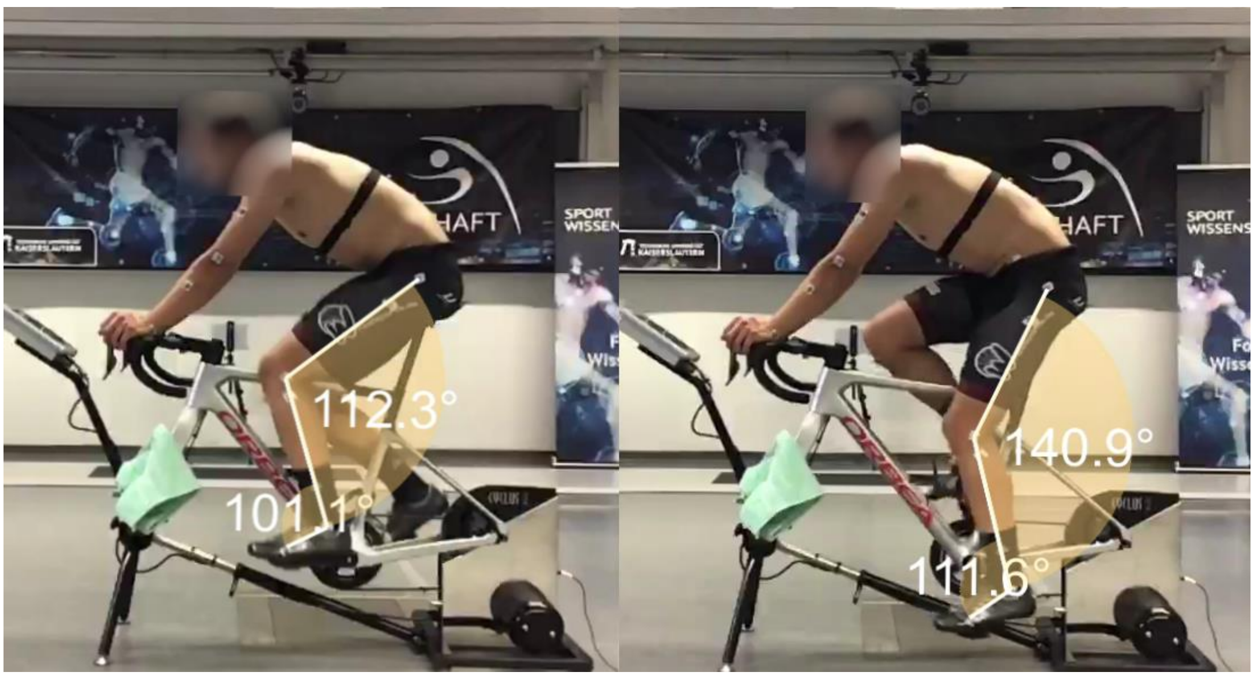


Figure 1. Measuring procedure and angle definition.

For the lower-body biomechanics, we focused on knee and ankle angles as shown in Figure 1; these angles are reliably measurable in 2D analysis, were observed in most of the previous studies, and are of high practical relevance (Swart et al., 2019). The 2D analysis was performed by simultaneously filming at 120 fps with two iPads (7th generation, Apple, Cupertino, USA/CA) that were positioned at a standardized distance perpendicular to the cyclists, as suggested by Fonda, Sarabon and Li (2013). The calculation of the joint angles based on the 2D video data was dependent on four markers for each body side placed on the metatarsophalangeal joint, the lateral malleolus, the lateral part of the articulatio genus, and the greater trochanter. Marker placement and angle calculation were performed according to Bini et al. (2014). Lactate was measured using a lactate scout (EKF Diagnostics, Barleben, Germany), and heart rate was measured using a Polar V800 (Polar Electro GmbH, Büttelborn, Germany) with the matching pulse sensor. Angles were determined using Dartfish ProSuite 8.0 (Dartfish, Freiburg, Switzerland) (see Image 1). Six images for each measurement time point (three images at 90° plus three images at the 180° position) were selected. The mean values of the three images separately for the 90° and 180° positions were used for further calculations.

Data pre-processing and analysis method

To allow a comparison of the subjects relative to their (a) fitness level and (b) initial individual posture on the bike, an individual standardization was performed. Therefore, (a) the power outputs relative to the individual anaerobic threshold (IAT) were determined. To answer the question (2), cubic spline interpolation was additionally applied to enable a comparison of the angles relative to the same relative power output. Furthermore, (b) standardized angles were calculated by dividing each angle by the mean angle for the measurements under the IAT (only for (1); this was based on the assumption that the angles below the IAT are likely to be relatively similar due to lower fatigue).

Due to the relatively small sample size, inferential statistical methods were inappropriate. Therefore, an idiographic analysis of the individuals was performed. In order to further discuss the corresponding results using objective metrics, (1) regression equations of the lower-body biomechanics of the standardized angles as a function of the relative power output were reported. Therefore, outliers were identified and removed if values reached three times the interquartile range. Further, to discuss question (2), a dependent t-test was additionally performed to compare the values between the pre- and post-conditions for intensity levels of 60% and 80% of the IAT. The underlying assumptions were checked and confirmed before the calculations. It should be emphasized again at this point that these calculations are intended to support the idiographic analysis and must be interpreted with caution. Calculations were performed using Python (Python Software Foundation, Wilmington, DE, USA) and SPSS Statistics (version 16, SPSS Inc., Chicago, USA).

RESULTS

The test was terminated after total subjective exhaustion (power output: 373.3 ± 37.7 W; min: 320 W; max: 440 W; lactate: 11.58 ± 2.82 mmol/l min: 8.1 mmol/1 max: 15.4 mmol/l; heart rate: 186 ± 16 1/min). The results showed side asymmetries for the knee and foot relative to the IAT. For riding at 80% IAT, the lowest mean absolute difference was found for the knee in the 180° position (2.98 ± 1.31°). The highest mean absolute side difference was found for the foot in the 90° position (5.89 ± 4.85°).

Changes with increasing power output

The visualizations of the changes in the knee and foot angles during progressive intensity increase are presented in Figures 2 and 3. Looking at the quality of the fit (R^2) shows that for the left and right foot in the 180° position, the fit was the worst ($R^2 < 0.25$). Further, the right knee in the 180° position showed a noticeably low R^2 ($R^2 = 0.15$) compared to the other models ($R^2 \geq 0.37$), which can be classified as a strong effect according to Cohen (Ellis, 2010). Visually, between-subject variability increased for riding intensities over the IAT, and the changes seem highly individual.

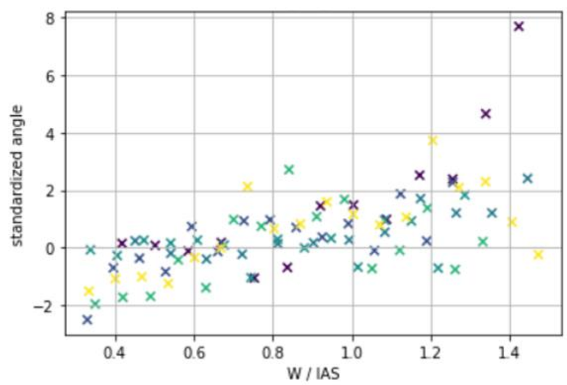
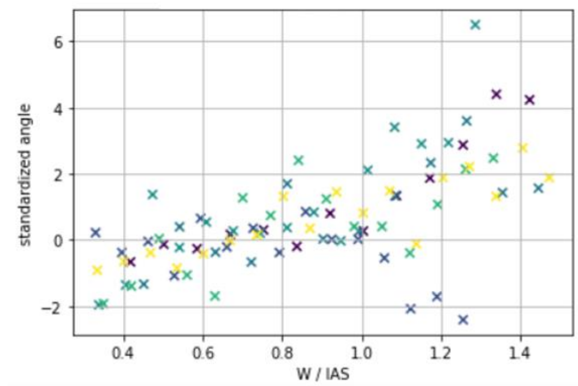
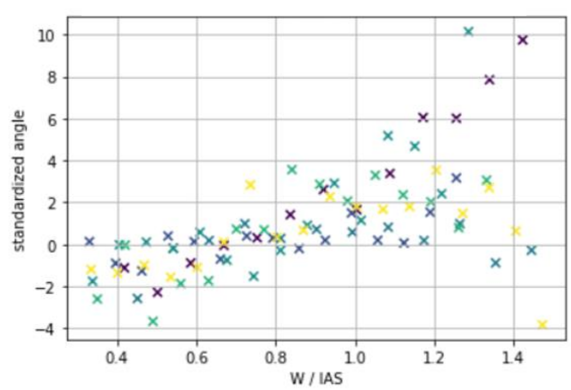
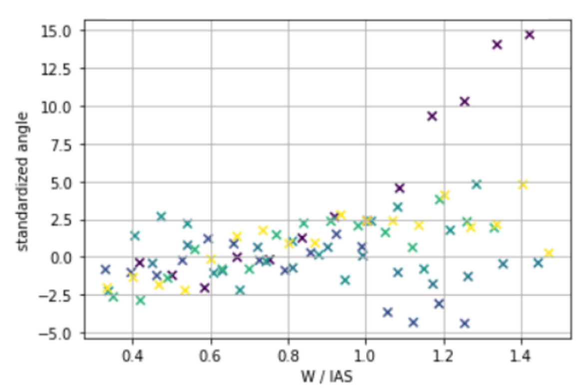
Left knee angle at 90° crank position	**Right knee angle at 90° crank position**
	
$F(1,85) = 55.47$, $p < .001$; $R^2 = .40$; $y = -1.719 + 2.497*x$	$F(1,84) = 74.79$, $p < .001$; $R^2 = .47$; $y = -2.039 + 3.057*x$
Left knee angle at 180° crank position	**Right knee angle at 180° crank position**
	
$F(1,83) = 64.70$, $p < .001$; $R^2 = .44$; $y = -2.903 + 4.383*x$	$F(1,84) = 14.85$, $p < .001$; $R^2 = .15$; $y = -2.061 + 3.059*x$

Figure 2. Changes in knee angle relative to each subject's IAT. Individual standardization was performed. A knee value of 0 represents the mean angle of the individual measurements under the IAT. The colour coding differentiates the individual athletes.

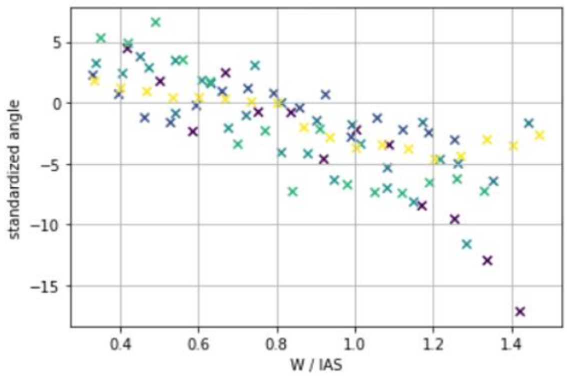
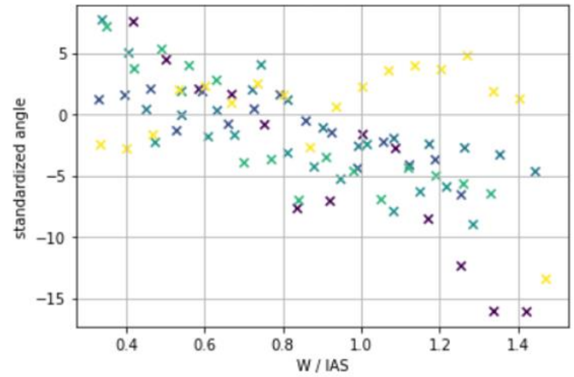
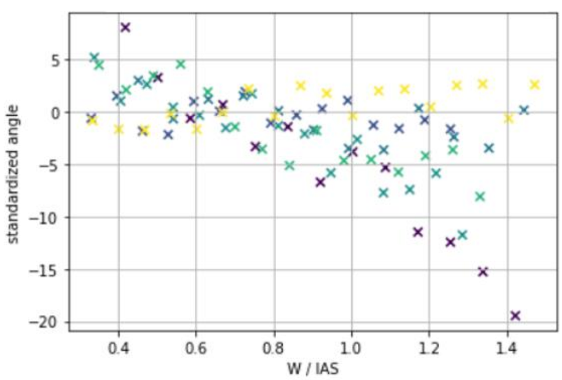
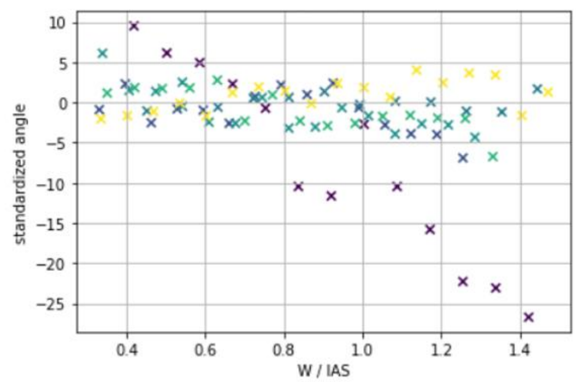
<table>
<tr><th>Left ankle angle at 90° crank position</th><th>Right ankle angle at 90° crank position</th></tr>
<tr><td></td><td></td></tr>
<tr><td>$F(1,85) = 124.74$, $p < .001$; $R^2 = .59$; $y = 6.277 - 9.504*x$</td><td>$F(1,86) = 49.78$, $p < .001$; $R^2 = .37$; $y = 6.306 - 9.135*x$</td></tr>
<tr><th>Left ankle angle at 180° crank position</th><th>Right ankle angle at 180° crank position</th></tr>
<tr><td></td><td></td></tr>
<tr><td>$F(1,85) = 27.64$, $p < .001$; $R^2 = .25$; $y = 4.078 - 6.243*x$</td><td>$F(1,83) = 9.00$, $p = .004$; $R^2 = .0.10$; $y = 2.487 - 3.769*x$</td></tr>
</table>

Figure 3. Changes in foot angle relative to each subject's IAT. Individual standardization was performed. A foot value of 0 represents the mean angle of the individual measurements under the IAT. The colour coding differentiates the individual athletes.

Fatigue-introduced differences

The pre- and post-test comparison showed no differences for the knee and foot angles ($p > .05$). Table 1 shows the respective results.

Table 1. Mean differences between pre- and post-test for the knee and foot angles while riding at intensity levels of 60% and 80% of the IAT.

	90		**180**	
	Left	**Right**	**Left**	**Right**
Knee 60 % IAT	0.58 ± 0.63 *p = .076*	1.41 ± 2.50 *p = .226*	-0.13 ± 1.76 *p = .867*	1.24 ± 3.15 *p = .380*
Foot 60 % IAT	-0.49 ± 3.24 *p = .728*	0.64 ± 2.55 *p = .565*	0.31 ± 3.09 *p = .816*	0.44 ± 4.36 *p = .815*
Knee 80 % IAT	0.32 ± 1.00 *p = .465*	1.22 ± 1.78 *p = .156*	-0.26 ± 1.54 *p = .695*	0.63 ± 2.94 *p = .623*
Foot 80 % IAT	0.75 ± 1.96 *p = .392*	1.11 ± 2.82 *p = .379*	0.82 ± 2.79 *p = .502*	1.44 ± 3.23 *p = .326*

DISCUSSION

The current study's results indicate that with higher power output relative to the IAT, the joint angles change (1). An additional validation is given due to the presence of similar characteristics and effects for both body sides. Overall, the knee angles increase, while the foot angles decrease. These findings are in accordance with the results of other research (Galindo-Martínez et al., 2021; Swart et al., 2019) in which it was stated that the muscles of the lower leg (M. gastrocnemius, M. soleus, M. tibialis anterior) are the first to show differences in range of motion and activation. Regarding the targeted muscles, M. gastrocnemius and soleus seem to be the first to reach exhaustion, resulting in a decrease in the ankle angle and, consequently, an increase in the knee angle (Swart et al., 2019). Under the IAT, the change trend of the respective angles appears almost linear, while with higher levels of fatigue, the interindividual differences change drastically, and the change seems to be nonlinear. This may be caused by different muscle exhaustion and compensation mechanisms, which seem to be highly individual among the subjects due to their individual physical capacities. Further, additional factors, e.g., pain (two subjects mentioned slight pain in the perineum at the end of the test), limited flexibility, or the presence of side asymmetries, might have resulted in highly individual responses. Nevertheless, the individuality of the changes underlines the recommendation of bike fitting under more realistic conditions.

As a possible reason for the low R^2 value for the foot in the 180° position, changes in the angles might be highly individual due to possible differences in muscular status. Further research should evaluate potential relationships. The low fit of the right knee in the 180° position might be due to the presence of side asymmetries, which could possibly be explained by the presence of scoliosis in two subjects.

The pre–post comparison (2) showed that there were no differences present for the knee and foot angles between the rested and fatigued states after the all-out protocol. This may be due to the experience level of the cyclists, who potentially have the ability to (a) recover from exhaustion very quickly or (b) take a position that is economical even in highly fatigued states. Counter to these findings, the works of O´Bryan, Brown, Billaut and Rouffet (2014) and Billaut et al. (2005) explain that with increasing fatigue, intermuscular coordination and, therefore, power output decrease. The lack of differences in the pre–post comparison in the present study is also supported by the findings of Froyd, Milles and Noakes (2013), which stated that neuromuscular function is recovered very quickly (ca. 2 min after termination of the exercise). For more reliable determination of the extent of muscle fatigue and the cause of exercise termination, as well as the time course of central and peripheral fatigue, the present study should be supplemented by measurements via EMG (Hug, Laplaud, Savin & Grelot, 2003) and pressure sensors or special ergometers (Doyle-Baker, Temesi, Medysky, Holash & Millet, 2018). Further research should try to evaluate this aspect, e.g., through more precise evaluation of the level of fatigue and a fatigue that is more specific to that achieved during cycling.

Furthermore, the results show the presence of side asymmetries for the knee and foot. Possible reasons for this might be scoliosis or muscular imbalances. Looking at the posture measurements of the subjects indeed showed that scoliosis was present for two subjects. This also highlights the importance of analysing both body sides in addition to the general posture while performing bike fitting.

It should be mentioned that the fatigue in the present study after the lactate diagnostics probably does not correspond to the athletes' fatigue in practice, e.g., after a race. The extent of central and peripheral fatigue varies with intensity and duration (Thomas, Elmeua, Howatson & Goodall, 2016). Therefore, other results could be obtained, for example, when examining pre–post position after a long cycling race. Further research should address this in the future.

The study has some limitations, but the study was planned as an exploratory pilot study; therefore, these limitations are justifiable from our point of view. Of course, further work is necessary to check the results. The limitations relate to the following points: The representation of the sample is limited, because these were only male, professional, well-trained cyclists with years-long experience in road cycling. The results of this study may or may not be applicable to female, amateur, or recreational cyclists (e.g., amateurs may show greater differences in movement when fatigued). In addition, the sample size is very small, so for generalizable results, further research should aim for an increased sample size and to include cyclists of different performance levels and disciplines.

A few factors, such as the rotation of different body parts, the tracking of the markers, and, therefore, the movement of these body parts, cannot be determined via 2-dimensional recording. However, these lateral and rotational movements could be a factor in causing non-traumatic injuries. For future works, 3D analysis should be considered for movement analysis.

CONCLUSION

The present study's results show that with increasing load, the position and the posture on the bike change; this may be a reason why cyclists have a greater risk of developing a poor posture (Muyor, López-Miñarro., & Alacid, 2011). Therefore, it seems necessary to perform additional strength and posture training (with special focus on the M. erector spinae, the Mm. rhomboidei, the abdominal muscles, and the M. trapezius) to be capable of holding an optimal position (especially when an aerodynamic position is targeted) on the bike for as long as possible. Referring to the review by Streisfeld, Bartoszek, Creran, Inge, McShane and Johnston (2016), the authors hypothesize that cyclists change their position during loads to maintain an optimal force–length–velocity relationship of the muscles. Therefore, and to control the risk of non-traumatic injuries by maximal performance at the same time, it is indispensable to perform function and muscle tests to see which muscles and performance areas need to be trained. Furthermore, the results suggest that it is necessary to perform dynamic bike fitting involving real-world riding situations (e.g., in usual competitive performance or with usual competitive characteristics) to determine the positions during high-intensity or prolonged rides. This holds the potential both to improve cycling performance through a maximization of economy and to prevent non-traumatic injuries. Empirical examination of the topic must be continued in order to develop clearer, scientifically based recommendations for sports practice in the future.

AUTHOR CONTRIBUTIONS

Bartaguiz, Dindorf conceived and designed the experiments; Bartaguiz, Dully performed the experiments; Dindorf and Fröhlich. analysed the data; Fröhlich and Becker contributed materials/analysis tools; Bartaguiz, Dindorf, Dully, Becker and Fröhlich wrote the paper.

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DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

ETHICS STATEMENT

The study was conducted according to the guidelines of the Declaration of Helsinki and approved by "*Technische Universität Kaiserslautern*" for the project conducted. Informed consent was obtained from all subjects involved in the study.

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Goal orientation based relationship between coaching efficiency, athlete satisfaction, and team cohesion

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ABSTRACT

In this study, the mediating role of goal orientations in the relationship between a coach-athlete relationship (CAR) and collective effectiveness (CE), based on the results between the coaching efficiency variables, athlete satisfaction, and team cohesion was investigated. Participants were 252 professional athletes from four different sports. Data were obtained using questionnaires on coaching performance, athlete satisfaction, and team cohesion. Structural equation modelling showed that CAR has a positive indirect effect on athlete satisfaction and a positive direct effect on team cohesion. Athletes' satisfaction also had both direct and indirect positive effects on team cohesion. Also, the coaching effectiveness had the greatest effect on group cohesion. Coaches can use strategies and stimuli that create a sense of satisfaction in athletes and lead them to appropriate, professional, and athletic behaviour. The results show that a good quality CAR increases athletes' focus on their goals and develop their individual skills, thus improving team performance.

Keywords: Sport psychology, Physical activity psychology, Group identity, Motivations, Strategic capability, Social cohesion, Satisfaction, Professional team sports.

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INTRODUCTION

Sports team coaches need two important factors to improve team cohesion. Increase the abilities and satisfaction of athletes. An athlete's understanding of the coach's behaviors and feedback will have a major impact on his or her psychological aspects, including behavior, motivation, performance, and anxiety (Goffena & Horn, 2021). One of the most important factors related to these psychological aspects is coaching efficiency because it is related to coaching behavior (Li et al., 2019).

Performance is one of the characteristics of coaches that is influenced by their expectations, beliefs, and goals (Moore & Weiller-Abels, 2020). It is the effectiveness of awareness that influences coaching behaviors (Keatlholetswe & Malete, 2019). Based on the model of Myers et al. (2008), coaching behavior can affect athletes' performance and behavior. Rylander (2016) studied the role of coaches in influencing individual and team performance and concluded that coaches are the most effective source of performance for athletes.

The coaching structure was developed by Feltz et al. (1999). They used Bandura's (1997) theory of self-efficacy, as a framework and guideline and defined coaching efficiency by their capacity and ability to influence learning (Kamis et al., 2021). Based on the coaching efficiency model of Myers et al. (2008), a coaching performance criterion has four sub-principles: motivation, training technique, game strategy, and character-building (Knott et al., 2019). According to research, coaching is related to motivation, performance, and behavior (Tshube & Hanrahan, 2018). Coaching practice has attracted a lot of attention in sports psychology research in recent years, which shows the importance of this issue. Athletes who work with more efficient coaches have more satisfaction, better performance, more self-esteem, and a more positive attitude (Watson & Kleinert, 2019). Also, Pulido et al. (2020) stated that athletes' perceptions of more efficient coaches are effective in motivating and satisfying.

Various studies on the role of "*athletes 'perceptions of the importance of coaching*" have emphasized the importance of this issue and have said that athletes' perceptions of coaching behavior affect whether they continue or leave their activities (Rocchi & Pelletier, 2018). Also, Soto et al. (2021) argue that coaches have the greatest impact on the performance results of athletes. Coach behaviors can affect athletes' perceptions, motivations, attitudes, and behaviors (Tshube et al., 2018). The effectiveness of motivation is shown by two indicators, effort and satisfaction, and athletes while trying harder, express satisfaction with the sport (Günel & Duyan, 2020).

Inoue et al. (2020) Satisfaction is defined as a psychological structure that indicates the inner and psychological desire, and the athlete's decision to continue cooperation and satisfaction with it, which is influenced by various internal or external factors. In Riemer and Chelladurai's (1998) athlete satisfaction model, satisfaction is defined as a positive and effective response to sports experience that reflects the feeling of appropriate and useful behaviors (individual and group) (Teques et al., 2021). According to Riemer and Chelladurai's (1998) model, the criterion of athletes' satisfaction has four subscales of satisfaction with team performance, satisfaction with personal involvement, satisfaction with training, and satisfaction with individual performance. Erikstad et al. (2018) by examining the motivations for continuing to take part in sports activities, found that athlete satisfaction is the most important factor in the team cohesion model. According to research by Pacewicz et al. (2020), team cohesion is one of the most important indicators of success, regardless of win or loss.

Also, the two main factors, athlete satisfaction, and team cohesion are necessary for people to continue in sports activities, improve sports behavior, participation in physical activity, and the amount of effort of athletes

(Brisimis et al., 2018). According to the team cohesion model of Carron et al. (1985), the criterion of team cohesion has four components: teamwork attraction, social attraction to the group, task integration, and social cohesion (Schürer et al., 2021). Given the very important role of cohesion in maintaining sports participation, it is necessary to examine the factors affecting it. Coaches have a lot of interaction with athletes and that is why they can play an important role in increasing the integration of athletes towards each other or vice versa. Thus, the need to study the behaviors of coaches also shows that coach performance is related to their behavior (Bezaire, 2020). The project design and its results can have many educational applications for coaches and athletes in the country because coaches who have survived coach training are more effective than coaches who have passed this course (Junior et al., 2018). As Smittick et al. (2019) have shown that athletes who have worked with trained coaches experience less anxiety, higher levels of anxiety and self-esteem, less stability and solidarity with the coach and team, and are less likely to leave training.

Given that most of the studies conducted on athletes' perceptions of coaching and coaching capacity, and unfortunately the previous research process, less reference to an important feature, (direct relationship between coaching performance and coaching behavior), this article uses Structural equation testing has examined the causal relationships between research variables, perception of athletes 'performance as an effective factor in athletes' satisfaction and their team integration (CE). Thus, using the data and results of this research, dear coaches can identify effective strategies to improve the perception of athletes and their satisfaction and use them to strengthen individual and team cohesion. Also, respected officials of federations and sports officials can use the results of the article to enrich the training courses of coaches at different levels of coaching.

Coaching efficiency

The special role of coaches in sport has led researchers to focus on the impact of "*coaches 'effectiveness beliefs on athletes' learning, development, and performance*" (Wagstaff, 2017). Feltz et al. (1999) developed a conceptual model for coaching effectiveness, based on Bandura's (1997) theory and the performance model of teachers Denham and Michael (1981), which was developed as a measure of coach effectiveness in practice (Kamis et al., 2021; Kao et al., 2021; Kaya, 2019). In this conceptual model, Feltz et al. (1999) four dimensions were considered for coaching effectiveness, which affected the results of coaches, individual athletes, and teams. These dimensions include coaches 'confidence in (a) their ability to coach the team during the match and guide it to deliver successful performance (game strategy effectiveness), (b) their ability to influence players' skills and mental states (motivational efficiency). , (C) their ability to develop and recognize skills (technical efficiency), and (d) their ability to develop their athletes' personality (characterization efficiency) (Parent & Chappelet, 2017).

The effectiveness of the trainers was expressed in the form of several main factors. (A) Strategic performance refers to the coaches' confidence in coaching during the match and their ability to lead the team to achieve successful team performance. (B) Motivational efficiency refers to a coach's confidence in his or her ability to change the mental state and abilities of athletes. (C) The effectiveness of teaching methods refers to the degree to which educators are confident in their diagnostic and training skills. (D) Finally, personality building efficiency involves coaches' perceptions of their abilities to influence personality, maturity, and the development of positive athletic attitudes in the athlete (Potrac et al., 2013).

Athlete satisfaction

Satisfaction is an inner and mental state of participating and enjoying sports. Without satisfaction, athletes look for other sources of success and enjoyment. In this regard, some researchers believe that the main purpose of the exercise is to provide opportunities for athletes through sports participation (Loughead et al., 2014). It is very important to discuss the satisfaction of athletes because athletes are the main producers and stakeholders of sports. Exercise is like a hobby for athletes, and, athletes spend more time training than competing (Schinke et al., 2016). The study of athlete satisfaction is important for several reasons: First, Daniel (1983) believes that the study of satisfaction is important and vital because the compatibility between achieving an organizational goal and the satisfaction of people within the organization is a necessary and clear goal. And are complementary. Coaches and managers must be sensitive to the satisfaction and enjoyment of the athlete experience (Kroupis et al., 2019). Second, Kendall and Hulin (1969) argue that measuring athlete satisfaction is an important step in developing a general theory that can be used in future research. Finally, although athlete satisfaction has been used as a variable in research, the methods used to do so have been inadequate (Tavakoli et al., 2018). Riemer and Chelladurai (1998) define athlete satisfaction as a positive emotional state that is achieved by a complex evaluation of the structures, processes, and consequences associated with sports experiences. This assessment is based on the difference between what the athlete wanted and what he received. The parameters of this assessment include psychological, physical, and environmental contexts (Baker et al., 2017).

Team cohesion

Team cohesion is the strength and level of interpersonal communication of team members and is a determining factor in team development, for successful teams. It is the interpersonal bond that facilitates the participation of members and keeps them motivated to achieve their goals. Cohesive teams have a "*us*" attitude (Weinberg & Gould, 2019). Sports psychologists believe that athletes not only need to increase self-awareness but also need to be able to understand the roles, perspectives, values, motivations, and needs of other team members. They have suggested that increasing mutual understanding between team members is the basis of the team-building process (Piasecki et al., 2021). The importance of mutual understanding between team members and the benefits of team dynamics has also been acknowledged by other sports psychologists. For example, Orlick and McCaffrey (1991) state that many problems between team members (which can undermine team dynamism) are the result of not understanding the needs, motivations, and feelings of their teammates (Gallucci, 2013).

Team or group cohesion in sport is defined as a dynamic process that reflects the intensity of the group's concerted efforts to stay united in pursuit of goals or to meet the affective needs of members. According to this definition, team cohesion in sports includes two main dimensions, task cohesion, and social cohesion. Task coherence indicates the degree to which group members are organized and the extent to which they are committed to achieving goals and tasks or tasks. In contrast, social cohesion reflects group attractiveness with aspects that create group attractiveness to strangers (Filho et al., 2015). Successful teams are in control of almost every single situation. Also, in unsuccessful teams, there is a difference in the perception of player cohesion. Researchers have identified differences in perceptions of teamwork cohesion as a possible determinant of team success (Najafi et al., 2018).

According to the model of Shanthi Jacob and Carron (1998), cohesion in sports is multidimensional, dynamic, instrumental, and emotional in nature, and environmental, individual, leadership, and team factors are related to or can predict team cohesion. Leadership factors include leadership behaviours, leadership, decision-making style, personal relationship between coach and athlete, and coach-team relationship. The leadership factor is especially important because coaching behaviours can predict and influence cohesion in sports teams. The characteristics of coaches include the type and number of feedback, training, social support, type of leadership (authoritarian or democratic), and reaction to playing conditions and pressures (McLaren & Spink, 2020). The conceptual model of the research is shown in Figure 1.

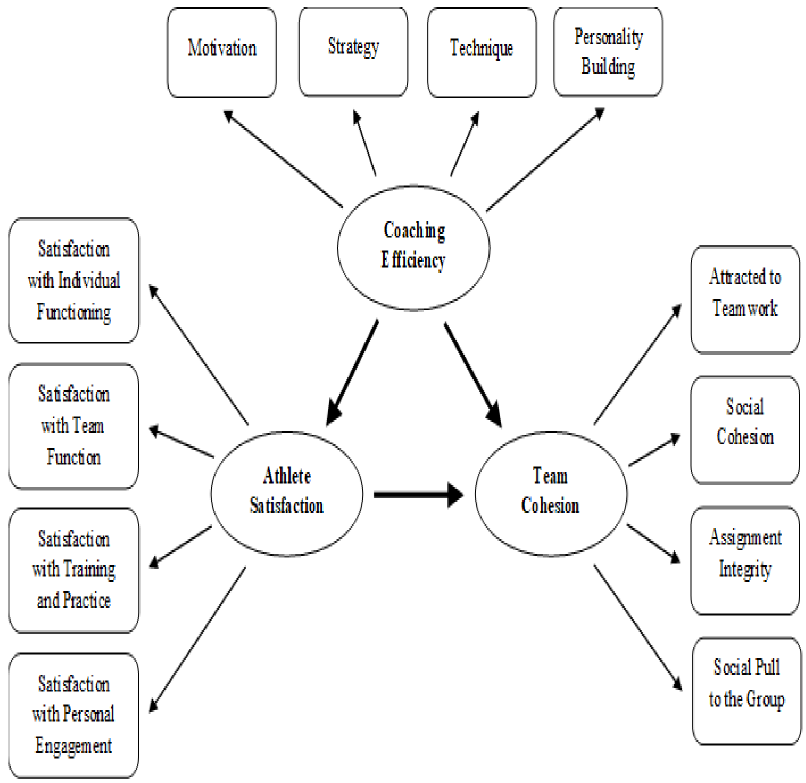

Figure 1. The conceptual model of the research.

MATERIAL AND METHODS

Participants

The statistical population of this study includes people who all have a history of professional and team sports and also have the least history of membership in a sports team in their field. Selected team sports include football, basketball, volleyball, and handball. The selected sports teams are a combination of men's and women's teams in different age categories. This criterion ensures that all participants are high-performing athletes and that participants in recreational sports are eliminated. The sample is selected by simple random sampling. In the factor analysis method, the number of samples should be at least twice the number of items, which according to the number of items in the research questionnaire (56 items), the number of samples is selected equal to 252 people (4.5 times). Thus, the statistical sample of this study includes 5 football teams (3 men's teams and 2 women's teams), 3 basketball teams (2 men's teams and 1 women's team), 3 volleyball teams (1 men's team and 2 women's teams) and 3 handball teams (2 men's teams and 1 women's team).

Procedures

The tools of the present study include a personal information questionnaire (such as name, age, gender, sports history, type of sport, team history, etc.), and a coaching performance questionnaire (athletes' views on the performance of coaches). Myers et al. (2008) include 26 items, Athlete Satisfaction Questionnaire (level of satisfaction that athletes experience by participating in training), Riemer and Chelladurai (1998) includes 16 items and Team Cohesion Questionnaire (Team Cohesion Assessment) Carron et al. (1985) includes 18 cases (Carron et al., 1985; Myers et al., 2008; Riemer & Chelladurai, 1998). These are based on a Likert value range of 5 (1 = agree, 2 = agree, 3 = no opinion, 4 = disagree, and 5 = disagree). To test the validity of the research tool, the opinions of 10 professors of sports management and 10 successful coaches in sports teams are used. After a random study of 42 members of the research sample, Cronbach's alpha results show that the research tools are very reliable (Cronbach's alpha coaching efficiency = 0.92, Cronbach's athlete satisfaction = 0.79, and Cronbach's team cohesion = 0.84). The procedures adopted in this research obey the Criteria of Ethics in Research with Human Beings according to Resolution no. 466/12 of the National Health Council. This research is applied, descriptive and correlational purpose. With the coordination of the trainers of the sample research teams, the mentioned questionnaires are distributed among the players of the teams, and the research data are prepared in this way.

Analysis

The results of confirmatory factor analysis confirm the construct validity of all research variables. These results also show that all research questions have good external validity in evaluating research variables. The KMO (Kaiser-Mayer-Olkin) test confirms the adequacy of the sample members for path analysis (above 0.7 acceptable). The results of the Bartlett test also show that the correlation matrix between the research variables is not a single matrix. Thus, the structure (factor model) can be identified and defined based on the correlation of variables (Ho et al., 2017). Omit, SPSS, and Amos software is used to analyse the research data. Table 1 shows the results of the above two tests.

Table 1. Results of KMO Test and Bartlett's Test.

KMO Test	Bartlett's Test	
	Chi-Square	2169.863
0.749	Degrees of freedom	52
	Significant	.000**

*Note. **significant at the level of p ≤ .01.*

RESULTS

Description of research topics

The statistical sample of the study includes 252 professional athletes who work with sports teams. Of these, 165 are male (65.5%) and 87 are female (34.5%). Omit, 41 are under 20 years (16.3%), 68 are between 20 and 25 years (27%), 94 are between 25 and 30 years (37.3%) and 49 are over 30 years (19.4%). Also, 39 people are between 1 and 3 years old (15.5%), 66 people are between 3 and 5 years old (26.2%), 84 people are between 5 and 7 years old (33.3%) and 63 people are between 7 and 9 years old (25%). Who has a history of professional sports and membership in a sports team?

Normality of research variables

Normality of research data is one of the necessary conditions for path analysis. In some studies, multivariate normality, cortisone, and skewness have been used to assess normality (Bardakcı, 2019). Table 2 shows the normality of the research variables.

Table 2. Normality of research variables.

Indicator / Variable	Coaching efficiency	Athlete satisfaction	Team cohesion
Mean	42.94	21.37	17.27
Standard Deviation	8.94	3.59	3.28
Kurtosis	-0.484	-0.240	-0.335
Skewness	-0.365	-0.518	-0.223

According to the table above, Acceptable values of skewness fall between −3 and +3, and kurtosis is appropriate from a range of ±10 when utilizing SEM (Brown, 2006). In addition, the multivariate normality, the kurtosis, and the skewness are also significant. Therefore, we conclude that the distribution of research data is normal. Table 3 shows the correlation matrix between the study variables.

Table 3. Correlation matrix between the study variables.

Variable	Coaching efficiency	Athlete satisfaction	Team cohesion
Coaching efficiency	1		
Athlete satisfaction	0.792**	1	
Team cohesion	0.430**	0.567**	1

Note. **significant at the level of $p \leq .01$.

According to Table 3, the results of the Pearson correlation coefficient show that there is a positive and significant relationship between the variables of Coaching Efficiency, Athlete Satisfaction, and Team cohesion at the level of $p \leq .01$ (Helwig, 2017).

Factor model and data analysis

In this model, the coaching efficiency variable is considered as an exogenous variable and the variables of athlete satisfaction, and team cohesion are considered as endogenous variables. Various statistics and indicators have been presented to measure the model fit. Because each of these indicators reflects only a particular aspect of the model fit. Thus, several indicators are usually used to measure model fit. To test the fit of the model, among the absolute fit indices, the relative chi-square index (CMIN/DF) (Chi-square fit statistics/degree of freedom) and the second root index, estimating the variance of approximation error (RMSEA) (Root Mean Square Error of Approximation), and among the adaptive fit indices, the CFI (Comparative fit index), TLI (Tucker–Lewis index), IFI (Incremental fit index) and NFI (Normed fit index) indices are used. Figures 2 and 3 show the results of standard and non-standard regression coefficients of structural equation modelling.

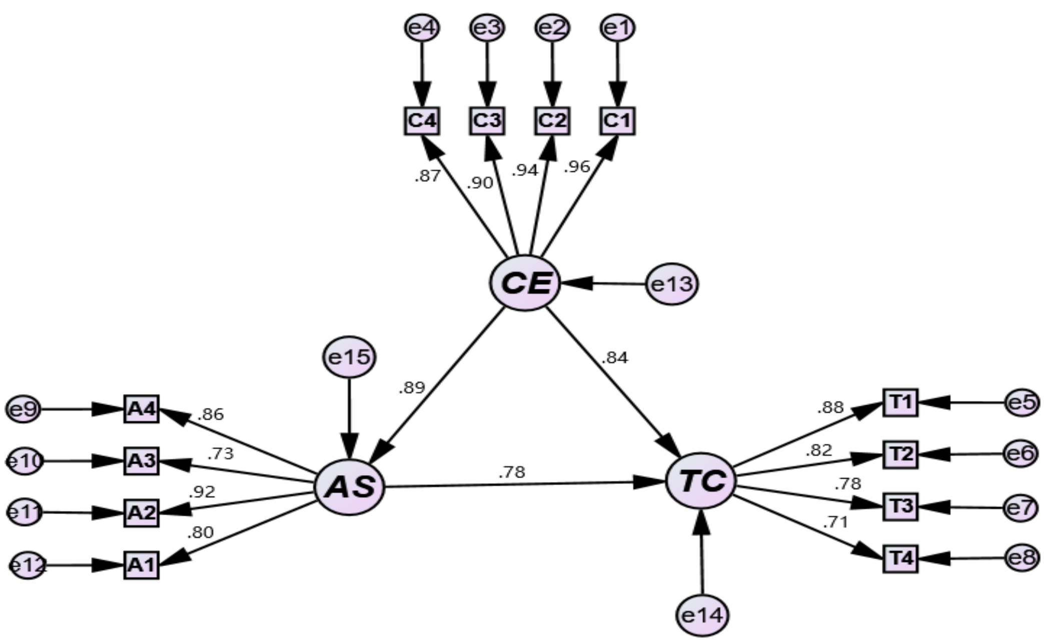

Figure 2. Standard regression coefficients.

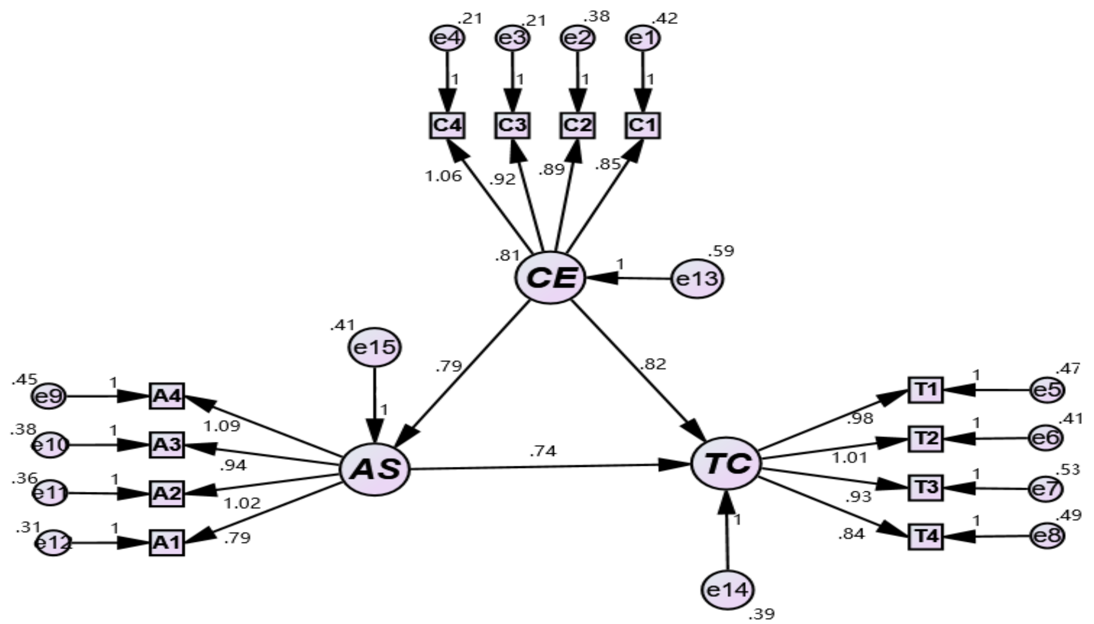

Figure 3. Non-standard regression coefficients.

According to the above figures, standard coefficients, non-standard coefficients, and significant numbers are shown in Table 4.

Table 4. Standard and non-standard coefficients of structural equation modelling.

Path	Standard coefficient	Non-standard coefficient	Significant number
CE→AS	0.89	0.79	9.53
CE→TC	0.84	0.82	6.81
AS→TC	0.78	0.74	6.02

Note. CE (Coaching Efficiency), AS (Athlete Satisfaction), and TC (Team Cohesion).

According to Table 4, all paths are statistically significant. Because the standard coefficients are in the range of ±1 and close to +1, the paths have strong and positive coefficients (Mukaka, 2012). Significance means that the absolute value of the numbers must be greater than 1.96. The greater the significance number than 1.96, indicates that the independent variable has a stronger effect on the dependent variable (Deng, 2016). Table 5 shows the direct, indirect, and total effects of the research variables on each other.

Table 5. Direct, indirect, and total effects.

Path	Direct effect	Indirect effect	Total effect
CE→AS	0.000	0.413	0.413
CE→TC	0.541	0.000	0.541
AS→TC	0.291	0.183	0.474

According to the above table, coaching efficiency has a positive and indirect effect on athletes' satisfaction (β = 0.413). Also, the effect of coaching efficiency on team cohesion is positive and direct (β = 0.541). With a positive and direct effect on team cohesion (β = 0.291), athletes' satisfaction has a positive and indirect effect on it (β = 0.183). Examination of the total effect column also shows that coaching efficiency has the greatest effect on team cohesion (β = 0.541). The model fit indices are shown in Table 6.

Table 6. Results of structural equation modelling fit.

Indicator	Value
CFI	0.997
TLI	0.959
IFI	0.989
NFI	0.974
CMIN/DF	1.487
RMSEA	0.042
p-value	.000

The table above shows that the research fit indicators of the conceptual model are very appropriate. Since CFI, TLI, IFI, and NFI indices are all higher than 0.95, CMIN / DF index is less than 2 and RMSEA index is less than 0.5 (Kline, 2015). Finally, according to the obtained values, the fit of the research model is reported to be good and acceptable.

DISCUSSION

This study examines the mechanism by which the relationship between the three variables, coaching efficiency, athlete satisfaction, and team cohesion in sports teams is examined. Based on the research literature, a preliminary model is proposed to investigate the relationship between the above variables. The results show that there is a positive and significant relationship between coaching efficiency and team cohesion and athlete satisfaction. Also, other research in this field has confirmed the relationship between coaching performance and athlete satisfaction as well as team cohesion in sports teams (Günel & Duyan, 2020; Junior et al., 2018; Kamis et al., 2021).

For coaches of sports teams, efficiency is an essential feature. Because this feature can help in choosing the best methods and tactics for team success, motivate athletes during training and competition, and create a positive attitude towards sports, and sports behaviours. Thus, the reflection of a coach's behaviour and performance can be reflected in the team performance and individual performance of the athletes who work with him (Keatlholetswe & Malete, 2019; Smittick et al., 2019). The effective behaviour of the coach can affect the athlete's perception and increase and enhance individual satisfaction and improve team cohesion. Only then will the athlete feel satisfied with the coach, his teammates, and his sport. Thus, the coach, according to his efficiency, can strengthen the sense of satisfaction, and individual and group cohesion (CE) in the athlete. Developing and promoting such behaviours in sports environments can improve team performance and cohesion and foster a spirit of satisfaction in athletes. Thus, athletes who experience coaching behaviours with their perception will be more satisfied and better on the team than in training activities(McLaren & Spink, 2020; Pacewicz et al., 2020; Watson & Kleinert, 2019).

In general, the results of the study showed that "*athletes' perceptions of the effectiveness of coaches*" affect their performance, team cohesion, and level of satisfaction. In mediator analysis, the athlete satisfaction variable can play a mediating role between the variables, coaching efficiency, and team cohesion. The effectiveness of the coach tests the athlete's understanding of the coach's ability to promote athlete satisfaction and professional behaviour in the team, to deal with pride and superiority in the team, instil respect for others and technical principles, and to build team cohesion. Technical factors in sports have a significant impact on promoting the professional personality of athletes, increasing athlete satisfaction and cohesion within the athlete team (García-Calvo et al., 2014; Kao & Tsai, 2016; Kim & Cruz, 2016). Finally, coaches can use strategies and stimuli that give the athlete a sense of satisfaction and effectiveness in the team and lead him to appropriate athletic behaviour and professional cohesion within the team. Such a process can increase the experience of discussing CE (and in groups) and the satisfaction of athletes.

CONCLUSIONS

Coaches who have passed coaching courses have been more effective, and, the athlete's perception of coaching effectiveness, so affects their motivation, attitude and performance, satisfaction, and individual and group cohesion. Thus, the model presented in this research has many applications for better management of team sports in the departments of coaching training and coaching courses to increase the level of coaching efficiency by including the principles of training efficiency in coaching courses. It also helps the dear coaches to increase the cohesion in the group under their guidance and the level of satisfaction of the athletes, to provide suitable conditions for improving the performance, development, and maintenance of qualified athletes.

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DISCLOSURE STATEMENT

No potential conflict of interest was reported by the author.

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SCIENTIFIC JOURNAL OF SPORT AND PERFORMANCE

ORIGINAL ARTICLE

Investigation into the accuracy of subjective load parameters in comparison to analytical load measurements in NCAA Division I women's volleyball

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ABSTRACT

Monitoring athletes' workload has become common practice in sports and differs depending on the sport's physical demands. Within volleyball, an inertial measurement unit can be utilized to track the number of jumps performed by players. However, other methods of measuring jump frequency are needed for teams without access to this equipment. The purpose of this study was to determine if volleyball athletes can accurately predict the number of jumps performed after training and matches when given a perceptual scale and if player position, session rating of perceived exertion (sRPE), and perceived sets played affected the players' accuracy. Less than half of the team's jump count estimations (23.2%) were within 25 of the actual number of jumps and over half of the players' responses (58%) were within 50 of the measured number of jumps. A generalized estimating equation (GEE) with a binary response was used to investigate the impact of position, sRPE, and sets played. Position was the only variable to have a significant impact on jump count accuracy. Based on these results, a perceptual scale could be useful in better understanding players' jump counts following training, but number of jumps allotted to each jump range and position could impact accuracy.
Keywords: Performance analysis of sport, Physical conditioning, Jump count, Workload, Sports performance, Collegiate sports.

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INTRODUCTION

Volleyball is in the top ten of the most popular sports worldwide and has over 18,000 athletes participating at the collegiate level in the United States (Baugh et al., 2018). With such high participation rates, better understanding of athlete injury within the sport are of value to reduce time lost (Soligard et al., 2016). Epidemiologically centred research focused on injuries sustained by volleyball players, report that volleyball athletes are at the greatest risk for acute ankle injuries and overuse injuries in the knee and shoulder (Baugh et al., 2018; Ferretti et al., 1984; Reeser, 2006). Specifically, these common lower body injuries predominantly take form as ankle sprains or patellar tendinitis of the knee (Cuñado-González et al., 2019; Reeser, 2006). While ankle sprains are often an acute injury, the development of patellar tendinitis is an injury that develops overtime due to continuous loading of the knee without sufficient recovery (Couppé et al., 2008; Richards et al., 1996). Of particular interest, is how the onset of patellar tendinitis is impacted by training volume and correspondingly, jump frequency (Bahr & Bahr, 2014; Cuñado-González et al., 2019; Visnes & Bahr, 2012).

Jumping is a primary movement performed repetitively by players during training and matches, with the exception of defensive specialists (liberos), (Bahr & Bahr, 2014; Skazalski et al., 2018a). Over the course of a professional season, Skazalski and colleagues (2018) recorded 129,173 jumps performed across 142 sessions (practices and matches), equating to a team total of 910 jumps per session (Skazalski et al., 2018a). For comparison, research in basketball players observed an average of 371 jumps over the course of approximately 7.19 sessions (practices and games) (Ghali et al., 2020). Given the higher volume of jumping in volume, the prevalence of symptoms of jumper's knee are greater in volleyball athletes compared to basketball (Lian et al., 2005).

Interestingly, research examining jump frequency in volleyball athletes has provided evidence that training volume (number of hours per week) may not be as indicative of risk for jumper's knee, as individual player jump volume. While a team may train the same number of hours in a week, particular players may jump more than others during each training session, resulting in more loading of the knee and ankle joints, putting them at an increased risk for injury(Bahr & Bahr, 2014). Specifically, Ferretti and colleagues (1984) determined that frequency of play was a significant factor contributing to incidence of jumper's knee (patellar tendinitis) in volleyball players, with a peak incidence occurring in athletes who played five or more times a week(Ferretti et al., 1984). However, Visnes & Bahr (2013) determined match exposure and every extra hour of training to be sports-related predictors for developing jumper's knee (Visnes & Bahr, 2012). Players who developed jumper's knee, recorded 10.5 ± 6.2 h/week of volleyball training prior to the start of the study, while the asymptomatic players only participated in 7.6 ± 4.6 h/week.

Volleyball specific wearable technology to monitor training was developed using inertial measurement unit (IMU). Vert (Mayfonk Athletic, Fort Lauderdale, FL, USA) is a hip worn device that tracks various jump parameters (jump count, jump height, landing impact and kinetic energy), which are all registered via energy (from contacting the ground) traveling up the kinetic chain and being registered by the device at centre of mass. Validity and reliability of Vert's jump counting capabilities are well established in the literature (Borges et al., 2017; Brooks et al., 2018; Charlton et al., 2017; MacDonald et al., 2017; Skazalski et al., 2018a). Currently over 450 teams at the collegiate, professional and Olympic level teams utilize the technology but with 113 collegiate men's teams and 1,071 collegiate women's in the NCAA alone, there is an apparent wide range of teams and athletes not utilizing this device to track external load (Baugh et al., 2018), potentially cost being a limited factor to widespread adoption. One alternative to the use of Vert, when attempting to track player jump count in volleyball, is video analysis. However, this analysis requires recording of all practices and matches to be reviewed after play, which can be very time intensive, especially considering multiple players, are jumping at the same time (Bahr & Bahr, 2014). Therefore, for teams who do not have the resources to implement any of these jump-tracking practices, an easy, inexpensive, sports-specific alternative could be beneficial. Although sRPE by time is often used for monitoring workload in sport, it fails to provide insight into jump count as it can be influenced by other fatiguing factors like mechanical load (change of direction, acceleration, and decelerations) and total impacts (digs and jumps). Linell (2015) only observed a moderate correlation when examining sRPE and mechanical load ($r = 0.581$) and total impacts ($r = 0.640$). Therefore, the purpose of this study is to determine if Division I women's volleyball players can accurately estimate jump frequency utilizing a perceptual scale following practice and matches as an alternative method to IMU systems. We hypothesized that players will not be able to accurately estimate jump count and position will play a role in accuracy with those who jump less being more accurate. Lastly, higher ratings of sRPE and perceived sets played will also result in greater inaccuracy compared to those with lower.

MATERIAL AND METHODS

Participants

Thirteen female NCAA Division I volleyball players competing on a team in the South-eastern Conference participated in the present study (Table 1). The age of participants ranged between 18 and 22 years old. The completion of a set number of practice sessions and matches in which Vert data was collected and surveys were completed was included in the analysis. All participants signed an informed consent form prior to the start of the study and approval from the University of Mississippi Institutional Review Board was obtained.

Table 1. Participant demographics and results from question 1 of pre-study questionnaire.

Variables	Mean ± SD	Range
Age (years)	19 ± 1.2	18 - 22
Height (cm)	180.3 ± 9.7	165.1 – 190.5
Body Mass (kg)	75.1 ± 14.0	55.2 - 97.3
Q1 (months)	21.5 ± 15.2	2 - 42

Note. Q1. Experience monitoring personal jump count during training. N = 13.

Procedures

Participants completed a pre-study survey directed at assessing the extent of their experience with the VERT technology, along with determining their self-perceived ability to predict jump frequency following training. Following completion of the pre-study survey, all participants were familiarized with the four-question, post-training workload survey they complete following all of their practices and matches for the remainder of the season.

Preliminary survey

With the consideration that this is a novel investigation, the surveys were created by the researcher and are not direct replicas of surveys used in previous research. Therefore, the development of the pre-study survey was done by following specific steps as specified by Kyriazos & Stalikas (2018). An expert panel comprised of the team's head coach (former volleyball Olympian), two Division I assistant volleyball coaches, the team strength coach (6 years using Vert system with the volleyball team), the performance lab director for Vert, and a scientist with experience in survey development was sent the survey prior to its use in the study to rate the questions and provide feedback. Following the panel's feedback, the pre-study survey was adjusted. In addition, further refinement of the pre-study questionnaire followed in line with suggestions from Podsakoff et al. (2003) and Flake and Fried (2019) in an effort by the researcher to avoid bias and questionable measurement practices when dealing with the development and utilization of subjective measurements (Podsakoff et al., 2003).

Workload survey development

The workload survey was administered following each practice and match through which sRPE, perceived sets played, jump count, and any self-counting of jumps is inquired. For sRPE, the modified Borg scale was utilized, with the scale ranging from 1, signifying very light activity, to 10, signifying maximal exertion (Borg, 1990). This sRPE as a measure of internal load has been used previously in volleyball specific studies (Kraft et al., 2020; Mendes et al., 2018; Vlantes & Readdy, 2017), as well as in other sports, such as soccer and running (Costa et al., 2022; Mann et al., 2019). Following sRPE, the players were asked to provide how many sets it felt like they had just played. The players were given a scale (<1 to 10), which is based on their responses when asked how many perceived sets they felt like they had played following their hardest and longest practice and match. The highest response given was 6, thereby resulting in the cap on the scale to be 10. Without measuring the player's duration of activity, this is a sports-specific measurement designed to see how it interacts with the other dependent variables being questioned. Thirdly, the players were prompted to estimate their jump range. The ranges for this question were generated based off the compilation of jump averages provided by Vert from fall and spring jump counts of 50 volleyball teams that use Vert, along with average jump numbers from the previous season data of the team being used in this study. The jump frequencies provided to the player's had a minimum of <25, and a maximum of >350, with each interval being separated by 25 jumps. Lastly, the players were asked if they counted jumps in their head during the preceding practice or match. This question served as insurance that the players accuracy or inaccuracy in predicting jump count is not based on any sort of self-counting.

Procedures

Participants were familiarized with the workload survey and a mock example of how each participant would receive the survey on their phone following training was conducted. The automated message containing the workload survey was sent out by the researcher to each participant via the Teams messenger app (Teammates Pty. Ltd., Australia). Once all participants received the message, they were asked to fill out the survey and sent it back ensuring they had a full understanding of the protocol prior to the start of the study. Following familiarization, the study began the next practice and concluded at the end of the season. Ten to fifteen minutes before the end of each practice and match, the participants received the questionnaire as an automated message. Therefore, the participants had access to the survey once they returned to their phones following practices and matches. Considering post-practice and match cool-downs and meetings, players had access to the survey approximately 15 minutes after training and matches. Thus, players that had not completed the survey 30 minutes after the survey opening received a reminder to complete the survey. If the survey had not been submitted by the 45-minute mark, the player's survey was considered missed data. The collection of subjective workload perception approximately 20 minutes following training was modelled after previous studies (Kraft et al., 2020; Vlantes & Readdy, 2017).

In addition to the collected survey responses, analytical workload data was collected via Vert, an IMU device (Mayfonk Athletic, Fort Lauderdale, FL, USA). Each player wore a Vert device during practices and matches in a waistband specified to them by their jersey number. All of the jump count data collected by each players Vert device and was extrapolated from the Vert team database and loaded into an excel sheet to be de-identified.

Analysis

Responses collected from the pre-study survey are seen in Table 2. Determining the accuracy of the players jump range selection was done by block coding each jump range. Every day, after the collection of surveys and jump count data, each player's accuracy (accurate = jump count falls in range selected) was established. In this case, we would note the percent of times individuals selected the correct jump block, were off by 1 block, 2 blocks, and 3 or greater jump blocks, and report those percentages. The effect that months of experience players have had monitoring jump count during training has on player accuracy throughout the study was determined by running a binary logistic regression. Additionally, a generalized estimating equation (GEE) was utilized to determine if the players' jump count accuracy differed based on player position, session rating of perceived exertion (sRPE), or perceived sets played. Each predictor variable was implemented into the GEE as an individual factor. Furthermore, to account for the small population size of this study, use of bias-corrected empirical SE estimators & df estimation methods were used, rather than the empirical sandwich estimator, ensuring small type one error rates. All analyses were conducted using SPSS version 26 (IBM Corporation, New York, NY, USA).

RESULTS

Thirteen NCAA DI women's volleyball players were included in the study. Participant demographics are reported in Table 1, along with the results from question 1 on the pre-study survey, pertaining to the players' reported months of experience monitoring jump count during volleyball training.

All thirteen players completed the pre-study questionnaire prior to starting the study. The majority of the players had previous experience using Vert, which was anticipated given its utilization by the team in previous seasons. Concerning their awareness of their jump count, most players reported never or rarely looking at or being aware of their jump count during training, but almost always checking the Vert for their jump count post training. Lastly, the majority of players reported that predicting their jumps would be slightly difficult, but they were predominantly slightly to moderately confident they could do it.

The response rate on the post-training survey was 96%. The average response time on the post-training survey, across all players, was 28.75 minutes for matches and 33.75 minutes for practices. It should be noted that players did not have access to their phones until approximately 15 minutes after training, on average. Over the course of 6 weeks, data was collected from 24 training sessions (20 practices and 4 matches). Overall, with the consideration of missed player data over the course of the study, 284 data points were used for analysis.

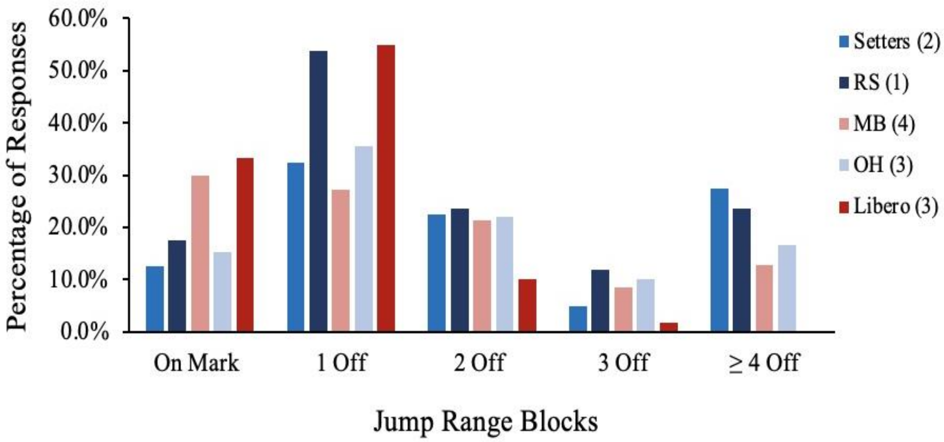
Table 2. Average jump volume among player positions.

Position	N	Mean ± SD	Range
Setter	2	185.4 ± 109.4	6 - 427
Right side hitter	1	106.9 ± 48.8	20 - 215
Middle blocker	4	125.7 ± 71.5	7 - 270
Outside hitter	3	114.5 ± 51.9	35 - 238
Libero	3	48.9 ± 19.0	26 - 85
Total	13	113.1 ± 78.1	6 - 427

Player jump volume data across positions are reported in Table 2. Out of all practices, setters jumped the most and had the greatest jump frequency range, followed by middle blockers, outside hitters, and right side.

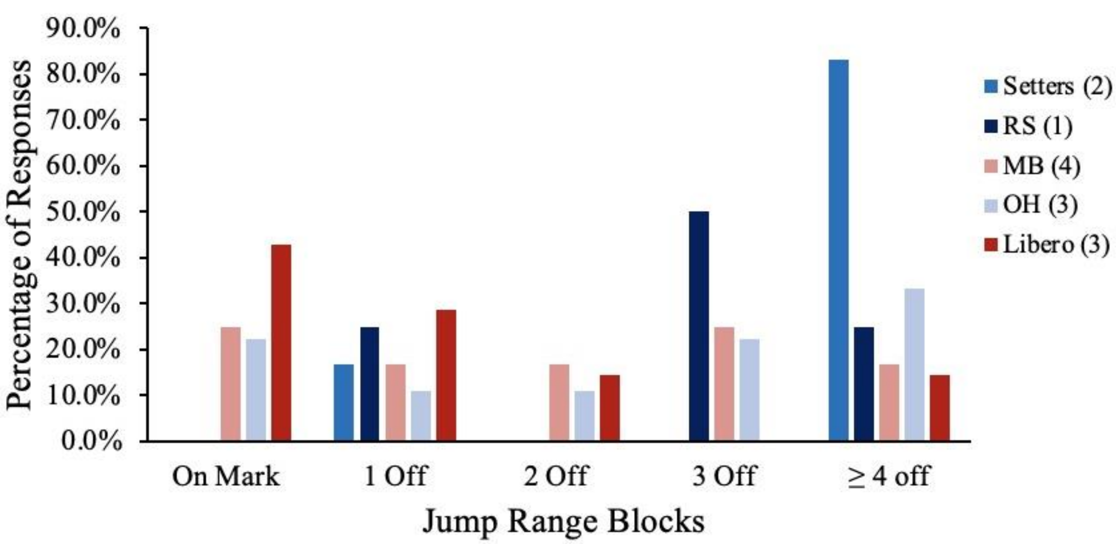
Liberos were found to have the lowest jump volume, as well as the lowest range between the maximum and the minimum number of jumps performed across all practices and matches.

Player accuracy on the post-training survey was defined as players selecting the jump range that their actual number of jumps performed (reported by Vert) fell into. Results of player accuracy are separated by position and illustrated in Figure 1, for all practices, and Figure 2, for all matches. We found that 58% of the player's jump range selections, over the course of the study, were within 50 jumps of the actual number of jumps they performed, with the remaining 42% of selections being 2 or more jump ranges off from the number of jumps actually performed by the players.



Note. Player percent accuracy for correct jump range selection (on mark) or inaccurate by 1, 2, 3, or 4 or more jump ranges. Player positions: setters, RS = right side, MB = middle blockers, OH = outside hitters, and liberos, and the number next to each position indicates the number of players playing that position.

Figure 1. Players jump range selection accuracy for practices.



Note. Jump count estimation accuracy across matches (total measures = 38).

Figure 2. Player jump range selection accuracy for matches.

A binary logistic regression revealed that months of experience monitoring personal jump count during training, reported by the players prior to the start of the study, had a nonsignificant effect (p = .533) on player accuracy. Furthermore, the results from the GEE are shown in Table 3. The only predictor variable that reached significance (p < .05) was player position. Therefore, there was a significant interaction found between jump count estimation accuracy and position (p < .001), but not for sRPE and accuracy (p = 0.62) or perceived sets played and accuracy (p = .93). Additionally, the small, yet positive coefficient in the interaction between player position and accuracy, based on how the positions were coded, is likely due to low accuracy among setters (coded as 1) and the high accuracy among liberos (coded as 5). More specifically, out of all of the players jump count estimations, setters were only 10.8% accurate, followed by right sides (13.6%), outsides (16.2%), and middle blockers (27.4%), with liberos having the highest accuracy with 32.8% of responses being accurate. Thus, all of the hitting positions' accuracies fell between that of the setters and liberos.

Table 3. GEE outputs for the predictor variables' interactions with player estimation accuracy.

Accuracy	**Coef.**	**Std. Error**	**z**	***p* > |z|**	**95% Conf. Interval**	
Position	0.263	0.07	3.76	*< .001	0.125	0.4
sRPE	-0.079	0.161	-0.49	.623	-0.394	-0.236
Perceived Sets Played	-0.014	0.161	-0.09	.931	-0.331	0.303
Constant	-1.639	0.534	-3.07	.002	-2.687	-0.593

*Note: *Indicates the independent variable has a statistically significant (p < .05) effect on accuracy.*

DISCUSSION

The main purpose of this study was to determine if NCAA Division I volleyball players could accurately estimate their jump frequency utilizing a perceptual scale following practices and matches as a cost effective alternative to wearable sensors. Additionally, the study aimed to identify how and if player experience with monitoring jump count, session rating of perceived exertion, position, and perceived sets played during training, affected their jump range selection accuracy. Overall, for the majority of the training sessions, the players were unable to accurately estimate their jump frequency using a scaling of 25 jump increments (Figure 1-2). When considering accuracy as selecting a range within 50 jumps of the number of jumps performed by the players (including the percentage from '1 off'), player selection accuracy increased to over 50% of player responses (Figure 1-2).

The players' months of experience using any type of jump count methodology during training, was not found to have a significant effect on player jump count estimation accuracy. Therefore, a player's ability to accurately estimate the number of jumps performed in training was not dictated by their previous amount of experience tracking their jump count. This could potentially be due to the variability in jump frequency that players experience across practices and matches. Skazalski and colleagues (2018) illustrated that, over the course of a season, low and high weekly jump counts for right sides, outsides, middles and setters can vary from below 100 jumps to upwards of 500 jumps (Skazalski et al., 2018a). Similar frequencies were also reported by Bahr and Bahr (2014) with recorded jump frequencies ranging from 0 to 379 jumps across players, over the course of a week of training (Bahr & Bahr, 2014). Similar variability in jump frequency for positions across training sessions was also observed in the current investigation. For example, the recorded jump range for the starting setter was 42-427 jumps and one of the outside hitters ranged from 29-187 jumps across all training sessions. A lack of consistency in the number of jumps performed by specific positions could lead to the inaccuracy for jump count estimation. The positions that have more jump count variability, also recorded the highest jump volumes. Vlantes and Ready (2017) determined that setters have the greatest mean player load, in addition to performing the highest number of jumps (Vlantes & Readdy, 2017). Furthermore, Skalzalski et al. (2018) reported setters as having the greatest volume of jumps out of all position groups with an average of 121 jumps performed per session, and the middles are next closest position performing an average of 92 jumps per session (Skazalski et al., 2018b). Theoretically, the higher the volume of jumping an athlete completes in training, the more difficult it will be for an athlete to accurately perceive jump volume following training. In support of this, liberos (position that performs the lowest volume of jumps) were found to be the most accurate in selecting their jump count following training and had lower jump volume range (26-85) (Table 2). This suggests a lower volume of jumps performed could make it easier on the player to accurately estimate the total number of jumps completed. Bahr and Bahr (2014) found similar jump frequency (number of jumps performed per hour of training) variability across a week of training and matches in male players, with setters ranging from 20.3-128.2 jumps and liberos only ranging from 5.7-29.2 (Bahr & Bahr, 2014). Thus, greater variability in jump frequency across trainings between positions plausibly has an effect on accuracy. Potentially modifications to the current scale and recording frequency (every hour vs. post-practice) could improve accuracy across positions given improved accuracy with lower jump volumes.

sRPE is taken and multiplied by the length of the training session, as done by Kraft et al. (2020) in their recent study on volleyball players to produce a training load value (Kraft et al., 2020). Yet, practices and matches may be potentially impacted by a multitude of factors including drill selection (decelerations, jumping, diving, etc.), rest periods, and duration. Subsequently this can make it difficult to determine the injury risk relationship. Interestingly, Vlantes and Readdy (2017) found that, while jump volume is low, liberos recorded the highest sRPE overall for 15 matches (Vlantes & Readdy, 2017). However, that was not found to be a significant variable when considering predicting jump count. sRPE and perceived sets played were not found to significantly affect jump count selection accuracy in the current study. However both variables could still be useful tools for gathering an all-encompassing view of the athlete's workload. Subjective measures, such as these, are relatively inexpensive and easy to implement and monitor among players. In their systematic review, Saw and colleagues (2016) determined that subjective measures (i.e., mood/perceived stress scales/questionnaires) detect acute and chronic training loads among athletes with greater sensitivity, compared to objective measures (i.e., blood markers, heart rate, oxygen consumption, etc.) (Saw et al., 2016). In addition, sRPE is a valid tool for assessing internal workload and has been used in a multitude of studies on volleyball athletes (Duarte et al., 2019; Kraft et al., 2020; Vlantes & Readdy, 2017). Although, the relationship with sRPE by time may not be sensitive enough to determine risk for development of knee tendonitis. Conversely when training volume (expressed as hours spent training) has been shown to increase the risk of developing jumper's knee in volleyball athletes (Visnes & Bahr, 2012). Therefore, the aim with this variable was to potentially control for the static times accrued during training by assessing how long the player had felt the practice had been, based on their perception of how many sets they felt like they had played, rather than just timing the practice from beginning to end.

Research investigating injury rates in NCAA women's volleyball players has shown that the majority of the injuries incurred are to a lower extremity and primarily resort from overuse (Baugh et al., 2018). This is believed to be the cause of long-term habitual loading of the patellar tendon, without proper rest, resorting in onset of patellar tendinitis (Couppé et al., 2008). While specific jump volumes for volleyball positions have not been established to put players at an increased risk for injury, Visnes and Bahr (2013) did establish that volume of training in volleyball increases the risk of developing jumper's knee, for every addition hour or set played (Visnes & Bahr, 2012). Thus, allowing teams to track jump volumes among players could aid in specifically establishing the appropriate jump volume per position, over the course of training, to best reduce the risk of overloading, knee injuries in volleyball athletes. While objectively measuring jump volume in players via an IMU would be the most accurate practice available, further research on widely accessible inexpensive methods to monitor this variable to improve load management in volleyball is warranted. The current post-training survey used in this study provides insight into variables that affect jump count estimation accuracy in players and could be improved based on findings to be used in further research in this area.

Some limitations exist in the current study. First, the team in this study was using the Vert device technology prior to the study. Therefore, while experience with the technology varied, every player had some exposure to identifying their jump count during training via Vert. This would impact the generalizability of the study results to apply to teams with no experience using Vert technology. Another substantial limitation was COVID-19 limiting match data and the number of home matches with potential differentiation between match and practice team data. Lastly, because there was only one team included in this analysis, the use of additional teams to increase the sample size and potential applications would be beneficial in future research.

CONCLUSIONS

While advancements in microtechnology now allow for tracking of jump count, such technology requires financial resources and time to interpret data in order to be effectively implemented. Thus, the inexpensive and simple nature of subjective collection of training load is an alternative to objective microsensor tracking but there is no insight on jump count. On the formulated post-training survey, the aim was to assess volleyball athletes' ability to gauge their jump frequency following training and match play, using a perceptual scale, in addition to assessing internal training loads via RPE and perceived sets played. This preliminary data, in this area of research, yields evidence that volleyball players may not be able to accurately estimate their jump volume when given a perceptual scale, without previous experience monitoring jump count or feedback period where athletes are provided jump count following training or matches. Future studies could implement a feedback window, where athletes are provided jump count, so athletes potentially have a better gauge how many jumps they performed going forward and see if accuracy improves. Further studies need to be conducted in which more data is collected, across more than one team, to discern the reliability of this survey in assessing jump volume. Potentially the proposed perceptual scale may need to be modified or administrated multiple times during a practice to improve player accuracy.

AUTHOR CONTRIBUTIONS

The idea for this study and design was proposed by Pierce. Pierce collected and analysed the data and drafted the manuscript. Loprinzi, Jessee, Andre and Valiant provided mentorship, aided in data analyses, results interpretation and writing process. Phillips and Nelson critically reviewed and edited the manuscript.

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No potential conflict of interest was reported by the authors.

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ORIGINAL ARTICLE

Visual tracking speed threshold in NCAA Division I women's soccer predicting match performance: A preliminary study

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ABSTRACT

Correlations between sport performance and visual training have been previously demonstrated. However, it remains unclear if these relationships exist between visual tracking thresholds and in-competition decision-making metrics. Therefore, the purpose of this study was to investigate the relationship between visual tracking speed (VTS) and soccer-specific performance measures. 19 NCAA Division I soccer players VTS was measured from 1-core session on a 3-demensional multiple object tracking (3D-MOT) software NeuroTracker (NT) and soccer performance metrics were obtained from WyScout. Spearman's rank order correlation coefficient was utilized to examine potential correlations between criterion variables. There was nonsignificant correlation between VTS score and passing accuracy (r = -0.380). However, there was a strong correlation found between consistency score and passing accuracy (r = 0.650). When examining players based on their positional role, for attacking players there were nonsignificant strong correlation with consistency and passing accuracy (r = 0.730). For defenders, consistency and defensive win rate had a strong correlation (r = 0.731). Although there was no significant correlation seen between VTS and decision-making variables when examining the entire team, there was a significant strong positive relationship between consistency scores and passing accuracy. Future research should seek to include multiple teams for improved sample size.
Keywords: Performance analysis of sport, Physical conditioning, Perceptual-cognitive processing, Executive function, Task transfer, Soccer performance.

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INTRODUCTION

Individual differences in executive function are primarily genetic in origin (Friedman et al., 2008), however the development of the brain is postulated to be epigenetic (Fagiolini et al., 2009). This suggests genes alone cannot fully elucidate brain development, whereas specific experiences and or cognitive training on specific skills are required to further enhance development(Moen et al., 2018). 3-dimensional multiple object tracking (3D-MOT) has previously been utilized to improve processing speed (Parsons et al., 2016) and peripheral vision (Nyquist et al., 2016). Cognitive training has been shown to benefit and have transfer to general population in specific tasks and those with brain injuries. These benefits appear to have a stimulus threshold, when analysing 3D-MOT improvement curves there appears to be a plateau beyond 40 sessions and a new stimulus needs to be introduced to see further improvements (Faubert & Sidebottom, 2012). The theoretical concept behind 3D-MOT suggests when neurons and or a group of neurons build stronger associations into networks in the brain, these networks can transfer to other tasks that utilize the same networks. There are currently two primary theories to potentially explain this. The first is Edelman's theory of "*neural group selection*" which claims learning and development are caused by specific neural brain development in which experience will influence specific neurons that are needed for a particular skill and organize the neurons into groups that connect different areas of the brain for execution of that skill(Moen et al., 2018). The second theory to support the idea is neural plasticity, which claims neurons or a group of neurons that are active at the same time will strengthen their connection and fire simultaneously (Moen et al., 2018). These two theories are used to explain the potential transfer of cognitive training and executive function to real world experience and sports performance benefits.

Sports performance at the highest level requires attention, decision making and working memory to function at optimal levels in stressful and cognitively demanding environments (Walton et al., 2018). Executive functions are part of specific task related perceptual-cognitive functions and are related to level of expertise in performance (Vestberg et al., 2012). For example, greater perceptual-cognitive function has been observed in higher level professional soccer in males and females (mean score: 15.52AU) comparatively to lower professional division male and female players (mean score: 13.18AU). They both however have superior scores compared to standard population (mean score: 9.51AU) when using a design fluency test (Delis-Kaplan Executive Function System- assesses flexibility of thinking, inhibition, problem solving, planning, impulse control, concept formation, abstract thinking and creativity) (Homack et al., 2005; Vestberg et al., 2012). Furthermore, investigations comparing cognitive training modalities have examined VTS and light board reaction time's ability to predict in-game performance related decision statistics (assists, turnovers, assist-to-turnover ratio, steals) during a professional basketball season (82 games). Reaction time was not related to any performance measures (visual reaction time; p = .829, motor reaction time; p = .747, physical reaction time; p = .716) (Mangine et al., 2014). However, VTS was determined as having a "*most likely positive*" relationship with magnitude-based inferences between VTS and assists (r = 0.78; p = .003), steals (r = 0.77; p = .003, and assist-to-turnover ratio (r = 0.78; p = .003) throughout the NBA season (Mangine et al., 2014). While there is evidence to support a link between cognitive training and improvements in athletic performance, further research is justified within this paradigm and specifically with the use of 3D-MOT training. Potentially the utilization of 3D-MOT in soccer could be beneficial to improve performance related decision-making statistics, but this concept is yet to be examined.

MATERIAL AND METHODS

Participants

The participants for this study consisted of 19 NCAA Division I soccer athletes. All participants were 18-22 years old and were members of the team during the 2021 spring season. Players were excluded if they were a goalkeeper or players who averaged less than 10-minutes per game. This time criteria was decided to avoid the influence of those who play a few minutes with only 1 or 2 actions that would influence the averages of the group. After exclusion criteria only 13 players were utilized for analysis. All participants signed an informed consent form prior to the start of the study and approval from the University of Mississippi's Institutional Review Board was obtained.

Measures and procedures

The player's NT baseline measures were the players' VTS and were assessed by completing 1-core session on the NT (NT; CogniSens Athletic, Inc., Montreal, Quebec, Canada) device by each player using 3D glasses similar to the methods utilized by Mangine et al. (2014). Core assessment took place in the team film room in the team complex prior to training. A core session consisted of 20 individual trials used to quantify spatial awareness by determining the player's threshold speed for effective perceptions and processing of visual information sources while sitting upright in a chair. The session lasted approximately 10 minutes and were given 3 practice trials prior to the 20 trials. The individual trial began with four of the eight total balls being illuminated for two seconds before returning to baseline colour. These four balls were the same for all 20 trials. The participants were instructed to track these four balls for the eight second duration of individual trial. During the trial all 8 of the yellow balls moved simultaneously throughout all regions of the 3D cube for eight seconds. After eight seconds, the balls froze and were assigned a number, 1-8, by the computer. The participants were then be asked to identify by number, which four balls out of the eight they believed to be the ones originally illuminated at the start. The numbers were verbally repeated back to the participants by an experimenter to verify they were clicking the correct balls. After each individual trial, the program identified which balls were the correct four. If the participant was able to correctly identify all four balls, the speed was increased for the next trial. If one or more of the balls was incorrect, the speed was slowed down on the next trial until 20 trials are completed. At the end of the 20 trials, VTS was determined as the average of the last 4 reversals of the staircase speed (meter per second). Consistency was also used which is a measure of performance consistency across all 20 trials. For the first trial (out of 20), the speed of the balls was at a standardized 0.68 meter per second. To avoid a training effect confounder, all players began their core session completely unfamiliar to the NeuroTracker device. Instructions were provided to participants and a demo prior to beginning the test. Participants were asked to abstain from using alcohol 24-hours prior to testing and no caffeine for 4-hours.

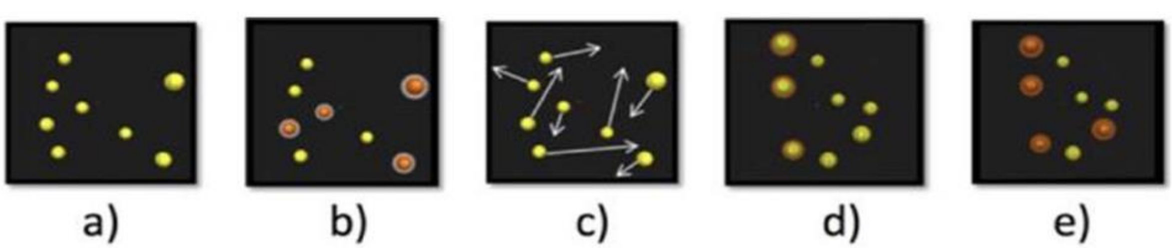

Figure 1. NeuroTracker single trial stages (Romeas, 2016).

WyScout (Wyscout, Chiavari, Italy) camera system was utilized to collect players performance metrics (e.g., goals, assists, passing accuracy, shots, balls lost, and defensive win rates) over the course of the entire season. The games were recorded and uploaded to the online database where the games are tagged and a game report was automatically generated to individual player statistics and team statistics. After each game a packing and impact rate were given for each player, position (forward, defender and midfield) and team totals. This was subjective scoring measure; however, the same researcher scored this metric for all players and matches. Intra-ratter reliability was tested prior utilizing a previous match. Scoring criteria (Table 1) below provides an explanation of scoring and defines each measure. Performance data was de-identified from a convenience sample of the NCAA Division I Women's Soccer team and groups within their sport-specific position groups (Defenders, Midfielders, Forwards).

Table 1. Packing and Impect scoring criteria.

Packing: rewards players on the ball for advancing the ball forward breaking a line with a pass or beating a player or players off the dribble.

Impect: rewards players who put themselves in position to receive the ball that breaks lines.

Points breakdown

Each opposing player is assigned a number based on the position they are playing

- Forwards =1 point
- Midfield = 2 point
- Defender = 3 points

Players receive points for every time the players pass/dribble past an opposing team player or are on the receiving end of a pass that breaks a line (Example: An outside back pass the ball to a midfielder and breaks a line with 2 forwards and a midfielder from the opposing team, the outside back will get 4 points for packing and the midfielder will get 4 points for impect).

Inside the 18-yard box, points are also given on crosses or pass that find a teammate based on how many players it takes out of the play as a result (Example: A player takes the ball endline and cuts a cross back across the box to a teammate and that pass takes out 2 defenders and a midfield, the passer will get 8 points for packing, while the player receiving the pass will get 8 points for impect).

Note. The table outlines the measure of packing and impect used to quantify player decision making and field awareness to advance the ball to a player in better position and players ability to find space to receive the ball.

Analysis

The Shapiro-Wilk test of normality was used prior to data analysis to examine for normality of each variable. The data from each participant for passing accuracy from the 9-matches was presented as the mean over the duration of the season and other variables were converted to per minute played to account for differences in playing time. The relationships between the criterion variables were analysed through Spearman's (rho) rank order correlation coefficient. The 95% confidence intervals (CIs) for the correlation coefficients were calculated through JASP (JASP; JASP 0.9.2; The JASP Team, Amsterdam, Netherlands). The relationship between VTS, consistency and performance metrics were interpreted through ranked data in a nonlinear, monotonic and run through Statistical Software (SPSS; V.27.0.0.0; SPSS, Inc, Chicago, IL, USA) to calculate Spearman's rho and the p-value of the relationship. The magnitude of the strength of the associations was considered very weak if Spearman's rho values are between 0-0.20, weak if between 0.21-0.40, moderate if between 0.41-0.60, strong if between 0.61-0.80, and very strong if between 0.81-1 (Prion & Haerling, 2014). Statistical analysis was performed using Statistics Package for the Social Sciences (version 26.0, SPSS Inc. Chicago, IL) and $p < .05$ as a statistical significance criterion.

RESULTS

From the 19 participants, 6 participants were excluded from analysis from not meeting minutes played criteria. Shown in Table 2, Visual tracking speeds ranged from 33.3 to 121.7 cm/s (avg.: 75.3 ± 23.7 cm/s) for the 13 participants. There was weak nonsignificant correlation between VTS and passing accuracy (r = -0.380, 95% CI: -0.770, 0.216, *p* = .20), moderate nonsignificant correlation between VTS and packing rate (r = -0.466, 95% CI: -0.809, 0.114, *p* = .108) and a very weak nonsignificant correlation between VTS and average turnovers per 90-minute game (r = -0.030, 95% CI: -0.572, 0.530, *p* = .922). Similarly, there was a negative nonsignificant moderate correlation between participants fastest trial and passing accuracy (r = -0.491, 95% CI: -0.786, 0.176, *p* = .088) and fastest trial and packing rate (r = -0.489, 95% CI: -0.801, 0.136, *p* = .090) and a very weak nonsignificant correlation between fastest trial and average turnovers per 90-minute game (r = 0.126, 95% CI: -0.345, 0.706, *p* = .681). A weak nonsignificant correlation was observed for consistency and packing rate (r = 0.296. 95% CI: -0.305, 0.728, *p* = .326) and a very weak nonsignificant negative correlation between consistency and average turnover per 90-minute game (r = -0.101, 95% CI: -0.618, 0.476, *p* = .742); however, there was a strong significant correlation for consistency and passing accuracy (r = 0.650, 95% CI: 0.158, 0.884, *p* = .016). When examined between attacker (n = 7) and defenders (n = 6), there were some metrics that correlated better based on role. For defenders, there was a nonsignificant strong correlation for consistency and defensive win rate (r = 0.731, 95% CI: -0.197, 0.968, *p* = .099). For attackers, VTS and impact rate per minute (r = 0.607, 95% CI: -0.269, 0.933, *p* = .148) had a moderate non-significant correlation. There was a strong correlation between consistency and offensive win rate (r = 0.767, 95% CI: 0.033, 0.964, *p* = .044) and a nonsignificant strong correlation with consistency and passing accuracy (r = 0.730 95% CI: -0.052, 0.957, *p* = .063).

Table 2. VTS and decision-making performance variable (n = 13).

	Avg ± SD	**Range**	**95% CI**
VTS (cm/s)	75.3 ± 23.7	33.3 – 121.7	[60.9, 89.6]
Consistency (%)	53.1 ± 7.0	42 – 63	[48.8, 57.3]
Fastest Trial (cm/s)	99.9 ± 21.3	70.7 – 129.2	[85.1, 112.0]
Passing accuracy (%)	60.2 ± 8.1	48.8 – 70.9	[55.3, 65.1]
Packing/min	0.43 ± 0.16	0.22– 0.76	[0.34, 0.53]
TO per 90	15.6 ± 3.2	9.5 – 20.4	[13.6, 17.5]

Note. Table depicts each player's VTS and an average of the 9 game performance metrics. Consistency is the accuracy at which a player correctly identified the 4 balls during the 20 trails, Visual tracking speed (VTS) is fastest speed where a player could correctly identify the 4 balls 50% of the time. Fastest Trial is the fastest trial at which a player could successfully identify all 4 balls.

Table 3. Comparison of attacking vs defensive players and NT.

	VTS (cm/s)	**Fastest Trial (cm/s)**	**Consistency %**	**Passing accuracy (%)**	**Turnovers per 90 minutes**
Defenders (n = 6)	77.6 ± 21.6	96.7 ± 23.3	53.5 ± 0.08	60.5 ± 0.08%	13.1 ± 2.26
Attackers (n = 7)	73.2 ± 27.0	102.7 ± 20.8	52.7 ± 0.06	60.0 ± 0.09%	17.7 ± 2.22

Note. Defenders (n=6) included centerbacks, outside backs and holding midfielder. Attackers (n=7) include attacking midfielders, wide midfielders, and forwards.

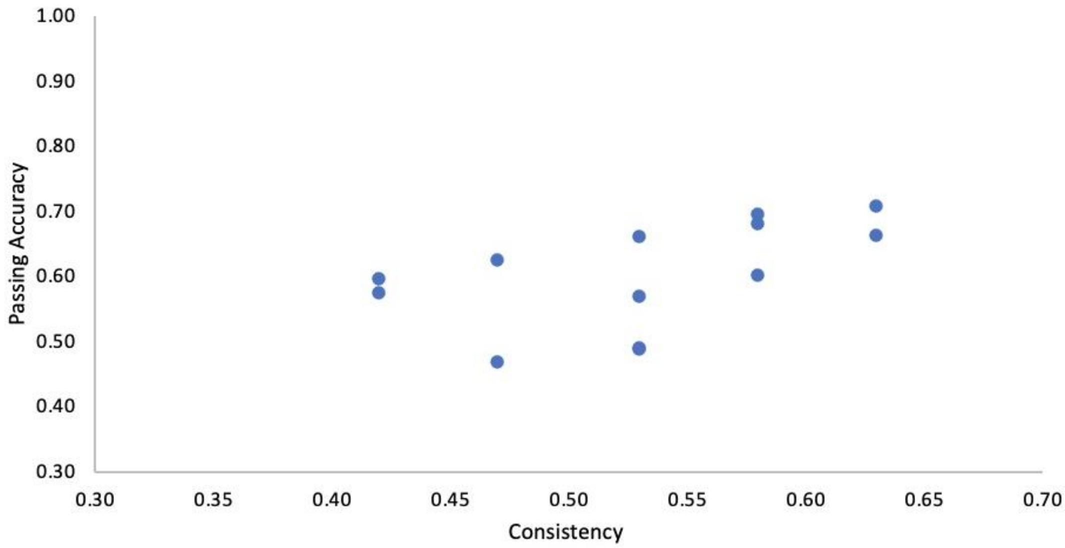

Figure 2. Scatterplot of passing accuracy and consistency. Consistency score is the accuracy at which a player correctly identified the 4 balls during the 20 trails Passing accuracy is the average completion rate of passes over the 9 games. A positive correlation was seen examining passing accuracy and consistency score (r = 0.650; *p* = .016).

DISCUSSION

The purpose of this study was to examine the potential relationship between visual tracking speed and efficiency measures associated with in-game sport specific decision-making variables. There was no significant correlation seen between visual tracking speed and decision-making performance variables when examining the team as a whole. However, there was a significant strong positive relationship between consistency scores and passing accuracy (Figure 2).

There is evidence to support NT and other forms of vision training potentially have a transfer effect into improvements in sports performance or increases in game performance statistics (Causer et al., 2011; Clark et al., 2012; Deveau et al., 2014; Komarudin et al., 2020; Nyquist et al., 2016; Oudejans et al., 2005; Romeas et al., 2016; Vine & Wilson, 2010). Most vision training studies are examining the effects of different perceptual training devices across varied sports and populations, which can make comparisons difficult. Some sports are more standardized and examining a transfer effect to in-game performance are more apparent. The research is limited for soccer and in-game improvements from vision training devices. Although, there is evidence to support improvements in a standardized soccer training session. Romeas et al. (2016) examined passing, dribbling, and shooting decision-making in a controlled training session observing passing improving by 15% after 10 training session, 2 times per week for 5 weeks (Romeas et al., 2016). In another study Nimmeritchter et al. (2016) examined 1 v 1 success rate in a controlled training session, which improved by 34% after vision training 2 times per week for 6 weeks (Nimmerichter et al., 2015). There appears to be potential evidence of a training effect in a standardized setting, however it remains unclear if this will translate to competition performance improvements and may be a worthwhile exploration. Prior to this study, there was only one other study examining VTS and decision-making metrics throughout a competitive sport season producing differing results from the current investigation. Baseline VTS in NBA players (n = 12) had a strong positive correlation with VTS and performance metrics (assists: r = 0.78, steals: r = 0.77, assist-to-turnover: r = 0.78) (Mangine et al., 2014). However, the previous studies results differed compared to the current investigation, which observed negative nonsignificant moderate correlations and very weak correlations for decision-making performance metrics and VTS with the whole team. The differences in strength of correlation could be due to the differences in statistical analysis utilized as their study utilized Pearson's product-moment analysing the magnitude of their relationships, the different cognitive and visual demands of each sport, and performance metrics of interest of basketball compared to soccer, or the lack of interaction between VTS and sport. However, a more plausible explanation for the difference in VTS results could be due to the population employed with differences in age, gender, and expertise level.

Current literature suggests the separation between elite, amateur and novice decision makers are their pattern recognition (Gorman et al., 2012) and different visual search strategies (Klostermann et al., 2018). All the participants in the current study were amateurs, which could explain the nonsignificant weak to moderate correlations observed with VTS. Comparatively, Mangine et al. (2014) observed strong positive correlation in professional athletes with performance metrics (Mangine et al., 2014). Faubert (2013) demonstrated a difference exists in baseline VTS between elite athletes, amateurs, and non-athlete college students (Faubert, 2013). A recent investigation utilizing the transfer of NT to in-game basketball performance in a younger population (19.9 ± 1.1 years) produced nonsignificant results compared to the control group of conventional training (Komarudin et al., 2021). One possible explanation is the brain does not fully develop until 25 years old with the frontal lobe being one of the last areas to develop, which is responsible for higher executive function (Sowell et al., 1999). Mangine et al. (2014) study had an average age of 23.3 ± 2.6 years for the front court players and 26.8 ± 2.9 years for the backcourt with a range of 19.4 – 30.7 years old indicating nearly half their sample potentially had fully developed while the other half were still developing. The current study utilized similar aged athletes (19.8 ± 1.4 years) as Komarudin et al., (2021), which may potentially explain why there were no significant correlations seen with VTS with in-game metrics (Komarudin et al., 2020).

The strong positive correlation finding between consistency and passing accuracy could possibly be explained by those with higher consistency scores were able to sustain the same level of alpha power throughout the 20 trails and limited mental fatigue, which could indicate player's attenuation to in game mental fatigue leading to better in game decision making. Those with faster visual tracking speed trials and scores could have had greater increases in alpha power, which is responsible for processing distracting information (Foxe & Snyder, 2011). Plausibly it could be due to the maintenance of producing the same level of alpha waves, as opposed to alpha power, however this was not measured in the current investigation so can only be inferred. Another explanation could be the gamma waves production aiding in cortical cooperation for memory and attention as well aiding in the "*binding rhythm*" (Jensen et al., 2007). A combination of these two factors possibly contributed to higher consistency score minimizing the effects of cognitive fatigue. There is evidence to suggest cognitive tasks that require executive control show effects on mental fatigue and the degree at which performance is affected depends on the level of which the task engages the prefrontal regions (Kurzban et al., 2013; Petruo et al., 2018). In the case of these studies, they were all repeated tasks of much longer durations and trials compared to the 8 minutes and 20 trials of NT. However, brain activity and event related potentials (ERP) were not examined within the current investigation to know if cognitive fatigue or brain wave activity levels contributed to consistency score.

In addition, a role-based analysis was constructed for attacking and defending positional roles, the data appears to show weak positive correlations with VTS. When separated into attacking and defensive players, similar to methods in previous research (Table 3), position specific metrics showed positive correlations. Interestingly, Mangine et al. (2014) observed differences between groups examining score differences in frontcourt (n = 7) and backcourt (n = 5) players in professional basketball athletes providing evidence of scores based on position and role. With additional investigation, the potential to generate a positional profile may be feasible.

When examining the whole teams' VTS and performance and efficiency measures, the data presented negative nonsignificant correlations. It could be these performance variables were not accurate measures when examining the team as a whole, as players depending where they are on the field can take risks while some have to play more conservative which could have influenced performance variables. The criterion variable of interest was passing accuracy given this metric is characteristically examined in relation to team success in soccer (Collet, 2013; Longo et al., 2019). Average turnover per 90 minutes played was also examined in this study producing conflicting results compared to Mangine et al. (2014) who observed a likely positive correlation (r = 0.49). Potentially this is because turnovers are more frequent in soccer and positionally bias, as attacking players take more risks compared to defenders seen in Table 3.

This study is not without limitations. The first limitation of this study was the sample size and criteria for inclusion of analysis. However, the sample size is comparable to previous research published in this space. Secondly, the research team had no control over competition level in the season, player tactical style, and rotation. However, all teams competed against were other NCAA Division I institutions and the team maintained the same tactical formation during the season.

CONCLUSION

The investigation did not see any significant correlations between VTS and success rate, passing accuracy or turnover per 90 minutes. Similar nonsignificant results were seen when examining fastest trial speed and these performance metrics. These results found were not similar to those seen in the Mangine et al., paper done with professional basketball players. The relationship between consistency and success rate and turnover rate were nonsignificant as well; however, there was a strong significant correlation between consistency and passing accuracy. When examining consistency and VTS further between positional specific metrics for attackers and defenders, some metrics correlated better based on role. Future investigations should look to include multiple teams to further elucidate these relationships and the potential for implementing a visual cognitive training program.

AUTHOR CONTRIBUTIONS

Andre and Phillips came up with the study design. Phillips collected and analysed the data and drafted the manuscript. Andre critically reviewed and edited the manuscript.

SUPPORTING AGENCIES

No funding agencies were reported by the authors.

DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

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ORIGINAL ARTICLE

Immediate effects of isometric versus isotonic exercise on pain sensitivity and motor performance of ankle plantiflexor muscles

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ABSTRACT

Introduction: This study aimed to quantify the differences on pain sensitivity and motor performance ankle plantiflexor muscles after performing an isometric versus an isotonic exercise task. Method: A parallel experimental trial was carried out at the European University of the Canary Islands. A total of 47 healthy volunteers were recruited and randomly assigned to a group receiving an isometric exercise (n = 23) and a group receiving an isotonic exercise (n = 24). Pain threshold to pressure was measured at four specific points of the triceps surae neurosensory territory in medial gastrocnemius (MG), (2) lateral gastrocnemius (LG), (3) Tendo Achilles osteotendinous unit (TA) and (4) aponeurosis plantar insertion (AP). Furthermore, the two-point discriminatory threshold (2DP) of the osteotendinous junction of the Achilles tendon and maximum voluntary contraction for plantar flexion (MVC-PF) were assessed before and after the intervention. Results: There were no statistically significant intergroup differences for any of the variables PPT-MG (U Mann Whitney = 25; [1.265-0.650], *p* = .527), PPT-LG (U Mann Whitney = 25; [1.325-0.945]; *p* = .527) y PPT-TA (U Mann Whitney = 25; [-1.465-0.405] *p* = .527), D2P (U Mann Whitney = 30.5, IC95% [-0.800-1.300], *p* = .630) and MVC-PF (U Mann Whitney = 26.5, IC95% [-8.400, 2.900], *p* = .386). Conclusions: Isometric exercise (Exe_Isom) was the only one able to modify the PPT-AP before and after treatment in a statistically significant way. In contrast, isotonic exercise (Exe_Isot) was the training that demonstrated clinically significant changes in 2PD and MVC-PF before and after treatment. No statistically significant changes were identified between both groups in any of the variables studied.

Keywords: Sport Medicine, Ankle, Plantiflexors, Pain, Athletic performance.

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INTRODUCTION

Exercise provides physiological and psychological health benefits. Recent studies show a 13% reduction in the mortality rate, positive changes in psychological aspects such as vitality, mental health, and quality of life. (Carraça et al., 2021; Posadzki et al., 2020) It is usually prescribed in the treatment of musculoskeletal conditions for the improvement of strength and the restoration of function but, without a doubt, one of the main objectives of exercise is the reduction of pain. (Breda et al., 2021) The exercise-induced hypoalgesia (EIH) that can generate a single session of physical activity depends largely on the modalities and intensity with which it is carried out. This response occurs in different modalities of both aerobic and resistance exercise and at different intensities, although some studies indicate that EIH occurs more consistently in healthy subjects after high-intensity exercise. (Naugle et al., 2012).

In any case, these changes are characterized by elevations in thresholds of pain tolerance, as well as as well as a reduction of pain intensity indexes. (Koltyn, 2002; Naugle et al., 2012).

The mechanisms underlying this process are not fully understood, but the hypothesis that acquires more relevance is the one that affirms an activation of the endogenous analgesia system during exercise producing changes in peripheral, spinal, and central sites. (Koltyn, 2002; Rice et al., 2019) Moreover, recent studies show that not only the opioid system is involved in hypoalgesia, but also the endocannabinoid and serotonin systems cooperate in this process. (Crombie et al., 2018; Tour et al., 2017).

Endogenous analgesia system involves the periaqueductal gray matter (PAG), the dorsal horn and the rostral ventromedial medulla (RVM), which constitute a descending pain inhibitory system that facilitates or inhibits non-cerebral stimuli. RVM contains three populations of neurons: ON cells, that enable pain when they are activated, OFF cells, that inhibit nociception by firing, and neutral cells that do not respond to these harmful cells. (Lima et al., 2017).

Physical exercise produces analgesic effects induced by opioids at the central level. In a study where naloxone was administered in MVR and PAG, analgesic effects were blocked. Therefore, when a peripheral antagonist was injected there was not inhibition of analgesia, suggesting that exercise analgesia response depends on central mechanism but not peripheral. (Lesnak & Sluka, 2020; Lima et al., 2017; Sluka et al., 2018). In another study performing water aerobic exercise, it was observed how phosphorylation of the intercellular messenger phospholipase PLCy-1 in the dorsal horn of the medulla leads to a normalization and reversion of hyperactivity of astrocytes and microglia after nerve injury. (Almeida et al., 2015; Lesnak & Sluka, 2020). Apart from the opioids endogenous system, physical exercise also promotes pain relief by increasing the expression of serotonin transporter due to the elevation of serotonin levels (Sluka et al., 2018).

In sedentary conditions, there is less endogenous opioids in the brainstem and, in general, less inhibition. This causes neurons to show greater facilitation after nociceptive input, with increases in phosphorylation of the NR1 subunit of the NMDA (N-Methyl-D-aspartic acid) receptor and increased expression of the serotonin transporter (SERT). Conversely, regular physical activity increases the release of endogenous opioids in the brainstem inhibiting facilitating neurons. This would be associated with a lower phosphorylation of the NR1 subunit of the NMDA receptor and a lower expression of the SERT. In general, in the condition of physical activity there would be more inhibition by opioids, serotonin and less arousal. (Sluka et al., 2018). Another implicated mechanism in EIH is the decreasing in the dorsal horn expression of calcitonin gene related peptide (CGRP). (Ishikawa et al., 2019).

Peripheral nervous system (PNS) may play a critical role regading to EIH. Some studies conducted in animals showed changes in PNS that can be responsible of the EIH. For example, in injuries of peripheral nerves of the lower limb, running on the treadmill promotes reinnervation and attenuates pain by up-regulating adipokines releasing. In another study, daily exercise increased the number of cells in the nucleus pulposus and annulus fibrosus, as well as increased markers of cell proliferation in the intervertebral disc and adjacent epiphyseal cartilage, compared to sedentary controls. All these results indicate that a peripheral damage may be eased or eliminated by exercise through pronociceptive changes in these remote locations. (Lesnak & Sluka, 2020).

Some authors point out that the intensity and duration which the exercise is performed may act as relevant factors in EIH. However, to date no blinded controlled intervention study has been performed comparing the immediate effect of isotonic versus isometric exercise on pain tolerance and motor performance in healthy subjects. In addition, the results that we can obtain would demonstrate which intervention generates more analgesia in the short term and would allow us to open lines of study on subclinical populations that suffer from pain of musculoskeletal origin in the plantar flexor region. The main objectives of our work were to compare the clinical efficacy of an isotonic versus an isometric exercise programme on pain sensitivity and motor output of triceps surae.

METHODS

Study design

A parallel experimental trial was conducted from 11 February 2022 to 1 June 2022 following CONSORT declaration. Researchers P.L.R, and E.C.C. were responsible for administering the written informed consents of all participants included in the study before starting the experiment. The procedure was conducted in accordance with the *Declaration of Helsinki* on Experimentation on Human Subjects.

Participants

Healthy volunteers belonging to the community of students and workers of the European University of the Canary Islands (Santa Cruz de Tenerife, Spain) were selected using a consecutive non-probability sampling technique from May 12, 2022 to May 24, 2022. Patients were contacted using word-of-mouth technique and publication on bulletin boards and social networks of the study researchers, inclusion criteria and main objectives. See Figure 1.

Inclusion criteria

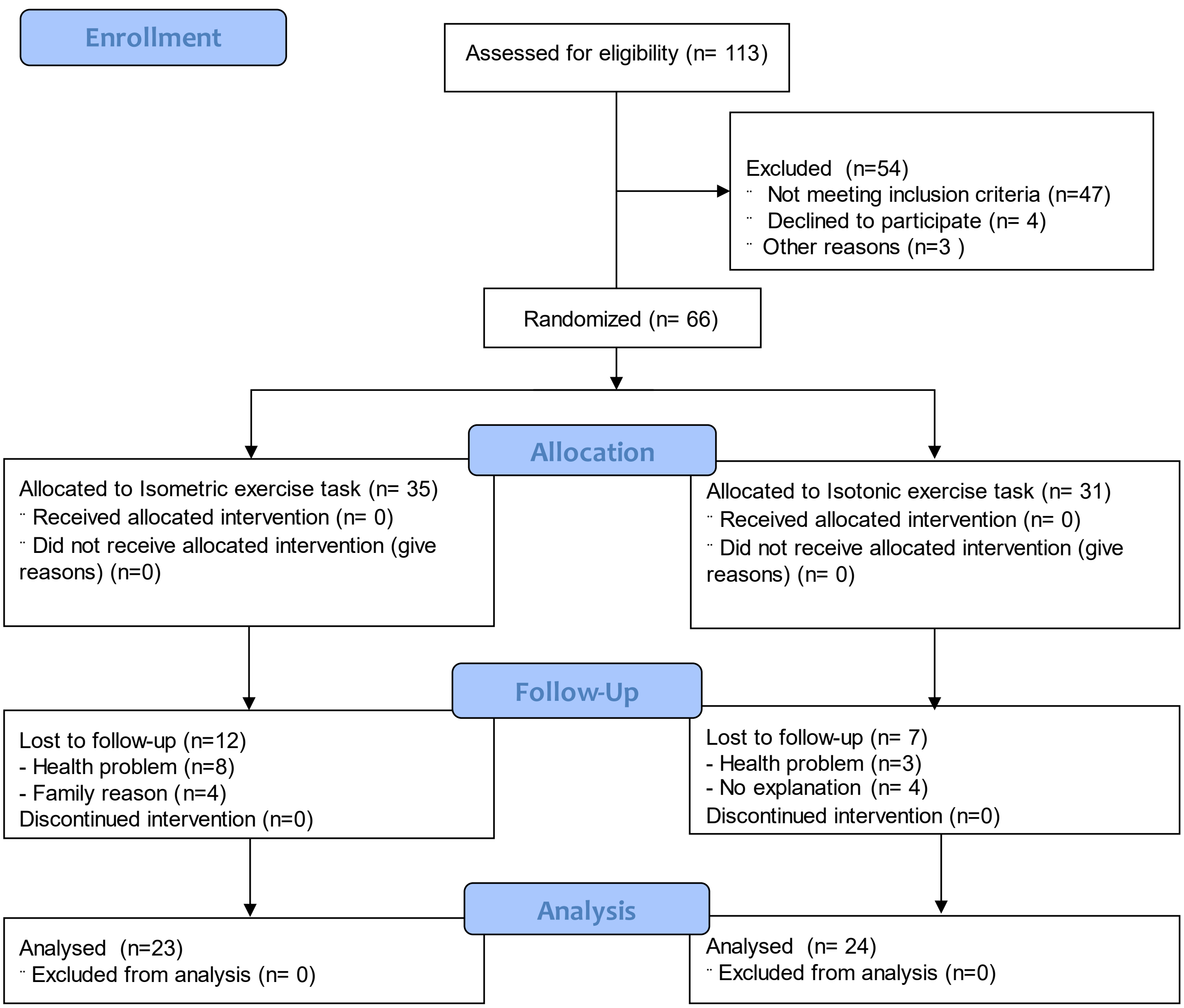
Inclusion criteria were: (1) aged between 18 and 30 years old, (2) no pain or altered sensation in the lower limb or lumbosacral spine at the time of the study, (3) no history of traumatic illness in the lower limb or lumbosacral spine, (4) no presentation of psychological or psychiatric illness, (5) no have being treated by *anti-inflammatory drugs* (NSAIDs), *analgesics*, *antidepressants*, *anti-inflammatory drugs*, *contraceptives*, and *calcium channel blockers* during the study period, (6) no have being surgically treated for a musculoskeletal disease in the lower limb or lumbosacral spine, (7) no presents toxic habits (alcohol intake, smoking, etc…).

Sample size determination

Sample size and power calculations were performed with SPSS Statistic v.28 software. The calculations were based on the minimum classically detectable difference (MCID) of PPT in healthy subjects which is 0.806 Kg/cm^2 assuming a standard deviation of 0.150 Kg/cm^2, a 2-tailed test, an alpha level of .05 and a desired power of 80%. (Gatz et al., 2020) The estimated sample size for each of the arms was n = 23 individuals.

Randomized assignment

Participants were randomly assigned to the isometric exercise intervention group (*Exe_ISOM*) and to the control the isotonic exercise (*Exe_ISOT*) with a sequence of random numbers generated by an investigator (P.L.R.) who was not involved in the recruitment of subjects. Randomization was performed using a random sequence generator (http://www.random.org) program.



Note. Participants were randomly assigned to the isometric exercise (Exe_ISOM) intervention group and isotonic exercise control (Exe_ISOT) with a sequence of random numbers generated by an investigator (P.L.R.) who was not involved in the recruitment of subjects. Randomization was performed using a random sequence generator (http://www.random.org) program.

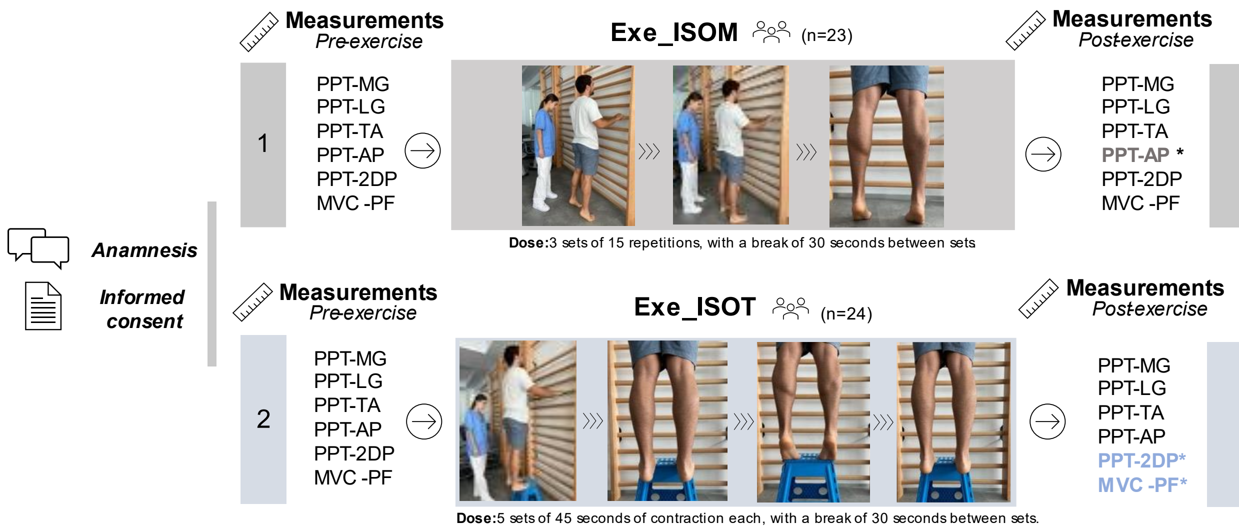
Figure 1. *CONSORT diagram of the participant selection process.*

Concealment

A blinded evaluator (A.R.P.T) was responsible for obtaining measurements at baseline (Pre-Exe) and immediately after the treatment period (Post-Exe). The interventions in both groups were applied by the same physiotherapist (S.M.) with 10 years of experience in manual therapy and management of musculoskeletal pain disorders. Both groups received the same instructions and information about the effectiveness of the treatment.

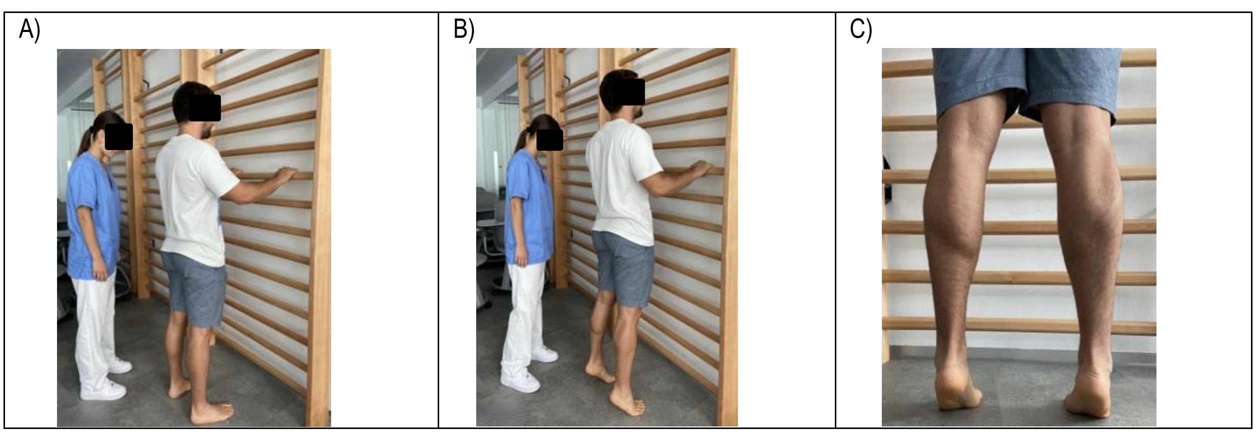
Intervention

The intervention was performed in consultation 1 of the Simulated Hospital of the European University of the Canary Islands (Santa Cruz de Tenerife, Spain) from March 12, 2022 to June 24, 2022. See Figure 2. The participants were divided into two groups that were treated:



Note. The participants were previously interviewed to assess whether they met the inclusion criteria and were subsequently given voluntary consent to participate in the study. They were randomly assigned to isometric exercise intervention (Exe_Isom) and isotonic exercise control (Exe_Isot) groups with a random number sequence generated by an investigator (P.L.R.) who was not involved in subject recruitment. A measurement was made before and after the intervention with the aim of evaluating intra-group changes as well as inter-group changes in the indicated variables. It was observed that isometric exercise (Exe_Isom) was the only method able to modify PPT-AP in a statistically significant manner before and after treatment. In contrast, isotonic exercise (Exe_Isot) was the exercise that showed clinically significant changes in 2PD and MVC-PF before and after treatment.

Figure 2. Study protocol.



Note. A) Information. The participants were informed of the technique to follow through a verbal instruction common to all subjects who participated in the experiment, B) Patient Location. The starting position of the participant was standing, with his hands resting on the trellises to maintain stability, C) Development of the test. Task description: A maximum heel lift was performed while maintaining the support on the fingers. Then, we proceeded to make the complete support of the sole of the foot on the ground and the contraction will be repeated. Dose: 5 sets of 45 seconds of contraction each, with a break of 30 seconds between sets. Speed and amplitude: They were adjusted so that there was no pain.

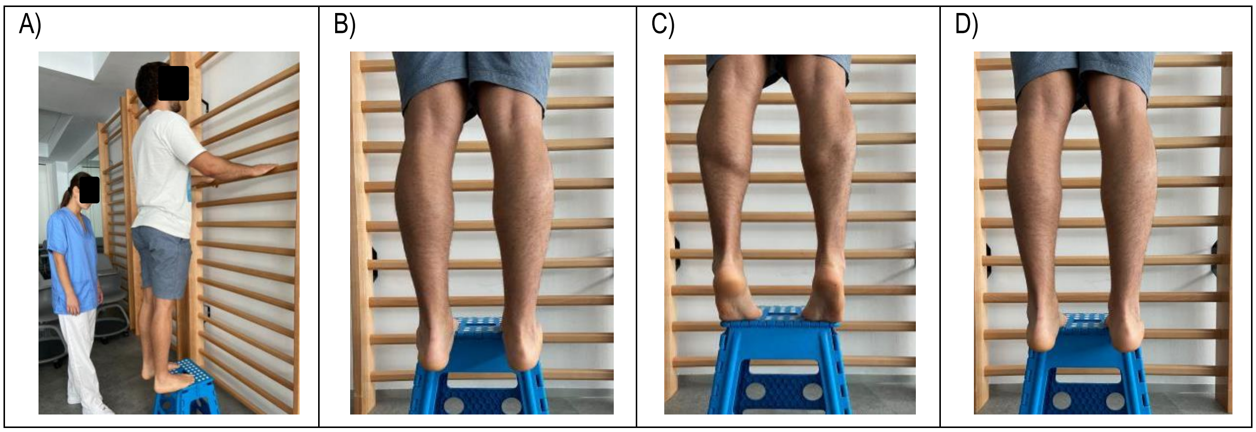
Figure 3. Isometric exercise group intervention.

Group 1. Isometric exercise (Exe_ISOM)

The participants had to perform an isometric exercise based on the Rio *et al.* (2015) protocol. The starting position was standing and with the hands resting on the wall to maintain stability. The exercise was developed in a single session of 5 sets of 45 seconds of contraction with a rest between sets of 30 seconds. These movements were recorded through a metronome (Korg, MA-1, USA). The speed and range of motion were adjusted so that there was no pain. See Figure 3.

Group 2. Isotonic exercise (Exe_ISOT)

The participants had to perform an isotonic exercise based on Alfredson *et al.* (1998) protocol in which the participant must perform an eccentric exercise that consists of placing the subject on a step, performing an elevation with both legs, and finally descending slowly for 5 seconds to the position of maximum ankle flexion with the leg that will be measured. The exercise was developed in a single session of a total of 3 sets of 15 repetitions considering a total of 30 seconds of rest. (Stasinopoulos & Manias, 2013) These movements were recorded through a metronome (Korg, MA-1, USA). The speed and range of motion were adjusted so that there was no pain. See Figure 4.



Note. A) Information. The participants were informed of the technique to follow through a verbal instruction common to all subjects who participated in the experiment, B) Patient Location. The starting position of the participants was standing on a step with the heels outside it, leaving the base of the metatarsals supported, C) Development of the test. Task description: Held on a step, you must perform an elevation of both legs and then D) descend slowly for 5 seconds to the position of maximum ankle flexion. Dose: 3 sets of 15 repetitions, with a break of 30 seconds between sets. Speed and amplitude: They were adjusted so that there was no pain.

Figure 4. Isotonic exercise group intervention.

Study variables

Pre-treatment measurements were collected by a blinded blinded (E.C.C.) to the subjects' intervention assignment. To reduce the error of measurement procedure, a random evaluation order was generated among the participants taking three measurements with a pause of 1 min between measurements. Before, the intervention a questionnaire of affiliation was carried out as well as the taking of anthropometric measurements such as weight and height. Next, the measurement sites were identified and the Pre-ExeISOM and Pre-ExeISOT pre-treatment measurement protocol was developed, which contributes to define the baseline before the intervention. After the test, the Post-ExeISOT and Post-ExeISOM after-treatment measures were performed 5 minutes after the application of the procedure. The following outcome variables were evaluated:

Pain pressure threshold (PPT)

Mechanosensitivity was measured through the threshold of pain to pressure (PPT) using a digital Pain Tester (FPX™ Algometer, Wagner) with a unit of measurement of kg/cm² at four specific points of the neurosensory territory of the triceps surae: (*1) Medial gastrocnemius (MG), (2*) *lateral gastrocnemius (LG), (3*) *Tendo Achilles osteotendinous unit (TA) and (4) aponeurosis plantar insertion (AP).* The measurements were made just before and after the intervention, taking the average of 3 measurements for the main analysis. This procedure has reported a good inter-examiner reliability with a mean intra-class correlation coefficient (ICC) of 0.75 and an excellent intra-examiner reproducibility(mean ICC = 0.84). (Antonaci et al. 1998).

Two-point discrimination threshold (PPT-2DP)

The threshold of discrimination of two points was measured with an aesthesiometer (Aesthesiometer Baseline 12-1480) calibrated and graduated to perform minimum measurements of 0.1 cm using as a starting point the osteotendinous junction of the Achilles tendon, understanding the measurement in the direction proximal to the myotendinous junction between gastrocnemius and Achilles tendon. The instrument consists of two movable (sliding) vinyl-coated tips. Vinyl coatings help minimize the impact of temperature on contact perception. To check the minimum distance between two points perceived, the patient was asked to confirm when he began to perceive two different points. The measurements were made just before and after the intervention, taking the average of 3 measurements for the main analysis. This procedure has reported moderate to good inter-examiner reliability 0.83-0.96(Dellon et al., 1987; Levin et al., 1978).

Maximal voluntary contraction in plantar flexion (MVC-PF)

The maximum voluntary contraction of plantar flexion was measured with the BIOFET dynamometer (V3, MuscTec). The measurements were made just before and after the intervention taking the average of 3 measurements for the main analysis. The participant was measured supine with the hip, knee and ankle in a neutral position, with the foot on the edge of the examination table. The therapist placed the hand in the posterior region of the foot, locating the dynamometer in the plantar region (metatarsal bases) requiring the realization of a maximum plantar flexion for 5 seconds. The measurements were made just before and after the intervention taking the average of 3 measurements for the main analysis. This procedure has reported moderate to good interexaminer reliability 0.65-0.87 and moderate to good intraexaminer 0.77-0.97. (Kelln et al., 2008).

Statistical analysis

Statistical analysis was carried out using SPSS Statistic v.28 software. for the analysis and representation of data. First, the researcher E.C.C. performed a record in an electronic database of the results of the evaluation instruments used to measure each study variable while A.R.P.T. verified the accuracy of the data by completing the double data entry. Secondly, the researcher S.E.M.P. performed the calculation of the descriptive statistics of centralization (mean, and median), dispersion (standard deviation) and position (minimum, maximum) to describe the study variables. Thirdly, the Shapiro-Wilk test was carried out for quantitative variables to determine the normality of the data obtained. The variables that met the assumptions of normality ($p > .05$) were analyzed with an analysis of the intragroup (T-student for paired samples) and intergroup (T-student for independent means) mean differences. If they did not meet the assumptions of normality, it was decided to perform an analysis with non-parametric techniques to determine the intragroup (Wilcoxon sign range test) and intergroup (Mann-Whitney U test) differences comparing the data before (Pre) and after treatment (Post). Finally, the effect size (Cohen's d or biserial's correlation coefficient) was calculated to quantify the size of the difference between two groups. The statistical significance was set at a value of $p < .05$.

RESULTS

Demographic description of the sample

First, we included a total of 47 patients (23 women and 24 men) aged 18 to 37 years who were randomly chosen and assigned to the two study groups. See Figure 1. Secondly, the experimental group, which participated in an *isometric exercise* task (*Exe_Isom)* included a total of 23 subjects (Women, n = 12; Men, n = 11) had a mean age of 25.25 years (SD = 5.97) with a BMI of 24.42 Kg/m^2 (SD = 5.63) while the control group that was treated with an isotonic exercise task (*Exe_Isot*) consisted of a total of 24 subjects (Women, n = 11; Men, n = 13) had a mean age of 23.56 (SD = 3.04) years with a BMI of 22.79 kg/m^2 (SD = 2.19). On the other hand, most of the subjects who were finally included in this study turned out to be students (n = 30, 63.8%) and were considered active (n = 17, 36.2%). See Table 1.

Table 1. Anthropometric characteristics of the study population (n = 47).

			Descriptive										Shapiro-Wilk	
			95% C. I.											
	Group	Mean	Lower	Upper	Median	SD	Var.	IQR	Range	Min.	Max.	W	*p*
Age, (yrs.)	Exe_Isom	25.25	21.11	29.39	23.00	5.97	35.64	5.2500	0.19	0.18	0.37	0.907	.334
	Exe_Isot	23.56	21.57	25.55	23	3.04	9.27	2.0000	0.11	0.20	0.31	0.762	.7
Height, (m)	Exe_Isom	1.65	1.58	1.71	1.61	0.09	0.00871	0.0900	0.270	1.51	1.78	0.873	.163
	Exe_Isot	1.75	1.70	1.79	1.76	0.06	0.00473	0.0500	0.250	1.61	1.86	0.955	.746
Weigh, (Kg)	Exe_Isom	66.38	55.18	77.57	68.50	16.15	260.83	17.2500	49.000	43.00	92.00	0,952	.733
	Exe_Isot	69.44	62.84	76.05	68.00	10.11	102.27	13.0000	32.000	57.00	89.00	0.946	.646
BMI (Kg/m^2)	Exe_Isom	24.42	20.51	28.32	23.80	5.63	31.77	2.0453	19.349	16.59	35.94	0.889	.228
	Exe_Isot	22.79	20.74	24.85	22.34	3.14	9.916	0.8451	10.734	19.35	30.08	0.823	.37

Note. C. I. = Confidence Interval. SD = Standart Deviation. Var = Variance. IQR = Interquartilic Range. Min = Minimum. Max = Maximum.

Table 2. Description of variables of the study (n = 47).

	Descriptive						Shapiro-Wilk	
	Mean	Median	SD	Var.	IQR	Min.	Max.	W	p
Pre_PPT-MG	2.13	1.67	1.29	1.667	1.620	0.860	4.84	0.81	.003
Pre_PPT-MG	2.08	1.75	1.20	1.450	0.850	0.710	5.36	0.83	.005
Pre_PPT-LG	2.25	2.20	1.17	1.368	1.785	1.000	4.90	0.90	.072
Post_PPT-LG	2.29	1.74	1.10	1.226	1.355	1.100	5.00	0.87	.024
Pre_PPT-TA	2.55	2.17	1.01	1.023	1.440	1.145	4.29	0.93	.266
Post_PPT-TA	2.38	2.32	0.85	0.724	0.855	1.120	4.10	0.95	.536
Pre_PPT-AP	2.79	2.50	0.99	0.983	1.315	1.705	4.62	0.87	.026
Post_PPT-AP	2.97	3.10	1.040	1.081	1.105	1.445	4.92	0.93	.279
Pre_2PD	3.70	3.40	1.93	3.757	1.100	0.600	10.10	0.76	< .001
Post_*2PD*	3.65	3.40	1.26	1.598	1.200	2.200	7.70	0.80	.002
Pre_MVC-PF	26.77	25.20	5.33	28.415	4.400	20.900	42.20	0.85	.014
Post_MVC-PF	28.12	28.60	5.60	31.397	6.500	20.200	43.00	0.92	.195

Note. SD = Standart Deviation. Var = Variance. IQR = Interquartilic Range. Min = Minimum. Max = Maximum.

Key findings

Pain Pressure Threshold (PPT)

First, in relation to the group that received isotonic exercise (Exe_Isot), statistically significant intragroup increases in PPT-AP were detected with a difference between the threshold measured before 2.92 (1,028) Kg/cm^2 and after treatment 3.13 (1,054) Kg/cm^2 (Δ = 0.235 Kg/cm^2, Wilcoxon W = 8, 95% CI [0-.020)]; *p* =

.048). In relation to the rest of the variables, there was in general a response of decrease of the thresholds studied as is the case of PPT-MG, PPT-LG and PPT-TA in which a decrease in the thresholds of pain to pressure was demonstrated without reaching statistical significance.

Secondly, in the group that received isometric exercise (*Exe_Isom*) no statistically significant changes were detected although an immediate decrease in the thresholds was recorded in the variables PPT-MG, PPT-LE and PPT-AP. The same does not happen with the clinical change detected in the PPT-TA variables that increased from 1.94 Kg/cm^2 to 2.01 Kg/cm^2 (Δ = 0.213 Kg/cm^2, Wilcoxon W =25; *p* = .527).

Finally, if we look at the comparison between the groups, the analysis showed that there were no statistically significant differences between the intervention groups for any of the variables studied PPT-MG (U Mann Whitney = 25; [1.265-0.650], *p* = .527), PPT-LG (U Mann Whitney = 25; [1.325-0.945]; *p* = .527) and PPT-AT (U-Mann Whitney = 25; [-1.465-0.405]; *p* = .527).

Table 3. Intragroup analysis of isometric exercise (n = 23).

Paired Samples T-Test									
							95% Confidence Interval		
			Statistic	*p*	Mean difference	SE difference	Lower	Upper	Effect Size
Pre_PPT-MG	Post_PPT-MG	Wilcoxon W	19.0	.578	0.02875	0.136	-Inf	0.320	0.0556
Pre_PPT-LG	Post_PPT-LG	Wilcoxon W	12.0	.230	-0.14250	0.158	-Inf	0.252	-0.3333
Pre_PPT-TA	Post_PPT-TA	Wilcoxon W	25.0	.844	0.21375	0.166	-Inf	0.525	0.3889
Pre_PPT-AP	Post_PPT-AP	Wilcoxon W	18.0	.527	0.00500	0.127	-Inf	0.313	0.0000
Pre_2PD	Post_2PD	Wilcoxon W	15.5	.389	-0.10004	0.443	-Inf	0.900	-0.1389
Pre_MVC-PF	Post_MVC-PF	Wilcoxon W	10.5	.163	-1.24996	0.818	-Inf	1.000	-0.4167

Table 4. Intragroup analysis of isotonic exercise (n = 24).

Paired Samples T-Test									
							95% Confidence Interval		
			Statistic	*p*	Mean difference	SE difference	Lower	Upper	Effect Size
Pre_PPT-MG	Post_PPT-MG	Wilcoxon W	18.00	.318	-0.1950	0.2867	-Inf	0.6450	-0.2000
Pre_PPT-LG	Post_PPT-LG	Wilcoxon W	24.00	.594	0.0324	0.0950	-Inf	0.2051	0.0667
Pre_PPT-TA	Post_PPT-TA	Wilcoxon W	15.00	.363	-0.1752	0.3205	-Inf	0.8500	-0.1667
Pre_PPT-AP	Post_PPT-AP	Wilcoxon W	8.00	.48	-0.2350	0.1113	-Inf	-0.0200	-0.6444
Pre_2PD	Post_2PD	Wilcoxon W	31.00	.857	0.5501	0.5325	-Inf	1.2500	0.3778
Pre_MVC-PF	Post_MVC-PF	Wilcoxon W	8.00	.48	-1.8501	0.8905	-Inf	-0.1500	-0.6444

Table 5. Intergroup analysis of isometric exercise versus isotonic exercise (n = 47).

Independent Samples T-Test							
					95% Confidence Interval		
		Statistic	*p*	Mean difference	Lower	Upper	Effect Size
Post_PPT-MG	Mann-Whitney U	31.0	.673	-0.188	-1.265	0.650	0.139
Post_PPT-LG	Mann-Whitney U	30.0	.606	-0.170	-1.325	0.945	0.167
Post_PPT-TA	Mann-Whitney U	24.0	.277	-0.530	-1.465	0.405	0.333
Post_PPT-AP	Mann-Whitney U	31.5	.699	0.155	-1.030	1.530	0.125
Post_2PD	Mann-Whitney U	30.5	.630	0.229	-0.800	1.300	0.153
Post_MVC-PF	Mann-Whitney U	26.5	.386	-2.600	-8.400	2.900	0.264

Two-point discrimination (PPT-2PD)

In subjects participating in the isotonic task (*Exe_Isot*), there was a clinical decrease in the discriminating threshold of two points from 3.66 cm (SE 0.436) to 3.38 cm (SE 0.209) after activity without reaching statistical significance (Wilcoxon W = 31, 95% CI [0-1.25], *p* = .857). Secondly, unlike the isotonic task, the isometric achieved slight clinical increases of the discriminatory threshold from two points 3.91 cm (SE 0.903) to 3.95 cm (SE 0.613) (Wilcoxon W = 15.5, 95% CI [0-0.900], *p* = .389). If we made a comparison between both groups, the analysis showed that there were no statistically significant differences between the intervention groups for this variable (U Mann Whitney = 30.5, 95% CI [-0.800-1.300], *p* = .630).

Maximal voluntary contraction in plantar flexion (MVC-PF)
Statistically significant changes in MVC-PF were detected in the isotonic exercise group (*Exe_Isot*) with a difference between before treatment 29.28 (2,550) Kg/f and after treatment 31.11 (2.52) Kg/F (Δ = 1.85 Kg/f, Wilcoxon W = 8, 95% CI [0-.015)]; *p* = .048). In relation to the group that received isometric exercise (*Exe_Isom*) clinical changes were detected before 25.40 (SE 1.571) Kg/f and after treatment 26.32 (SE 1.663) Kg/f (Δ = 0.90 Kg/f, Wilcoxon W = 10.5, 95% CI [0-1)]; *p* = .163). Finally, if we look at the comparison between the groups, the analysis showed that there were no statistical differences for both the experimental group and the control at the end of treatment for any of the study variables (U Mann Whitney = 26.5, 95% CI [-8,400, 2,900], *p* = .386). See Table 3 and Table 4. Intragroup analysis of *isometric exercise* (n = 23) and isotonic exercise (n = 24).

DISCUSSION

This is one of the few randomized clinical studies comparing the efficacy of isometric exercise versus isotonic exercise at PPT, PPT-2PD threshold and MVC of triceps surae.

According to our results, the performance of isotonic exercise was the intervention that produced the greatest changes in the mechanical threshold and motor performance. On the one hand, mechanical pain threshold could be modified in remote regions such as aponeurosis plantar (PPT-AP) immediately. On the other hand, discriminative threshold of the Achilles tendon (PPT-2DP) increased in the group that performed an isotonic exercise task. Moreover, there was a statistically significant difference in MVC of ankle plantiflexor muscles (MVC-PF) were also detected in the isotonic exercise group.

However, it should be noted that, despite the results obtained, it has not been possible to demonstrate the superiority of one mode of contraction over the other. Unlike other studies made on clinical populations if we perform a comparative analysis between both treatments, the absence of statistically significant changes leads us to state that the type of contraction and neither doses are ultimately responsible of the observed changes in pain sensitivity tolerance and motor performance triceps surae muscles.

Abounding in the above, the absence of superiority or inferiority of both treatment modalities is a controversial issue and widely discussed in the literature. In fact, a clinical study by Kanniappan and Sathosh (2020) concluded that there is a significant improvement in Achilles tendonitis when pain and functionality are evaluated for both eccentric and isometric exercise with no significant differences between them. In another work by van der Vlist et al. (2020) they also found no difference when isometric exercise was added in patients with tendinopathy to chronic pain, so they do not recommend isometric exercises if the goal is to provide immediate pain relief. Even when program exposure reaches 3 months, Gatz et al. (2020) demonstrated that isometric exercises have no additional benefit when combined with eccentric exercises. Despite these studies, we are struck by the fact that other high methodological quality clinical studies support the idea that isometric exercise is better than isotonic exercise on reducing pain tolerance and increasing motor output. In this regard, Rabusin et al. (2021) noted that isometric heel lift exercise was more effective than eccentric exercise in reducing pain and improving function at 12 weeks. Also, supporting its use but in other type of tendinopathies of the lower limb, Rio et al. (2017) defends the superiority of the isometric over the isotonic in the relief of immediate pain of subjects suffering from patellar tendon pain. Despite these controversies, we identified well made reviews such as those carried out by Lim and Wong (2018) and Vang and Niznik (2021) that conclude that isometric exercises would be more effective in relieving pain in the short term, while isotonic eccentric exercises would be better for long-term pain reduction and improvement of knee function.

Strengths

As strengths of this study, we have identified some advantages that can improve the internal validity of the study.

First, the use of blinding in the treatment assignment sequence in each group reduced selection bias. In addition, blinded allocation sequence allocation by the investigators reduced the likelihood of participants being screened for prognostic criteria or potential benefit or harm of the intervention.

Secondly, all participants received the same instructions throughout the protocol, except for using the same treatment room and wearing the same therapist. Through this aforethought procedure avoids the possible contextual interactions that have been described by other authors as responsible for modifying outcome measures that might alter comparisons between the same group of subjects.

Thirdly, it should be noted that the this study was conducted with the masked raters, meaning that at no point did the raters have any information about which group of participants was assigned during the intervention protocol. In this sense, we argue that this procedure reduces detection bias, that is, the influence of the fact that participants would know detailed information about the treatment they received, on the results.

Limitations

Several limitations were detected in this study.

First, regarding the sample, recruitment was conducted using a non-probabilistic consecutive sampling technique which may implies the extraction of biased samples. However, given the possible impact of this participant selection technique, we believe that this is the easiest recruitment system from an organizational perspective during project implementation, as it allows us to achieve a significant sample size, ultimately allow data collection to be comparable.

Secondly, we argue that a large proportion of participants recruited primarily in the university education community on the list of recruiting subjects have both theoretical and practical knowledge of the expected impact of the intervention.

Thirdly, the study protocol did not include familiarity with the instruments used to measure the outcome variable, so the variability obtained in the sample could be a bias due to the participants' inexperience at the time of measurement.

Fourthly, regarding interventions, we believe that the lack of a control group and/or placebo group may be a limitation, as this design may not allow us to determine the nonspecific effects of interventions and whether they exist without considering treatment.

Finally, the short duration of this design or pre-experimental protocol hinders the understanding of clinical changes that may occur during mid- to long-term follow-up. In this same sense, we can assume that the lack of cumulative training dose, only one training session, can usually explain the few clinical changes noted not only between groups but also within the same experimental protocol.This question compels us to emphasize the need for studies with extended follow-up of outcome variables, as our results suggest that the use of changes measured immediately after exercise in healthy subjects is not sufficient to justify their use in the population with musculoskeletal pain.

CONCLUSIONS

Isometric exercise (*Exe_Isom*) was the only one able to modify the PPT-AP before and after treatment in a statistically significant way. In contrast, isotonic exercise (*Exe_Isot*) was the training that demonstrated clinically significant changes in PPT-2PD and MVC-PF before and after treatment. No statistically significant changes were identified between both groups in any of the variables studied.

AUTHOR CONTRIBUTIONS

Theoretical conceptualization, S.E.M.P., E.A.S.R., J.L.A.P.; literature searching, P.L.R., A.R.P.T., E.C.C.; conducted data collection P.L.R., A.R.P.T. and E.C.C.; statistical analysis, I.M.P., E.A.S.R. and S.E.M.P.; elaboration of draft S.M.P., I.M.P.; review E.A.S.R., S.E.M.P., M.D.S.R., J.H.V, J.F.C.

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DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

Ethical approval was obtained by an internal committee and informed consent was requested from all participants in the study.

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