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Dear Esteemed Readers, Authors, and Reviewers,

We are pleased to announce the release of the latest issue of Montenegrin Journal of Sports Science and Medicine, which showcases a diverse array of groundbreaking research and insights in the field of sport science. This issue reflects the dedication and hard work of our contributors, and I invite you to explore the valuable findings presented within its pages.

We would like to extend our heartfelt gratitude to all authors who submitted their manuscripts and to our diligent reviewers whose expert evaluations ensured the high quality of our published work. Your commitment to advancing knowledge in sport science is truly commendable, and your contributions play a vital role in the journal's success.

In addition to the release of this new issue, we are excited to share some significant news regarding our journal's impact factor released by. We are proud to announce that we have achieved a new impact factor released by Thomson Reuters (Clarivate Analytics) of 1.3 that positions us as the most influential journal in sport science within our region. This milestone is a testament to the quality of research published in our journal and the increasing recognition it receives in the academic community.

As we continue to strive for excellence, we encourage our readership to engage with the articles, share your insights, and contribute to the ongoing conversation in the field of sport science. Thank you once again for your unwavering support, and I look forward to bringing you more exceptional research in the future.

Warm regards,
Prof. dr. Dusko Bjelica
Prof. dr. Damir Sekulic

ORIGINAL SCIENTIFIC PAPER

The international study of movement behaviours in the early years: A pilot study from Bosnia and Herzegovina

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Abstract

The World Health Organization (WHO) released guidelines for physical activity (PA), sedentary behavior, and sleep for children under 5 years of age in 2019, but there are no reports on the adherence to the guidelines in southeastern Europe. This study aimed to: (i) determine the proportion of preschool children (aged 3-5 years) who met the WHO guidelines and examine the feasibility of the proposed protocol for the SUNRISE study in Bosnia and Herzegovina (B&H), and (ii) define sex-, and urban/rural-living-specifics in movement-behaviors, anthropometrics, gross-motor-skills, fine-motor-skills, and cognitive-skills. The sample comprised 115 preschool children (63 girls and 52 boys), residing in urban (n = 66) and rural areas (n = 49) from B&H. Participants were tested on movement behaviors (PA, sleep time, screen time) by accelerometry and comprehensive questionnaires. Body height, weight, body mass index, executive function, fine-, and gross-motor skill, and cognitive function were also measured. The results showed that PA-, sleep duration-, and screen time guidelines were met by 64%, 74% and 53% of children, respectively, while only 23% of the children met all three guidelines on movement behaviors. Boys exhibited higher PA than girls, but no differences in gross- and fine motor skills and cognitive functioning were recorded between the sexes. Children living in urban and rural environments did not differ in any of the studied variables. Results evidenced preschool children from B&H being in line with other samples globally about study variables. Although PA was higher in boys than in girls it was not translated to differences in motor skills. Further studies on larger samples and other environments are warranted.

Keywords: *SUNRISE study; preschool children; screen time; sleep; sedentary behaviour*

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Introduction

The worldwide outbreak of childhood obesity continues to pose a significant challenge to public health. Over the course of four decades, the number of girls and boys affected by obesity has surged from 5 million to 50 million and from 6 million to 74 million, respectively (Abarca-Gómez et al., 2017; Montesano & Mazeo, 2019). In addition to impacting their immediate health and quality of life, children who suffer from obesity are also at an increased risk of developing various non-communicable diseases, including diabetes, cardiovascular diseases, hy-

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pertension, stroke, and cancer (Kim et al., 2022; Park, Falconer, Viner, & Kinra, 2012). Furthermore, obesity during childhood often persists into adolescence and adulthood, leading to chronic illness and premature death (Ward et al., 2017).

Physical inactivity is recognized as a significant contributor to the prevalence of overweight and obesity, and studies have established clear correlations between healthy levels of physical activity, screen time, sleep, and adiposity in middle and late childhood (de Fátima Guimarães, Mathieu, Reid, Henderson, & Barnett, 2021; Martinovic, Jaksic, Spahic, Lukic, and Nedovic-Vukovic, 2021). Since movement behaviors may persist from early- into middle- or later-childhood, researches have focused on the relationship between these factors even in pre-school and early-school-age (Janz, Burns, & Levy, 2005; Malina, 1996; Vukelja, Milanovic, & Salaj, 2022). For example, a study on 15651 children aged 6-9 years reported a negative association between high screen time and lower physical activity levels (Whiting et al., 2021). Also, optimal and high sleep time and high physical activity levels led to better cardiometabolic health and lower adiposity in children aged 5-17 years (Saunders et al., 2016). Also, more sedentary time was associated with higher odds of being classified as metabolically unhealthy individuals, while increased moderate-to-vigorous physical activity was beneficial for weight status and metabolic health in 5-18-year-old children (Kuzik et al., 2017).

Collectively, there is a general consensus that physical activity plays a significant role in attaining the health and well-being of children (Sheldrick, Tyler, Mackintosh, & Stratton, 2018). In their efforts to increase the level of physical activity in children and youth, the World Health Organization (WHO) issued global guidelines in 2019 for children under the age of five concerning movement behaviors. The guidelines were developed based on systematic reviews conducted in this age group, and suggest that children aged three and four should engage in 180 minutes of physical activity daily, out of which 60 minutes should be of moderate to vigorous intensity (Organization, 2019). Additionally, they should limit their sedentary screen time to no more than one hour and strive to get 10 to 13 hours of quality sleep per day. However, the global guidelines for physical activity, sedentary behavior, and sleep have been primarily informed by evidence from studies conducted in high-income countries.

Since their release, several studies have evaluated the prevalence of adherence to WHO guidelines and their correlation with adiposity and other health indicators (Berglind, Ljung, Tynelius, & Brooke, 2018; Chaput et al., 2017; Draper et al., 2020; Tanaka et al., 2020). Briefly, a study on 830 children aged 4-5 years from Sweden reported that 18% of the studied children met the combined recommendations of MVPA, screen time and sleep duration, while those factors were not associated with obesity at this age (Berglind et al., 2018). Similar, results were reported in a study on Canadian children aged 3-4 years (Chaput et al., 2017). However, there is a dearth of research in low- and middle-income countries, which is concerning given that approximately 90% of overweight or obese children worldwide reside in these regions (Kim & von dem Knesebeck, 2018).

The introduction of the global and national 24-hour movement guidelines for children up to 5 years (i.e., early years) emphasized the need for adequate surveillance methods. As a result, the International Study of Movement Behaviors in the Early Years (SUNRISE) was developed (Draper et al., 2020). The primary goal of The SUNRISE study is to assess the proportion of children adhering to the WHO Global guidelines from countries of different socioeconomic statuses. In addition to this, it aims to determine how 24-h movement behaviors are linked with overweight and obesity, gross and fine motor skills and executive function in the early years, and the variations among the countries (Carson et al., 2017). However, prior to conducting the study on a large scale, it was essential to assess the feasibility of the protocol in each participating country, including Bosnia and Herzegovina (B&H). Therefore, this study aimed to determine the proportion of preschoolers from B&H who adhere to the WHO global guidelines on movement behaviors and to explore the differences between genders (boys vs girls), and living environment (children living in urban- vs rural- communities) in guideline adherence, anthropometrics, indices of executive function, fine motor skills, and gross motor skills. Following the results of the previous SUNRISE studies, we hypothesized that: (i) low proportion of children would meet all WHO guidelines, (ii) boys will exhibit better movement behaviors and motor-skill status than girls, and (iii) rural children will exhibit better movement behaviors and motor-skill status than urban children.

Materials and Methods

Participants

Following the recommendations from the SUNRISE project, in this study, we observed preschool children from B&H, residing in urban and rural areas. All children were included in the regular preschool education in Tuzla Canton in B&H. In total, one hundred and fifteen children (boys: n = 52; girls: n = 63 girls) from five schools in the urban area (n = 66;) and three schools in the rural area (n = 49), participated in the study. The sample size was based on a previous study that suggested 50 participants each in urban and rural areas (Draper et al., 2020).

The sampling was done throughout several phases. In the first phase, we randomly selected preschools in both areas, and approval to conduct the study was sought from the principal of each preschool. Then, parents of eligible children were contacted through the preschool class teachers and were recruited for the study. After expression of interest, the researchers presented the idea, aims and protocol of the project, as well as benefits and risks of the participation to parents who expressed the interest for their child to be involved in the project. presentation of the aims of the study and protocol. A written informed consent was collected from the parents, before further participation. Each preschool supported to arrange in case the participating child became unsettled during the study. The protocol of this study was approved by the University of Wollongong Human Ethics Research Committee (ref. no. 2018/044) and by the Ethics Research Committee of the Faculty of Physical Education and Sports, University of Tuzla (ref. no. 03/2022).

Variables, measurement and protocol

Variables included anthropometric indices, physical activity levels, variables of executive function, fine motor skills, and gross motor skills.

Anthropometrics included body height, body mass, and calculated body mass index. Body height was measured using a portable anthropometer (Martin Type Anthropometer) and mass was measured barefoot using a digital scale (EGER www.eger.com). Measurements were taken twice and the average of a measure was used for analysis. Body mass index (BMI) was

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computed using the RedCap software (Vanderbilt University Australia). The BMI classification of the children were done according to the reference standards of the WHO (Di Cesare et al., 2019).

The 24-h movement behavior of the children was assessed using Actigraph GT3X + accelerometers (ActiGraph, LLC, USA) following the evidence-guided recommendation (Cliff, Reilly, & Okely, 2009). The devices were attached to an elastic belt and positioned on the right side of the child's body, just above the iliac crest. The sampling intervals, or epochs, were set at 15 s and the sampling rate at 30 Hz. Children were instructed to keep the accelerometers continuously on their waist for at least 72 h and only remove them for any water-based activities. The children were asked to wear the accelerometers for 5 days, as defined by SUNRISE study protocol. Children who had at least one full day of 'valid' data were included in the later analysis. A valid day (i.e., 24 h) of data was confirmed by visual inspection of the acceleration graph via the ActiLife 6 software, ensuring that acceleration peaks are present during the monitoring days. SUNRISE parental questionnaire, translated into local language, was utilized to gather demographic information (Okely et al., 2021). Also, the questionnaire was used to acquire the subjective screen time, sleep time, and physical activity (TPA and MVPA) duration. Sleep time and non-wear time were excluded from the analysis. Sleep time was predetermined based on the average parent-reported wake-up and bedtime of the children. Non-wear time was defined as > 20 min of consecutive zero counts during waking hours. This included the time when the monitor was taken off for water activities and daytime naps. The final time was used to calculate time spent in total physical activity (TPA), sedentary behavior (SB), light physical activity (LPA), and moderate to vigorous physical activity (MVPA). SB, LPA, MVPA were defined using the cutoffs of 0–199, 200–419, 420–841, and 842 and above counts per 15 s epochs, respectively.

To evaluate the executive function of the children, the visual-spatial working memory and inhibition of the children were assessed using the Go/No-Go and Mr. Ant tablet games (Ipad, Apple, USA) in the Early Years Toolbox (EYT) (Howard & Melhuish, 2017), respectively. In Mr. Ant, an ant character with sticker/s appears on the screen. After, children are asked to point the location of the sticker/s when an ant character with no sticker appears. The game starts with one sticker (Level 1) up to eight stickers (Level 8), and the game stops when 3 unsuccessful attempts are made. In the Go/No-Go the children are requested to tap the screen every time they see a fish and avoid touching the screen when a shark is present. The scoring for this game range from 0 (incorrect performance on all fish, shark) to 1 (perfect performance on both shark and fish trials), with 1 as the highest score (Hossain et al., 2021).

The Nine-hole Pegboard Test (NHPT) was used to assess dexterity and fine motor skills in children. In the NHPT, the children pick up nine pegs from the container one at a time, place them in a pegboard, remove the pegs in the holes, and place the pegs back in container. Only one hand is allowed for NHPT, but the other hand can be used to stabilize the board. The recording time for NHPT starts as soon as the children touch the first peg and ends when the last peg is placed in the container. After the task, NHPT is repeated on the other hand (Aneesha Acharya & Choudhary, 2023).

Gross motor skills were evaluated throughout standing long jump, supine timed up and go, single leg balance, and hand grip test. The standing long jump (ST-LJ) was used for assessment of lower body strength and mobility. In this test, the children jump as far as possible from a starting mark. A practice trial is administered, followed by two trials, and the average of two trials was used for analysis.

Supine-timed up and Go (S-TUG) was utilized to assess posture and mobility. From supine position with feet positioned at the starting line, the children stand up and sprint for 3 m and back. One trial was facilitated for familiarization the two trials were performed for the S-TUG, and the average of two S-TUG trials was included for analysis.

In the Single-Leg Balance test (SLB) the one-leg standing time is recorded, wherein recording starts after one leg leaves the ground. Arms were allowed to move freely. Timing stops when the standing leg is deemed unstable or the free leg is hooked to the standing leg to maintain balance. The test is also concluded if SLB reached 30 seconds. The recorded time in seconds was the result of this test. The test is repeated on the other leg.

Handgrip Test (HGT) with dynamometer (TKK5825, Grip-A, Takei, Tokyo) was utilized for assessment of upper body strength. In the HGT, children were asked to squeeze the dynamometer for 3 seconds as hard as possible without the equipment touching the body. Two practice trials were facilitated prior to recording three trials per limb. The average of the three trials was used for analysis.

All children were tested throughout two sessions, separated by 5 days, between December 2022 and March 2023. Testing was done at a designated area in each school.

Measurement of anthropometric indices, executive function, and fine and gross motor skills of the children were carried out in the first session. Parents/caregivers were also asked to complete a locally-translated questionnaire to obtain demographic information and subjective movement behaviors of their child. Additionally, children were asked to wear accelerometers for five days. After five days, the accelerometers were collected for processing and analysis. The testers in this study underwent extensive training prior to conducting field-level data collection.

Data analysis

TheREDcap application and REDcap web platform were used for data management All statistical analyses were performed using SPSS Statistics for Window version 26.0 (IBM Corp, Armonk, NY). Descriptive statistics (mean and standard deviation) were computed for all variables. T-test for independent samples was conducted to examine differences in anthropometrics, movement behaviors and motor skills between the sexes and residential settings. All hypothesis testing should be treated as preliminary and treated with caution due to the study being underpowered.

Results

Table 1 presents the age and anthropometric characteristics of the children, and no significant differences were observed between boys and girls for age or any anthropometric outcomes ($p>0.05$). Moreover, there were no significant differences in anthropometric characteristics between the urban and rural sub-samples. Using the World Health Organization's cut-offs, 79.1% of the sample were within the normal range for BMI, while 9.6% were identified as overweight, 5.2% as obese, and 4.3% were classified as underweight.

Table 1. Children's age and anthropometric characteristics, by sex and setting (community)

Variable	Total (n = 115)	Boys (n = 52)	Girls (n = 63)	p value ¥	Rural (n = 49)	Urban (n = 66)	p value ≠
Age (y)	4.6 ± .6	4.6 ± .1	4.6 ± .1	.658	4.7 ± .1	4.6 ± .1	.202
Height (cm)	111.2 ± 6.6	111.0 ± .7	111.4 ± .9	.781	111.1 ± .9	111.2 ± .7	.933
Weight (kg)	19.5 ± 3.4	19.4 ± .3	19.4 ± .4	.722	19.4 ± .3	19.7 ± .5	.591
BMI (kg.m-2)	15.7 ± 1.7	15.7 ± .1	15.7 ± .2	.898	15.8 ± .2	15.6 ± .1	.418

Note: Data are presented as mean ± SD for normally distributed data;; ¥p value for comparison by sex; ≠p value for comparison by setting.

The results of the accelerometry are presented in Table 2. According to the findings, boys exhibited a significantly higher level of physical activity than girls, and lower sedentary time (SED, $p<0.009$; MPA, $p<0.007$; VPA, $p<0.007$, and MVPA, $p<0.004$). However, there was no significant difference in physical activity levels between urban and rural children.

Table 3 displays the gross and fine motor skill scores of boys and girls, which were found to be comparable (both $p>0.05$), indicating no significant differences between the sexes. Furthermore, no statistically significant differences in motor skill scores were observed between urban and rural children.

Table 2. Acelerometry by sex and seting (community)

Variable	Total (n = 101)	Boys (n = 46)	Girls (n = 55)	p-value ≠	Rural (n = 42)	Urban (n = 59)	p-value ≠
SED (min/d)	622.0 ± 48.3	608.3 ± 48.5	633.4 ± 45.4	.009	623.6 ± 6.0	620.8 ± 7.04	.770
LPA (min/d)	97.4 ± 16.5	98.7 ± 18.1	96.3 ± 15.0	.476	17.3 ± 2.6	15.9 ± 2.0	.510
MPA (min/d)	70.5 ± 18.9	76.0 ± 20.7	65.9 ± 16.0	.007	15.7 ± 2.4	20.8 ± 2.7	.269
VPA (min/d)	24.1 ± 13.3	28.0 ± 15.3	20.8 ± 10.4	.007	10.4 ± 1.6	25.8 ± 1.9	.136
MVPA (min/d)	94.6 ± 30.5	104.0 ± 34.2	86.8 ± 24.7	.004	23.5 ± 3.6	34.4 ± 4.4	.181
TPA (min/d)	192.0 ± 41.2	202.7 ± 45.5	183.1 ± 35.2	.005	35.2 ± 5.4	44.7 ± 5.8	.210

Note: Data are presented as mean ± SD for normally distributed data; ¥p value for comparison by sex; ≠p value for comparison by setting. SED, sedentary behaviour; LPA, light-intensity physical activity; MPA, moderate-intensity physical activity; VPA, vigorous-intensity physical activity; MVPA, moderate - to vigorous-intensity physical activity; TPA, total physical activity

Table 3. Motor skills by sex and setting (community)

Variable	Total (n = 115)	Boys (n = 52)	Girls (n = 63)	p value ¥	Rural (n = 49)	Urban (n = 66)	p value ≠
STUG	5.1 ± 1.3	5.2 ± 1.6	5.1 ± .9	.570	5.0 ± 1.6	5.2 ± 1.03	.521
SLB-R	10.6 ± 9.2	9.1 ± 8.0	11.9 ± 10.0	.113	10.4 ± 9.8	10.9 ± 8.9	.770
SLB-L	10.8 ± 8.6	9.1 ± 7.4	12.1 ± 9.3	.066	11.3 ± 9.7	10.4 ± 7.7	.587
STLJ	72.7 ± 20.5	74.5 ± 22.6	71.2 ± 18.8	.390	71.2 ± 22.8	73.8 ± 18.8	.501
F-R	8.1 ± 3.0	8.5 ± 3.0	7.7 ± 2.9	.175	7.5 ± 3.1	8.5 ± 2.8	.099
F-L	8.2 ± 2.9	8.6 ± 2.7	7.8 ± 3.0	.196	7.9 ± 3.1	8.4 ± 2.7	.420
9H-R	34.6 ± 10.7	35.8 ± 13.2	33.5 ± 8.1	.252	32.9 ± 7.4	35.8 ± 12.5	.159
9H-L	38.2 ± 9.7	38.7 ± 10.2	37.8 ± 9.4	.608	36.3 ± 8.4	39.6 ± 10.4	.081

Note: Data are presented as mean ± SD for normally distributed data; ¥p value for comparison by sex; ≠p value for comparison by setting. STUG, Mobility and posture: Supine-Timed up and go; BA-R, Posture: One-leg standing balance test right leg; BA-L, Posture: One-leg standing balance test left leg;; ST-LJ, Lower body strength and mobility: Standing long jump; F-R, Upper body strength: hand grip dynamometer right hand; F-L, Upper body strength: hand grip dynamometer left hand; 9H-R - Manipulation: 9-hole peg-board test right hand; 9H-L - Manipulation: 9-hole peg-board test left hand.

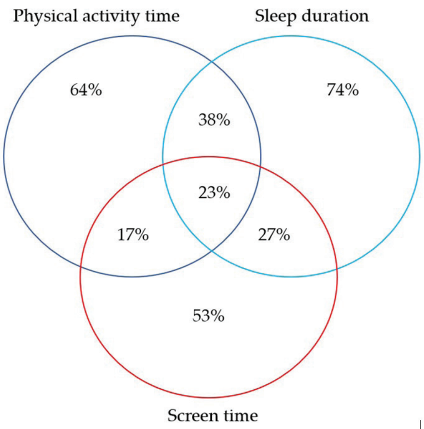

Figure 1. The Venn diagram displaying the proportion of children meeting the 24-hour movement guidelines

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The number of children meeting the different components of the 24-hour movement guidelines is presented in Figure 2. The proportion of children meeting the physical activity (MVPA + TPA) guidelines was 64%, while the screen time and sleep guidelines were met by 53% and 74% of the sample, respectively. When considering all three guidelines together, only 23% of the sample met the integrated guidelines (Figure 1).

Figure 3 displays the time spent in various movement behaviors. Total physical activity (TPA) was found to be 3.2 hours per day, which is slightly above the World Health Organization's guidelines. However, sedentary time was much higher than the recommended guidelines, at 10.5 hours per day. It can be assumed that a significant portion of this sedentary time is spent in front of screens.

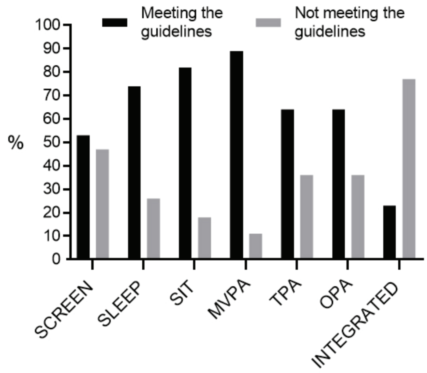

Figure 2. Proportion of children meeting the 24-hour movement guidelines (MVPA - moderate - to vigorous-intensity physical activity; TPA - total physical activity; OPA - overall physical activity; SCREEN – screen time; SLEEP – sleep time; SIT – restrained sitting time; INTEGRATED – integrated guidelines).

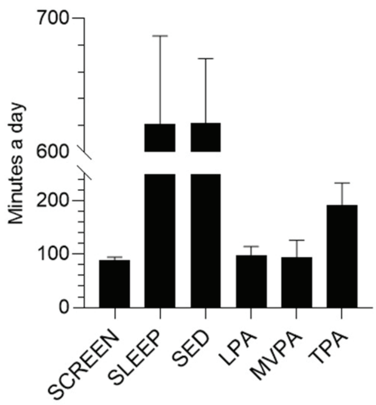

Figure 3. Time spent in different movement behaviors (SCREEN – screen time; SLEEP – sleep time; SED – sedentary behaviour; LPA - light physical activity; MVPA - moderate - to vigorous-intensity physical activity; TPA - total physical activity).

Discussion

This study investigated the compliance of B&H preschoolers with the World Health Organization (WHO) guidelines on movement behaviors. There are several most important findings with regard to study aims. First, results showed that only 23% of the children met all three guidelines (e.g., physical activity time, sleep duration, and screen time), with 64%, 74%, and 53% complying with the guidelines on physical activity time, sleep duration, and screen time, respectively. Second, girls demonstrated greater SED, and lower MPA, MVPA, VPA, and TPA compared to boys, with no significant differences in gross motor skills, fine motor skills, and cognitive skills between sexes. Third, urban and rural children did not differ in movement behaviors, gross- motor, fine-motor and cognitive skills.

Movement behaviors and body-weight status

Our results revealed that 23% of participants met all the three WHO guidelines. Since in this investigation we used standardized measurement protocols and tools, our results are easily comparable to previous SUNRISE reports, which in generally have reported similarly low compliance rates with the WHO guidelines on movement behaviors. In brief, previous reports from SUNRISE consortium reported 4.7% of children in Bangladesh 17.5% of children from Vietnam, 19.4% of children from Sweden and 26% of children from South Africa meeting all components of the WHO movement behavior guidelines (Delisle Nyström et al., 2020; Draper et al., 2020; Hossain et al., 2021; T. V. Kim et al., 2022).

In terms of specific facets of movement behaviors, our results are also in line with previous reports. Specifically, proportion of B&H preschoolers meeting the physical activity time was 64%, while previous reports showed higher prevalence in Sweden (90.3%) Australia (89%), South Africa (84%), Japan (75.4%), and China (64.5%), but lower prevalence in Canada (61.8%), and Vietnam (50.4%) (Delisle Nyström et al., 2020; T. V. Kim et al., 2022). Additionally, B&H preschoolers demonstrated approximately 1.6 h in LPA, which is lower compared to the reported LPA among Chinese (3.7 h), Canadian (3.5 h), and South African (2.1 h). On the other hand, it is encouraging that 89% of our participants met the recommended 60 minutes of moderate-to-vigorous physical activity (MVPA), which is higher than children from Sweden (71%) and Bangladesh (41%)(Delisle Nyström et al., 2020; Hossain et al., 2021).

Sleep time plays a crucial role for maintaining normal physiological processes for growth and development. Therefore, it is encouraging that 75% of our participants met the WHO sleep guideline of 10-13 h/day. Once again, our results coincide with the findings posted in China (83.9%) and Australia (93%) (Chaput et al., 2017; Matarma et al., 2018). However, screen time of Bosnian children was better compared to other studied countries. While we found that 53% of our participants met the WHO guideline of ≤1 hour/day of screen time, this was considerably higher than the rates observed in Canada (24.4%), Australia (23%), and Japan (15.9%) (Chaput et al., 2017; Hinkley et al., 2020; Tanaka et al., 2020).

In this study, 22.3% of the Bosnian preschool children were classified as overweight/obese. Identical overweight/obesity prevalence was previously evidenced in children from Vietnam (22.3%) while higher prevalence of overweight/obesity was found in Sweden (31%) (Delisle Nyström et al., 2020; T. V. Kim et al., 2022). Meanwhile, with 11.2% overweight/obese children lower rates are evidenced in South Africa (Draper et al., 2020). The relatively low overweight/obesity in B&H preschoolers can be at least partially explained by the fact that nine of ten children achieve appropriate levels of daily MVPA (please see previous discussion for details)

Sex- and living-environment differences

Pre-school boys exhibited better movement behaviors than girls, which is particularly evident in MVPA. Surprisingly, these differences were not translated in motor-skills, where boys and girls achieved similar results in gross- and fine-motor-skills. Although at first glance may seem surprising, the lack of sex-differences in motor skills is in line with previous SUNRISE studies conducted in South Africa and Vietnam (Draper et al., 2020; T. V. Kim et al., 2022). While this can imply relative non-influence of increased physical activity on motor skills within this age, it is important to overview some possible reasons for the lack of sex-differences in motor skills, despite significant differences in movement behaviors between boys and girls.

First, it is possible that the type of PA our children were involved at doesn't have strong influence on tested capacities. Precisely, capacities we have tested here are more under the influence of power- and strength-based activities (i.e., jumping, climbing, throwing heavy objects). Meanwhile, we can witness that MVPA among boys in this age is mostly a consequence of playing some sports (particularly soccer), which directly influence cardiorespiratory fitness, the ability we didn't observe in this project. Second, it is possible that the higher PA among boys, and their PA templates are relatively „recent", and therefore were not yet translated to better motor-skills. Irrespective of the explanation, there is an evident necessity to further explore the connection of movement behaviors and performance variables during early childhood.

The lack of sex-differences in cognitive-skills was not surprising, and previous studies from other world regions consistently reported similar cognitive-function in boys and girls of pre-school age (Draper et al., 2020; Hossain et al., 2021). These results however, at least partially can explain the similar results in fine-motor skills among boys and girls in our study. Specifically, quality of the cognitive functioning in early childhood is known to be the most important determinant and predictor of fine motor control, which directly translates even to execution of precise motor tasks we applied as a way of evaluating fine motor skills (Bala & Katić, 2009).

Living environment (urban vs. rural living environment) didn't differentiate children in studied variables. Previous studies done within SUNRISE protocol reported similar results. Precisely, a SUNRISE study which included data from 19 countries reported no significant differences in movement behaviors between urban and rural residential settings (Kariippanon et al., 2022). The authors of that study explained such findings by a lack of a consistent classification criteria of a rural and urban setting. Similar explanation could be given for our results. Namely, territory where our study was done is densely populated, and there is no clear boundary between urban and rural areas. Therefore, life habits of children living in rural and urban communities are very similar. It is not rare that adults living in rural areas work in urban centers, which additionally contribute to similar way of life in both communities, resulting in similar anthropometrics, movement behaviors, and motor skills of urban and rural children.

Limitations and strengths

The main limitation of this study comes from the fact that we studied a limited number of children, from only one region in B&H. Therefore, results should be observed as preliminary and cannot be generalized for the whole country territory. Second, this is cross-sectional study, and causality cannot be interpreted. Therefore, for a more profound analysis of the relationships between studied variables, intervention studies should be performed.

This is one of the first studies in the region, and probably the first one in B&H which specifically observed movement behaviors in pre-school children. Also, this study is the first to provide a comprehensive overview of the movement behaviors of preschoolers from B&H using an objective assessment of physical activity. Also, we used standardized measurement protocols and standards, which allowed objective comparison with other reports worldwide, allowing relevant analysis of the status in studied variables.

Conclusions

Although we have found that only 23% of the pre-school children from B&H meet WHO guidelines on movement behaviors, it seems that when observed separately for each behavior screen-time deserves particular attention. Namely, 53% of preschoolers meet the WHO recommendation of being less than one-hour in front of the screen, it seems that this issue should be the main focus on future interventions aimed at reaching WHO-defined standards on movement behaviors.

Girls exhibit lower PA than boys, especially in terms of MVPA. While reaching appropriate levels of PA is one of the most important prerequisites of WHO health standards in early childhood, girls should be observed as a targeted population in that manner. Although more extensive investigations with larger samples are needed to confirm our results, we may suggest that interventions aimed at increasing PA should pay special attention on girls, and try to find a way to increase the MVPA among them.

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Based on our results, urban and rural children did not differ in movement behaviors, gross motor skills, fine motor skills, and cognitive skills. While we studied a specific region in the country, where urban and rural living environments are not strictly separated, our findings may be partially a consequence of such a geographical situation. Therefore, future studies in other parts of the country are needed to confirm these findings.

Informed Consent Statement

Written consent was obtained from parents of all subjects involved in the study.

Data Availability Statement

Data are available upon reasonable request.

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References

Abarca-Gómez, L., Abdeen, Z. A., Hamid, Z. A., Abu-Rmeileh, N. M., Acosta-Cazares, B., Acuin, C., . . . Aguilar-Salinas, C. A. (2017). Worldwide trends in body-mass index, underweight, overweight, and obesity from 1975 to 2016: a pooled analysis of 2416 population-based measurement studies in 128· 9 million children, adolescents, and adults. *The lancet, 390*(10113), 2627-2642.

Aneesha Acharya, K., & Choudhary, A. (2023). Manual Dexterity Assessment Using a Nine-Hole Pegboard Test. In *Smart Sensors Measurement and Instrumentation: Select Proceedings of CISCON 2021* (pp. 449-459): Springer.

Bala, G., & Katić, R. (2009). Sex differences in anthropometric characteristics, motor and cognitive functioning in preschool children at the time of school enrolment. *Collegium antropologicum, 33*(4), 1071-1078.

Berglind, D., Ljung, R., Tynelius, P., & Brooke, H. L. (2018). Cross-sectional and prospective associations of meeting 24-h movement guidelines with overweight and obesity in preschool children. *Pediatric Obesity, 13*(7), 442-449. doi:10.1111/ijpo.12265

Carson, V., Lee, E. Y., Hewitt, L., Jennings, C., Hunter, S., Kuzik, N., Tremblay, M. S. (2017). Systematic review of the relationships between physical activity and health indicators in the early years (0-4 years). *BMC Public Health, 17*(Suppl 5), 854. doi:10.1186/s12889-017-4860-0

Chaput, J. P., Colley, R. C., Aubert, S., Carson, V., Janssen, I., Roberts, K. C., & Tremblay, M. S. (2017). Proportion of preschool-aged children meeting the Canadian 24-Hour Movement Guidelines and associations with adiposity: results from the Canadian Health Measures Survey. *BMC Public Health, 17*(Suppl 5), 829. doi:10.1186/s12889-017-4854-y

Cliff, D. P., Reilly, J. J., & Okely, A. D. (2009). Methodological considerations in using accelerometers to assess habitual physical activity in children aged 0-5 years. *Journal of Science and Medicine in Sports, 12*(5), 557-567. doi:10.1016/j.jsams.2008.10.008

de Fátima Guimarães, R., Mathieu, M.-E., Reid, R. E., Henderson, M., & Barnett, T. A. (2021). Physical activity, screen time, and sleep trajectories from childhood to adolescence: The influence of sex and body weight status. *Journal of Physical Activity and Health, 18*(7), 767-773.

Delisle Nyström, C., Alexandrou, C., Henström, M., Nilsson, E., Okely, A. D., Wehbe El Masri, S., & Löf, M. (2020). International Study of Movement Behaviors in the Early Years (SUNRISE): Results from SUNRISE Sweden's Pilot and COVID-19 Study. *International Journal of Environmental Research and Public Health, 17*(22). doi:10.3390/ijerph17228491

Di Cesare, M., Sorić, M., Bovet, P., Miranda, J. J., Bhutta, Z., Stevens, G. A., Bentham, J. (2019). The epidemiological burden of obesity in childhood: a worldwide epidemic requiring urgent action. *BMC medicine, 17*, 1-20.

Draper, C. E., Tomaz, S. A., Cook, C. J., Jugdav, S. S., Ramsammy, C., Besharati, S., van Heerden, A., Vilakazi, K., Cockcroft, K., Howard, S., Okely, A. D. (2020). Understanding the influence of 24-hour movement behaviours on the health and development of preschool children from low-income South African settings: the SUNRISE pilot study. *South African Journal of Sports Medicine, 32*(1), v32i31a8415. doi:10.17159/2078-516X/2020/v32i1a8415

Hinkley, T., Timperio, A., Watson, A., Duckham, R. L., Okely, A. D., Cliff, D., Carver, A., Hesketh, K. D. (2020). Prospective associations with physiological, psychosocial and educational outcomes of meeting Australian 24-Hour Movement Guidelines for the Early Years. *International Journal of Behavioral Nutrition and Physical Activity, 17*(1), 36. doi:10.1186/s12966-020-00935-6

Hossain, M. S., Deeba, I. M., Hasan, M., Kariippanon, K. E., Chong, K. H., Cross, P. L., Ferdous, S., Okely, A. D. (2021). International study of 24-h movement behaviors of early years (SUNRISE): a pilot study from Bangladesh. *Pilot Feasibility Study, 7*(1), 176. doi:10.1186/s40814-021-00912-1

Howard, S. J., & Melhuish, E. (2017). An Early Years Toolbox for Assessing Early Executive Function, Language, Self-Regulation, and Social Development: Validity, Reliability, and Preliminary Norms. *Journal of Psychoeducational Assessment, 35*(3), 255-275. doi:10.1177/0734282916633009

Janz, K. F., Burns, T. L., & Levy, S. M. (2005). Tracking of activity and sedentary behaviors in childhood: the Iowa Bone Development Study. *American Journal of Preventive Medicine, 29*(3), 171-178. doi:10.1016/j.amepre.2005.06.001

Kariippanon, K. E., Chong, K. H., Janssen, X., Tomaz, S. A., Ribeiro, E. H. C., Munambah, N., Okely, A. D. (2022). Levels and Correlates of Objectively Measured Sedentary Behavior in Young Children: SUNRISE Study Results from 19 Countries. *Medicine and Science in Sports and Exercise, 54*(7), 1123-1130. doi:10.1249/mss.0000000000002886

Kim, T. J., & von dem Knesebeck, O. (2018). Income and obesity: what is the direction of the relationship? A systematic review and meta-analysis. *BMJ Open, 8*(1), e019862. doi:10.1136/bmjopen-2017-019862

Kim, T. V., Pham, T. N., Nguyen, C. L., Nguyen, T. T., Okely, A. D., & Tang, H. K. (2022). Prevalence of physical activity, screen time, and sleep, and associations with adiposity and motor development among preschool-age children in Vietnam: the SUNRISE Vietnam pilot study. *Indian Journal of Pediatrics, 89*(2), 148-153.

Kuzik, N., Carson, V., Andersen, L. B., Sardinha, L. B., Grøntved, A., Hansen, B. H., & Ekelund, U. (2017). Physical Activity and Sedentary Time Associations with

Metabolic Health Across Weight Statuses in Children and Adolescents. *Obesity (Silver Spring), 25*(10), 1762-1769. doi:10.1002/oby.21952

Malina, R. M. (1996). Tracking of physical activity and physical fitness across the lifespan. *Research Quarterly for Exercise and Sports, 67*(3 Suppl), S48-57. doi:10.1080/02701367.1996.10608853

Martinovic, M. B., Jaksic, M. Z., Spahic, E. S., Lukic, M. Z., & Nedovic-Vukovic, M. M. (2021). Physical Activity and Nutritional Status of Schoolchildren in Montenegro. *Sport Mont, 19*(1), 65-70. doi: 10.26773/smj.210216

Matarma, T., Lagström, H., Hurme, S., Tammelin, T. H., Kulmala, J., Barnett, L. M., & Koski, P. (2018). Motor skills in association with physical activity, sedentary time, body fat, and day care attendance in 5-6-year-old children-The STEPS Study. *Scandinavian Journal of Medicine and Science in Sports, 28*(12), 2668-2676. doi:10.1111/sms.13264

Montesano, P., & Mazzeo, F. (2019). Sports activities in obese teenagers improve social inclusion and health. *Sport Mont, 17*(1), 55-60. doi: 10.26773/smj.190210

Okely, A. D., Reilly, J. J., Tremblay, M. S., Kariippanon, K. E., Draper, C. E., El Hamdouchi, A., . . . Katzmarzyk, P. T. (2021). Cross-sectional examination of 24-hour movement behaviours among 3-and 4-year-old children in urban and rural settings in low-income, middle-income and high-income countries: the SUNRISE study protocol. *BMJ Open, 11*(10), e049267.

Organization, W. H. (2019). *Guidelines on physical activity, sedentary behaviour and sleep for children under 5 years of age*: World Health Organization.

Park, M. H., Falconer, C., Viner, R. M., & Kinra, S. (2012). The impact of childhood obesity on morbidity and mortality in adulthood: a systematic review. *Obesity reviews, 13*(11), 985-1000.

Saunders, T. J., Gray, C. E., Poitras, V. J., Chaput, J. P., Janssen, I., Katzmarzyk, P. T., . . . Carson, V. (2016). Combinations of physical activity, sedentary behaviour and sleep: relationships with health indicators in school-aged children and youth. *Appliedl Physiology and Nutrition Metabolism, 41*(6 Suppl 3), S283-293. doi:10.1139/apnm-2015-0626

Sheldrick, M. P. R., Tyler, R., Mackintosh, K. A., & Stratton, G. (2018). Relationship between Sedentary Time, Physical Activity and Multiple Lifestyle Factors in Children. *Journal of Functional Morphology and Kinesiology, 3*(1), 15. Retrieved from https://www.mdpi.com/2411-5142/3/1/15

Tanaka, C., Okada, S., Takakura, M., Hashimoto, K., Mezawa, H., Ando, D., . . . Okely, A. D. (2020). Relationship between adherence to WHO "24-hour Movement Guidelines for the Early Years" and motor skills or cognitive function in preschool children: SUNRISE pilot study. *Japanese Journal of Physical Fitness and Sports Medicine, 69*(4), 327-333.

Vukelja, M., Milanovic, D., & Salaj, S. (2022). Physical Activity and Sedentary Behaviour in Croatian Preschool Children: A Population-Based Study. *Montenegrin Journal of Sports Science & Medicine, 11*(1).

Ward, Z. J., Long, M. W., Resch, S. C., Giles, C. M., Cradock, A. L., & Gortmaker, S. L. (2017). Simulation of growth trajectories of childhood obesity into adulthood. *New England Journal of Medicine, 377*(22), 2145-2153.

Whiting, S., Buoncristiano, M., Gelius, P., Abu-Omar, K., Pattison, M., Hyska, J., . . . Breda, J. (2021). Physical Activity, Screen Time, and Sleep Duration of Children Aged 6-9 Years in 25 Countries: An Analysis within the WHO European Childhood Obesity Surveillance Initiative (COSI) 2015-2017. *Obesity Facts, 14*(1), 32-44. doi:10.1159/000511263

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ORIGINAL SCIENTIFIC PAPER

Anthropometrical and Physical Performance Profiles of Military Cadets from Angola

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Abstract

Military efforts must include different evaluations to prepare for battles around the world. This study aimed to characterize the body composition and physical performance levels of military cadets from Angola. Ninety military academy participants (males: n=48, females: n=42) aged 18-24 years old performed a battery of physical fitness tests to evaluate upper and lower limbs muscle strength, cardiorespiratory fitness, and body composition. Significant differences between sexes were observed in all variables ($p<0.05$). Males and females, respectively, showed normal-range values in the body mass index (BMI) (23.32±3.95; 24.75±4.01 Kg/m2), body fat (9.09±6.17; 14.59±8.86 kg), push-ups (36.88±9.81; 20.67±6.62 repetitions), sit-ups (71.04±17.14; 61.95±19.05 repetitions) and medicine ball throwing (5.06±0.89; 4.00±0.84 m). However, countermovement jump (36.14±6.54; 23.53±7.62 cm), 80-meter sprint (13.08±1.90; 14.96±2.01 s), cardiorespiratory fitness (maximal oxygen uptake: 38.02±6.3; 33.18±6.49 ml/kg/min), and fat-free mass values (54.17 ± 8.06; 46.18 ± 6.9 kg) were considered low, specifically in females. Military cadets from Angola, especially females, presented low values of fat-free mass, cardiorespiratory fitness, and neuromuscular maximal performances (countermovement jump and sprint). This highlights a need for body composition and physical condition improvement to perform physical tasks with high military relevance.

Keywords: *cadets, military, profile, body composition, physical fitness*

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Introduction

Recent wars have highlighted the need to maintain military performance capabilities in demanding operations. These soldiers are expected to engage in regular vigorous physical activity to maintain the highest possible level of physical fitness (Okhrimenko et al., 2023). This is the only way they can maintain their physical standards to perform their duties at all times (Friedl, 2012). It has been shown that soldiers who are physically active on a daily basis perform better in combat and are more resilient in stressful situations (Flanagan et al., 2012). In addition, previous findings have shown that performance on military-specific tasks is improved by higher levels of physical fitness and scores on tests throughout the service (Harty et al., 2022; Romanchuk et al., 2021). Furthermore, these soldiers

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are less likely to develop diseases and musculoskeletal injuries due to the protective effects of physical activity on the entire body structure and better long-term health (Jones et al., 2017; Havenetidis et al., 2013). Physical fitness also has an impact on mental health, with several studies showing the benefits of physical fitness on mental health (Okhrimenko et al., 2023).

Some have argued that the physical fitness level of a military member should be higher than that of the general population because their missions are performed in a large variety of environments and require different physical abilities (Santtila et al., 2009; Maupin et al., 2018). Among the most commonly assessed and monitored components of physical fitness in the military are body composition, muscular strength, endurance, speed, and cardiorespiratory fitness (Maupin et al., 2018). Good levels of strength and endurance are essential to support the physical skills that are required for successful military combat activities (Santtila et al., 2009; Santtila et al., 2008). For example, a high level of physical fitness can increase the ability to generate strength and power, delay fatigue, and speed up recovery (Bulmer et al., 2022; Booth, 2006). In addition, the development of specific physical characteristics affects the overall ability to perform simple and complex motor activities. As a result, it is widely accepted that this is the foundation of military forces readiness (Knapik et al., 2012).

In addition to physical ability, the importance of body composition to overall performance cannot be ignored. Previous research has shown that body composition is associated with aerobic capacity and muscular endurance (Moreno et al., 2019). In fact, soldiers with more fat mass tend to have more difficulty performing lower and upper body strength tests, jumping and sprinting tasks, and cardiorespiratory fitness tests (Santtila et al., 2009; Campos et al., 2018, Hollerbach et al., 2022). In addition, health is known to be influenced by body composition, body weight, and body mass index (BMI), which are commonly associated with an increased risk of cardiovascular disease, type 2 diabetes, musculoskeletal disorders, and certain types of cancers (Santtila et al., 2008; Santtila et al., 2019).

Over the years, there seems to have been a trend toward a decline in physical fitness among military recruits (Hoerster et al., 2012; Meadows et al., 2018). For example, the physical fitness levels of 3.875 female recruits changed significantly between 2005 and 2015, with body mass and BMI increasing by 4.2% and 3.8%, respectively (Santtila et al., 2019). Moreover, the proportion of female recruits with poor endurance performance increased by approximately 8% during these 10 years. This reinforces the need to monitor and evaluate military performance to help design appropriate training programs for this population. A deeper understanding of the physical fitness profiles of the military forces is important for analyzing recruit selection and supporting the development of specific strength and conditioning programs, particularly in some countries where this knowledge is scarce. Specific physical fitness profiles would make it possible to assess specific performance measures that determine success, address areas of weakness within the individual's fitness profile, and thus design a customized training program for each unit or individual (Maupin et al., 2018; Hall et al., 2022). In addition, these profiles would allow reduce the risk of injury and provide information for the design of specific training programs (e.g., return to training after a period of inactivity) (Roy et al., 2012). Therefore, the present study aimed to analyze the body composition, upper and lower limb muscle strength, and cardiorespiratory fitness of military cadets from the Instituto Superior Técnico Militar of Angola.

Methods

Study Design

In this cross-sectional study, the participants were recruited from the Instituto Superior Técnico Militar from Angola by convenience sampling. Participants ranged in age from 18 to 24 years old and had no recent history (within 6 months) of medical disorders that limited participation in their physical training activities. Participants were informed about the study protocol, and once they agreed, they voluntarily signed the informed consent form. The evaluation tests have been selected for their relevance in assessing the physical condition and their common use by conditioning specialists and coaches in sports training. The procedures were performed according to the Declaration of Helsinki and were approved by the review board of the Research Center in Sports Sciences, Health Sciences and Human Development of the University of Beira Interior, Portugal.

Participants

Ninety military personnel (48 male and 42 female) from the Instituto Superior Técnico Militar in Angola volunteered to participate in the study. Subjects were asked to report any previous illnesses, injuries, or other physical problems, and were excluded if there was any evidence of an orthopedic or clinical problem or any other self-reported problem that would compromise their health. Inclusion criteria to participate in the study were to be cadets at the Instituto Superior Técnico Militar of Angola, to be free of injury, and able to complete all physical and anthropometric assessments. They were excluded if they had any medical condition (temporary or permanent) or injury preventing exercise participation, had an implanted electrical medical device, or were pregnant. Participants were carefully informed about the study design, with specific information about potential risks and discomforts that may occur.

Procedures

After two familiarization sessions, the evaluations were performed in different sessions (48 hours between) for two weeks. In the first session, height was determined by a stadiometer (Seca, Hamburg, Germany), and body mass, body fat, and fat-free mass were determined by bioelectrical impedance analysis (OMRON HBF 510, Omron Healthcare, Inc., Illinois, USA). The device that was used was shown to be both reliable and valid for predicting fat-free mass and appropriate to use for body composition assessment in the adult population (Vasold et al., 2019). Participants' age, height, and sex were entered into the device and then the participant stepped barefoot onto it with feet width apart. Participants were instructed to hold the display unit with both hands and extend their arms parallel to the floor. The body composition assessment was performed after waking up and the participants were instructed to avoid alcohol and vigorous exercise 24 hours before evaluation. Body mass index (BMI) was calculated afterward. For ethical reasons, there was no recording of menstrual cycle time in female participants.

The following sessions were used to assess physical fitness, randomly: push-ups, medicine ball throwing, sit-ups, countermovement jump (CMJ), 80-meter sprint, and shuttle run

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test. The push-ups assessment was performed with the subject lying prone on the floor with both hands under the shoulders and pushed up off the floor until the elbows were straight while keeping the entire body straight. The participant then lowered the body with the arms until the elbows were bent at a 90° angle. Participants were instructed to repeat the exercise for 1 minute as many times as possible, stopping if they could not perform the push-up correctly (Santilla et al., 2019).

For the sit-ups evaluation, participants started with their feet and shoulders flat on the floor and their knees at a 90º angle with their arms crossed over their chest. A second person held the lower legs or ankles. At the beginning of the exercise, they were asked to lift their torso, bringing their chest toward their knees. When the subjects reached an angle of about 30º between their torso and the floor, they could return to the starting position. They were instructed to repeat the exercise as many times as possible for 2 minutes, stopping if they could not perform the sit-up correctly (Lin et al., 2022).

For the strength assessments, upper-body and lower-body muscular power were assessed by medicine ball throwing and CMJ, respectively. For lower-body assessment, sprint performance was also evaluated. In the medicine ball throwing assessment, each participant seated against a wall at a 90°angle with his legs straight out and his head against the wall and then threw a 3kg medicine ball horizontally with as much force as possible without moving his back or head. The distance was then measured with a tape measure. Each participant had three attempts (3 minutes rest) and the highest value was recorded (Borms et al., 2018). In the CMJ, each participant performed three maximal jumps (3 minutes of rest between trials), and the height was measured (Optojump photocell system, Microgate, Bolzano, Italy). All CMJs were performed with the hands on the hips throughout the test. While standing upright, participants were instructed to bend their knees to a squatting position (90º) and immediately rebound in a maximal vertical jump. The best height score was recorded for analysis (Claudino et al., 2017). Regarding sprint, two test trials of 80m linear sprint running were performed (10 minutes of rest between trials). The time taken to complete the 80 m distance was measured by two experienced coaches using a chronometer (Golfinho Sports MC 815, Aveiro, Portugal). The mean value was recorded for further analysis.

The cardiorespiratory fitness was evaluated by a shuttle run test. This test required running between two lines set 20 meters apart at a speed dictated by a stereo system that played sounds at predetermined intervals. The initial speed was set at 8.5km/h for the first minute and increased by 0.5 km/h each minute. The test score achieved by the subject was the number of 20-meter shuttles completed before the participant either gave up voluntarily or failed to be within 3 meters of the end lines on two consecutive tones (Paradisis et al., 2014). Maximal oxygen uptake (VO2max) was then determined using a validated equation (Flouris et al., 2005): Vo2max = (MAS x 6.65-35.8) x 0.95 + 0.182, where MAS is the maximal attained speed during shuttle run test (km/h) and Vo2max is the predicted maximal oxygen uptake (ml/kg/min).

Statistical analysis

Means and standard deviations (SDs) were calculated for all measures, and 95% confidence intervals were determined. The normality of all distributions was tested using the Kolmogorov–Smirnov test and non-parametric statistical analysis was applied. The Mann-Whitney U Test was used to compare means, and the level of statistical significance was set at $p \le 0.05$. A specific effect size calculator was used to determine the effect size of the non-normally distributed variables (Hopkins et al., 2009). The effect size calculator for non-parametric tests was used to determine the eta square and then converted to Cohen's d values for standardization (Lenhard et al., 2016). Cohen's d values were 0.20, 0.60, 1.20, and 2.00, corresponding to small, moderate, large, and very large magnitudes, respectively (Hopkins et al., 2009). A percentile distribution was then generated for each of the variables analyzed in the study. Statistical analyses were performed in Microsoft Office Excel® (Microsoft Inc., Redmond, WA, USA) and SPSS v28 (IBM Corp., Armonk, NY, USA). Data were plotted using GraphPad Prism v7 (GraphPad Inc., San Diego, CA, USA).

Results

Physical performance and anthropometric characteristics are presented in Table 1 for males and Table 2 for females. Differences between men and women were found for height ($p<0.001$, d=1.50), BMI ($p=0.019$, d=0.51), body fat (percentage: $p<0.001$, d=0.96; kg: $p<0.001$, d=0.75), fat-

Table 1. Anthropometric characteristics and physical test results of the male militaries (n = 48)

	Mean ± SD	Range	Percentiles		
			25	50	75
Age (y)	20.92 ± 1.49	19 – 24	20	20	23
Height (m)	1.69 ± 0.07	1.52 – 1.84	1.64	1.70	1.75
Body mass (Kg)	66.34 ± 10.02	51.8 – 102.2	58.63	64.65	72.35
BMI (Kg/m^2)	23.32 ± 3.95	18.67 – 38.47	21.09	22.28	24.60
Body fat (Kg)	9.09 ± 6.17	2.68 – 33.69	5.27	7.19	11.53
Body fat (%)	13.12 ± 7.07	5.0 – 38.2	8.38	10.95	16.10
Fat-free mass (Kg)	54.17 ± 8.06	25.0 – 71.7	50.15	53.30	58.75
VO$_2$max (ml/kg/min)	38.02 ± 6.30	23.03 – 54.62	32.51	38.41	41.98
Push-ups (n)	36.88 ± 9.81	15 – 56	30.0	35.5	45.0
CMJ (cm)	36.14 ± 6.54	17.71 – 47.14	33.16	37.09	40.90
Sit-ups (n)	71.04 ± 17.14	26 - 98	60.25	70.00	84.50
80-meter sprint (s)	13.08 ± 1.90	10.45 – 18.21	11.47	12.51	14.45
Medicine ball throw (m)	5.06 ± 0.89	3.2 – 6.9	4.40	5.00	5.78

free mass (p<0.001, d=1.06), push-ups (p<0.001, d=2.08), CMJ (p<0.001, d=1.79), sit-ups (p=0.019, d=0.50), 80-meter sprint (p<0.001, d=1.03), VO2max (p<0.001, d=0.75), and medicine ball throwing (p<0.001, d=1.27). Despite higher body height, body mass, and fat-free mass, men had lower BMI and fat mass. In addition, physical fitness variables showed higher mean values in men, specifically the number of push-ups, sit-ups, VO2max, medicine ball throwing, and CMJ. Men were also faster than women in the 80-meter sprint.

Table 2. Anthropometric characteristics and physical test results of the female militaries (n=42)

	Mean ± SD	Range	Percentiles		
			25	50	75
Age (y)	20.31 ± 1.49	18 – 24	19	20	21
Height (m)	1.60 ± 0.06	1.46 – 1.71	1.56	1.60	1.64
Body mass (Kg)	63.10 ± 11.03	45.3 – 89.5	53.83	64.10	69.20
BMI (Kg/m^2)	24.75 ± 4.01	16.82 – 35.33	22.55	24.50	27.13
Body fat (Kg)	14.59 ± 8.86	2.42 – 37.77	7.33	12.33	19.29
Body fat (%)	22.13 ± 10.19	6.0 – 42.4	12.13	23.55	28.98
Fat-free mass (Kg)	46.18 ± 6.90	34.9 – 62.7	40.25	46.00	51.13
VO_2max (ml/kg/min)	33.18 ± 6.49	23.03 – 48.30	29.35	32.51	38.82
Push-ups (n)	20.67 ± 6.62	10 – 40	16.75	20.00	25.00
CMJ (cm)	23.53 ± 7.62	9.61 – 42.69	17.71	22.69	28.25
Sit-ups (n)	61.95 ± 19.05	30 – 95	48	64	75
80-meter sprint (s)	14.96 ± 2.01	11.41 – 20.55	13.44	14.63	16.41
Medicine ball throw(m)	4.00 ± 0.84	2.9 – 6.1	3.48	3.80	4.50

The individual plots presented in Figure 1 and Figure 2 allow an understanding of the distribution of results by percentiles, in each variable analyzed. In Figure 1, the anthropometric variables confirm the higher values for height, weight, and fat-free mass, and the lower values for body mass index and body fat in men. Figure 2 shows the fitness variables and confirms the higher performance of the males.

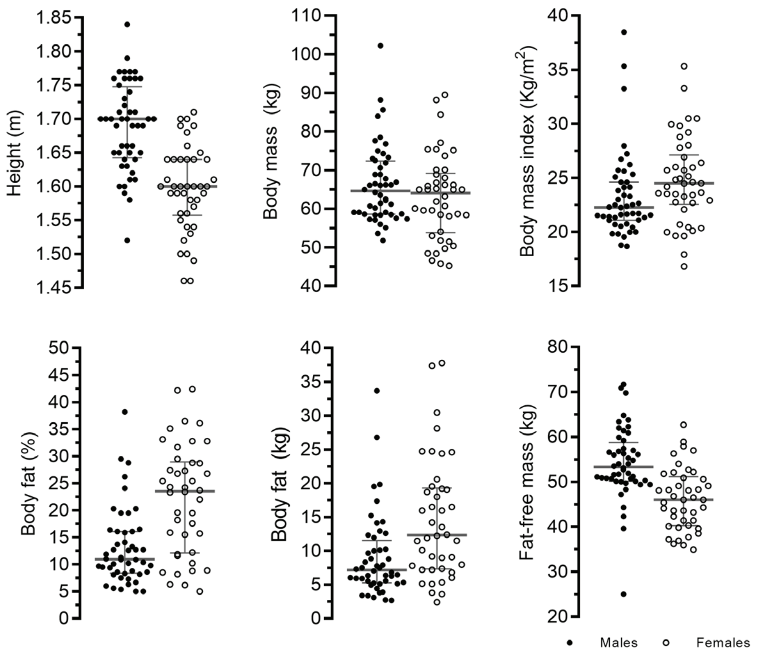

Figure 1. Individual value plot of anthropometrical variables observed in males and females. Median with interquartile range are also presented (gray lines).

Discussion

The current study aimed to characterize the fitness levels and body profiles of military cadets from the Military Higher Technical Institute of Angola. The results showed gender differences in body anthropometrics and physical performance, with males having higher body mass, fat-free mass, and lower body fat, as well as greater strength (push-ups, sit-ups, CMJ, and medicine ball throwing), speed (80m

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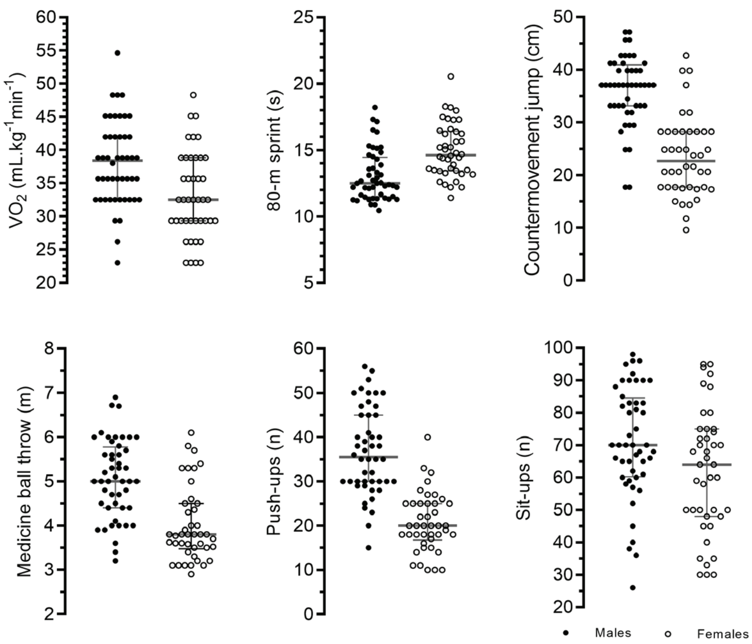

Figure 2. Individual value plot of physical performance variables observed in males and females. Median with interquartile range are also presented (gray lines).

sprint), and cardiorespiratory fitness. In addition, although anthropometric variables showed normal ranges, physical fitness tests showed low performance values, especially in women. It was also possible to determine data percentiles, which allowed the researchers to understand the spread within a distribution of values to provide a reference interval estimate. This is an important step in understanding the anthropometric and physical performance characteristics of military forces in Angola.

With respect to anthropometric measures, body fat mass and BMI recorded in other military forces were consistent with those in this study (Hall et al., 2022). For example, female and male recruits in Army Basic Training in New Zealand had mean BMI values of 26.0±3.1 kg/m2, and 24.3±3.0 kg/m2, respectively. Overall, these values are within a healthy range, although they are close to the upper limit. Thus, the potential for a higher BMI to have a protective effect against injury may hypothetically be due in part to the greater absolute muscle mass in the military. However, it is known that BMI can significantly affect physical performance and all its components (Friedl, 2022). Increases in BMI and body fat percentage may be associated with some decline in physical fitness (e.g., cardiorespiratory fitness) and reduced ability to bear external loads (Knapik et al., 2012; Romanchuk et al., 2021). Additionally, in some athletic movements, such as running or jumping, high body fat harms performance (Moreno et al., 2017; Santtila et al., 2019; Aandstad, 2020). Studies suggested that the elite military units generally have a lower body fat percentage (~15%) than the general population (~20%) and the general military (~17%) (Maupin et al., 2018). Nevertheless, recent data showed higher obesity rates among USA military officers than previous studies, especially for women (Hollerbach et al., 2022).

Despite normal BMI and body fat levels, the previously reported fat-free mass values were higher than those presented in the current study (Avila et al., 2013). Given the detrimental effects of high body fat and BMI and the need for high levels of lean body mass, exercise programs specifically designed for military newly recruits are important. For example, a 12-week training program with a total of 32 sessions of both aerobic and neuromuscular training in a sample of 130 male soldiers aged 18-19 years showed higher values at baseline (57.50±6.00kg) that increased after training (58.80±6.00kg) (Campos et al., 2017). With this in mind, it would be interesting to perform a similar exercise training program in this study to see if fat-free mass increases in the same proportion. In reference studies, exercise training programs of between 3 and 12 months, depending on the characteristics of the study, intensity, and volume of training, contribute to increases in fat-free mass (Oliver et al., 2017).

Interestingly, the physical performance assessment showed some low results for the Angolan military forces. For instance, previous studies have reported mean VO2max values slightly higher than ours in different military forces (e.g., Santtila et al., 2008; Campos et al., 2018; Figueiredo et al., 2022). The current results were relatively low and may be representative of the low cardiorespiratory fitness of this sample for males and females. The participants in the current study were at the beginning of their military service, and therefore their physical fitness is expected to change significantly with the implementation of an exercise training program. For example, aerobic exercise training has been associated with significant increases in VO2max (Santtila et al., 2008). In addition, VO2max is an important determinant of physical fitness, so higher levels may translate into better military performance (Santtila et al., 2008; Knapik et al., 2017).

For the push-up performance test, the present results are consistent with the literature, which reported trend values of around 15 repetitions for females and around 35 repetitions for males (Jones et al., 2017, Knapik et al., 2017). In addition to push-ups, medicine ball throwing was also analyzed, as this was found to be the best of eight muscle fitness tests in predicting performance in both heavy lifting and carrying a task (Knapik et al., 2012; Harman et al., 2008). In addition, it was suggested that this assessment would make a significant contribution to defining the Army's mission performance (Aandstad et al., 2020). Some studies of military personnel at the beginning of their careers have shown an average of between 3 and 2m for men and women, respectively. These values are much lower than those presented in the current study for males and females. It should also be noted that the recruits who participated in the current study had no prior experience with military physical training. Perhaps the explanation for the higher upper body explosive strength could be due to the age and somatic characteristics of this sample, as previously reported (Aandstad et al., 2020).

Regarding the lower body neuromuscular performance, some authors have used similar tests, such as standing vertical and horizontal jumps, to simulate military tasks that could be added to field tests to expand the range of movement skills tested (e.g., Knapik et al., 2017). The values of both female and male cadets in this study were lower than some previous findings (e.g., Havenetidis et al., 2013), but similar to other results (e.g., Knapik et al., 2017; Pihlainen et al., 2018). These inconsistencies may arise due to differences in the study population, context, and testing equipment (Merrigan et al., 2020). Sprint times were also recorded to assess lower-body neuromuscular performance. The current sprint times were similar to those reported in recent studies (Romanchuk et al., 2021). However, the distance ran in the present study was lower (80 m vs. 100 m), which reveals the low sprint performance of the participants of the current study. Although no studies have reported 80-meter sprint running times in this context, the results presented suggest that the military personnel included in this study should train to improve their performance on this speed test. Contrary to most of the physical variables in the current study, the sit-up performance was consistent with previous findings in military forces (Oliver et al., 2017). This measure is used to determine the effect of physical fitness on the risk of musculoskeletal injury in Army training, but it should be interpreted carefully (Jones et al., 2017; Roy et al., 2021).

In summary, this research showed that body composition assessment and physical fitness can provide a characterization of military cadets, with a percentile distribution of military cadets from Angola. Low values of fat-free mass, cardiorespiratory fitness, and neuromuscular maximal performances highlight a need for specific training programs for body composition and physical condition improvement. Future studies should analyze innovative training protocols designed to stimulate strength and aerobic gains. Some limitations should be acknowledged, including the lack of circumference measurements and skinfolds for body composition assessment or other physical variables to complement evaluations. Also, despite the participants being instructed regarding diet and exercise, we should be aware that bioimpedance analysis for body composition assessment may be influenced by factors such as hydration status, skin temperature, or menstrual cycle. Interpreting and generalizing the findings of the present study must be done with caution and these data do not represent the whole population. Nevertheless, the representative sample used in the present study showed a significant contribution that can help design new strategies for the quality of future research and practical applications regarding military investigations.

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References

Aandstad, A. (2020). Association Between Performance in Muscle Fitness Field Tests and Skeletal Muscle Mass in Soldiers. *Military Medicine*, *185*(5-6), e839–e846. https://doi.org/10.1093/milmed/usz437

Avila, J. A., Lima Filho, P. D. B., Páscoa, M. A., & Tessutti, L. S. (2013). Efeito de 13 semanas de treinamento físico militar sobre a composição corporal e o desempenho físico dos alunos da escola preparatória de cadetes do exército. *Revista Brasileira De Medicina Do Esporte*, *19*(5), 363–366. https://doi.org/10.1590/S1517-86922013000500013

Booth, C. K., Probert, B., Forbes-Ewan, C., & Coad, R. A. (2006). Australian army recruits in training display symptoms of overtraining. *Military Medicine*, *171*(11), 1059–1064. https://doi.org/10.7205/milmed.171.11.1059

Borms, D., & Cools, A. (2018). Upper-Extremity Functional Performance Tests: Reference Values for Overhead Athletes. *International Journal of Sports Medicine*, *39*(6), 433–441. https://doi.org/10.1055/a-0573-1388

Bulmer, S., Aisbett, B., Drain, J. R., Roberts, S., Gastin, P. B., Tait, J., & Main, L. C. (2022). Sleep of recruits throughout basic military training and its relationships with stress, recovery, and fatigue. *International Archives of Occupational and Environmental Health*, *95*(6), 1331–1342. https://doi.org/10.1007/s00420-022-01845-9

Campos, L. C. B., Campos, F. A. D., Bezerra, T. A. R., & Pellegrinotti, Í. L. (2017). Effects of 12 Weeks of Physical Training on Body Composition and Physical Fitness in Military Recruits. *International Journal of Exercise Science*, *10*(4), 560–567.

Claudino, J. G., Cronin, J., Mezêncio, B., McMaster, D. T., McGuigan, M., Tricoli, V., Amadio, A. C., & Serrão, J. C. (2017). The countermovement jump to monitor neuromuscular status: A meta-analysis. *Journal of Science and Medicine in Sport*, *20*(4), 397–402. https://doi.org/10.1016/j.jsams.2016.08.011

Lin, Y. K., Tsai, K. Z., Han, C. L., Lee, J. T., & Lin, G. M. (2022). Athlete's heart assessed by sit-up strength exercises in military men and women: the CHIEF heart study. *Frontiers in Cardiovascular Medicine*, *8*, 737607. https://doi.org/10.3389/fcvm.2021.737607

Figueiredo, P. S., Looney, D. P., Pryor, J. L., Doughty, E. M., McClung, H. L., Vangala, S. V., Santee, W. R., Beidleman, B. A., & Potter, A. W. (2022). Verification of Maximal Oxygen Uptake in Active Military Personnel During Treadmill Running. *Journal of Strength and Conditioning Research*, *36*(4), 1053-1058. https://doi.org/10.1519/JSC.0000000000004019

Flanagan, S. C., Kotwal, R. S., & Forsten, R. D. (2012). Preparing soldiers for the stress of combat. *Journal of Special Operations Medicine: a peer reviewed journal for SOF medical professionals*, *12*(2), 33–41. https://doi.org/10.55460/RPAT-ESAK

 DOI 10.26773/mjssm.240902

Flouris, A. D., Metsios, G. S., & Koutedakis, Y. (2005). Enhancing the efficacy of the 20 m multistage shuttle run test. *British Journal of Sports Medicine*, *39*(3), 166–170. https://doi.org/10.1136/bjsm.2004.012500

Friedl K. E. (2012). Body composition and military performance--many things to many people. *Journal of Strength and Conditioning Research*, *26 Suppl 2*, S87–S100. https://doi.org/10.1519/JSC.0b013e31825ced6c.

Hall, N., Constantinou, M., Brown, M., Beck, B., Steele, M., Rousseau, J., & Kuys, S. (2022). Profiles of Recruits Entering Army Basic Training in New Zealand. *Military medicine*, usac090. Advance online publication. https://doi.org/10.1093/milmed/usac090

Harman, E. A., Gutekunst, D. J., Frykman, P. N., Nindl, B. C., Alemany, J. A., Mello, R. P., & Sharp, M. A. (2008). Effects of two different eight-week training programs on military physical performance. *Journal of Strength and Conditioning Research*, *22*(2), 524–534. https://doi.org/10.1519/JSC.0b013e31816347b6

Harty, P. S., Friedl, K. E., Nindl, B. C., Harry, J. R., Vellers, H. L., & Tinsley, G. M. (2022). Military Body Composition Standards and Physical Performance: Historical Perspectives and Future Directions. *Journal of Strength and Conditioning Research*, *36*(12), 3551–3561. https://doi.org/10.1519/JSC.0000000000004142

Havenetidis, K., & Paxinos, T. (2013). Delineation and classification of physical conditioning in Greek Army Officer cadets. *Journal Military Veterans Health, 21*, 19–25.

Hoerster, K. D., Lehavot, K., Simpson, T., McFall, M., Reiber, G., & Nelson, K. M. (2012). Health and health behavior differences: U.S. Military, veteran, and civilian men. *American journal of preventive medicine*, *43*(5), 483–489. https://doi.org/10.1016/j.amepre.2012.07.029

Hollerbach, B.S., Haddock, C.K., Kukić, F., Poston, W.S.C., Jitnarin, N., Jahnke, S.A., DeBlauw, J.A., Heinrich, K.M. (2022). Comparisons of Baseline Obesity Prevalence and Its Association with Perceived Health and Physical Performance in Military Officers. *Biology*, *11*, 1789. https://doi.org/10.3390/biology11121789

Hopkins, W. G., Marshall, S. W., Batterham, A. M., & Hanin, J. (2009). Progressive statistics for studies in sports medicine and exercise science. *Medicine and Science in Sports and Exercise*, *41*(1), 3–13. https://doi.org/10.1249/MSS.0b013e31818cb278

Jones, B. H., Hauret, K. G., Dye, S. K., Hauschild, V. D., Rossi, S. P., Richardson, M. D., & Friedl, K. E. (2017). Impact of physical fitness and body composition on injury risk among active young adults: A study of Army trainees. *Journal of Science and Medicine in Sport*, *20 Suppl 4*, S17–S22. https://doi.org/10.1016/j.jsams.2017.09.015

Knapik, J. J., Harman, E. A., Steelman, R. A., & Graham, B. S. (2012). A systematic review of the effects of physical training on load carriage performance. *Journal of Strength and Conditioning Research*, *26*(2), 585–597. https://doi.org/10.1519/JSC.0b013e3182429853

Knapik, J. J., Sharp, M. A., & Steelman, R. A. (2017). Secular trends in the physical fitness of United States Army recruits on entry to service, 1975–2013. *The Journal of Strength & Conditioning Research*, *31*(7), 2030-2052. https://doi.org/10.1519/JSC.0000000000001928

Lenhard, W., & Lenhard, A. (2016). Calculation of Effect Sizes. Retrieved from: https://www.psychometrica.de/effect_size.html. Dettelbach (Germany): Psychometrica.

Maupin, D., Wills, T., Orr, R., & Schram, B. (2018). Fitness Profiles in Elite Tactical Units: A Critical Review. *International journal of exercise science*, *11*(3), 1041–1062.

Meadows, S. O., Engel, C. C., Collins, R. L., Beckman, R. L., Cefalu, M., Hawes-Dawson, J., Doyle, M., Kress, A. M., Sontag-Padilla, L., Ramchand, R., & Williams, K. M. (2018). 2015 Department of Defense Health Related Behaviors Survey (HRBS). *Rand health quarterly*, *8*(2), 5.

Merrigan, J. J., Stone, J. D., Thompson, A. G., Hornsby, W. G., & Hagen, J. A. (2020). Monitoring Neuromuscular Performance in Military Personnel. *International Journal of Environmental Research and Public Health*, *17*(23), 9147. https://doi.org/10.3390/ijerph17239147

Moreno, M.R., Dulla, J. M., Dawes, J., Orr, R. M., Cesario, K. A., & Lockie, R. G. (2019). Lower-body Power and its Relationship with Body Drag Velocity in Law Enforcement Recruits. *International Journal of Exercise Science, 12*(4), 847 - 858.

Okhrimenko, I. M., Chornous, V. D., Nikolaiev, O. T., Shtykh, V. A., Yuriev, S. O., Slivinskyi, Y. S., & Kotov, S. M. (2023). Formation of Psychophysical Readiness of Cadets During Applied Exercises. *Polski merkuriusz lekarski: organ Polskiego Towarzystwa Lekarskiego*, *51*(1), 48–53. https://doi.org/10.36740/Merkur202301107

Oliver, J. M., Stone, J. D., Holt, C., Jenke, S. C., Jagim, A. R., & Jones, M. T. (2017). The Effect of Physical Readiness Training on Reserve Officers' Training Corps Freshmen Cadets. *Military Medicine*, *182*(11), e1981–e1986. https://doi.org/10.7205/MILMED-D-17-00079

Paradisis, G. P., Zacharogiannis, E., Mandila, D., Smirtiotou, A., Argeitaki, P., & Cooke, C. B. (2014). Multi-Stage 20-m Shuttle Run Fitness Test, Maximal Oxygen Uptake and Velocity at Maximal Oxygen Uptake. *Journal of Human Kinetics*, *41*, 81–87. https://doi.org/10.2478/hukin-2014-0035

Pihlainen, K. A. I., Santtila, M., Häkkinen, K., & Kyröläinen, H. (2018). Associations of physical fitness and body composition characteristics with simulated military task performance. *The Journal of Strength & Conditioning Research*, *32*(4), 1089-1098. https://doi.org/10.1519/JSC.0000000000001921

Romanchuk, S., Oderov, A., Klymovych, V., Lototskiy, I., Iedynak, G., Mazur, V., ... & Ovcharuk, I. (2021). The effect of training in military pentathlon on the physiological characteristics of academy cadets. *Sport Mont*, *18*(1), 95-99.

Roy, T. C., Knapik, J. J., Ritland, B. M., Murphy, N., & Sharp, M. A. (2012). Risk factors for musculoskeletal injuries for soldiers deployed to Afghanistan. *Aviation, Space, and Environmental Medicine*, *83*(11), 1060–1066. https://doi.org/10.3357/asem.3341.2012

Santtila, M., Häkkinen, K., Karavirta, L., & Kyröläinen, H. (2008). Changes in cardiovascular performance during an 8-week military basic training period combined with added endurance or strength training. *Military Medicine*, *173*(12), 1173–1179. https://doi.org/10.7205/milmed.173.12.1173

Santtila, M., Kyröläinen, H., & Häkkinen, K. (2009). Changes in maximal and explosive strength, electromyography, and muscle thickness of lower and upper extremities induced by combined strength and endurance training in soldiers.

Journal of Strength and Conditioning Research, *23*(4), 1300–1308. https://doi.org/10.1519/JSC.0b013e3181a884bc
Santtila, M., Pihlainen, K., Koski, H., Ojanen, T., & Kyröläinen, H. (2019). Physical Fitness and Body Anthropometrics Profiles of the Female Recruits Entering to Voluntary Military Service. *Military Medicine*, *184*(1-2), e200–e205. https://doi.org/10.1093/milmed/usy145
Vasold, K. L., Parks, A. C., Phelan, D. M., Pontifex, M. B., & Pivarnik, J. M. (2019). Reliability and validity of commercially available low-cost bioelectrical impedance analysis. *International journal of sport nutrition and exercise metabolism*, *29*(4), 406-410.

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ORIGINAL SCIENTIFIC PAPER

Does the Final Score Influence the Physical Demands of Women's Handball Matches?

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Abstract

The purpose of this study was twofold: to analyze and compare the influence of the final score of the match (close, balanced and unbalanced) on physical demands during official competitions in women's handball; and to investigate if the physical demands of each playing position are affected by the final score. Twenty-two semi-professional female players from the Spanish 2nd Division were monitored across 13 official matches. Total distance (TD), high-speed running (HSR), high-intensity braking distance (HIBD), accelerations (ACC), decelerations (DEC) and PlayerLoad (PL) were collected in absolute and relative values using a local positioning system (WIMU PRO™, Realtrack Systems S.L., Almería, Spain). Two-way ANOVA with partial Eta-squared and Cohen's d were used to determine the differences between playing positions and match types. Unbalanced (16.4 ± 4.1 n·min^{-1}) and balanced matches (15.2 ± 3.8 n·min^{-1}) elicited higher DEC/min than close matches (13.1 ± 2.8 n·min^{-1}) ($p<0.001$, moderate effects). In relation to playing positions, wings covered the largest TD and registered the highest values of PL in balanced and unbalanced matches ($p<0.001$, large effects). Also, wings presented the highest values of HIBD, HSR and HSR/min regardless of the final score ($p<0.05$, moderate effects). Moreover, wings performed largely more number of ACC and DEC compared to pivots in unbalanced matches ($p<0.05$, large effects). In conclusion, this study showed that the final score of the match influences the physical demands experienced by female handball players during official competitions. This information should be considered by coaches to adapt and periodize the training load across the microcycle.

Keywords: *external load; tracking system; load monitoring; local positioning system; microsensors; wereables*

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Introduction

Handball is an intermittent team-sport characterized by high physical efforts with strenuous body contact against the opponents, interrupted by variable length periods with low-intensity movements (e.g., walking and standing still) (Karcher and Buchheit, 2014). The occurrence of these high-intensity actions is highly unpredictable, random and variable during the match (Wagner et al., 2014). Additionally, the intensity and speed of the game have increased considerably in recent years, mainly due to relatively recent changes in the rules of the game

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(e.g., throw- off not on the line but inside the center circle) and constant improvements in the tactical use of unlimited substitutions (e.g., goalkeeper substitution rule) (Hatzimanouil et al., 2024). Therefore, coaches and practitioners should analyze the physical demands encountered during official competitions to: (1) design short- and long-term training programmes to maximize performance, reduce injury risk and minimize the risk of overtraining; (2) develop and implement individualized physical training programmes for each playing position; and (3) adapt and periodize weekly training loads to manage stress and recovery (García-Sánchez et al., 2025). To achieve this purpose, technical staff can use new monitoring tools with a good level of validity (Bastida-Castillo et al., 2019) and reliability (Luteberget et al., 2018), such as local positioning system (LPS) including ultra-wideband technology (UWB) and inertial measurement units (IMUs) (e.g., accelerometer, magnetometer and gyroscope) to measure and analyze physical demands in real-time during training and competitions.

Given these technological advances, a recent systematic review indicated that elite handball players usually cover between 2000 and 4500 m per match, with high-intensity running and sprinting accounting for 5% to 15% of this distance (Michalsik et al., 2013; Michalsik et al., 2014; Póvoas et al., 2012; Póvoas et al., 2014). Nevertheless, the physical demands are highly variable due to the influence of gender, competition level, playing positions and contextual factors (García-Sánchez et al., 2023). More specifically, these researchers reported that wings covered a moderately greater total distance than backs and pivots (García-Sánchez et al., 2023). Additionally, another study showed that backs performed the highest number of high-intensity events per minute followed by pivots and then by wings (Luteberget and Spencer, 2017). Furthermore, a recent study conducted with elite female players during the European Championship 2020 showed that wing players covered higher distances in the high-intensity locomotive categories than the rest of the playing positions (Zapardiel et al., 2024).

In relation to contextual factors, previous studies conducted in other team sports (e.g. basketball, soccer or ice hockey) have shown that physical demands are highly influenced by several factors, such as match location (playing home or away) (Augusto et al., 2021; García-Unanue et al., 2018), halves of the match (first half or second half) (García-Unanue et al., 2018; Pino-Ortega et al., 2019), level of the opponent (high-level teams, intermediate-level teams or low-level teams) (Augusto et al., 2021; García-Unanue et al., 2018; Pino-Ortega et al., 2019), match outcome (win, draw or loss) (Augusto et al., 2021; Douglas et al., 2019), final score (balanced or unbalanced matches) (Alonso et al., 2023; Fox et al., 2019) and player role (starter or non-starter) (Oliveira et al., 2023). However, in handball a reduced number of studies have investigated the impact of contextual factors on the external load experienced by players (García-Sánchez et al., 2023). Most of these studies have focused on analyzing differences according to the halves of the match (Michalsik et al., 2013; Michalsik et al., 2014; Póvoas et al., 2012; Wik et al., 2017), but none have examined the impact of the goal difference at the end of the match on physical demands.

As mentioned above, evidence-based knowledge about the influence of final score on physical demands during official matches in female handball is currently limited. Therefore, the aims of this study were: (1) to analyze and compare the influence of the final score of the match (± goal difference) on physical demands during official competitions in women's handball, and (2) to investigate if the physical demands of each playing position are affected by the final score of the match.

Methods

Design

We conducted a retrospective observational design to analyze and compare the influence of the final score of the match (± goal difference) on physical demands during official competitions in women's handball. The LPS data collected correspond to the average values of 13 official home matches from the Spanish 2nd Division during the 2021–2022 season (18th September 2021 – 2nd April 2022). We excluded goalkeepers because running-based demands do not reflect their performance needs (Bassek et al., 2023; García-Sánchez et al., 2024). Also, we excluded LPS registers from field players with less than 1 minute of playing time (Wik et al., 2017).

Participants

Twenty-two semi-professional female handball players from the same team participated voluntarily in the study. Playing positions were: wings (n = 4; age: 18.8±0.5 years; height: 162.0±3.8 cm; body mass: 55.5±4.3 kg), backs (n = 14; age: 20.9±3.6 years; height: 168.7±3.9 cm; body mass: 65.4±6.8 kg) and pivots (n = 4; age: 21.0±1.8 years; height: 171.3±4.8 cm; body mass: 79.1±11.0 kg). The players belong to the third tier of competition (highly trained or national level), according to the Participant Classification Framework provided by McKay et al. (2022). During the season, players typically performed four handball training sessions and two strength training sessions per week. Also, they participated regularly in one match per week. All players were informed of the study requirements and provided written informed consent prior to the start of the study. Additionally, all the ethical procedures used in this study were in accordance with the Declaration of Helsinki (Harris & Atkinson, 2015) and were approved by the European University of Madrid Ethics Committee (CIPI/18/195).

Procedures and data analysis

All players were monitored using a local positioning system (LPS) (WIMU PRO™, RealTrack System SL, Almería, Spain) with ultra-wideband technology (UWB) and inertial measurement units (IMUs) with a good level of reliability (Bastida-Castillo et al., 2019). The LPS was installed on the official handball court where the team played their home matches according to user manual and previous studies (Font et al., 2021; Font et al., 2023; García-Sánchez et al., 2024). All players were already familiarized with the data-collection procedures during previous training sessions and friendly matches. Manufacturer's specific software (SPRO™, version 958, RealTrack System SL, Almería, Spain) was used to calculate the perimeter of the court to determine the effective playing time. In accordance with previous studies (Font et al., 2021; Font et al., 2023; García-Sánchez et al., 2024), playing time was recorded only when the players were inside the court, omitting periods when the match was interrupted (e.g. team time-outs, consultations between the referees, interruptions to wipe the court, or 2-minutes suspensions). After the match, the LPS files were exported to an USB memory and analyzed using the manufacturer's specific software. Finally, raw data were exported post-match in Excel format and imported into the statistical software for statistical analysis. At the end of this process, a total of 153 individual LPS registers from 13 official home matches were collected.

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Match types categorization

Consistent with previous studies (de Paula et al., 2020), we grouped (using k-means cluster analysis) the total number of matches (n = 182) played by all the teams in the entire competition (Spanish Women's 2^{nd} Division) into different match types according to goal difference at the end of the match. Subsequently, we classified the 13 matches played by the team into three types of matches: 4 close matches (0-3 goals), 7 balanced matches (4-8 goals), and 2 unbalanced matches (>9 goals).

External load variables

Similar to previous research (Font et al., 2021; Font et al., 2023; García-Sánchez et al., 2024), the following external load variables (distance and accelerometry) were collected in absolute and relative values (normalized by playing time): (1) Total distance (TD); (2) High-speed running (HSR) corresponding to the distance covered above 18.1 km/h; (3) High-intensity braking distance (HIBD) corresponding to the distance covered with deceleration above 2 $m\cdot s^{-2}$; (4) Number of accelerations (ACC); (5) Number of decelerations (DEC); (6) PlayerLoad (PL).

Statistical analysis

Descriptive statistics are presented as means and standard deviations (M ± SD). Statistical significance level was set at $p<0.05$. The Kolmogorov-Smirnov test was performed to confirm data distribution normality and Levene's test for equality of variances. A two-way analysis of variance (ANOVA) followed by Tukey post-hoc was used to examine differences between playing positions and match types. Playing positions (i.e., backs, pivots and wings) and match types (i.e., closed, balanced and unbalanced) were set as independent variables. Furthermore, partial Eta-squared (ηp2) was calculated for group effects with the following interpretation: small (0.010–0.059), moderate (0.060–0.139), and large effect (>0.14) (Cohen, 1988). For the post-hoc analysis, Cohen's d (ES) was calculated and interpreted using Hopkins' categorization criteria, where 0.2, 0.6, 1.2 and >2 are considered small, moderate, large and very large effects, respectively (Hopkins et al., 2009). Data analysis was performed using SPSS for Windows (Version 26, IBM Corp., Armonk, NY, USA).

Results

Differences between match types

In relation to accelerometry variables, there were differences between types of matches with moderate effect size in DEC/min ($p<0.001$, ηp2 = 0.091), but there were no differences in the rest of accelerometry variables ($p>0.05$) (Figure 1). More specifically, unbalanced matches (16.4±4.1 $n\cdot min^{-1}$) and balanced matches (15.2±3.8 $n\cdot min^{-1}$) elicited higher DEC/min than close matches (13.1±2.8 $n\cdot min^{-1}$) ($p<0.001$, ES = 0.88; $p<0.01$, ES = 0.55, respectively). Similarly, DEC values were higher during unbalanced matches (476.2±386.1) compared to balanced matches (457.8±275.5) and close matches (404.6±259.2), although not statistically significant. Furthermore, no significant differences were found in any distance variables ($p>0.05$).

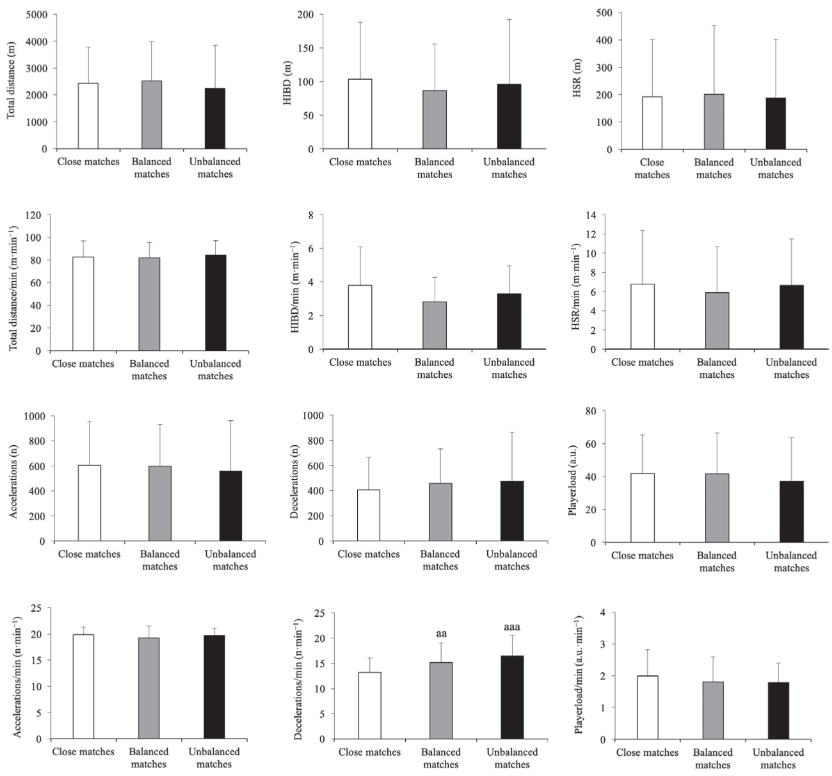

Figure 1. Influence of final score on external load variables. Significance level is indicated by the number of symbols: one symbol for $p < 0.05$, two for $p < 0.01$, and three for $p < 0.001$; [a] significant differences vs. close matches; [b] vs. balanced matches; [c] vs. unbalanced matches.

Differences between playing positions

In relation to distance variables, there were significant differences between playing positions with large effect size in TD ($p<0.001$, ηp^2 = 0.178), HIBD ($p<0.001$, ηp2 = 0.350), HSR ($p<0.001$, ηp2 = 0.502), HSR/min ($p<0.001$, ηp^2 = 0.390) (Figure 2). Wings covered largely more TD than pivots in balanced (3702.7±1656.3 m vs. 1667.3±1459.5 m) and unbalanced matches (3390.8±2128.1 m vs. 894.1±425.8

m) ($p<0.001$, ES = 1.54; $p<0.05$, ES = 1.90, respectively). Also, wings covered largely more TD than backs in balanced matches ($p=0.002$, ES = 1.11). Wings covered largely more HIBD than backs and pivots in close (+78.8 m, $p=0.012$, ES = 1.23; +133.1 m, $p<0.001$, ES = 2.08, respectively), balanced (+94.9 m, $p<0.001$, ES = 1.49; +132.4 m, $p<0.001$, ES = 2.08, respectively) and unbalanced matches (+124.3 m, $p=0.003$, ES = 1.95; +168.2 m, $p<0.001$, ES = 2.64, respectively). Additionally, wings covered largely more HSR than backs and pivots in close (+317.5 m, $p=0.012$, ES = 1.23; +367.1 m, $p<0.001$, ES = 2.08, respectively), balanced (+441.8 m, $p<0.001$, ES = 1.49; +482.8 m, $p<0.001$, ES = 2.08, respectively) and unbalanced matches (+352.8 m, $p=0.003$, ES = 1.95; +425.0 m, $p<0.001$, ES = 2.64, respectively).

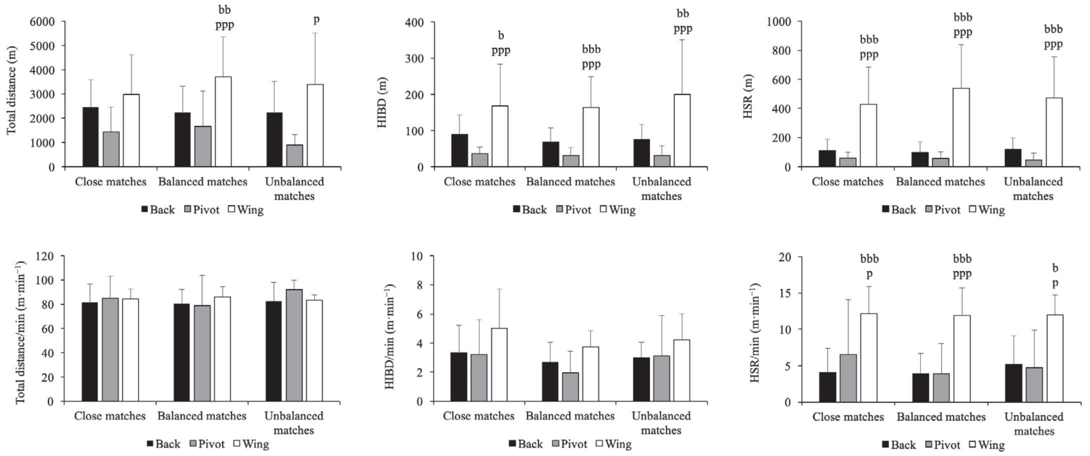

Figure 2. Influence of final score on distance variables of each playing position. Significance level is indicated by the number of symbols: one symbol for $p < 0.05$, two for $p < 0.01$, and three for $p < 0.001$; [b] significant differences vs. backs; [p] vs. pivots; [w] vs. wings.

In relation to accelerometry variables, there were significant differences between playing positions with moderate to large effect size in ACC ($p<0.001$, $\eta p2 = 0.130$), DEC ($p<0.001$, $\eta p2 = 0.108$), PL ($p<0.001$, $\eta p2 = 0.163$) (Figure 3). Wings performed largely more number of ACC (775.5±467.3) and DEC (667.5±496.9) compared to pivots (190.0±95.1, $p<0.05$, ES = 1.76) (178.8±95.3, $p<0.05$, ES = 1.74) in unbalanced matches. Also, wings registered moderately more PL than backs and pivots in balanced and unbalanced matches ($p<0.05$, ES = 0.88-1.74). Furthermore, no significant interaction effect (playing positions vs. final score) was found in any external load variables ($p>0.05$).

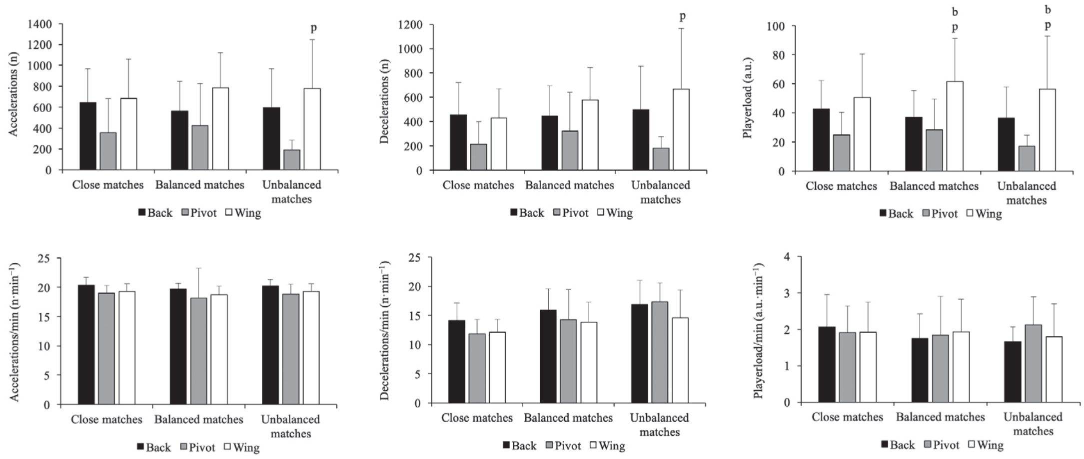

Figure 2. Influence of final score on accelerometry variables of each playing position. Significance level is indicated by the number of symbols: one symbol for $p < 0.05$, two for $p < 0.01$, and three for $p < 0.001$; [b] significant differences vs. backs; [p] vs. pivots; [w] vs. wings.

Discussion

To our knowledge, this is the first study to analyze and compare the influence of the final score on physical demands during official matches in women's handball. The main findings associated with match types indicated that: (1) unbalanced and balanced matches elicited higher values of DEC/min compared to close matches. Furthermore, the results connected to playing positions were the following: (1) wings covered largely more TD than pivots in balanced and unbalanced matches and more TD compared to backs in balanced matches; (2) wings covered largely more HIBD, HSR and HSR/min than backs and pivots regardless of the final score of the match; (3) wings performed largely more number of ACC and DEC compared to pivots in unbalanced matches; (4) wings registered moderately more PL than backs and pivots in balanced and unbalanced matches.

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In relation to match types, unbalanced and balanced matches elicited higher values of DEC/min compared to close matches. A possible explanation for these differences could reside in the combination of various characteristics of unbalanced matches: (1) a higher number of stolen balls and blocked throws (de Paula et al., 2020), (2) a higher game pace and a great number of ball possessions (Gómez et al., 2014), and (3) a higher number of quick transitions (counter-attacks) and quick goals (de Paula et al., 2020). Additionally, these results could also be related to some features of close matches: (1) a slower game pace, (2) a reduced number of ball possessions, and (3) a longer duration of attacks (Gómez et al., 2014). Consequently, if the number of counter-attacks increases in unbalanced matches, the players must tolerate a greater number of intense eccentric contractions during these matches, because each counter-attack action is followed by strong decelerations from a high velocity. This information suggests that players may experience high neuromuscular fatigue and tissue damage during unbalanced matches, especially if these high braking forces cannot be dissipated and distributed efficiently (Harper et al., 2019). Therefore, handball coaches and strength and conditioning specialists should incorporate different interventions (e.g., increase player substitutions) to mitigate the appearance of fatigue and tissue damage during matches with a large goal difference. Furthermore, handball coaches should employ small-sided games with different rules constraints (e.g., goal difference, number of players, duration and court dimensions) to best prepare players to cope the external load experienced during each match type (Corvino et al., 2014). This type of tasks could be an effective training tool to enhance aerobic and anaerobic capacities, as well as technical and tactical skills of the handball players (Buchheit et al., 2009).

Regarding playing positions, wings covered the largest TD and registered the highest values of PL in balanced and unbalanced matches. We hypothesized that these results could be related to their position on the court, because the handball playing area is longer in the outer aisles than the central domain of the court because of the design of the goal areas, enabling wings to cover larger distances (Póvoas et al., 2014). Additionally, wings covered largely more HIBD, HSR and HSR/min than backs and pivots regardless of the final score of the match. Recent research carried out with multi-directional team-sport athletes suggests that repeated high-intensity actions (associated with intense eccentric contractions) may produce fatigue, tissue damage, inflammatory responses, and impair neuromuscular performance (Markus et al., 2021; Harper et al., 2019; Harper et al., 2022). Likewise, wings performed largely more number of ACC and DEC compared to pivots in unbalanced matches. These results could also be related to the specific technical activity of each playing position. Previous studies indicate that wings usually perform more counter-attack actions than the other playing positions (Michalsik et al., 2015), so it seems reasonable to assume that if the number of counterattacks increases in unbalanced matches (de Paula et al., 2020) wings must tolerate more number of ACC and DEC. However, when these values were normalized according to the time the players spend on the court (n·min-1), backs performed moderately more ACC and DEC per minute than the other positions, although not statistically significant. Therefore, our results indicate that wings and backs players should incorporate different training interventions to mechanically protect players from these damaging consequences of high-intensity actions: (1) increase maximal and rapid force production with different strength training methods (e.g., eccentric and accentuated eccentric exercises, plyometric exercises, and weightlifting movements and their derivatives) to develop robust musculoskeletal structures (Harper et al., 2022); (2) increase the capacity of muscles and tendons with various training strategies (e.g., single- and double-leg landing stabilization exercises, pre-planned and unanticipated COD and rapid decelerations from a high velocity) to attenuate efficiently high braking eccentric forces (Harper et al., 2019); (3) improve aerobic-anaerobic capacity and repeated-sprint ability (Manchado et al., 2013; Póvoas et al., 2012). Nonetheless, despite the pivots performed lower total number of ACC and DEC compared to backs and wings, they should also be prepared to support the intensity of these actions during the competition. Consequently, coaches and practitioners should incorporate specific training interventions to properly prepare these players to cope the match demands.

Nevertheless, when interpreting the findings of this study, some notable limitations should be considered. First, external load was monitored only during thirteen official home matches. Accordingly, it should be noted that match location (away matches were not monitored) could have influenced our results. Second, the use of a very particular sample (i.e., a Spanish 2nd Division team) and not particularly large (n = 22), which does not represent the whole population. Third, LPS and IMUs may not reflect (tend to underestimate) the real physical demands of pivots, because these players usually perform some high-intensity actions (e.g., blocks and screenings) that not produce a displacement or acceleration. Fourth, our results did not differentiate specialist players (offensive or defensive). Fifth, the playing position of each player was established exclusively according to her position in attack, without taking into account her defensive position. Lastly, as it being an observational study, player rotations could not be controlled or influenced by researchers. Thus, coaches and practitioners should generalize and extrapolate these results with caution. In this regard, future research should include professional players (e.g., national teams or first-division clubs) and away matches.

In conclusion, the present study indicates that the final score of the match influences the physical demands experienced by semi-professional female handball players during official competitions. More specifically, our results revealed that unbalanced matches and balanced matches elicited higher DEC/min than close matches. In relation to playing positions, wings covered the largest TD and registered the highest values of PL in balanced and unbalanced matches. Also, wings presented the highest values of HIBD, HSR and HSR/min regardless of the final score of the match. Moreover, wings performed largely more number of ACC and DEC compared to pivots in unbalanced matches. Consequently, handball coaches and strength and conditioning specialists should consider the findings of the present study to adapt and periodize the training load across the microcycle. Also, they should take these results into account to make better strategical or tactical decisions during each match type (e.g. player substitutions) to mitigate fatigue and maintain physical performance throughout the match.

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References

Alonso Pérez-Chao, E., Gómez, M. Á., Scanlan, A., Ribas, C., Trapero, J., & Lorenzo, A. (2023). Influence of game and quarter results on external peak demands during games in under-18 years, male basketball players. *Biology of sport*, *40*(2), 365–375. https://doi.org/10.5114/biolsport.2023.116010

Augusto, D., Brito, J., Aquino, R., Figueiredo, P., Eiras, F., Tannure, M., Veiga, B., & Vasconcellos, F. (2021). Contextual Variables Affect Running Performance in Professional Soccer Players: A Brief Report. *Frontiers in sports and active living*, *3*, 778813. https://doi.org/10.3389/fspor.2021.778813

Bassek, M., Raabe, D., Memmert, D., & Rein, R. (2023). Analysis of Motion Characteristics and Metabolic Power in Elite Male Handball Players. Journal of sports science & medicine, 22(2), 310–316. https://doi.org/10.52082/jssm.2023.310

Bastida-Castillo, A., Gómez-Carmona, C., De la Cruz-Sánchez, E., Reche-Royo, X., Ibáñez, S., & Pino Ortega, J. (2019). Accuracy and Inter-Unit Reliability of Ultra-Wide-Band Tracking System in Indoor Exercise. *Applied Sciences*, *9*(5), 939. http://dx.doi.org/10.3390/app9050939

Buchheit, M., Laursen, P. B., Kuhnle, J., Ruch, D., Renaud, C., & Ahmaidi, S. (2009). Game-based training in young elite handball players. *International journal of sports medicine*, *30*(4), 251–258. https://doi.org/10.1055/s-0028-1105943

Cohen, J. (1988). Statistical Power Analysis for the Behavioral Sciences (2nd. Ed.) Hillsdale, NJ: Lawrence Earlbaum Associates

Corvino, M., Tessitore, A., Minganti, C., & Sibila, M. (2014). Effect of Court Dimensions on Players' External and Internal Load during Small-Sided Handball Games. *Journal of sports science & medicine*, *13*(2), 297–303.

de Paula, L. V., Costa, F. E., Mello, R., Menezes, R. P., Filipino, E. C., Werneck, F., & Greco, P. (2020). Analysis of discriminatory game variables between winners and losers in women's handball world championships from 2007 to 2017: Discriminatory variables in women's handball championships. *Kinesiology*, *52*(01), 54–63. https://doi.org/10.26582/k.52.1.6

Douglas, A., Johnston, K., Baker, J., Rotondi, M. A., Jamnik, V. K., & Macpherson, A. K. (2019). On-Ice Measures of External Load in Relation to Match Outcome in Elite Female Ice Hockey. *Sports (Basel, Switzerland)*, *7*(7), 173. https://doi.org/10.3390/sports7070173

Font Ribas, R., Karcher, C., Loscos-Fàbregas, E., Altarriba-Bartés, A., Peña, J., Vicens-Bordas, J., Mesas, J. A., & Irurtia, A. (2023). The effect of training schedule and playing positions on training loads and game demands in professional handball players. *Biology of sport*, *40*(3), 857–866. https://doi.org/10.5114/biolsport.2023.121323

Font Ribas, R., Karcher, C., Reche, X., Carmona, G., Tremps, V., & Irurtia, A. (2021). Monitoring external load in elite male handball players depending on playing positions. *Biology of sport*, *38*(3), 475–481. https://doi.org/10.5114/biolsport.2021.101123

Fox, J. L., Stanton, R., Sargent, C., O'Grady, C. J., & Scanlan, A. T. (2019). The Impact of Contextual Factors on Game Demands in Starting, Semiprofessional, Male Basketball Players. *International journal of sports physiology and performance*, *15*(4), 450–456. https://doi.org/10.1123/ijspp.2019-0203

García-Sánchez, C., Navarro, R. M., Karcher, C., & de la Rubia, A. (2023). Physical Demands during Official Competitions in Elite Handball: A Systematic Review. *International journal of environmental research and public health*, *20*(4), 3353. https://doi.org/10.3390/ijerph20043353

García-Sánchez, C., Karcher, C., Navarro, R.M., Nieto-Acevedo, R., Cañadas-García, E., de la Rubia, A. (2024). Same Training for Everyone? Effects of Playing Positions on Physical Demands During Official Matches in Women's Handball. *Montenegrin Journal of Sports Science and Medicine, 20*(1), 11–18, https://doi.org/10.26773/mjssm.240302.

García-Sánchez, C., Navarro, R.M., Nieto-Acevedo, R., de la Rubia A. (2025). Are fluctuations in physical performance affected by contextual factors in women's handball matches? An analysis using five- minute fixed phases. *Biology of Sport*, 42(1), 113–121. https://doi.org/10.5114/biolsport.2025.139086

Gómez, M.A., Lago-Penas, C., Viaño, J. i González-Garcia, I. (2014). Effects of game location, team quality and final outcome on game-related statistics in professional handball close games. *Kinesiology, 46.* (2.), 249-257. https://hrcak.srce.hr/131933

García-Unanue, J., Pérez-Gómez, J., Giménez, J. V., Felipe, J. L., Gómez-Pomares, S., Gallardo, L., & Sánchez-Sánchez, J. (2018). Influence of contextual variables and the pressure to keep category on physical match performance in soccer players. *PloS one*, *13*(9), e0204256. https://doi.org/10.1371/journal.pone.0204256

Harper, D. J., Carling, C., & Kiely, J. (2019). High-Intensity Acceleration and Deceleration Demands in Elite Team Sports Competitive Match Play: A Systematic Review and Meta-Analysis of Observational Studies. *Sports medicine (Auckland, N.Z.)*, *49*(12), 1923–1947. https://doi.org/10.1007/s40279-019-01170-1

Harper, D. J., McBurnie, A. J., Santos, T. D., Eriksrud, O., Evans, M., Cohen, D. D., Rhodes, D., Carling, C., & Kiely, J. (2022). Biomechanical and Neuromuscular Performance Requirements of Horizontal Deceleration: A Review with Implications for Random Intermittent Multi-Directional Sports. *Sports medicine (Auckland, N.Z.)*, *52*(10), 2321–2354. https://doi.org/10.1007/s40279-022-01693-0

Harriss, D. J. and Atkinson, G. (2015) Ethical standards in sport and exercise science research: 2016 update. *International Journal of Sports Medicine 36*(14), 1121–1124.

Hatzimanouil, D., Lola, A., Giatsis, G., Pérez Turpin, J. A., Scandalis, V., & Kepesidou, M. (2024). Trends of the fast game in men's EHF European handball championships. *Journal of Human Sport and Exercise: JHSE*, *19*(1), 68-82.

Hopkins, W. G., Marshall, S. W., Batterham, A. M., & Hanin, J. (2009). Progressive statistics for studies in sports medicine and exercise science. *Medicine and science in sports and exercise*, *41*(1), 3–13. https://doi.org/10.1249/MSS.0b013e31818cb278

Karcher, C., & Buchheit, M. (2014). On-court demands of elite handball, with special reference to playing positions. *Sports medicine (Auckland, N.Z.)*, *44*(6), 797–814. https://doi.org/10.1007/s40279-014-0164-z

Luteberget, L. S., & Spencer, M. (2017). High-Intensity

Events in International Women's Team Handball Matches. *International journal of sports physiology and performance*, *12*(1), 56–61. https://doi.org/10.1123/ijspp.2015-0641

Luteberget, L. S., Holme, B. R., & Spencer, M. (2018). Reliability of Wearable Inertial Measurement Units to Measure Physical Activity in Team Handball. *International journal of sports physiology and performance*, *13*(4), 467–473. https://doi.org/10.1123/ijspp.2017-0036

Manchado, C., Tortosa-Martínez, J., Vila, H., Ferragut, C., & Platen, P. (2013). Performance factors in women's team handball: physical and physiological aspects--a review. *Journal of strength and conditioning research*, *27*(6), 1708–1719. https://doi.org/10.1519/JSC.0b013e3182891535

Markus, I., Constantini, K., Hoffman, J. R., Bartolomei, S., & Gepner, Y. (2021). Exercise-induced muscle damage: mechanism, assessment and nutritional factors to accelerate recovery. European journal of applied physiology, 121(4), 969–992. https://doi.org/10.1007/s00421-020-04566-4

McBurnie, A. J., Harper, D. J., Jones, P. A., & Dos'Santos, T. (2022). Deceleration Training in Team Sports: Another Potential 'Vaccine' for Sports-Related Injury?. *Sports medicine (Auckland, N.Z.)*, *52*(1), 1–12. https://doi.org/10.1007/s40279-021-01583-x

McKay, A. K. A., Stellingwerff, T., Smith, E. S., Martin, D. T., Mujika, I., Goosey-Tolfrey, V. L., Sheppard, J., & Burke, L. M. (2022). Defining Training and Performance Caliber: A Participant Classification Framework. *International journal of sports physiology and performance*, *17*(2), 317–331. https://doi.org/10.1123/ijspp.2021-0451

Michalsik, L. B., Aagaard, P., & Madsen, K. (2013). Locomotion characteristics and match-induced impairments in physical performance in male elite team handball players. *International journal of sports medicine*, *34*(7), 590–599. https://doi.org/10.1055/s-0032-1329989

Michalsik, L. B., Aagaard, P., & Madsen, K. (2015). Technical activity profile and influence of body anthropometry on playing performance in female elite team handball. *Journal of strength and conditioning research*, *29*(4), 1126–1138. https://doi.org/10.1519/JSC.0000000000000735

Michalsik, L. B., Madsen, K., & Aagaard, P. (2014). Match performance and physiological capacity of female elite team handball players. *International journal of sports medicine*, *35*(7), 595–607. https://doi.org/10.1055/s-0033-1358713

Oliveira, R., Canário-Lemos, R., Morgans, R., Rafael-Moreira, T., Vilaça-Alves, J., & Brito, J. P. (2023). Are non-starters accumulating enough load compared with starters? Examining load, wellness, and training/match ratios of a European professional soccer team. *BMC sports science, medicine & rehabilitation*, *15*(1), 129. https://doi.org/10.1186/s13102-023-00743-y

Pino-Ortega, J., Rojas-Valverde, D., Gómez-Carmona, C. D., Bastida-Castillo, A., Hernández-Belmonte, A., García-Rubio, J., Nakamura, F. Y., & Ibáñez, S. J. (2019). Impact of Contextual Factors on External Load During a Congested-Fixture Tournament in Elite U'18 Basketball Players. *Frontiers in psychology*, *10*, 1100. https://doi.org/10.3389/fpsyg.2019.01100

Póvoas, S. C., Seabra, A. F., Ascensão, A. A., Magalhães, J., Soares, J. M., & Rebelo, A. N. (2012). Physical and physiological demands of elite team handball. *Journal of strength and conditioning research*, *26*(12), 3365–3375. https://doi.org/10.1519/JSC.0b013e318248aeee

Póvoas, S. C., Ascensão, A. A., Magalhães, J., Seabra, A. F., Krustrup, P., Soares, J. M., & Rebelo, A. N. (2014). Physiological demands of elite team handball with special reference to playing position. *Journal of strength and conditioning research*, *28*(2), 430–442. https://doi.org/10.1519/JSC.0b013e3182a953b1

Wagner, H., Finkenzeller, T., Würth, S., & von Duvillard, S. P. (2014). Individual and team performance in team-handball: a review. *Journal of sports science & medicine*, *13*(4), 808–816.

Wik, E. H., Luteberget, L. S., & Spencer, M. (2017). Activity Profiles in International Women's Team Handball Using PlayerLoad. *International journal of sports physiology and performance*, *12*(7), 934–942. https://doi.org/10.1123/ijspp.2015-0732

Zapardiel, J. C., Asín-Izquierdo, I., Manchado, C., Marcos-Jorquera, D., Gilart-Iglesias, V., & Lozano, D. (2024). Competitive profile analysis according to playing positions of female handball players during the European Championship 2020. *International Journal of Performance Analysis in Sport*, 1–19. https://doi.org/10.1080/24748668.2024.2333655

ORIGINAL SCIENTIFIC PAPER

Beyond Winning: Examining Sociodemographic and Sport Factors Associated with Doping Attitudes in High-Performance Sport Coaches Involved in Olympic Team Sports

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Abstract

Coaches have a significant impact on the lives and development of athletes, so understanding the factors that influence their doping attitudes (DA) are particularly important. The aim of this study was to investigate sport-specific and sociodemographic correlates of DA among high-level sport coaches involved in Olympic team sports (soccer, basketball, handball, and volleyball). The participants were high-level coaches from Kosovo (n = 113, age: 42.99±10.9 years). Previously validated questionnaires were used for testing all participants, asking them about sociodemographic-, sport- factors, doping-related-factors (all predictors), and DA (criterion). Logistic regression for binarized criterion (negative DA vs. neutral/positive DA) was applied to define the associations between the studied predictors and the DA as an outcome. The results revealed a greater likelihood of neutral/positive DA among male coaches (OR = 2.01, 95% CI: 1.11–2.33) and among those coaches who believe that doping is prevalent in their sport (OR = 1.55, 95% CI: 1.25–1.87). No further associations between the studied predictors and DA were found. Additional studies analyzing other samples, sports and variables are warranted.

Keywords: *performance enhancement; predictors; sport success; logistic regression; coaching*

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Introduction

The use of performance-enhancing drugs and techniques (doping) is recognized as one of the most important problems in sports (Kondric, Sekulic, Uljevic, Gabrilo, & Zvan, 2013; Rodek, Idrizovic, Zenic, Perasovic, & Kondric, 2013), and the global fight against doping in sports is a concerted effort by various organizations, governments, and athletes (Kondric et al., 2011). This fight is essential to maintain the integrity of sport, protect the health of athletes, and ensure a level playing field for all competitors (Özkan et al., 2020). Despite the overall efforts,

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the problem of antidoping rule violation is still ongoing due to several of the most important challenges.

First, and probably most important, is the constant development of new performance-enhancing drugs and methods, which poses a challenge for anti-doping authorities. Second, athletes and organizations involved in doping constantly employ sophisticated methods to avoid detection, such as microdosing or the use of masking agents. Furthermore, it is clear that anti-doping programs require significant financial resources for testing, research, and education. Finally, some countries and organizations do not fully cooperate with antidoping efforts, hindering the global fight against doping. While testing and sanctions remain crucial deterrents, education is increasingly recognized as a fundamental pillar in the global fight against doping in sports. It aims to foster a culture of clean sport by proactively addressing the root causes of doping, empowering athletes and supporting personnel in making informed, ethical choices (Liposek et al., 2018; Sajber, Maric, Rodek, Sekulic, & Liposek, 2019).

In developing educational anti-doping programs, the correlates of doping attitudes (DA) are specifically targeted (Varfolomeeva, Kozyreva, & Beresneva, 2023). The idea is to target athletes with positive DA, which will allow the development of targeted and precise anti-doping education. For this purpose, numerous studies have examined the different factors associated with DA in sports, including sociodemographic, cultural, sport, and psychological correlates of doping (Versic, Uljevic, & Pelivan, 2022). For this purpose, sociodemographic factors are frequently studied. Specifically, in a study examining the correlates of DA in different types of sports, religiousness was found to be a protective factor against doping in weightlifting, whereas racket sport athletes who observed doping behavior in their sport were more likely to engage in doping themselves (Rodek et al., 2013). Social factors, including the influence of coaches and contact with doping users, also contribute to doping attitudes and behaviors (Zucchetti, Candela, & Villosio, 2015). A review reported that younger age, male gender, and higher levels of competitiveness, and perception of a lenient anti-doping climate are linked to increased likelihood of doping (Ntoumanis, Ng, Barkoukis, & Backhouse, 2014).

It is well known that coaches hold a unique position of influence and trust in the lives of athletes (Liposek et al., 2018). Their role extends far beyond developing athletic skills; they shape attitudes, behaviors, and ultimately, the culture of the sport, making them pivotal figures even in the fight against doping in sports (Liposek et al., 2018; Matosic, Ntoumanis, Boardley, Stenling, & Sedikides, 2016; Nicholls et al., 2020; Sajber, Rodek, Escalante, Olujic, & Sekulic, 2013). There are numerous reasons why coaches should be observed as highly important persons in antidoping efforts. First, coaches are often seen as role models by athletes, especially at younger ages (Sullivan, Paquette, Holt, & Bloom, 2012). Their actions can significantly impact an athlete's perception of fair play and ethical conduct in sports. They create a training environment, which can either foster a culture of clean sport or inadvertently encourage the pursuit of performance at any cost. Also, coaches are responsible for educating athletes about the dangers of doping, the rules, and the available support systems; however, they can help dispel myths and misconceptions and encourage open communication about doping issues. Therefore, identifying the factors associated with attitudes toward doping among coaches, not only athletes, is crucial. However, although a certain number of studies have examined DA in coaches, their knowledge of a problem and their willingness to report doping suspicions, studies have rarely reported correlates of DA in coaches (Backhouse & McKenna, 2012; Whitaker, Backhouse, & Long, 2014) .

Therefore, this study aimed to investigate sport-specific and sociodemographic correlates of DA among high-level sport coaches involved in four Olympic team sports (soccer, basketball, handball, and volleyball). We hypothesized that sociodemographic factors would be significantly associated with DA in the studied coaches.

Methods

Participants

The participants in this study were high-level coaches involved in Olympic team sports (handball, volleyball, soccer, basketball) from Kosovo (n = 113, age: 42.99±10.9 years). The sample characteristics are presented in Table 1.

Table 1. Characteristics of the study sample (count and percentage in each group)

	Basketball	Handball	Soccer	Volleyball	Total
Females	3 (8%)	5 (21%)	4 (11%)	4 (25%)	16 (14% of all)
Males	33 (92%)	18 (79%)	34 (89%)	12 (75%)	97 (86% of all)
Total	36 (32% of all)	23 (20% of all)	38 (34% of all)	16 (14% of all)	113 (100%)

The participants were invited to participate in the study by their sport federation. At study entry, they were informed that participation was voluntary, that they would remain anonymous, and that no personal details that would allow them to be connected individually with the provided answers would be asked. The study was approved by the ethical committee of the University of Zagreb, Faculty of Kinesiology.

Variables

Previously validated questionnaires were used for testing all participants, asking them about sport factors, sociodemographic factors, and doping-related factors (including DA) (Devcic et al., 2018; Sekulic, Bjelanovic, Pehar, Pelivan, & Zenic, 2014; Zenic, Stipic, & Sekulic, 2013).

Sociodemographic questions included questions on age (in years), gender (male, female), marital status (married/partnership, single), education level (high school, college/university students, college level, university level), and religiousness. The Santa Clara Strength of Religious Faith Questionnaire (SCSRF), a 10-item tool, was used to measure religious intensity and involvement. This questionnaire has been previously validated for use in sports research (Zenic et al 2013.).

The sport factors included questions about the coaches' experience in sports: (i) as athletes and (ii) as coaches (both in years) and their highest competitive achievements as coaches (local competitions, national competitions, international competitions).

Doping-related factors included questions on personal opinion on the main problem of doping in sports (doping is mainly a health hazard, doping is mainly a problem of fair-play, doping is equally a health hazard and a fair-play issue, not

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sure), coaches' personal opinions about the presence of doping in their sport (I do not think doping is used, not sure, doping is rare, doping is common), and personal DA (I never suggest the usage of doping, I do not know/not sure, I will suggest the usage of doping if it will help my athletes with no health hazard, I will suggest the use of doping). For the purpose of the later logistic regression calculations (please see Statistics for details), DA was categorized into "Negative DA" (first answer) and "Neutral and positive DA" (remaining answers).

Statistics

Given that most variables were not normally distributed according to the Kolmogorov-Smirnov test, we reported frequencies and percentages for descriptive statistics (with means and standard deviations for normally distributed variables).

To compare genders, we used the Mann-Whitney test for ordinal variables, the chi-square test ($\chi 2$) for nominal variables, and the independent samples t test for normally distributed variables.

To evaluate the associations between sociodemographic factors, sport factors (predictors), and DA, we employed logistic regression. The DA was binarized into two categories: "Negative DA" (scored as 1) and "Neutral and positive DA" (scored as 2). In the first phase, each predictor was independently correlated with the criterion. In the second phase, we performed multivariate logistic regression, with significant predictors simultaneously included in the regression calculation to control for potential covariates. The results are presented as odds ratios (ORs) and 95% confidence intervals (CIs).

Statistica 13.5 (Tibco, Inc., CA, USA) was used for all calculations, and a p value of 0.05 was applied.

Results

Table 2 presents the gender differences in the study variables. Evidently, male coaches were more involved in sports as athletes/players and as coaches than their female peers were (t test = 2.83 and 2.34, $p < 0.05$, respectively). No significant differences were detected in terms of age (t test = 1.58, $p > 0.05$) or religiousness evaluated by SCSRF (t test = 0.91, $p > 0.05$).

Table 2. Descriptive statistics for normally distributed variables with differences between sexes

	Males (n = 97)		Females (n = 16)		T test		
	Mean	Std.Dev.	Mean	Std.Dev.	t value	df	p
Age (years)	43.65	11.04	39.00	9.81	1.58	111	0.12
Experience as a player (years)	16.91	5.55	12.19	9.28	2.83	111	0.01
Experience as a coach (years)	10.64	5.92	7.00	4.60	2.34	111	0.02
Santa Clara Strength of Religious Faith (score)	36.46	5.55	37.75	2.11	-0.91	111	0.37

Male coaches were more likely to be single (not married) than females were (Chi square = 5.13, p = 0.05). No significant gender-differences were detected, and/or null frequencies did not allow calculation of the χ^2 for the remaining variables (Table 3).

The logistic regression results for the binarized criterion DA

Table 3. Descriptive statistics (F – frequencies; % - percentages) and gender differences for nonparametric variables

	Males		Females		Mann–Whitney/ χ^2 (p)
	F	%	F	%	
Marital status (χ^2)					5.13 (0.02)
Single	86	88.66	11	68.75	
Married/partnership	10	10.31	5	31.25	
Education level (χ^2)					-
High school	17	17.53	0	0	
College/University Student	14	14.43	2	12.50	
College degree	49	50.52	11	68.75	
University degree	17	17.53	3	18.75	
Coaching achievement (Mann–Whitney)					0.67 (0.49)
Local level	51	52.58	10	62.50	
National level	29	29.90	3	18.75	
International level	11	11.34	2	12.50	
Prevalence of doping in (their) sport (χ^2)					-
I do not think doping is used	73	75.26	15	93.75	
Not sure	17	17.53	1	6.25	
Used. but rarely	6	6.19	0	0	
Used, often	1	1.03	0	0	

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Table 3. Descriptive statistics (F – frequencies; % - percentages) and gender differences for nonparametric variables

	Males		Females		Mann–Whitney/ χ^2 (p)
	F	%	F	%	
Doping attitudes (χ^2)					-
I will suggest usage of doping if it will help	8	8.25	0	0	
I will suggest usage if there will be no health hazard	5	5.15	2	12.50	
Not sure	23	23.71	2	12.50	
No, never	61	62.89	12	74.50	
Main problem of doping (χ2)					1.43 (0.69)
Doping is health hazard	59	60.82	8	50.00	
Fair play issue	20	20.62	3	18.75	
Both health hazard and fair play issue	15	15.46	4	25.00	
Not sure	3	3.09	1	6.25	

(negative DA vs. neutral/positive DA) are presented in Figure 1. Among all the studied variables, two correlations reached statistical significance. Specifically, a greater likelihood of positive DA was found for males (OR = 2.01, 95% CI: 1.11–2.33) and for those coaches who were of the opinion that their sport is doping contaminated (Figure 1A). When both significant predictors were included in the analysis, male sex was retained as a single significant predictor of DA (OR = 1.68, 95% CI: 1.05–2.01) (Figure 1B).

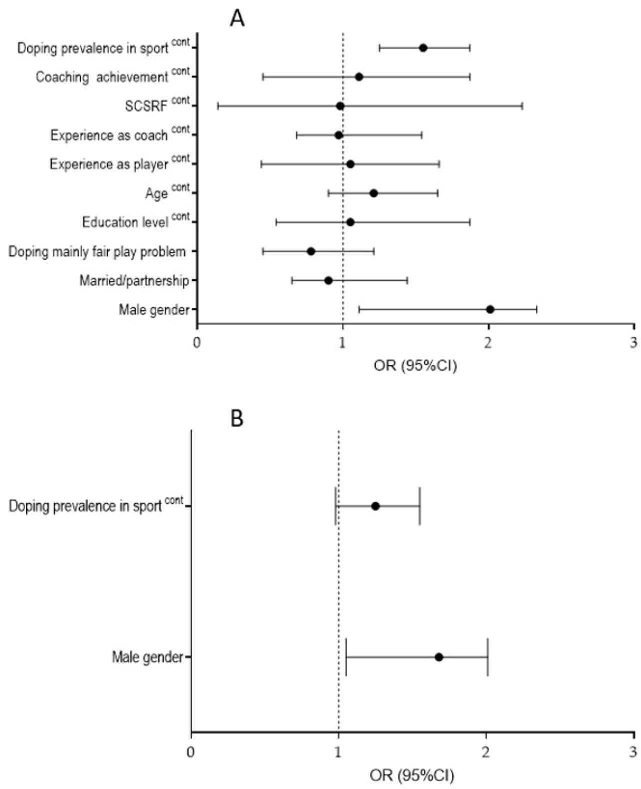

Figure 1. Results of the univariate (Figure 1A) and multivariate (Figure 1B) logistic regressions for the binarized criterion "doping attitudes" with neutral/positive doping attitudes as the reference value (^{cont} indicates variables observed as continuous for the purpose of logistic regression calculation; SCSRF – Santa Clara Strength of Religious Faith)

Discussion

There are several important findings of this study. First, there is an influence of gender on DA in coaches, with males being more positively oriented toward doping than their female peers. Second, in addition to gender, sociodemographic factors were poorly related to DA among coaches. Therefore, our initial study hypothesis could be only partially accepted. Finally, no significant associations between sport factors and DA were established.

Our results revealed a greater likelihood of a neutral/posi-

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tive DA among male coaches. We could not find studies where gender differences in DA were established for caches, but this issue is frequently emphasized in athletes. In most cases, male athletes are more prone to doping than their female peers are (Devcic et al., 2018; Kondric et al., 2011). However, the background of these findings in athletes cannot be simply transferred to coaches, since in some cases, the positive DA in athletes is related to physiological factors that could contribute to the "personal usage" of doping among them. For example, "societal pressures" for men to achieve a muscular physique may contribute to the use of performance-enhancing substances, but naturally, this is the case for athletes and not for coaches. Therefore, in explaining the possible background of the greater tendency for positive DA in male coaches, several unique mechanisms and factors should be discussed.

There is no doubt that people who are professionally involved in sports as coaches should be competitive (Popovych, Blynova, Nosov, Zinchenko, & Kononenko, 2021). While both men and women can be highly competitive, societal expectations and norms may place greater pressure on men to win at all costs. Indeed, throughout history and across many cultures, men have often been associated with traits such as strength, competitiveness, and the pursuit of victory (Skillen, 1993). This association has been reinforced through various channels, such as traditional gender roles (men were historically expected to be providers and protectors), sports as a masculine domain (sports have often been viewed as a predominantly male domain), and media representation (i.e., the portrayal of male athletes in the media often focuses on their competitive drive, ambition, and willingness to push boundaries to achieve success). Coaches are not immune to these societal pressures (Kroshus, Garnett, Hawrilenko, Baugh, & Calzo, 2015). Therefore, they may naturally feel pressure to produce winning athletes and therefore feel that their own success and reputation are tied to their athletes' performance. It could result in pushing athletes to their limits and potentially condone or even encourage doping. Furthermore, by prioritizing winning over everything else, coaches can inadvertently create an environment where athletes feel pressured to use performance-enhancing drugs. Therefore, desire to win can lead some coaches to rationalize or justify unethical practices such as doping, believing it is necessary to level the playing field or achieve success.

However, it is important to emphasize that the gender differences in this context and the greater likelihood of neutral/positive DA in males are probably influenced by a complex interplay of factors rather than a simple gender binary. As stated previously, traditional gender roles and societal expectations often place greater pressure on men to achieve success and demonstrate dominance, sometimes at any cost. However, certain sports may foster a culture that is more accepting of doping practices, particularly those that emphasize power, strength, and aggression (Rodek et al., 2013). If male coaches are disproportionately represented in such sports, this could contribute to the observed difference. Further, it is known that men might be more inclined toward risk-taking behavior than women are (Byrnes, Miller, & Schafer, 1999). This could translate into a greater willingness to engage in or condone doping practices, despite known health and ethical concerns. Finally, and from our perspective, most important is the fact that, in most sporting contexts, power imbalances favor male coaches. This naturally creates a scenario where they feel more entitled to bend or break the rules to achieve desired outcomes.

The sociodemographic factors observed herein have already been studied in relation to DT in athletes. For example, one study indicated that doping experiences outside competitive sports are more prevalent among individuals with lower education levels (Pedersen & Benjaminsen, 2006). Additionally, religiousness was found to be a significant protective factor against doping behavior, such as weightlifting, in highly energetically demanding sports (Rodek et al., 2013). Further, studies have shown an association between paternity and marital status with doping, with a lower tendency toward doping in athletes who are married and have children (Sekulic, Kostic, Rodek, Damjanovic, & Ostojic, 2009). Meanwhile, this is one of the first studies in which sociodemographic factors were specifically studied as correlates of DA in coaches who are engaged in specific groups of sports—team sports. In general, other than gender (please see the previous discussion), no specific associations between the studied sociodemographic indices and DA were observed. The possible reasons are discussed in the following text.

First, the lack of association between sociodemographic factors and DA among the studied coaches could be attributed to differences in the sports coaches involved. Specifically, our participants were coaches involved in four team sports, which are very distinct in regard to doping. Studies conducted thus far have shown clear differences in the DA of athletes involved in Olympic team sports, with athletes involved in handball being the most vulnerable to doping, followed by basketball players and soccer players, whereas the lowest prevalence of positive DA was found among volleyball players (Sekulic et al., 2016). These differences are probably translated even to coaches involved in these sports. Consequently, such differences and "sport influence" could diminish the influence of the studied sociodemographic factors on DA in observed coaches.

Second, the number of males and females involved in some of the studied sports could also contribute to the lack of association between other sociodemographic factors (predictors) and DA in coaches. Specifically, males are more prone to positive DA than their female peers. At the same time, there is a certain discrepancy in the involvement of male and female coaches in the studied sports. The most balanced situation (although males dominate) is in volleyball (please see Table 1), and this sport is known to have a low prevalence of positive DA (Sekulic et al., 2016). This could also result in certain bias in evaluating the correlations between predictors and criteria, simply because of the previously presented differences in DA in athletes.

In regard to religiousness and possible associations with DA among coaches, specifics of the sample of participants and testing should be briefly presented. Because of anonymity, we did not ask coaches about their specific religious affiliation, and the measurement tool we used allowed us to obtain data on the level of their religiousness irrespective of their affiliation (Plante & Boccaccini, 1997). Although some previous studies confirmed certain protective effects of religiosity against DA in athletes, to the best of our knowledge, all studies performed thus far have examined one specific religion (Rodek, Sekulic, & Kondric, 2012; Zenic et al., 2013; Zvan, Zenic, Sekulic, Cubela, & Lesnik, 2017). Finally, there is a certain possibility that different religions are differentially oriented toward doping, which could bias our results, leading to a nonsignificant association between religiousness and DA among the studied coaches.

Sports factors, such as sport experience and sport competitive success, are frequently studied in relation to DA in athletes, and the results of previous studies confirmed dynamic and relatively sport-specific associations in different sports and cultures. For example, while in some sports, greater competitive success was associated with a (more) positive likelihood of doping, in other sports, athletes who achieved better sport success were negatively oriented toward doping (Kondric, Sekulic, & Mandic, 2010; Kondric et al., 2011; Rodek et al., 2012). Additionally, studies highlighted a greater risk for doping in athletes who achieved better success at the youth level, particularly if they did not achieve sport success at later stages of their career (Sekulic et al., 2014). On the other hand, sport factors were not related to DA in the coaches studied here. Possible explanations are briefly discussed in the following text.

Sports achievement was frequently found to be associated with DA in athletes (please see previously). However, sport achievement in athletes is determined by physical factors (i.e., natural talent and physical attributes), training and conditioning (allows athletes to develop their skills and physical capacities), psychological factors (i.e., motivation and goal settings, mental toughness and resilience), and various environmental factors (i.e., socioeconomics, social support, and cultural determinants) (Tucker & Collins, 2012). Doping is clearly associated with some of these factors, mostly physical ones (Nikolopoulos, Spiliopoulou, & Theocharis, 2011). Therefore, it is logical that doping (as a way of enhancing physical capacity) is associated with sport achievement in athletes, either positively (with a higher likelihood of doping in those who do not possess necessary physical attributes) or negatively (with a lower likelihood of doping in those athletes who are physically "well equipped" for success).

On the other hand, factors that determine sport success in coaches are quite different than those in athletes. Competitive achievement in sport coaches is determined by a multifaceted interplay of factors encompassing personal qualities, professional expertise, and external circumstances (Batista et al., 2019; Côté, 2006; Shanmugam & Jowett, 2016). Coaching expertise and knowledge likely play the most important role, with paramount importance to the deep understanding of the sport's rules, techniques, tactics, and training methodologies. Furthermore, pedagogical and communication skills are also important, with crucial roles of effective teaching, clear communication, and proper ability to motivate and inspire athletes. Coaches need to lead their teams, create a positive environment, resolve conflicts, and make sound decisions under pressure while being able to adapt their primary coaching styles to different athletes and situations. Collectively, it is clear that doping is not related to any of these attributes that contribute to sport achievement. Together, it possibly explains the lack of correlation between sport factors (sport success as the most important factor) and DA among sport coaches, although these factors were consistently found to be important predictors of DA in athletes.

The most important limitation of this study is its cross-sectional nature. Therefore, causality cannot be interpreted, although in some cases, the cause−effect relationship is intuitively clear (i.e., gender is "the cause" and not the "consequence" of DA). Meanwhile, for most variables, a prospective study design in which changes in the studied variables are observed is necessary to clearly elucidate the possible relationships. Additionally, we included more males than females in the sample of participants. However, this is the global situation in sports, where females are generally underrepresented in coaching professions, especially in the team sports we have studied here. Therefore, our results should be further evaluated in samples involving more females.

This is one of the first investigations on the factors associated with DA, specifically in team sport coaches, Additionally, the highly competitive level of our participants is an important strength of the study. Therefore, although no being the final word on a topic we hope that our results will initiate further research in the field.

Conclusion

Analyzing the factors associated with DA in sports could contribute to the development of more accurate and targeted antidoping education. While coaches play a significant role in the life and development of athletes, the factors associated with their DA are also important. We found that male sex was a risk factor for positive DA among team sport coaches. Therefore, anti-doping education should specifically target male coaches. Future (qualitative) studies should explore the background of this association and the factors that "protect" female coaches from having positive DA.

This study confirmed the association between one's opinion that doping is present in the sport and positive DA. Although this is one of the first studies where such correlation is emphasized for caches, the mechanisms of the relationships are relatively well known and include a lack of confidence in anti-doping measures, and level playing field (i.e. concept of the fairness based on the idea that all should play by the same set of rules).

The sport factors observed in this study (i.e., experience, success) were not associated with DA among team−sport coaches, indicating the need to identify other factors that could be correlated with DA among team−sport coaches. In doing so, it would be particularly important to highlight eventual differences in the possibility of achieving sport success in different sports. For example, the popularity of some sports directly defines the possibility of achieving success, which could logically blur the associations between sport factors and DA when participants from different sports are observed as one sample.

References

Backhouse, S. H., & McKenna, J. (2012). Reviewing coaches' knowledge, attitudes and beliefs regarding doping in sport. *International Journal of Sports Science & Coaching, 7*(1), 167-175.

Batista, J., Goncalves, B., Sampaio, J., Castro, J., Abade, E., & Travassos, B. (2019). The influence of coaches' instruction on technical actions, tactical behavior, and external workload in football small-sided games. *Montenegrin Journal of Sports Science and Medicine, 8*(1), 29-36. DOI: 10.26773/mjssm.190305

Byrnes, J. P., Miller, D. C., & Schafer, W. D. (1999). Gender differences in risk taking: A meta-analysis. *Psychological bulletin, 125*(3), 367.

Côté, J. (2006). The development of coaching knowledge. *International Journal of Sports Science & Coaching, 1*(3), 217-222.

Devcic, S., Bednarik, J., Maric, D., Versic, S., Sekulic, D., Kutlesa, Z., . . . Liposek, S. (2018). Identification of Factors Associated with Potential Doping Behavior in Sports: A Cross-Sectional Analysis in High-Level Competitive Swimmers. *Int J Environ Res Public Health, 15*(8). doi:10.3390/ijerph15081720.

DOI 10.26773/mjssm.240904

Kondric, M., Sekulic, D., & Mandic, G. F. (2010). Substance use and misuse among Slovenian table tennis players. *Subst Use Misuse, 45*(4), 543-553. doi:10.3109/10826080903452553

Kondric, M., Sekulic, D., Petroczi, A., Ostojic, L., Rodek, J., & Ostojic, Z. (2011). Is there a danger for myopia in anti-doping education? Comparative analysis of substance use and misuse in Olympic racket sports calls for a broader approach. *Subst Abuse Treat Prev Policy, 6*, 27. doi:10.1186/1747-597X-6-27

Kondric, M., Sekulic, D., Uljevic, O., Gabrilo, G., & Zvan, M. (2013). Sport nutrition and doping in tennis: an analysis of athletes' attitudes and knowledge. *J Sports Sci Med, 12*(2), 290-297.

Kroshus, E., Garnett, B., Hawrilenko, M., Baugh, C. M., & Calzo, J. P. (2015). Concussion underreporting and pressure from coaches, teammates, fans, and parents. *Social Science & Medicine, 134*, 66-75.

Liposek, S., Zenic, N., Saavedra, J. M., Sekulic, D., Rodek, J., Marinsek, M., & Sajber, D. (2018). Examination of Factors Explaining Coaching Strategy and Training Methodology as Correlates of Potential Doping Behavior in High-Level Swimming. *J Sports Sci Med, 17*(1), 82-91.

Matosic, D., Ntoumanis, N., Boardley, I. D., Stenling, A., & Sedikides, C. (2016). Linking Narcissism, Motivation, and Doping Attitudes in Sport: A Multilevel Investigation Involving Coaches and Athletes. *J Sport Exerc Psychol, 38*(6), 556-566. doi:10.1123/jsep.2016-0141

Nicholls, A. R., Fairs, L. R. W., Plata-Andres, M., Bailey, R., Cope, E., Madigan, D., . . . Chanal, B. (2020). Feasibility randomized controlled trial examining the effects of the Anti-Doping Values in Coach Education (ADVICE) mobile application on doping knowledge and attitudes toward doping among grassroots coaches. *BMJ Open Sport Exerc Med, 6*(1), e000800. doi:10.1136/bmjsem-2020-000800

Nikolopoulos, D. D., Spiliopoulou, C., & Theocharis, S. E. (2011). Doping and musculoskeletal system: short-term and long-lasting effects of doping agents. *Fundamental & clinical pharmacology, 25*(5), 535-563.

Ntoumanis, N., Ng, J. Y., Barkoukis, V., & Backhouse, S. (2014). Personal and psychosocial predictors of doping use in physical activity settings: a meta-analysis. *Sports Med, 44*(11), 1603-1624. doi:10.1007/s40279-014-0240-4

Özkan, Ö., Torğutalp, Ş., Kara, Ö., Dönmez, G., Demirel, A., Karanfil, Y., . . . Korkusuz, F. (2020). Doping knowledge and attitudes of Turkish athletes: a cross-sectional study. *Montenegrin Journal of Sports Science and Medicine, 9*(1). DOI: 10.26773/mjssm.200307

Pedersen, I. K., & Benjaminsen, L. (2006). Er dopingerfaringer forbeholdt lavtuddannede? Doping som en social praktik. *Dansk Sociologi, 17*(3), 51-71.

Plante, T. G., & Boccaccini, M. T. (1997). The Santa Clara strength of religious faith questionnaire. *Pastoral Psychology, 45*(5), 375-387.

Popovych, I., Blynova, O., Nosov, P., Zinchenko, S., & Kononenko, O. (2021). Psychological factors of competitiveness of the women's youth handball team. *Journal of Physical Education and Sport, 21*(1), 227-235. DOI: 10.7752/jpes.2021.01030

Rodek, J., Idrizovic, K., Zenic, N., Perasovic, B., & Kondric, M. (2013). Differential analysis of the doping behavior templates in three types of sports. *Coll Antropol, 37 Suppl 2*, 211-217.

Rodek, J., Sekulic, D., & Kondric, M. (2012). Dietary supplementation and doping-related factors in high-level sailing. *J Int Soc Sports Nutr, 9*(1), 51. doi:10.1186/1550-2783-9-51

Sajber, D., Maric, D., Rodek, J., Sekulic, D., & Liposek, S. (2019). Toward Prevention of Doping in Youth Sport: Cross-Sectional Analysis of Correlates of Doping Tendency in Swimming. *Int J Environ Res Public Health, 16*(23). doi:10.3390/ijerph16234851

Sajber, D., Rodek, J., Escalante, Y., Olujic, D., & Sekulic, D. (2013). Sport nutrition and doping factors in swimming; parallel analysis among athletes and coaches. *Coll Antropol, 37 Suppl 2*, 179-186.

Sekulic, D., Bjelanovic, L., Pehar, M., Pelivan, K., & Zenic, N. (2014). Substance use and misuse and potential doping behavior in rugby union players. *Res Sports Med, 22*(3), 226-239. doi:10.1080/15438627.2014.915839

Sekulic, D., Kostic, R., Rodek, J., Damjanovic, V., & Ostojic, Z. (2009). Religiousness as a protective factor for substance use in dance sport. *J Relig Health, 48*(3), 269-277. doi:10.1007/s10943-008-9193-y

Sekulic, D., Tahiraj, E., Zvan, M., Zenic, N., Uljevic, O., & Lesnik, B. (2016). Doping Attitudes and Covariates of Potential Doping Behavior in High-Level Team-Sport Athletes; Gender Specific Analysis. *J Sports Sci Med, 15*(4), 606-615.

Shanmugam, V., & Jowett, S. (2016). Creating a successful and effective coaching environment through interpersonal sports coaching. *Sport and Exercise Psychology*, 215-238.

Skillen, A. (1993). Sport: An historical phenomenology. *Philosophy, 68*(265), 343-368.

Sullivan, P., Paquette, K. J., Holt, N. L., & Bloom, G. A. (2012). The relation of coaching context and coach education to coaching efficacy and perceived leadership behaviors in youth sport. *The sport psychologist, 26*(1), 122-134.

Tucker, R., & Collins, M. (2012). What makes champions? A review of the relative contribution of genes and training to sporting success. *British journal of sports medicine, 46*(8), 555-561.

Varfolomeeva, Z. S., Kozyreva, D. A., & Beresneva, M. L. (2023). Attitudes toward Doping in Adolescent Athletes. *Sport Mont, 21*(1), 65-69. DOI 10.26773/smj.230211

Versic, S., Uljevic, O., & Pelivan, K. (2022). Factors Associated with Potential Doping Behavior in Windsurfing. *Sport Mont, 20*(1), 89-92. DOI: 10.26773/smj.220215

Whitaker, L., Backhouse, S., & Long, J. (2014). Reporting doping in sport: National level athletes' perceptions of their role in doping prevention. *Scandinavian journal of medicine & science in sports, 24*(6), e515-521.

Zenic, N., Stipic, M., & Sekulic, D. (2013). Religiousness as a factor of hesitation against doping behavior in college-age athletes. *J Relig Health, 52*(2), 386-396. doi:10.1007/s10943-011-9480-x

Zucchetti, G., Candela, F., & Villosio, C. (2015). Psychological and social correlates of doping attitudes among Italian athletes. *International Journal of Drug Policy, 26*(2), 162-168.

Zvan, M., Zenic, N., Sekulic, D., Cubela, M., & Lesnik, B. (2017). Gender- and Sport-Specific Associations Between Religiousness and Doping Behavior in High-Level Team Sports. *J Relig Health, 56*(4), 1348-1360. doi:10.1007/s10943-016-0254-3

ORIGINAL SCIENTIFIC PAPER

Intra- and inter-session reliability of countermovement jump and gait analysis in collegiate athletes measured using an inertial measurement unit (BTS G-Walk)

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Abstract

This study assessed the intra- and inter-session reliability of the inertial measurement unit (IMU) in measuring countermovement jump (CMJ) and 10m-walking gait-related outcomes. Thirty collegiate-level athletes (15 males [age: 21.0 ± 2.5 years] and 15 females [age: 21.5 ± 2.1 years]) were recruited to perform CMJs and 10m-walking test that were simultaneously recorded using the commercially available body-worn IMU – BTS G-walk. The coefficient of variation (CV), the analysis of variance with repeated measures (ANOVA), and the interclass correlation coefficient (ICC) were used for intra-session reliability. While the Pearson's correlation coefficient (r) and the ICC were used to analyze inter-session reliability. Measurement of CMJ and 10m-walking test gait variables using the IMU resulted in moderate to excellent intra-session reliability for CMJ (ICC = 0.881 to 0.988) and gait analysis (ICC = 0.807 to 0.978) with acceptable CV (≤10%). Inter-session reliability for CMJ variables ranged from poor to excellent (ICC = 0.134 to 0.963), and 10-m walking test gait analysis variables were moderate to excellent (ICC = 0.683 to 0.931). The IMU (BTS G-walk) provides reliable data for most CMJ and gait variables. Future studies may determine the accuracy of the equipment to monitor changes over time (e.g., after a training intervention).

Keywords: *Plyometric exercise, athletic performance, exercise, sports medicine, athletic performance, human movement*

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RELIABILITY OF JUMP AND GAIT ANALYSIS
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Introduction

Tests, measurements, and evaluations play an important role in sports science settings in monitoring athletes' health and performance (Lacy & Williams, 2018). In this context, an assessment that can fulfill multiple objectives is desirable (e.g., performance benchmarking, fatigue monitoring). The countermovement jump (CMJ) can be used to assess neuromuscular fatigue during different types of training sessions (e.g., endurance running) (García-Pinillos et al., 2021; Gathercole et al., 2015). Indeed, the reliability of CMJ in assessing neuromuscular fatigue has also been reported in a meta-analysis (Claudino et al., 2017). In addition, the CMJ can be used for performance profiling (e.g., force-velocity curve) and to assess post-injury progress and preparedness to return to sports (Bishop et al., 2023). The CMJ can also be used to assess an individual's capability to produce lower body force through a stretch-shortening cycle movement (Van Hooren & Zolotarjova, 2017), an important reflection of an individual's ability to store and use elastic energy (Van Hooren & Zolotarjova, 2017).

Furthermore, besides CMJ performance, gait-related measures may also help in the assessment of human performance preparedness by identifying the likelihood of future running-related lower limb injury among university-level athletes (Gogoi et al., 2021). Moreover, incorporating gait analysis within a training programme may also help identify gait-related injuries (Tao et al., 2012). In addition, gait analysis may be an important assessment tool for athletes undergoing rehabilitation following lower limb injuries (e.g., anterior cruciate ligament reconstruction) (DeVita et al., 1998; Timoney et al., 1993). The CMJ and gait analyses can be performed using different reliable technologies and equipment, such as force platforms (Moir et al., 2009), wireless microelectromechanical-based systems (Requena et al., 2012), linear position transducers (Wadhi et al., 2018), among others. The gold standard for CMJ (force platforms) and gait analyses (3D motion analysis) are usually performed in a laboratory setting with complex and expensive equipment, requiring qualified personnel to operate, laborious measurement protocols, and logistically restricted equipment, likely unavailable to most practitioners (Simon, 2004). However, fast technological advancement in the field allows new and more accessible instruments to be available at an increased rate, such as contact mat (Pueo et al., 2017), photoelectric cells (Glatthorn et al., 2011), and mobile applications (i.e., My Jump App) (Gallardo-Fuentes et al., 2016). Among accessible instruments, an inertial measurement unit (IMU) can be a particularly useful tool to provide an alternative solution to highly sophisticated and costly equipment (Clemente et al., 2022).

The IMU integrates three types of sensors, i.e., accelerometers (inertial acceleration measurement), gyroscopes (angular rotation measurement), and magnetometers (orientation measurement) (O'Reilly et al., 2018) used to measure velocity, orientation, and gravitational force (Camomilla et al., 2018). The IMU is easily portable and can measure different variables such as jump height during vertical jumps (e.g., countermovement jump [CMJ]) (Clemente et al., 2022), barbell velocity during strength training exercises (Clemente et al., 2021), monitor sleep quality (Nam et al., 2016), detect changes of direction (Alanen et al., 2021), and gait analysis (Andrenacci et al., 2021). Some IMUs (e.g., BTS G-walk, Italy) can be used for multiple assessments, including CMJ and gait analyses (Andrenacci et al., 2021).

Although the BTS G-Walk has been found valid and reliable for gait analysis in healthy subjects (mean age: 37.8 years) (De Ridder et al., 2019; Vítečková et al., 2020) and Parkinson's disease patients (Vítečková et al., 2020), its reliability for CMJ and gait analyses in collegiate athlete is under-researched. Indeed, good test reliability is obligatory for athletes, as any error may decrease the precision of the test and increase the smallest detectable change (Hopkins, 2000). Further, in the aforementioned studies, only intra-day reliability was calculated from five trials (De Ridder et al., 2019) or two trials (Vítečková et al., 2020) using an intraclass correlation coefficient (ICC). Therefore, this study aimed to identify the intra- and inter-session reliability of the BTS G-walk sensor for CMJ and gait analysis among male and female collegiate athletes. Based on the available literature on IMU, we hypothesized that the BTS G-walk sensor would demonstrate acceptable reliability for both CMJ and gait analyses.

Methods

Participants

A total of 30 collegiate athletes (i.e., basketball and handball) (15 male athletes [age: 21.0 ± 2.5 years; height: 169.6 ± 4.5 cm; body mass: 68.0 ± 3.9 kg] and 15 female athletes [age: 21.5 ± 2.1 years; height: 163.7 ± 6.6 cm; body mass: 56.7 ± 6.0 kg]) were recruited for the study, all training ≥5 hours per week. The number of participants were chosen based on a similar study conducted to assess the concurrent validity and reliability of BTS G-walk sensor (De Ridder et al., 2019). To be included in the study, the subjects had to be i) free from lower extremity injury in past six months, ii) free from any other injury in the past one month, iii) free from any other musculoskeletal or neuromuscular disorder that could potentially affect their jump and gait. The participants were informed about the study procedures, and informed consent forms were signed. The internal review board of the School of Physical Education and Sports, Rashtriya Raksha University approved this study.

Procedure

A familiarization session was conducted before the start of the data collection, and demographics data (i.e., age, height, body mass) were collected the same day. Thereafter, the experiment took place over a period of three weeks, with two sessions conducted for inter-session analysis and three trials conducted each session for intra-session analysis. The CMJ and gait analyses were conducted on separate days. The data collection took place inside a laboratory with a regulated temperature of 24 °C and was conducted during the same period (i.e., 1400 to 1700 hours).

Countermovement jump

A warm-up of 10 minutes was conducted prior to the CMJ test on each testing day, which included running on the treadmill at a self-selected pace (participants were asked to avoid fatigue) and dynamic stretching of lower limbs (same dynamic stretching protocol was used in all testing days). In addition, the participants were also allowed to practice CMJ prior to the data collection using IMU. Thereafter, to collect data, the IMU (BTS G-walk) was placed on the lower back of each participant using a belt with the center of the device at the fifth lumbar vertebrae (i.e., L5). The subjects were asked to perform a CMJ on a wooden platform with the aim of achieving maximum vertical height following a self-selected knee flexion during countermovement based on a protocol used in previous studies (Kumar et al., 2023; Thapa & Kumar, 2023). However, the flexing of knees was not allowed during the flight. Three trials were conducted for each subject with a recovery period of ~1 minute. All successful trials were used for analysis.

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Gait analysis

The gait analysis was conducted on a concrete floor inside a laboratory. The sensor was placed at the same place (i.e., L5) as mentioned above for CMJ. To record gait data, the 10 m walk test was conducted as mentioned in a previous study (Andrenacci et al., 2021). The participant walked 10 m in a straight line (participants were instructed to walk in their normal pace), thereafter changed direction around a placed cone and returned back to the start point. The participants were asked to stand in an immobile upright position (i.e., orthostatic) before starting. Three trials were conducted for each participant with a recovery period of ~30 seconds. All trials were kept for analysis.

Statistical analysis

The normality of the data was verified using the Shapiro-Wilk test. Intra-session reliability for both the CMJ and gait assessments in the two test sessions (TS1 and TS2) was determined utilizing the calculation of the coefficient of variation (CV), the analysis of variance with repeated measures (ANOVA) and the ICC (using two-way random effects model). The inter-session reliability between both sessions (variation between TS1 and TS2) was calculated using Pearson's correlation coefficient (r) and the ICC (using a two-way random effects model). Differences between TS1 and TS2 mean values were calculated using Student's t-test for related samples. The significance level chosen for the statistical analysis was $p \leq 0.05$. The ICC were interpreted as poor (<0.50), moderate (≥0.50 – <0.75), good (≥0.75 – <0.90), and excellent (>0.90) reliability based on the lower bound of the 95% confidence interval (CI) (Koo & Li, 2016). The Pearson's correlation coefficient was interpreted as low (r = 0.1 – 0.3), moderate (r= ≥0.3 – 0.5) and high (r = ≥0.50) (Cohen, 1992). The CV represented the typical error of measurements expressed as a percentage of the mean, and a value ≤10% was considered acceptable (Cormack et al., 2008). All data were analysed using SPSS for Windows (version 28; SPSS Inc, Armonk, NY).

Results

The mean and standard deviation obtained during the CMJ and gait assessments are reported in Table 1 and Table 2, respectively.

Table 1. Mean and standard deviation (SD) of countermovement jump variables during the testing sessions.

	Testing Session 1						Testing Session 2					
	Combined		Male		Female		Combined		Male		Female	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
	27.14	5.90	31.10	5.84	23.17	2.10	26.54	5.61	30.84	4.87	22.23	1.37
Jump height (cm)	27.22	5.91	31.26	5.71	23.17	2.16	26.61	5.97	31.13	5.11	22.08	1.93
	27.36	6.12	31.85	5.57	22.87	1.86	26.71	6.23	31.51	5.44	21.91	1.27
	0.76	0.28	0.85	0.25	0.66	0.28	0.72	0.28	0.92	0.23	0.53	0.17
Take-off force (kN)	0.77	0.29	0.86	0.26	0.67	0.30	0.71	0.25	0.88	0.21	0.54	0.16
	0.78	0.27	0.89	0.25	0.68	0.26	0.71	0.27	0.91	0.20	0.51	0.16
	0.71	0.26	0.84	0.23	0.58	0.21	0.77	0.28	0.92	0.21	0.62	0.25
Impact force (kN)	0.72	0.28	0.86	0.26	0.58	0.23	0.76	0.27	0.91	0.20	0.62	0.26
	0.72	0.25	0.84	0.22	0.60	0.23	0.73	0.28	0.92	0.21	0.54	0.19
	2.87	0.79	3.31	0.74	2.44	0.60	2.81	0.94	3.44	0.81	2.18	0.56
Maximal concentric power (kW)	2.87	0.79	3.29	0.71	2.45	0.64	2.79	0.88	3.37	0.72	2.21	0.63
	2.92	0.85	3.43	0.73	2.42	0.64	2.80	0.91	3.45	0.74	2.14	0.50
	1.28	0.21	1.28	0.24	1.28	0.19	1.30	0.17	1.28	0.21	1.32	0.12
Average concentric phase speed (m/s)	1.32	0.22	1.36	0.25	1.29	0.19	1.33	0.15	1.32	0.19	1.33	0.10
	1.32	0.24	1.34	0.28	1.31	0.19	1.34	0.19	1.33	0.25	1.36	0.12
	2.55	0.26	2.68	0.28	2.41	0.15	2.52	0.28	2.71	0.25	2.34	0.15
Peak concentric speed (m/s)	2.56	0.27	2.68	0.28	2.44	0.20	2.52	0.27	2.70	0.25	2.35	0.17
	2.56	0.27	2.71	0.27	2.41	0.19	2.53	0.29	2.71	0.27	2.34	0.17
	2.40	0.27	2.45	0.33	2.34	0.20	2.36	0.28	2.48	0.33	2.24	0.14
Take-off speed (m/s)	2.40	0.29	2.46	0.34	2.33	0.21	2.36	0.28	2.48	0.32	2.24	0.18
	2.36	0.30	2.42	0.37	2.29	0.20	2.37	0.29	2.50	0.33	2.25	0.17

Table 2. Mean and standard deviation (SD) of gait variables during the testing sessions.

	Testing Session 1						Testing Session 2					
	Combined		Male		Female		Combined		Male		Female	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
	1.17	0.17	1.14	0.20	1.20	0.14	1.22	0.20	1.18	0.21	1.27	0.18
Speed (m/s)	1.19	0.16	1.14	0.17	1.24	0.14	1.23	0.19	1.17	0.18	1.29	0.19
	1.23	0.18	1.18	0.19	1.27	0.16	1.25	0.21	1.19	0.22	1.31	0.20

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Table 2. Mean and standard deviation (SD) of gait variables during the testing sessions.

	Testing Session 1						Testing Session 2					
	Combined		Male		Female		Combined		Male		Female	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Cadence (steps/min)	110.35	6.81	106.25	6.37	114.44	4.40	112.94	7.97	108.07	5.27	117.80	7.30
	111.67	6.89	107.27	5.49	116.07	5.16	112.79	7.71	108.05	5.11	117.52	7.00
	113.33	7.40	108.82	5.59	117.83	6.23	113.51	8.14	108.57	5.34	118.45	7.50
Stance phase left leg (%cycle)	60.48	2.04	60.73	1.67	60.24	2.39	60.44	2.12	60.05	1.79	60.83	2.42
	60.33	2.07	60.65	1.57	60.01	2.49	60.21	2.02	59.60	1.56	60.81	2.28
	60.21	2.29	60.41	2.15	60.02	2.48	60.30	1.88	59.79	1.58	60.82	2.06
Stance phase right leg (%cycle)	60.01	2.42	60.95	2.80	59.08	1.55	60.21	2.42	60.59	2.46	59.82	2.39
	59.79	1.96	60.41	1.84	59.17	1.94	60.07	2.34	60.72	2.30	59.43	2.27
	59.55	1.84	59.78	2.11	59.33	1.57	59.56	2.27	60.07	2.07	59.05	2.41
Swing phase left leg (%cycle)	39.70	2.11	39.66	1.84	39.74	2.42	39.72	2.15	40.27	1.76	39.17	2.42
	39.88	2.14	39.78	1.80	39.99	2.49	39.90	2.08	40.60	1.63	39.19	2.28
	39.84	2.32	39.77	2.17	39.91	2.53	39.81	1.86	40.44	1.44	39.18	2.06
Swing phase right leg (%cycle)	40.44	1.80	39.98	1.98	40.90	1.53	39.79	2.42	39.41	2.46	40.18	2.39
	40.32	2.08	39.81	2.16	40.83	1.94	40.01	2.44	39.43	2.55	40.58	2.26
	40.36	2.10	40.05	2.54	40.67	1.57	40.31	2.55	39.62	2.62	41.00	2.37
First double support phase left leg (%cycle)	9.66	1.63	10.13	1.33	9.19	1.80	10.17	2.19	10.20	1.76	10.13	2.61
	9.75	1.71	10.23	1.40	9.27	1.90	10.09	2.10	10.26	1.70	9.91	2.48
	9.52	1.87	9.97	1.93	9.06	1.76	9.87	1.88	10.07	1.66	9.66	2.12
First double support phase right leg (%cycle)	10.53	1.81	10.85	1.54	10.21	2.05	10.38	1.81	10.40	1.84	10.36	1.85
	10.49	1.75	10.75	1.42	10.23	2.04	10.43	1.84	10.44	1.94	10.41	1.82
	10.49	2.08	10.58	1.99	10.40	2.23	10.34	1.83	10.38	1.80	10.29	1.93
Single support phase left leg (%cycle)	40.33	1.63	39.71	1.54	40.95	1.53	39.94	2.30	39.44	2.22	40.43	2.35
	39.85	2.83	38.98	3.32	40.73	1.99	39.99	2.45	39.28	2.43	40.70	2.34
	40.27	1.90	39.78	2.21	40.75	1.45	40.24	2.25	39.49	1.93	40.99	2.36
Single support phase right leg (%cycle)	39.50	2.07	39.28	1.82	39.71	2.35	39.69	2.08	40.03	1.65	39.35	2.44
	39.73	1.94	39.65	1.54	39.81	2.32	39.74	2.01	40.38	1.55	39.11	2.27
	39.82	2.21	39.74	2.13	39.89	2.37	39.63	1.80	40.16	1.47	39.11	1.99
Stride length left leg (m)	1.26	0.16	1.27	0.18	1.25	0.13	1.29	0.16	1.29	0.17	1.29	0.15
	1.28	0.15	1.28	0.18	1.28	0.13	1.30	0.16	1.29	0.17	1.31	0.15
	1.29	0.16	1.29	0.18	1.29	0.13	1.32	0.17	1.31	0.18	1.33	0.15
Stride length right leg (m)	1.25	0.13	1.24	0.14	1.25	0.14	1.28	0.14	1.25	0.12	1.30	0.15
	1.26	0.13	1.25	0.14	1.28	0.13	1.30	0.15	1.28	0.14	1.31	0.15
	1.28	0.14	1.26	0.14	1.29	0.14	1.30	0.15	1.27	0.14	1.33	0.16
Step length left leg (%stride length)	50.04	1.62	50.44	1.86	49.63	1.28	49.97	1.59	50.11	1.90	49.82	1.25
	49.75	1.42	50.19	1.34	49.32	1.42	49.94	1.63	50.18	2.03	49.70	1.12
	49.85	1.79	50.52	1.78	49.18	1.60	50.02	1.47	50.32	1.76	49.73	1.10
Step length right leg (%stride length)	50.21	1.55	50.05	1.81	50.37	1.28	50.02	1.59	49.85	1.91	50.18	1.25
	49.98	2.96	49.28	3.89	50.68	1.42	50.14	1.52	49.95	1.86	50.34	1.13
	50.23	1.88	49.66	2.01	50.81	1.59	49.89	1.60	49.51	1.95	50.28	1.09

Intra- and inter-session reliability for CMJ

The detailed results of intra-session analyses for CMJ are presented in Table 3. The intra-session ICC values were good to excellent for the CMJ variables in both test sessions (TS1 ICC = 0.881 to 0.988; TS2 ICC = 0.885 to 0.993). In addition, similar reliability results were obtained for males and females. The CV was acceptable (≤10%) for all variables. The repeated measures ANOVA revealed no difference between the three trials during TS1 or TS2 except for CMJ average speed concentric phase ($p = 0.046$) during TS2.

The detailed results for inter-session reliability analyses are presented in Table 4. The inter-session ICC values ranged between poor to excellent for the CMJ variables between TS1 and TS2 (ICC = 0.134 to 0.963). There were moderate to high

Table 3. Intra-session reliability** for countermovement during testing session 1 and 2.

	TS1			TS2		
	ANOVA p-value	ICC	CV (%)	ANOVA p-value	ICC	CV (%)
Jump height (cm)						
All	0.805	0.988	3.90	0.807	0.989	4.03
Females	0.405	0.958	2.20	0.553	0.786	1.51
Males	0.321	0.978	4.59	0.327	0.984	4.20
Take-off force (kN)						
All	0.470	0.988	6.50	0.549	0.952	9.52
Females	0.848	0.979	10.43	0.468	0.954	7.63
Males	0.292	0.975	7.39	0.221	0.973	6.00
Impact force (kN)						
All	0.863	0.962	6.40	0.347	0.949	6.35
Females	0.515	0.977	9.55	0.106	0.937	9.76
Males	0.626	0.922	6.63	0.805	0.894	5.20
Maximum concentric power (kW)						
All	0.368	0.986	5.05	0.839	0.993	5.90
Females	0.817	0.989	6.57	0.334	0.990	6.62
Males	0.036	0.973	5.48	0.207	0.984	5.61
Average speed concentric phase (m/s)						
All	0.256	0.913	2.90	0.046*	0.885	2.19
Females	0.557	0.966	3.71	0.209	0.863	1.94
Males	0.296	0.882	4.53	0.126	0.894	3.99
Peak concentric speed (m/s)						
All	0.780	0.966	1.80	0.956	0.983	1.98
Females	0.515	0.905	1.78	0.803	0.971	1.71
Males	0.457	0.974	2.60	0.727	0.975	2.40
Take-off speed (m/s)						
All	0.693	0.881	1.97	0.532	0.984	2.16
Females	0.588	0.894	2.07	0.837	0.961	1.82
Males	0.827	0.871	3.27	0.609	0.984	3.33

*: denotes statistical significance; **: from 3 countermovement jumps trials; CV: coefficient of variation; ICC: intraclass correlation coefficient.

significant correlations between TS1 and TS2 for jump height, take-off force, impact force, max concentric power, average speed concentric phase, peak concentric speed, and take-off speed (r = 0.411 to 0.931). The Student's t-test revealed significant differences between TS1 and TS2 for impact force, average speed concentric phase, peak concentric speed and

Table 4. Reliability for countermovement jump between testing session 1 and 2.

	Student's t p-value	Intraclass correlation coefficient	Pearson's r
Jump height (cm)			
All	0.165	0.963	0.931**
Females	0.129	0.415	0.298
Males	0.580	0.938	0.882**
Take-off force (kN)			
All	0.061	0.859	0.770**
Females	0.006a	0.666	0.767**
Males	0.380	0.920	0.868**
Impact force (kN)			
All	<0.001[a]	0.287	0.545**
Females	0.001[a]	0.204	0.706**
Males	<0.001[a]	0.101	0.199

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Table 4. Reliability for countermovement jump between testing session 1 and 2.

	Student's t p-value	Intraclass correlation coefficient	Pearson's r
Maximum concentric power (kW)			
All	0.082	0.605	0.623**
Females	0.350	0.703	0.550**
Males	0.032	0.342	0.400
Average speed concentric phase (m/s)			
All	<0.001[a]	0.194	0.411*
Females	0.176	0.332	0.249
Males	<0.001[a]	0.171	0.531
Peak concentric speed (m/s)			
All	0.002[a]	0.134	0.471**
Females	0.088	0.815	0.719**
Males	<0.001[a]	0.017	0.103
Take-off speed (m/s)			
All	0.002[a]	0.184	0.595**
Females	0.083	0.684	0.570**
Males	<0.001[a]	0.160	0.735**

[a] – significant difference between testing session 1 and 2; *Correlation is significant at the 0.05 level (2-tailed); **Correlation is significant at the 0.01 level (2-tailed).

take off speed (p = <0.001 to 0.002). Furthermore, significant differences were observed among females for take-off force and impact force, and among males for impact force, average speed concentric phase, peak concentric speed, and take-off speed (p = <0.001 to 0.006).

Intra- and inter-session reliability for gait analysis

The detailed results of intra-session gait analyses are presented in Table 5. The intra-session ICC values were moderate to excellent in both test sessions (TS1 ICC = 0.807 to 0.978; TS2 ICC = 0.881 to 0.969) for the gait analysis variables. However, the

Table 5. Intra-session reliability for gait analysis during testing sessions 1 and 2.

	TS1			TS2		
	ANOVA p-value	ICC	CV (%)	ANOVA p-value	ICC	CV (%)
Speed (m/s)						
All	0.008*	0.939	2.52	0.090	0.969	1.48
Females	0.069	0.907	2.91	0.249	0.924	3.64
Males	0.090	0.956	4.00	0.421	0.981	0.95
Cadence (steps/min)						
All	0.001*	0.941	1.10	0.234	0.955	1.23
Females	0.025*	0.832	1.05	0.411	0.957	1.48
Males	0.024*	0.950	1.35	0.624	0.976	0.94
Stance phase left leg (%cycle)						
All	0.474	0.945	0.60	0.476	0.956	0.58
Females	0.449	0.962	1.02	0.999	0.955	0.91
Males	0.706	0.916	0.72	0.285	0.954	0.68
Stance phase right leg (%cycle)						
All	0.510	0.807	0.54	0.004*	0.960	0.69
Females	0.748	0.930	0.61	0.024	0.968	0.99
Males	0.201	0.685	0.77	0.122	0.949	0.69
Swing phase left leg (%cycle)						
All	0.420	0.953	0.95	0.595	0.962	0.90
Females	0.380	0.965	1.55	0.999	0.955	1.42
Males	0.876	0.937	1.18	0.140	0.965	0.99

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Table 5. Intra-session reliability for gait analysis during testing sessions 1 and 2.

	TS1			TS2		
	ANOVA p-value	ICC	CV (%)	ANOVA p-value	ICC	CV (%)
Swing phase right leg (%cycle)						
All	0.826	0.933	0.85	0.097	0.959	1.80
Females	0.764	0.930	1.00	0.008*	0.969	1.46
Males	0.762	0.933	1.36	0.862	0.948	0.99
First double support phase left leg (%cycle)						
All	0.523	0.931	3.10	0.380	0.950	3.57
Females	0.379	0.954	4.89	0.451	0.970	6.12
Males	0.734	0.855	3.61	0.872	0.907	1.57
First double support phase right leg (%cycle)						
All	0.974	0.922	3.00	0.872	0.947	3.05
Females	0.797	0.957	5.08	0.896	0.971	4.81
Males	0.838	0.859	3.53	0.975	0.968	3.97
Single support phase left leg (%cycle)						
All	0.472	0.843	0.87	0.222	0.967	1.03
Females	0.646	0.931	0.99	0.131	0.944	1.54
Males	0.558	0.766	1.33	0.776	0.959	4.47
Single support phase right leg (%cycle)						
All	0.292	0.942	1.00	0.845	0.941	0.85
Females	0.840	0.968	1.47	0.779	0.923	1.40
Males	0.338	0.699	1.02	0.193	0.926	1.35
Stride length left leg (m)						
All	0.040*	0.978	2.20	0.252	0.963	1.90
Females	0.109	0.848	2.59	0.122	0.969	2.90
Males	0.383	0.985	3.67	0.098	0.995	3.47
Stride length right leg (m)						
All	0.026*	0.968	1.90	0.018*	0.961	0.55
Females	0.086	0.906	2.58	0.077	0.970	2.97
Males	0.328	0.977	2.80	0.040*	0.962	2.60
Step length left leg (%stride length)						
All	0.085	0.954	0.57	0.822	0.915	0.55
Females	0.024*	0.958	0.70	0.818	0.914	0.55
Males	0.267	0.963	0.83	0.487	0.980	0.96
Step length right leg (%stride length)						
All	0.790	0.880	0.72	0.223	0.881	3.15
Females	0.025*	0.932	0.69	0.667	0.921	0.55
Males	0.196	0.960	1.25	0.107	0.974	0.97

*: denotes statistical significance; ICC: intraclass correlation coefficient; CV: coefficient of variation.

ICC values were good for cadence and stride length in females during TS1. In addition, ICC values were moderate for the stance phase (left leg) and single support phase (right leg) and good for the first double support phase (both left and right legs), single support phase (left leg), and stride length (left leg) among males during TS1. Other variables achieved excellent ICC values (>0.90) during TS1 and TS2 in males and females. The CV was acceptable (≤10%) for all variables in both TS. The repeated measure ANOVA revealed a significant difference for all participants in speed, cadence, and stride length (both legs) during TS1, and in the stance phase (right leg) and stride length (right leg) during TS2.

The detailed results for inter-session reliability gait analysis variables are presented in Table 6. The between TS1 and TS2 inter-session ICC values ranged between moderate to excellent (ICC = 0.683 to 0.931). However, ICC values among females were poor for step length (left leg) (ICC = 0.485). Further, a high significant Pearson correlation coefficient was obtained for each variable between TS1 and TS2 (r = 0.528 to 0.880). In addition, the Student's t-test reported a significant difference in gait speed between TS1 and TS2 (p = 0.045). Furthermore, significant differences were reported in females' speed (p = 0.030) and stride length (left leg) (p = 0.017), and in stance phase (left leg) for males (p = 0.037).

Table 6. Inter-session reliability for measure of gait between testing session 1 and 2.

	Student's t p-value	Intraclass correlation coefficient	Pearson's r
Speed (m/s)			
All	0.045a	0.878	0.813**
Females	0.030a	0.866	0.870**
Males	0.803	0.859	0.753**
Cadence (steps/min)			
All	0.127	0.887	0.811**
Females	0.168	0.781	0.700**
Males	0.382	0.814	0.682**
Stance phase left leg (%cycle)			
All	0.924	0.821	0.690**
Females	0.072	0.867	0/798**
Males	0.037a	0.764	0.677**
Stance phase right leg (%cycle)			
All	0.644	0.683	0.528**
Females	0.667	0.609	0.455
Males	0.875	0.698	0.529*
Swing phase left leg (%cycle)			
All	0.996	0.836	0.712**
Females	0.082	0.872	0.803**
Males	0.061	0.788	0.700**
Swing phase right leg (%cycle)			
All	0.303	0.796	0.681**
Females	0.697	0.611	0.456
Males	0.224	0.891	.818**
First double support phase left leg (%cycle)			
All	0.199	0.725	0.584**
Females	0.154	0.727	0.618*
Males	0.849	0.719	0.548*
First double support phase right leg (%cycle)			
All	0.666	0.774	0.626**
Females	0.862	0.768	0.614*
Males	0.382	0.796	.671**
Single support phase left leg (%cycle)			
All	0.763	0.796	0.664**
Females	0.851	0.610	0.453
Males	0.803	0.677	.788**
Single support phase right leg (%cycle)			
All	0.972	0.821	0.690**
Females	0.120	0.869	0.789**
Males	0.940	0.745	0.633*
Stride length left leg (m)			
All	0.061	0.931	0.880**
Females	0.017a	0.943	0.931**
Males	0.156	0.927	0.860**
Stride length right leg (m)			
All	0.645	0.910	0.850**
Females	0.329	0.950	0.944*
Males	0.271	0.861	0.754**

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Table 6. Inter-session reliability for measure of gait between testing session 1 and 2.

	Student's t p-value	Intraclass correlation coefficient	Pearson's r
Step length left leg (%stride length)			
All	0.658	0.793	0.651**
Females	0.280	0.485	0.331
Males	0.508	0.878	0.783**
Step length right leg (%stride length)			
All	0.645	0.805	0.693**
Females	0.329	0.563	0.403
Males	0.792	0.862	0.722**

[a] – significant difference between testing session 1 and 2; *Correlation is significant at the 0.05 level (2-tailed); **Correlation is significant at the 0.01 level (2-tailed).

Discussion

The aim of the study was twofold: firstly, to investigate the reliability of an IMU (BTS G-walk) to measure countermovement jump, and secondly, to investigate the reliability of the same instruments to measure the gait parameters among male and female collegiate athletes. For the study's first aim, the findings demonstrated the IMU to have good to excellent intra-session ICC values in both sessions for CMJ variables, indicating high reliability. Moreover, when the participants were categorized based on sex, similar results were obtained for both males and females, which indicates that the instrument is equally reliable for both sexes. In addition, acceptable CV values (i.e., typical error of measurement) were reported for all CMJ variables. Indeed, a previous systematic review has reported different IMUs (e.g., Myotest Pro, Vert Classic) to be valid and reliable for measuring jump height (Clemente et al., 2022). However, the inter-session ICC values ranged from poor (i.e., impact force, average speed concentric phase, peak concentric speed, take-off speed) to excellent (i.e., jump height), indicating that the reliability of the CMJ variables varied between TS1 and TS2. In addition, differences were also noted in the results for inter-session analyses (i.e., TS1 versus TS2) between sexes (Table 2). For example, jump height was significantly correlated between TS1 and TS2 for males but not for females. In contrast, impact force was significantly correlated between TS1 and TS2 for females but not for males. These differences in the results for both sexes may be plausible due to the differences in training sessions the participants were involved in during the course of data collection. Both male and female athletes were involved in separate training programs in their respective sports preparing for the inter-university competitions, due to which the training load could not be controlled, which may have resulted in such findings. Nevertheless, moderate to high significant correlations were observed for most of the CMJ variables between the two TS, indicating that the instrument may be generally reliable over time. Moreover, the differences obtained between the scores in the CMJ variables between TS1 and TS2, with good intra-session ICC within each TS, shows the ability of the IMU to detect the changes that may be possible due to unpredictable reasons (e.g., fatigue among the participants due to factors that couldn't be controlled in this study). Indeed, the CMJ test is valid to assess the neuromuscular fatigue of an athlete (Bishop et al., 2023; Claudino et al., 2017). However, if fatigue is related to the poor reliability values noted between TS1 and TS2 (Table 4), it is not clear, and only speculation would be possible.

For the study's second aim, the findings demonstrated moderate to excellent reliability for most gait analysis variables in both intra-session and inter-session testing. This suggests that the IMU can be a reliable tool for measuring gait patterns and monitoring changes over time among collegiate athletes. These findings are consistent with previous studies using IMUs from different manufacturers (e.g., Xsens, Opal) (Kobsar et al., 2020). The high intra-session reliability of the IMU data in this study can be related to the selected IMU placement (lower back), allowing predictable and consistent sensor position during walking, thus minimizing collected data variability due to sensor displacement (Niswander et al., 2020). However, some sex-specific differences in ICC values were observed, particularly for cadence and stride length in females, and for stance phase, single support phase, first double support phase, and stride length in males. These findings indicate that sex should be considered when analysing gait patterns using the IMU. The typical error expressed as CV was acceptable for all variables in both TS, indicating that the measurements taken by the IMU were accurate and precise. However, the significant differences observed between TS1 and TS2 in speed and stride length (left) for females, and in stance phase (left) for males, suggest some limitations and potential sources of error associated with the use of the IMU instrument. Indeed, caution should be taken when interpreting changes in gait patterns over time, as factors such as changes in speed can affect gait analysis results (Fukuchi et al., 2019). Additionally, while IMUs may be a reliable tool for gait analysis, they should not be used as the sole method for gait analysis. Rather, IMU data may be complemented with other measures of gait, such as video analysis or force plate data if available, to ensure more holistic assessments.

There are some potential limitations of this study that should be acknowledged. Firstly, the training load of the athletes could not be controlled during the two TS. Secondly, the study included only collegiate level basketball and handball athletes. Therefore, the results arising from this study should be used with caution for other sports athletes as well as high-level athletes. Thirdly, although a pilot study (n = 16) reported the IMU sensor to be valid and reliable (concurrent to MyJump 2 [ICC = 0.96, r = 0.973, mean difference = 0.2 ± 1.3, paired t test p = 0.550]) to measure the CMJ height. The concurrent measurement of CMJs with force platform (or other validated IMUs) would also help in validating other kinetic variables along with the jump height.

Conclusion

The IMU BTS G-walk is generally reliable for measuring CMJ variables, with some variation in reliability between males and females and between TS. The significant differences observed between TS and between sex suggest that caution should be exercised when interpreting these results and that further research is necessary to understand the factors that may influence the reliability of the instrument for different variables and populations. In addition, the IMU BTS G-walk can also be a reliable tool for measuring gait patterns and monitoring changes over time, with good to excellent reliability for most gait analysis variables among collegiate athletes. However, sex-specific differences and potential sources of error should be carefully considered when interpreting gait analysis results. Further investigation is also needed to better understand the factors contributing to these differences and to refine gait analysis protocols accordingly.

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Availability of data and material

All data generated or analyzed during this study will be/are included in the published article as Table(s). Any other data requirement can be directed to the corresponding author upon reasonable request.

References

Alanen, A., Räisänen, A., Benson, L., & Pasanen, K. (2021). The use of inertial measurement units for analyzing change of direction movement in sports: A scoping review. *International Journal of Sports Science & Coaching*, *16*(6), 1332-1353. https://doi.org/10.1177/17479541211003064

Andrenacci, I., Boccaccini, R., Bolzoni, A., Colavolpe, G., Costantino, C., Federico, M., Ugolini, A., & Vannucci, A. (2021). A comparative evaluation of inertial sensors for gait and jump analysis. *Sensors (Basel)*, *21*(18). https://doi.org/10.3390/s21185990

Bishop, C., Jordan, M., Torres-Ronda, L., Loturco, I., Harry, J., Virgile, A., Mundy, P., Turner, A., & Comfort, P. (2023). Selecting metrics that matter: Comparing the use of the countermovement jump for performance profiling, neuromuscular fatigue monitoring, and injury rehabilitation testing. *Strength & Conditioning Journal*, *45(5):p 545-553.* https://doi.org/10.1519/ssc.0000000000000772

Camomilla, V., Bergamini, E., Fantozzi, S., & Vannozzi, G. (2018). Trends supporting the in-field use of wearable inertial sensors for sport performance evaluation: A systematic review. *Sensors (Basel)*, *18*(3). https://doi.org/10.3390/s18030873

Claudino, J. G., Cronin, J., Mezêncio, B., McMaster, D. T., McGuigan, M., Tricoli, V., Amadio, A. C., & Serrão, J. C. (2017). The countermovement jump to monitor neuromuscular status: A meta-analysis. *J Sci Med Sport*, *20*(4), 397-402. https://doi.org/10.1016/j.jsams.2016.08.011

Clemente, F., Badicu, G., Hasan, U. C., Akyildiz, Z., Pino-Ortega, J., Silva, R., & Rico-González, M. (2022). Validity and reliability of inertial measurement units for jump height estimations: A systematic review [journal article]. *Human Movement*, 1-20. https://doi.org/10.5114/hm.2023.111548

Clemente, F. M., Akyildiz, Z., Pino-Ortega, J., & Rico-González, M. (2021). Validity and reliability of the inertial measurement unit for barbell velocity assessments: A systematic review. *Sensors (Basel)*, *21*(7). https://doi.org/10.3390/s21072511

Cohen, J. (1992). A power primer. *Psychological Bulletin*, *112*, 155-159. https://doi.org/10.1037/0033-2909.112.1.155

Cormack, S. J., Newton, R. U., McGuigan, M. R., & Doyle, T. L. (2008). Reliability of measures obtained during single and repeated countermovement jumps. *Int J Sports Physiol Perform*, *3*(2), 131-144. https://doi.org/10.1123/ijspp.3.2.131

De Ridder, R., Lebleu, J., Willems, T., De Blaiser, C., Detrembleur, C., & Roosen, P. (2019). Concurrent validity of a commercial wireless trunk triaxial accelerometer system for gait analysis. *J Sport Rehabil*, *28*(6). https://doi.org/10.1123/jsr.2018-0295

DeVita, P., Hortobagyi, T., & Barrier, J. (1998). Gait biomechanics are not normal after anterior cruciate ligament reconstruction and accelerated rehabilitation. *Med Sci Sports Exerc*, *30*(10), 1481-1488. https://doi.org/10.1097/00005768-199810000-00003

Fukuchi, C. A., Fukuchi, R. K., & Duarte, M. (2019). Effects of walking speed on gait biomechanics in healthy participants: A systematic review and meta-analysis. *Syst Rev*, *8*(1), 153. https://doi.org/10.1186/s13643-019-1063-z

Gallardo-Fuentes, F., Gallardo-Fuentes, J., Ramírez-Campillo, R., Balsalobre-Fernández, C., Martínez, C., Caniuqueo, A., Cañas, R., Banzer, W., Loturco, I., Nakamura, F. Y., & Izquierdo, M. (2016). Intersession and intrasession reliability and validity of the my jump app for measuring different jump actions in trained male and female athletes. *J Strength Cond Res*, *30*(7), 2049-2056. https://doi.org/10.1519/jsc.0000000000001304

García-Pinillos, F., Ramírez-Campillo, R., Boullosa, D., Jiménez-Reyes, P., & Latorre-Román, P. (2021). Vertical jumping as a monitoring tool in endurance runners: A brief review. *J Hum Kinet*, *80*, 297-308. https://doi.org/10.2478/hukin-2021-0101

Gathercole, R. J., Sporer, B. C., Stellingwerff, T., & Sleivert, G. G. (2015). Comparison of the capacity of different jump and sprint field tests to detect neuromuscular fatigue. *J Strength Cond Res*, *29*(9), 2522-2531. https://doi.org/10.1519/jsc.0000000000000912

Glatthorn, J. F., Gouge, S., Nussbaumer, S., Stauffacher, S., Impellizzeri, F. M., & Maffiuletti, N. A. (2011). Validity and reliability of optojump photoelectric cells for estimating vertical jump height. *J Strength Cond Res*, *25*(2), 556-560. https://doi.org/10.1519/JSC.0b013e3181ccb18d

Gogoi, H., Rajpoot, Y. S., & Borah, P. (2021). A prospective cohort study to predict running-related lower limb sports injuries using gait kinematic parameters. *Teorìâ Ta Metodika Fìzičnogo Vihovannâ*, *21*(1), 69-76.

Hopkins, W. G. (2000). Measures of reliability in sports medicine and science. *Sports Med*, *30*(1), 1-15. https://doi.org/10.2165/00007256-200030010-00001

Kobsar, D., Charlton, J. M., Tse, C. T. F., Esculier, J.-F., Graffos, A., Krowchuk, N. M., Thatcher, D., & Hunt, M. A. (2020). Validity and reliability of wearable inertial sensors in healthy adult walking: A systematic review and meta-analysis. *Journal of NeuroEngineering and Rehabilitation*, *17*(1), 62. https://doi.org/10.1186/s12984-020-00685-3

Koo, T. K., & Li, M. Y. (2016). A guideline of selecting and reporting intraclass correlation coefficients for reliability research. *Journal of chiropractic medicine*, *15*(2), 155-163. https://doi.org/10.1016/j.jcm.2016.02.012

Kumar, G., Pandey, V., Thapa, R. K., Weldon, A., Granacher, U., & Ramirez-Campillo, R. (2023). Effects of exercise frequency with complex contrast training on measures of physical fitness in active adult males. *Sports (Basel)*, *11*(1). https://doi.org/10.3390/sports11010011

Lacy, A. C., & Williams, S. M. (2018). *Measurement and evaluation in physical education and exercise science*. Routledge.

Moir, G. L., Garcia, A., & Dwyer, G. B. (2009). Intersession reliability of kinematic and kinetic variables during vertical jumps in men and women. *Int J Sports Physiol Perform*, *4*(3), 317-330. https://doi.org/10.1123/ijspp.4.3.317

Nam, Y., Kim, Y., & Lee, J. (2016). Sleep monitoring based on a tri-axial accelerometer and a pressure sensor. *Sensors (Basel)*, *16*(5). https://doi.org/10.3390/s16050750

Niswander, W., Wang, W., & Kontson, K. (2020). Optimization of imu sensor placement for the measurement of lower limb joint kinematics. *Sensors (Basel)*, *20*(21). https://doi.org/10.3390/s20215993

O'Reilly, M., Caulfield, B., Ward, T., Johnston, W., & Doherty, C. (2018). Wearable inertial sensor systems for lower limb exercise detection and evaluation: A systematic review. *Sports Med*, *48*(5), 1221-1246. https://doi.org/10.1007/s40279-018-0878-4

Pueo, B., Lipinska, P., Jiménez-Olmedo, J. M., Zmijewski, P., & Hopkins, W. G. (2017). Accuracy of jump-mat systems for measuring jump height. *Int J Sports Physiol Perform*, *12*(7), 959-963. https://doi.org/10.1123/ijspp.2016-0511

Requena, B., García, I., Requena, F., Saez-Saez de Villarreal, E., & Pääsuke, M. (2012). Reliability and validity of a wireless microelectromechanicals based system (keimove™) for measuring vertical jumping performance. *J Sports Sci Med*, *11*(1), 115-122.

Simon, S. R. (2004). Quantification of human motion: Gait analysis-benefits and limitations to its application to clinical problems. *J Biomech*, *37*(12), 1869-1880. https://doi.org/10.1016/j.jbiomech.2004.02.047

Tao, W., Liu, T., Zheng, R., & Feng, H. (2012). Gait analysis using wearable sensors. *Sensors (Basel)*, *12*(2), 2255-2283. https://doi.org/10.3390/s120202255

Thapa, R. K., & Kumar, G. (2023). Does complex contrast training induce higher physical fitness improvement in stronger compared to weaker individuals? *Montenegrin Journal of Sports Science and Medicine*, *12*(1), 43-51.

Timoney, J. M., Inman, W. S., Quesada, P. M., Sharkey, P. F., Barrack, R. L., Skinner, H. B., & Alexander, A. H. (1993). Return of normal gait patterns after anterior cruciate ligament reconstruction. *Am J Sports Med*, *21*(6), 887-889. https://doi.org/10.1177/036354659302100623

Van Hooren, B., & Zolotarjova, J. (2017). The difference between countermovement and squat jump performances: A review of underlying mechanisms with practical applications. *J Strength Cond Res*, *31*(7), 2011-2020. https://doi.org/10.1519/jsc.0000000000001913

Vítečková, S., Horáková, H., Poláková, K., Krupička, R., Růžička, E., & Brožová, H. (2020). Agreement between the gaitrite(®) system and the wearable sensor bts g-walk(®) for measurement of gait parameters in healthy adults and parkinson's disease patients. *PeerJ*, *8*, e8835. https://doi.org/10.7717/peerj.8835

Wadhi, T., Rauch, J. T., Tamulevicius, N., Andersen, J. C., & De Souza, E. O. (2018). Validity and reliability of the gymaware linear position transducer for squat jump and counter-movement jump height. *Sports*, *6*(4), 177. https://www.mdpi.com/2075-4663/6/4/177

ORIGINAL SCIENTIFIC PAPER

Assessing the Effect of Head and Neck Orientation on Head Injury Parameters in Taekwondo

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Abstract

Background: Brain injuries may be caused by the linear and rotational acceleration of the head and neck; in fact, head and neck orientation are one of the factors determining the type and severity of brain injury when the impact delivered to head is a less important consideration. This investigation has analyzed the effect of head and neck orientation on linear and rotational acceleration in Taekwondo. Methods: The ADAMS software model has been used to determine the linear and rotational acceleration in the taekwondo roundhouse kick in various orientations. Results: The results revealed that the maximum linear and rotational acceleration was related to neck 0° were 99g, and 4576$\frac{rad}{s^2}$, respectively. The head and neck orientation did not affect the magnitude of the linear and rotational acceleration in the sagittal plane. However, as the angle of the head and neck orientation increased in the frontal plane, the magnitude of the linear and rotational acceleration decreased. Conclusion: In general, the results indicate that only rotational acceleration was the cause of brain injury in taekwondo. Increasing the angle of orientation of the head and neck in frontal plane would lead to a reduction in intensity.

Keywords: *ADAMS software model, Brain injuries, Taekwondo, Orientation, Roundhouse kick*

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Introduction

In combat sports like taekwondo and boxing, intense head injuries have been the primary concern of sports administrators. Athletes are exposed to severe and repeated impacts to the head (Pieter, Fife, & O'Sullivan, 2012; Walilko, Viano, & Bir, 2005). Rider stated that the occurrence of head and neck injuries is 21.4 per 1000 athlete exposures among male taekwondo athletes and even among females it is 16.9 per 1000 (Pieter et al., 2012).Moreover, Kooh and Cassidy have reported that the concussion incidence in taekwondo competition is approximately four times greater than American football (Koh & Cassidy, 2004). The roundhouse kick is most commonly associated with mild traumatic brain injury in taekwondo competition (Pieter et al., 2012).

A concussion is known as a pathophysiological process leading to disorders of neurological function. It occurs due to

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severe biomechanical effects on the head, neck or face (Pieter et al., 2012). A few modern studies associated with the biomechanics of head injury and sport-relevant concussion in combat sports and martial arts have provided insights into the mechanisms of head injuries (Fife, 2010). It has been found that brain injuries are caused by the linear and rotational acceleration of the head and neck (Schmitt, Niederer, Muser, & Walz, 2019). Moreover, it has been determined that the impact force parameter is the cause of skull damage7. Rotational acceleration is considered to produce both focal and diffuse brain injuries, while linear acceleration produces focal brain injuries (Schmitt et al., 2019).The nature of most head injuries, as displayed in HIC and the Wayne State Tolerance Curve, are explained by these accelerations (Schmitt et al., 2019). Boroushak et.al has stated that rotational acceleration and linear acceleration in $4656\frac{rad}{s^2}$, and 104.4 g respectively resulting from a roundhouse kick to the head causes injury in taekwondo (Boroushak, Eslami, Kazemi, Daneshmandy, & Johnson, 2018). O'Sullivan et.al in his investigation entitled; "Biomechanical head impact characteristics in taekwondo", has indicated that of 461 (66.9%) impacts delivered to the head, rotational acceleration is less than $4600\frac{rad}{s^2}$,, and that of 121 (17.1%) are between 4600 and $7900\frac{rad}{s^2}$, and of 107 impacts (15.5%) are greater than $7900\frac{rad}{s^2}$. furthermore, they have noted that linear acceleration (87.1%) ranging between 10g and 39g, 66 (9.6%) impacts ranging between 40g and 69g, and 23 (3.3%) above 70g (O'Sullivan & Fife, 2016). Due to the unpleasant nature of brain injury and its irreversible symptoms and effects, examination of the mechanism of brain injury in humans remains a critical issue.

Furthermore, an accurate understanding of the parameters associated with brain injury, necessitates a rigorous investigation of the factors affecting these parameters. With regards to the head impact, the effective mass of the impact, the material of the impactor and its velocity, the locations, and direction of the impact, as well as the orientation of the head and neck to the body, are all important factors affecting the biomechanical parameters of the head injury (Green & Angelaki, 2004; Leonardi et al., 2012; Williams & Kirsch, 2008). Despite numerous investigations on the biomechanics of head injury, there are still many uncertainties about the effect of some factors upon brain injury, especially in martial arts.

Among a variety of parameters, the head and neck orientation are the most important factors in determining the type and severity of brain injury when an impact delivered to head. Unfortunately, it has been almost totally ignored. In previous research, diverse angles of the head and neck about an axis perpendicular to the impact plane when impact applied to head were discussed as well as their effects on acceleration (Green & Angelaki, 2004; Leonardi et al., 2012; Walsh, Rousseau, & Hoshizaki, 2011; Williams & Kirsch, 2008). This orientation has been covered in research on the effects of explosions on head and brain injury factors as well (Leonardi et al., 2012). Some studies also have examined the direction and severity of a head collision with the ground in falls (Wright & Laing, 2012). The conclusions of all the researchers confirm the massive influence of the head and neck orientation on the probability and severity of brain injury.

Consideration of the importance of brain injuries in the popular sport of taekwondo, the effects of head and neck orientation during impact should be study. The changes in the athlete's head and neck orientations during foot impacts in competitions, and the relationship of significant head injury to acceleration magnitude will be addressed in this paper. The impact of the roundhouse kick's foot to the head in various orientations of the athlete's head and neck will be studied, and then effect of this orientation on the linear and rotational acceleration magnitude will be discussed. In this way, it is possible to obtain better information about the amount of head and neck injuries of athletes in the field of competition in order to prevent these injuries by making the right decisions and making the right equipment.

Materials and Methods

In the present research, a computer simulation method has been used. Except for conditions and mechanical parameters of the athlete's foot strike, the other requirements for the head and neck impact were simulated in Mechanical Dynamics Incorporation (MSC) Automated Dynamic Analysis of Mechanical Systems (ADAMS) software (MSC Software Corporation, 2013 version). For the simulation target, an appropriate model of the head and neck was required. Head attributes like hardness, material, the properties of the impact (i.e., modulus of

Table 1. Physical and mechanical parameters of organs simulated with the MSC ADAMS software model

Body part	Physical parameters	Parameter dimensions
Neck and body	Equivalent length	30 cm
	Equivalent material	Steel
	Equivalent diameter	1 cm
Head	Diameter	25 cm
	Stiffness	200 N/m
	Damping coefficient	12
	Penetration depth in impact	4 cm
	Mass	5 kg
Leg	Length	95 cm
	Mass	12.4 kg
	Moment of inertia around the hip	3 kg.m^2
	Rotation angle for impact	270°
	Spring coefficient at hip joint	900 Nm/degree (for 13 m/s) 1350 Nm/degree (for 16 m/s)
	Pre-loading angle	20°

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elasticity of skin and skull), damping factor in the impact, and other elements were examined. Neck attributes contained equivalent flexibility, damping coefficient, mass, and length, to simulate a roundhouse kick's impact, Foot specifications subjected length, mass, rotational inertia, and foot end velocity at the time of impact. These attributes were derived from former studies and the outcome confirmed by this research (Boroushak et al., 2018). In this model, the dynamical and mechanical properties of head, neck and foot of human in a sport impact are presented (Table 1). This dynamic model of multi-body system is used for simulating Roundhouse kick impact in taekwondo.

For verifying this model, the peak of impact force in visual Nastran simulation and MSC ADAMS software are compared (Table 2) and results indicate the accuracy of the proposed model.

Table 2. Comparison of simulation results in the MSC ADAMS study with previous study (Boroushak et al., 2018)

velocity of foot (m/s)	time of impact (ms)	Peak of Impact Force (N)	
		simulation in MSC ADAMS	simulation in visual Nastran (Tsui & Pain, 2012)
12	25	5282	5620
14	20	6048	6380
16	18	7129	6810

For more insurance to validity of this model, the incline-sled apparatus test (Sato et al., 2014a) is simulated in ADAMS software and the proposed model is compare by the results of experimental test. This test is analyzed the dynamic of cervical vertebral motion during low-speed rear impact.

The anthropometry properties of head and neck are obtained from anthropometric table (Schmitt, Niederer, Cronin, Muser, & Walz, 2014) for average of height and weight of volunteers in (Sato et al., 2014a) and model of software are adopted by these properties. Some markers are posited in the locations as experiment are (Ono & Kaneoka, 1999) and used for Extract the results. Then, the conditions of incline-sled apparatus test are get ready in software and the sled from the top of the rails is released. It moved in effect of gravity force and a hydraulic damper decelerated the sled in the end of rails. Displacements and the linear and rotational velocity and acceleration of model are obtained from markers. The results are shown good accuracy by comparison the experimental test (Table 3).

Table 3. Comparison of simulation by experimental results

	Impact velocity= 4 km/h		Impact velocity= 6.2 km/h	
	Computer simulation	Experimental test (Ono & Kaneoka, 1999)	Computer simulation	Experimental test (Sato et al., 2014b)
Time of sled acceleration peak (s)	50	50	45	46
Time of head (C.G.) acceleration peak (s)	102.5	110	84.3	80
sled acceleration peak (m/s^2)	20	22	30	27
head (C.G.) acceleration peak (m/s^2)	34.7	32	53	50
Maximum of head rotational angle (degree)	22	20	42	35

Description: seatback angle from the vertical= 20 degree, sled angle from the horizontal= 10 degree and incline rail length= 4 m

So, the proposed model is ready to use in other orientation of head and neck relative to human body.

To explore the orientation of the head and neck, three main axes that determine its angles relative to the reference position were considered (fig. 1).

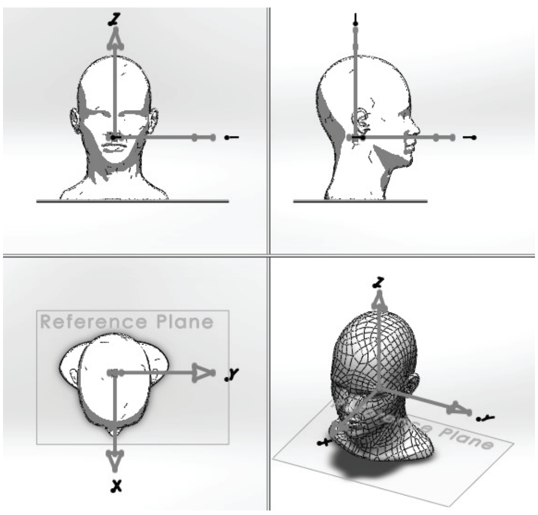

Figure 1. Three main axes of the head to determine the angles of orientation in impact moment

Euler ZXZ angles were used to rotate the head and neck set. The set rotates around the Z-axis, then by β about the X 'axis and eventually by У about the Z" axis respectively to achieve the desired orientation in space (equation 1).

$$R_{ZX'Z''}(\alpha,\beta,\gamma)=\begin{bmatrix}-s\alpha c\beta s\gamma+c\alpha c\gamma & -s\alpha c\beta c\gamma-c\alpha s\gamma & s\alpha s\beta\\ c\alpha c\beta s\gamma+s\alpha c\gamma & c\alpha c\beta c\gamma-s\alpha s\gamma & -c\alpha s\beta\\ s\beta s\gamma & s\beta c\gamma & c\beta\end{bmatrix}$$

If the rotation matrix is expressed by equation 2;

$$R_{ZX'Z''}(\alpha,\beta,\gamma)=\begin{bmatrix}r_{11} & r_{12} & r_{13}\\ r_{21} & r_{22} & r_{23}\\ r_{31} & r_{32} & r_{33}\end{bmatrix}$$

Applying inverse kinematics, and comparing 1 and 2 equations, arbitrary angles in the workspace could be converted to joint angles. Euler angles were obtained according to equation 3.

$$\beta = A\tan 2(\sqrt{r_{31}^2+r_{32}^2},\, r_{33})$$
$$\alpha = A\tan 2(r_{13}/s\beta,\, -r_{23}/s\beta)$$
$$\gamma = A\tan 2(r_{31}/s\beta,\, r_{32}/s\beta)$$

Found Euler angles suitable for different orientations as follows:

State 1: Bending the head to the sides or rotating around the X-axis by the angle θ (positive angle for right and negative for left):

$$R_X(\theta)=\begin{bmatrix}1 & 0 & 0\\ 0 & c\theta & -s\theta\\ 0 & s\theta & c\theta\end{bmatrix} \Rightarrow (\alpha,\beta,\gamma)=(0,\theta,0)$$

State 2: Bending the head to the anterior and posterior or rotating around the y-axis by the angle φ (positive angle for anterior and negative for Posterior):

$$R_Y(\varphi)=\begin{bmatrix}c\varphi & 0 & s\varphi\\ 0 & 1 & 0\\ -s\varphi & 0 & c\varphi\end{bmatrix} \Rightarrow (\alpha,\beta,\gamma)=(-\pi/2,\varphi,\pi/2)$$

State 3: rotation around the X-axis by the angle θ and then rotation of around the Y-axis by the φ angle:

$$R=R_X(\theta)R_Y(\varphi)=\begin{bmatrix}1 & 0 & 0\\ 0 & c\theta & -s\theta\\ 0 & s\theta & c\theta\end{bmatrix}\begin{bmatrix}c\varphi & 0 & s\varphi\\ 0 & 1 & 0\\ -s\varphi & 0 & c\varphi\end{bmatrix}=\begin{bmatrix}c\varphi & 0 & s\varphi\\ s\theta s\varphi & c\theta & -s\theta c\varphi\\ -c\theta s\varphi & s\theta & c\theta c\varphi\end{bmatrix}$$

Then, the inverse kinematics in the built mechanism was calculated (table 4). Finally, using the established model, the roundhouse kick impact was applied on the head at 0°, 5°, 10° and 15° degrees of rotation towards left and right, anterior and posterior at 13 m/s velocity, and then translational and rotational accelerations were obtained. Outcomes were compared with the threshold tolerances of head injury and then analyzed.

Table 4. Inverse kinematic Angles for different orientations

		θ (degree)			
		0	5	10	15
φ (degree)	0	(0,0,0)	(0,5,0)	(0,10,0)	(0,15,0)
	5	(-90,5,90)	(45,7,-45)	(-153,11/2,154)	(-161,16,162)
	10	(-90,10,90)	(-116, 11, 117)	(45,14, -45)	(-146,18,147)
	15	(-90,15,90)	(-108,16,109)	(-123,18,124)	(46,21, -44)
	20	(-90,20,90)	(77,21, -76)	(-116,22,117)	(-125,25,128)
	25	(-90,25,90)	(79,26, -78)	(70,27, -67)	(-120,29,122)

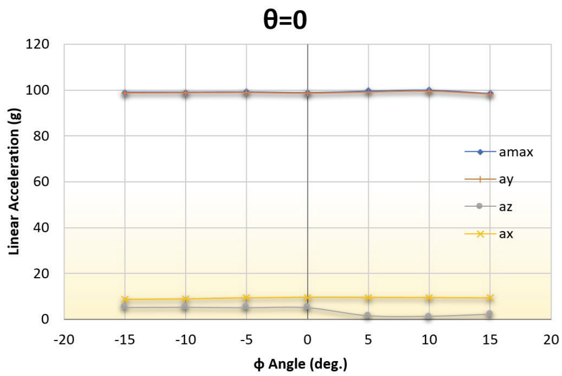

Figure 2. Linear acceleration of the head vs. φ angle

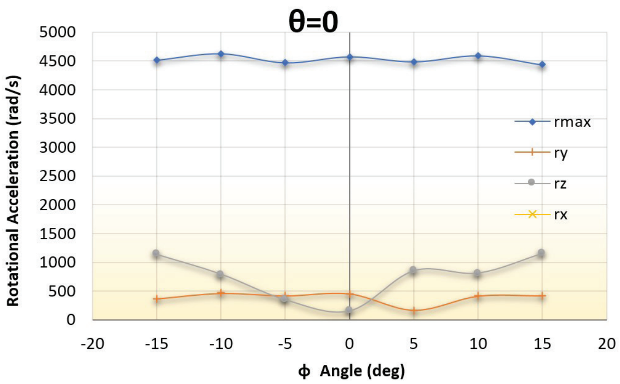

Figure 3. Rotational acceleration of the head vs. φ angle

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Results

Table 3 indicates Euler angles for different orientations of head and neck. Fig.s 2 and 3 illustrate the orientation of the head and neck in the sagittal plane. Moreover, Fig.s 4 and 5 depict the orientation of the head and neck in the frontal plane.

a_{max}, and r_{max} display linear and angular acceleration measures respectively. furthermore, a_x, r_x, a_y, r_y, a_z and r_z indicate a linear acceleration component along the x- axis, the rotational acceleration component around the anterior-posterior axis, a linear acceleration component along the y- axis, the rotational acceleration component around the lateral axis, a linear acceleration component along the z-axis, and the rotational acceleration component around the neck axis respectively.

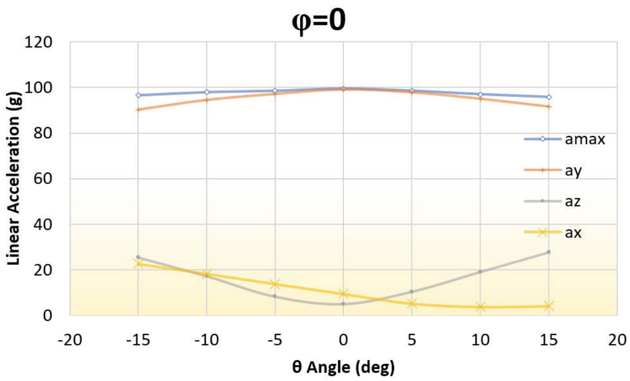

Figure 4. Linear acceleration of the head vs. θ angle

the present study has captured the peak of the linear acceleration of 99 g and a peak of rotational accelerations of 4576$\frac{rad}{s^2}$, in angle 0° of head and neck in reference condition. By comparing the linear acceleration with the threshold tolerance of the head in the Wayne State Tolerance Curve (Gurdjian, Roberts, & Thomas, 1966), it can be stated that the linear acceleration at 99 g is below the threshold of head injury. However the comparison of the rotational acceleration wi$\frac{rad}{s^2}$ the rotational acceleration threshold values of the head (1800 , concussion) expresses that the obtained values were within the head injury threshold (Ommaya, Goldsmith, & Thibault, 2002).

Fig. 2 presents that linear acceleration measured alteration and

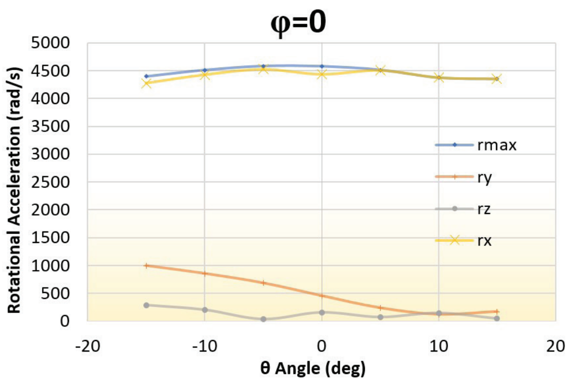

Figure 5. Rotational acceleration of the head vs. θ angle

its components, which are similar for diverse orientations of the head and neck on the sagittal plane. Fig. 3 indicates the same rotational acceleration measured alteration in all orientations. It is clear that the rotational acceleration component reduced with increasing of φ angle slightly, while the rotational acceleration component went up with increasing φ angle at the angle of 15°, 628.85% (Table 5). However, the rotational acceleration component remained almost constant in the head and neck orientation shift.

Table 5. Percentage of rotational acceleration changes relative to the reference state with orientation changes in the sagittal and coronal plane.

Degree of rotation		5	10	15	-5	-10	-15
φ=0	r_{max}	-1.39	-4.40	-4.88	0.062	-1.47	-3.94
	r_x	1.62	-1.37	-1.94	2.075	-0.16	-3.68
	r_y	-47.41	-72.95	-61.71	50.28	87.55	118.34
	r_z	-52.74	-5.96	-69.65	-75.55	30.05	83.23
θ=0	r_{max}	-1.44	-1.66	-3.16	-0.56	-1.00	-1.32
	r_x	-1.76	-2.64	-6.04	-1.54	-2.87	-4.18
	r_y	-10.77	-8.56	-7.61	-7.54	1.77	-19.22
	r_z	413.69	413.69	628.85	121.02	-19.22	617.31

Fig. 4 illustrates a_{max}, and major acceleration component (a_y) which decrease with increasing θ angle in the frontal plane. The linear acceleration component has shown an increase in the trend at an angle of 15°, 441.84% (Table 6). Furthermore, there is an asymmetry of the component in that the left and right sides of diagrams have an increasing and decreasing trend respectively.

Fig.5 demonstrates a decreasing trend for r_{max} and r_x. Besides, it has shown a slight increasing trend on the right side of the diagram, and slightly decreasing trend on the left side of the diagram, whereas, the opposite is true for the component.

Table 6. Percentage of linear acceleration changes relative to the reference state with orientation changes in sagittal and coronal plane

Degree of rotation		5	10	15	-5	-10	-15
φ=0	a_{max}	-0.91	-2.45	-3.64	-0.98	-1.58	-2.97
	a_x	-44.32	-59.39	-55.81	46.42	93.48	139.41
	a_y	-1.22	-4.06	-7.48	-1.97	-4.60	-8.85
	a_z	105.39	274.68	441.84	63.80	63.80	398.00
θ=0	a_{max}	0.18	-0.11	-0.51	0.27	-0.13	0.02
	a_x	-0.81	-1.52	-2.73	-2.56	-7.13	-9.12
	a_y	0.51	0.931	-0.41	0.31	0.20	0.10
	a_z	-2.34	1.562	-0.39	0.07	3.76	1.93

Discussion and Conclusions

The present investigation simulated the taekwondo roundhouse kick using MSC ADAMS software and assessing the linear and rotational acceleration responses of the head in the various orientations of the head and neck.

The results demonstrated that the peak of linear and rotational accelerations occurred at 99g and 4576$\frac{rad}{s^2}$, on the reference condition respectively. The research outcome exhibits φ angle variations do not affect the magnitude of linear and rotational accelerations on the sagittal plane. While the magnitude of linear and rotational accelerations decreased with increases of θ angle on the frontal plane. In other words, the magnitudes of accelerations remain constant when the roundhouse kick is delivered to head at different angles of neck flexion-extension. However, linear acceleration reduced by 3.64% (Table 5) and rotational acceleration decreased by 4.88% (Table 6). With increasing the angle in lateral bending, although these values are insignificant, or fairly low, they might decrease rotational acceleration under the injury threshold of the bridging veins in the brain (4500$\frac{rad}{s^2}$) (Löwenhielm, 1975).Therefore, it may be concluded that neck angle variation on the frontal plane of taekwondo fighters when an impact is delivered to the head may affect the type and severity of brain injury. Likewise, related studies suggest that there is a relationship between frontal plane movements and the severity of damage.

When an impact is delivered to the head in bending of the lateral neck, the angle of the F vector varies along the y-axis parse force into two vertical (f_n) and tangent (f_t) components with θ angle. f_n Creates acceleration, however, f_t is compensated for by the neck muscles (fig. 6). Therefore, the vertical component of the force is reduced and as a result, the linear acceleration decreases on the frontal plane. Such torque, which is a function of the force components, is reduced by the same proportion; consequently, it seems that torque component variations with θ angle change are the main reason for reducing rotational acceleration on the frontal plane. The Asymmetry of Inertial Moment Matrix is another reason.

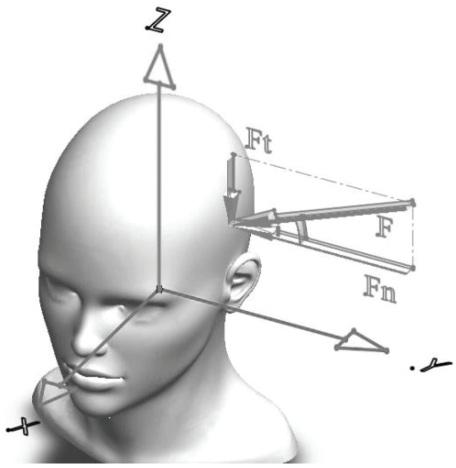

Figure 6. Impact force and its components

Among the acceleration components, the rz component had the most increase on the sagittal plane from 155$\frac{rad}{s^2}$ to 1155 $\frac{rad}{s^2}$. However, this is below the threshold for a head injury except that the rate of increase of this component could occur above the threshold of damage with a slight increase in φ angle, more than 15 degrees. Walsh et al have stated that changes in vector angles that are applied to head, alternates with acceleration component. They also found that acceleration magni-

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tudes alone have not been sufficient for rigorous investigation of the dynamic response of head (Walsh et al., 2011). Therefore, in addition to the magnitude of acceleration, its components are likely to influence the severity of the head injury too. Further research is necessary to obtain more precise results.

Due to the obtained results in the present and comparing it with a threshold of head injury tolerance, rotational acceleration is risk factor for head injury in taekwondo athletes, while linear acceleration does not play a significant role. Because linear acceleration can be countered by neck muscles, greater muscle strength may increase its resistance against impact force and linear acceleration. Linear acceleration is produced when resistance force or the neck force is lower than impact force. Although, the reaction that the neck has against the impact force would cause the impulse transmission through the neck to the brain. Translational acceleration commonly results in focal brain injury, while rotational acceleration also causes diffuse brain injury (Schmitt et al., 2019). Although neck resistance can protect the head against focal injury, it can, through rotating the head, can transmit the momentum to the brain. The structure and physical features of brain tissue are such, that demonstrate great resistance through tensile and pressure forces are applied to head Hence, the threshold of head injury tolerance for linear acceleration is more; however, the threshold of head injury tolerance for rotational acceleration is much lower due to the resistance of brain tissue layers against the shearing force. This leads to rotation and the creation of shearing in brain tissue.

Techniques to prevent and diminish the risk of head injury have been described in Rousseau's researches(Rousseau, 2008). Athletes familiar with an impending collision are able to protect themselves through a compound of the muscle tensioning and impact deflection techniques. Increasing neck compliance decreases stiffness, lessens linear acceleration and raises rotational acceleration; whereas a decrease in neck compliance (increased stiffness) increases linear acceleration and decreases rotational acceleration (Rousseau, 2008). The mechanical features of compliance provided by neck muscles in six degrees of freedom through location-specific impacts affects the dynamic response across all anatomical planes (Zhang, Yang, & King, 2004). The neck remains an ambiguous variable with regards to its contribution towards the dynamic impact response at various locations and orientations. Hence, to clarify, in addition to the head and neck model, we need to use a convenient neck muscle model. In addition to the orientation variable, a three-dimensional protocol for head injury and the threshold is required to determine more factors affecting the dynamic parameters associated with head injury and the development in helmet technology to reduce the risk of injuries as well. Therefore, this suggestion should be considered in future researches.

The results of this investigation indicate that the head and neck orientation during an impact influences its dynamic response. Generally, increasing the head and neck orientation angle is associated with a decrease in the magnitude of acceleration on the frontal plane. However, the head and neck orientation angle do not appear to have a visible effect in the magnitude of acceleration on the sagittal plane. The results reveal that only rotational acceleration causes brain injury in taekwondo, the severity of which is decreased with increasing the head and neck orientation in taekwondo fighters.

In order to assess helmet performance in this sport properly, it will be necessary to identify the most dangerous parameters of head injury, as well as the factors affecting them. These will need to be considered in helmet manufacturing industry.

At this moment, it is impossible to determine whether the additional knowledge of head and neck orientation during impact could ameliorate the assessment of helmet performance; however, according to the results of this study, it seems that such a protocol would require a more thorough helmet evaluation.

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References

Boroushak, N., Eslami, M., Kazemi, M., Daneshmandy, H., & Johnson, J. A. (2018). The dynamic response of the taekwondo roundhouse kick to head using computer simulation. Ido Movement for Culture. Journal of Martial Arts Anthropology, 18(2), 54-60. https://doi.org/10.14589/ido.18.2.8

Fife, G. (2010). An analysis of forces acting on the head from the taekwondo turning kick. University of Delaware.

Green, A. M., & Angelaki, D. E. (2004). An integrative neural network for detecting inertial motion and head orientation. Journal of neurophysiology, 92(2), 905-925. https://doi.org/10.1152/jn.01234.2003.

Gurdjian, E. S., Roberts, V., & Thomas, L. M. (1966). Tolerance curves of acceleration and intracranial pressure and protective index in experimental head injury. Journal of Trauma and Acute Care Surgery, 6(5), 600-604. https://doi.org/10.1097/00005373-196609000-00005

Koh, J. O., & Cassidy, J. D. (2004). Incidence study of head blows and concussions in competition taekwondo. Clinical Journal of Sport Medicine, 14(2), 72-79. https://doi.org/10.1097/00042752-200403000-00004

Leonardi, A. D. C., Keane, N. J., Bir, C. A., Ryan, A. G., Xu, L., & VandeVord, P. J. (2012). Head orientation affects the intracranial pressure response resulting from shock wave loading in the rat. Journal of Biomechanics, 45(15), 2595-2602. https://doi.org/10.1016/j.jbiomech.2012.08.024

Löwenhielm, P. (1975). Mathematical simulation of gliding contusions. Journal of Biomechanics, 8(6), 351-356. https://doi.org/10.1016/0021-9290(75)90069-X

O'Sullivan, D. M., & Fife, G. P. (2016). Impact attenuation of protective boxing and taekwondo headgear. European journal of sport science, 16(8), 1219-1225. https://doi.org/10.1080/17461391.2016.1161073

Ommaya, A., Goldsmith, W., & Thibault, L. (2002). Biomechanics and neuropathology of adult and paediatric head injury. British journal of neurosurgery, 16(3), 220-242. https://doi.org/10.1080/02688690220148824

Ono, K., & Kaneoka, K. (1999). Motion analysis of human cervical vertebrae during low-speed rear impacts by the simulated sled. Traffic Injury Prevention, 1(2), 87-99. https://doi.org/10.1097/00007632-199904150-00006

Pieter, W., Fife, G. P., & O'Sullivan, D. M. (2012). Competition injuries in taekwondo: a literature review and suggestions for prevention and surveillance. Br J Sports Med, 46(7), 485-491. https://doi.org/10.1136/bjsports-2012-091011

Rousseau, P. (2008). The influence of neck compliance and head displacement on impact dynamics of a Hybrid III head. University of Ottawa (Canada).

Sato, F., Nakajima, T., Ono, K., Svensson, M., Brolin, K., & Kaneoka, K. (2014a). Dynamic cervical vertebral motion of female and male volunteers and analysis of its interaction with head/neck/torso behavior during low-speed rear impact. Paper presented at the International Research Council on the Biomechanics of Impact (IRCOBI) Conference.

Sato, F., Nakajima, T., Ono, K., Svensson, M., Brolin, K., & Kaneoka, K. (2014b). Dynamic cervical vertebral motion of female and male volunteers and analysis of its interaction with head/neck/torso behavior during low-speed rear impact. Paper presented at the IRCOBI Conference.

Schmitt, K.-U., Niederer, P., Muser, M., & Walz, F. (2019). Trauma biomechanics (Fifth Edition ed.): Springer.

Schmitt, K.-U., Niederer, P. F., Cronin, D. S., Muser, M. H., & Walz, F. (2014). Verletzungen der Wirbelsäule Trauma-Biomechanik (pp. 91-131): Springer.

Tsui, F., & Pain, M. T. (2012). Utilising human performance criteria and computer simulation to design a martial arts kicking robot with increased biofidelity. Proceedings of the Institution of Mechanical Engineers, Part P: Journal of Sports Engineering and Technology, 226(3-4), 244-252. https://doi.org/10.1177/1754337112439275

Walilko, T., Viano, D. C., & Bir, C. A. (2005). Biomechanics of the head for Olympic boxer punches to the face. British journal of sports medicine, 39(10), 710-719. https://doi.org/10.1136/bjsm.2004.014126

Walsh, E. S., Rousseau, P., & Hoshizaki, T. B. (2011). The influence of impact location and angle on the dynamic impact response of a hybrid III headform. Sports Engineering, 13(3), 135-143. https://doi.org/10.1007/s12283-011-0060-9

Williams, M. R., & Kirsch, R. F. (2008). Evaluation of head orientation and neck muscle EMG signals as command inputs to a human–computer interface for individuals with high tetraplegia. IEEE Transactions on Neural Systems and Rehabilitation Engineering, 16(5), 485-496. https://doi.org/10.1109/TNSRE.2008.2006216

Wright, A. D., & Laing, A. C. (2012). The influence of headform orientation and flooring systems on impact dynamics during simulated fall-related head impacts. Medical engineering & physics, 34(8), 1071-1078. https://doi.org/10.1016/j.medengphy.2011.11.012

Zhang, L., Yang, K. H., & King, A. I. (2004). A proposed injury threshold for mild traumatic brain injury. J. Biomech. Eng., 126(2), 226-236. https://doi.org/10.1115/1.1691446

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ORIGINAL SCIENTIFIC PAPER

The use of Loss Velocity and the Rate of Perceived Exertion to Assess Effort Intensity During Sets of Bench Press Exercise Performed until Exhaustion

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Abstract

The objective of the present study was to verify the agreement and correlation between effort intensity determined from the rate of perceived exertion (RPE) and loss velocity in sets performed to exhaustion in the bench press exercise at a self-selected velocity. Thirty-five men and women practitioners of resistance training (33.61±8.16 years; 172.75±11.04 cm of stature; 76.79±15.57 kg of body mass) were evaluated. Participants were familiarized and then performed two sets of bench press performed until exhaustion at a self-selected velocity at 70% and 85% of one-repetition maximum (1RM). Loss velocity was measured by a linear position transducer (Ergonauta® encoder) applied to velocity-based training. A 3-point RPE scale was used to evaluate the perceived exertion of the individuals. The analysis of agreement (Kappa test) and correlation (Spearman test) were applied ($p<0.05$). The results of the study indicated the existence of a moderate degree of agreement ($\kappa = 0.499$; $\kappa = 0.509$ for 70% and 85% of 1RM, respectively), but a strong correlation ($\rho = 0.720$; $\rho = 0.753$ for 70% and 85% of 1RM, respectively) between the effort intensity determined by the Ergonauta and the RPE, at both intensities analyzed (70% and 85% of 1RM). Despite the lack of perfect agreement between methods, loss velocity and RPE seem to demonstrate strong consistency, allowing both to be used for controlling intensity in resistance training. The results of this study should be interpreted in light of individual characteristics, type of exercise, and training objectives.

Keywords: *resistance training, velocity-based training, rate of perceived exertion, movement velocity, bench press, biomechanics*

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Introduction

Movement velocity has been utilized in recent years as a reliable and objective variable for monitoring resistance training (RT) intensity (González-Badillo; Sánchez-Medina, 2010; González-Badillo et al., 2011). The concept of velocity-based training (VBT) in RT is a method in which prescription may be based on two perspectives: intensity control (i.e., lifted weight) through the load-velocity relationship and training volume control through the percentage drop in velocity over a set (González-Badillo et al., 2011). Several studies have demonstrated an inverse and linear relationship between relative loads (% of one maximum repetition - 1RM) and movement velocity, a relationship that remains stable regardless of the improvement or worsening of the assessed individual's physical condition (González-Badillo and Sánchez-Medina, 2010; Conceição et al., 2016; Sánchez-Medina et al., 2017). According to this relationship, it is possible to estimate the expected execution velocity for any relative load, allowing for load control based on a single repetition, eliminating the need for maximum tests (Galiano, 2020; Külkamp, 2021b).

Important to mention that these applications of VBT are conditioned on the exercise being performed at the maximum intended velocity, defined as the intention to move the external resistance (bar, equipment) at the highest possible velocity (Badillo; Medina, 2010; Medina et al., 2014; Conceicao et al., 2016; Loturco et al., 2016; 2017; Moreno et al., 2017). However, the use of ballistic/explosive resistance exercises may not be as suitable for certain populations in RT programs, such as beginners or individuals with some type of musculoskeletal compromise (Lachance; Hortobagyi, 1994), or even for practitioners with specific goals, such as hypertrophy (Scott et al., 2016).

In practice, the majority of RT practitioners often perform repetitions at self-selected velocity (SSV), which refers to voluntarily executed repetitions without external control (Nóbrega et al., 2018; Külkamp et al., 2021a). In Nóbrega et al. (2018) study, the effects of repetition duration with self-selected and fixed velocity (cadence 2:2) were compared in a resistance exercise regarding volume, muscle activation, and time under tension per repetition and session. The authors concluded that the duration of repetition at self-selected velocity resulted in greater volume and muscle activation compared to fixed duration in an RT session. Thus, SSV may be considered as a potential alternative to maximum intended velocity for real-time monitoring of resistance exercises, but still needs more investigation, especially in the context of VBT.

A linear position transducer recently introduced to the market (Ergonauta®) allows the determination of three distinct effort zones controlled by the loss of SSV (zone 1 - light or comfortable effort; zone 2 - moderate effort; and zone 3 - heavy effort, where concentric or voluntary failure is imminent) representing the effort throughout a set (Külkamp et al., 2021a, 2021b). This progressive loss of velocity during a set can be interpreted as a sign that neuromuscular function has been impaired; thus, its evaluation can also provide a simple and objective means of quantifying fatigue levels (Izquierdo et al., 2006; Sánchez-Medina; González-Badillo, 2011). Therefore, the use of these effort zones in a set of exercise may limit the amount of induced fatigue and provide better overall control of training volume, according to desired objectives (Külkamp, 2021b; Jovanovic; Flanagan, 2014).

Among the tools for controlling training intensity, the rate of perceived exertion (RPE) has also been widely used in different contexts of physical training (Bjarnason-Wehrens et al., 2004; Williams et al., 2007). As described by Tiggemann et al. (2010), some studies have sought to find relationships between RPE and different RT variables, such as relative intensity (% of 1RM), volume, and movement velocity. According to the authors, RPE seems to be a method related to different RT variables, especially the load. However, more investigations on the relationship between RPE and movement velocity are still necessary. In recent studies (Külkamp, 2017, 2021a), it has been suggested that progressive loss of SSV seems to correspond to changes in RPE, suggesting that SSV loss may be indicative of progressive neuromuscular fatigue.

Considering the growing interest and feasibility of using movement velocity for monitoring RT intensity and the scarcity of studies using SSV as a control variable in VBT, the objective of the present study is to verify the agreement and correlation between effort intensity determined by RPE and loss of SSV, measured by a device in sets performed to exhaustion in the bench press exercise. The main hypothesis of the study is that effort intensity assessed from both methods would show moderate agreement and correlation, given the distinction between the psychometric (RPE) and mathematical (encoder) evaluation methods.

Methods

Participants

Eighteen men and seventeen women practitioners of RT participated in this study (age 33.61±8.16 years, height 172.75±11.04 cm, body mass 76.79±15.57 kg). The selection of participants was non-probabilistic (non-random) and intentional (specific group focus). The inclusion criteria were: experience in RT for at least 6 months; to be familiarized with the bench press exercise; no history of musculoskeletal injuries in the upper limbs. Exclusion criteria were: failure to complete the experimental protocols and engaging in upper limb training sessions (chest, deltoid, and triceps) 48 hours before the tests.

All participants signed the Informed Consent Form before data collection, where they were informed about all procedures used during the research, potential benefits and risks associated with the study, assurance of anonymity, as well as the use of their data in the research and for scientific purposes. The project approved by the Ethics Committee on research involving human subjects at the Federal University of Santa Catarina - Brazil.

Design and procedures

This is an analytical descriptive study with a cross-sectional design. The study was conducted on two non-consecutive days. On the 1st day was performed the anthropometric measurements (height and body mass), estimation of 1RM load based on the velocity of a single repetition (using predictive equations), and the familiarization with movement and the 3-point RPE scale. Subsequently, two sets of bench press exercise to concentric failure were conducted at 70% or 85% of 1RM (randomly determined). On the 2nd day two sets of bench press exercise were performed at one of the intensities (70% or 85% of 1RM). A 10-minute interval was given between sets, and there was a minimum of 48 hours between assessment sessions.

All tests were preceded by a warm-up protocol, consist-

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ing of 5 minutes of vertical ergometer cycling (elevation series lifecycle®) at a light intensity and self-selected cadence, along with a set of 15 repetitions of the bench press exercise (40% of 1RM). The sets performed at 70% and 85% of 1RM were performed out to exhaustion, considering concentric failure. During the sets, individuals were instructed to perform the concentric and eccentric phases of the exercise at a self-selected velocity (freely, but not the slowest or fastest possible). The concentric phase was considered when the subject completed full elbow extension and the eccentric phase was when the bar touched the chest or reached at least a 90º angle at the elbow. The positioning of individuals was standardized as follows: a flat bench positioned so that the bar's trajectory coincided with the subject's chest line, both feet on the ground, and grip width adjusted so that the wrist was aligned with the elbow (90º angle).

Estimation of 1RM based on predictive equations

Two equations based on movement velocity were used to estimate 1RM for for males (1) and females (2) (Torrejón, 2019). These equations were selected based on the results of a pilot study, which revealed lower estimation errors compared to other equations available in the literature. A test consisting of two repetitions at the maximum intended velocity of the bench press exercise in the Smith machine was performed to determine movement velocity. A third attempt was made if there was a difference greater than 10% between the previous repetitions, ensuring greater reliability for the measure. A 15-second interval was given between repetitions. It was used a load typically used for warm-up in the participant's training routine, allowing velocity values between 0.6 m/s and 1.0 m/s, measured by using a linear encoder (Ergonauta®). The repetition with the highest velocity was used for analysis. Ultimately, the acquired values were used to estimate individuals' maximum dynamic load (1RM) and subsequently for calculating loads corresponding to 70% and 85% of 1RM.

Movement Velocity= -0,0165*%1RM+1,81 (Equation 1)

Movement Velocity= -0,0148*%1RM+1,72 (Equation 2)

Movement velocity acquisition and determination of intensity zones

Linear velocity during the bench press exercise was assessed using a position transducer (Ergonauta®, Florianópolis, Brazil), consisting of an incremental encoder (400 pulses per revolution), retractable cable, and an acquisition system. The Ergonauta has a resolution of 1mm/pulse and variable sampling frequency, where pulses are marked at high resolution (approximately every 10μs) (Külkamp, 2021b). Real-time data obtained by the Ergonauta were transmitted via Bluetooth to the Samsung Galaxy S6 Lite Android® 10 Tablet (Samsung®, Suwon, South Korea). The validity, reliability, and sensitivity of the Ergonauta encoder were recently confirmed (Külkamp et al., 2023).

The device determines three distinct effort zones (Figure 1), based on the identification of two transition thresholds. The first threshold marks the end of the zone considered light or comfortable effort (green color) and the beginning of the second zone, considered moderate effort (yellow color). According to the manufacturer, the first threshold occurs when there is a significant drop in SSV in the repetition corresponding to approximately 65% of the total possible repetitions. Finally, the device allows the identification of a third zone (failure zone - red color), considered heavy effort, where concentric or voluntary failure is imminent (Külkamp et al., 2021a).

In a recent study, Külkamp (2021a) concluded that, regardless of the type of resistance exercise and the number of repetitions performed, these thresholds behave very similarly, reaching approximately the same point within the sets. The study also concluded that these effort zones appear to correspond to changes in the intensity of perceived effort.

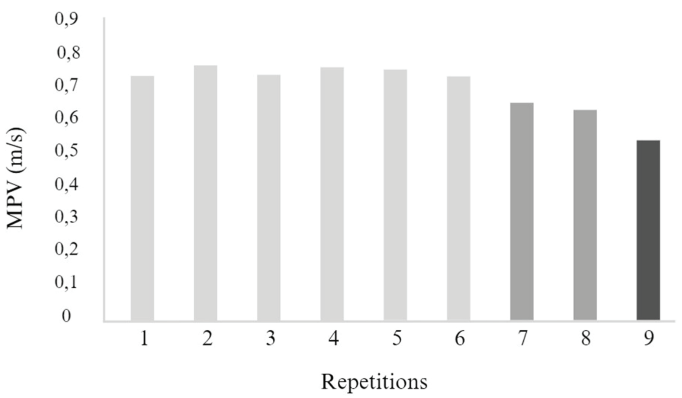

Figure 1. Illustration of a representative set showing the three effort zones determined by the Ergonauta (the colors used in the figure are in gray scale and are representative, with light gray representing the color green, medium gray representing yellow and dark gray representing red.)

RPE scale

A 3-point RPE scale (Figure 2) was used during the tests to assess the effort perceived by individuals. Visual descriptors of the scale were displayed and explained to the participants: Zone 1 (green), was associated with a sensation of "light/comfortable" effort; Zone 2 (yellow) was associated with a sensation of "moderate" effort; and Zone 3 (red) was associated with a sensation of "heavy/intense" effort. Then, the participants were instructed to report, repetition by repetition, one of the colors of the scale (green, yellow or red) at the end of the concentric phase of the movement, based on their perceived of effort, until concentric failure was reached.

The scores on the 3-point RPE scale are interval in nature and were developed based on scores from zero to 10 of the OMNI-Resistance Exercise scale (OMNI-RES) (Robertson et al., 2003). According to the study of Külkamp (2021a), which compared the three effort zones of the Ergonauta with the

OMNI-RES scale (Robertson et al., 2003), Zone 1 was associated with RPE values ≤6, Zone 2 with RPE values of 7 and 8, and Zone 3 with RPE values ≥9. Thus, three scores were determined on the scale to be used in the present study (3-point RPE scale), aiming to resemble the three effort zones present in the Ergonauta device.

Figure 2. 3-point adapted Rating of Perceived Exertion (RPE) scale. Scale adapted from the OMNI-RES scale by Robertson et al. (2003) (the colors used in the figure are in gray scale and are representative, with light gray representing the color green, medium gray representing yellow and dark gray representing red.)

Statistical analysis

The data were presented using descriptive statistics (mean and standard deviation). The Kappa concordance coefficient and Spearman correlation were employed to assess the agreement and correlation of effort zones determined by the Ergonauta and based on RPE. The Landis and Koch's classification (1977) was considered for Kappa test: κ <0: no concordance, κ = 0-0.2: minimal concordance, κ = 0.21-0.4: reasonable concordance, κ = 0.41-0.6: moderate concordance, κ = 0.61-0.8: substantial concordance, κ = 0.81-1: perfect concordance. For Spearman correlation test it was used the Mukaka's classification (2012): ρ = ±0 to ±0.19: very weak correlation, ρ = ±0.2 to ±0.39: weak correlation, ρ = ±0.4 to ±0.69: moderate correlation, ρ = ±0.7 to ±0.89: strong correlation, ρ = ±0.9 to ±1: very strong correlation. Only the sets that met all the previously established criteria in the study, particularly regarding exercise execution, were included in the analysis. A significance level of $p \leq 0.05$ was adopted for all inferential analyses. The SPSS software was used for statistical analyses.

Results

Table 1 presents the mean and standard deviation of age, height, body mass, and the load used during the tests (70%1RM and 85%1RM) for all subjects, separated by gender.

Table 1. Age, Height, Body Mass, and Load of the Subjects

	n	Age (years)	Height (m)	Body Mass (kg)	Load (kg) 70%1RM	Load (kg) 85%1RM
Male	18	33.11±7.53	1.80±6.93	86.89±12.44	66±19.16	73.7±19.13
Female	17	34.18±9.02	1.64±8.17	65.5±9.97	22.97±8.20	26.21±9.55
Total	35	33.61±8.16	1.73±11.04	76.79±15.57	44.47±26.14	50.64±28.30

In Tables 2 and 3 are presented the level of agreement between the effort intensity zones determined by the Ergonauta (Zone 1 = light; Zone 2 = moderate; Zone 3 = heavy) and the effort zones based on RPE (green = light/comfortable; yellow = moderate; red = heavy/intense) for relative loads of 70% and 85% of 1RM, respectively. The Kappa test indicated a moderate agreement between the intensity zones determined by the Ergonauta and the effort zones based on RPE at both intensities (κ = 0.499; κ = 0.509 for 70% and 85% of 1RM, respectively).

Table 2. Level of Agreement Between the Intensity Zones Determined by Ergonauta and the Effort Zones Based on RPE at 70% of 1RM

		Ergonauta		
		Zone 1	Zone 2	Zone 3
RPE	Zone 1	68.59%	6.91%	0.72%
	Zone 2	21.65%	34.39%	16.57%
	Zone 3	2.03%	17.54%	58.38%

Table 3. Level of Agreement Between the Intensity Zones Determined by Ergonauta and the Effort Zones Based on RPE at 85% of 1RM

		Ergonauta		
		Zone 1	Zone 2	Zone 3
RPE	Zone 1	69.25%	2.10%	0.00%
	Zone 2	24.05%	36.08%	7.33%
	Zone 3	4.06%	25.18%	59.23%

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The correlation analysis (Spearman test) indicated that at both intensities (70%1RM and 85%1RM), there was a strong correlation between the intensity zones determined by the Ergonauta and the effort zones based on RPE (ρ = 0.720; ρ = 0.753 for 70% and 85% of 1RM, respectively; p<0.0001).

Lastly, in Table 4 is presented the frequency (absolute and relative) of the agreement between the effort zones of RPE and determined by the Ergonauta for each repetition over the sets.

Table 4. Magnitude and Relative Frequency of the Agreement Differences Between the Zones Reported by the Subjects and Those Determined by Ergonauta in the Total Number of Repetitions Analyzed in the Study

70%1RM (n= 669 reps)				85%1RM (n= 739 reps)			
Difference	F	F (%)	∑%	Difference	F	F (%)	∑%
0	459	68.60		0	508	68.74	
1	196	29.30	97.9	1	210	28.42	97.16
2	14	2.1	100	2	21	2.84	100

Note. f: frequency; f(%): relative frequency; ∑%: sum of relative frequencies

Discussion

There has been a growing interest in the use of the movement velocity for monitoring RT intensity. However, there is still a lack of studies showing the possibilities of application and the relationship with the variables of RT. In this context, in the present study we aimed to verify if the loss velocity and the rate of perceived exertion show the same effort intensity during sets of bench press exercise performed until exhaustion.

The main results showed a moderate degree of agreement, but a strong correlation between the intensity of effort determined by the Ergonauta and the RPE at both analyzed intensities (70%1RM and 85%1RM). Despite not being broadly concordant, the strong relationship between the methods allows us to say that both can discriminate the intensity of individuals in a similar way during bench press sets. Notwithstanding both parameters may reflect the intensity training, it is important to highlight that RPE is a psychometric and subjective measure (Hackett et al., 2018) while the Ergonauta device provides a mathematical determination of effort intensity based on the progressive loss of self-selected movement velocity. Thus, a non-perfect agreement between them could be expected.

Some studies have suggested that monitoring movement velocity during RT allows for a precise estimation of how many repetitions are left in reserve in a given exercise set, corresponding to the concept of 'effort level' (González-Badillo; Marques, and Sánchez-Medina, 2011; González-Badillo et al., 2016; Pareja-Blanco et al., 2017; González-Badillo; Sánchez-Medina, 2011). Halperin et al. (2022) and Hackett et al. (2018) investigated the accuracy in predicting/estimating repetitions to failure in RT. The authors concluded that prediction accuracy might be better if predictions are made closer to failure, in sets with lower repetition volume, and when using heavier loads. Some of these results coincide with those found in the present study, where better agreement values were found in Zone 3 (failure zone) compared to Zone 2 (transition zone), as well as slightly higher agreement values at the higher intensity (85%1RM). In Halperin et al.'s (2022) study, the authors suggest that this occurs because performing more repetitions allows a wide range of errors compared to sets with a lower repetition volume.

Due to its feasibility, RPE is certainly one of the most used metrics for controlling the intensity in physical training. However, the method presents some limitations and particularities. According to Hackett et al. (2018), RPE seems unable to discriminate momentary failure and is a subjective measure for which accuracy cannot be quantified. Some researchers reported in their studies lower RPE values than the maximum during sets performed to volitional fatigue, indicating an incompatibility between RPE and maximal effort (Shimano et al., 2006; Pritchett et al., 2009). In addition, according to Borg (2000), regardless of the RPE method used, not all individuals will provide reliable and valid ratings. The author also reported that about 5 to 15% of these individuals may have difficulties understanding instructions and requests, as well as difficulties in verbal and mathematical understanding.

Another point to consider is that the previously mentioned study (Hackett et al., 2018), like the majority of studies related to RPE and RT, uses 10-point scales, such as the OMNI-RES scale (Robertson et al., 2003), and Borg's CR10 (Borg, 1982). In the present study we used of an adapted scale (from the OMNI-RES scale) with only 3 points, which, in addition to resembling the three effort zones present in the Ergonauta device, possibly facilitated subjects' understanding of perceived effort during the bench press. This suggests that the use of scales with fewer levels (points) may facilitate interpretation and classification of the effort by the individuals. Furthermore, Hackett et al. (2018) believe that with repeated applications and user experience with the scales, it is likely that individuals' reliability and accuracy will improve over time. According to Balsalobre-Fernández et al. (2021), subjective scales should be considered together with velocity measurements to obtain a more accurate estimate of relative load (%1RM).

Conclusion

Based on our results, it can be concluded that there is a moderate degree of agreement but a strong correlation between the intensity of effort determined by the Ergonauta and the RPE at both analyzed intensities (70%1RM and 85%1RM). Despite not being broadly concordant, the strong relationship between the methods allows us to say that both can discriminate the intensity of individuals in a similar way during bench press sets. It is important to emphasize that the results of this study should be interpreted according to the individual characteristics, context, exercise, periodization, and objectives at hand. It is recommended to undergo multiple sessions of familiarization with the technique, device operation, and the RPE scale, regardless of the individual's training level.

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Conflict of Interest

The author Wladymir Külkamp declares that he is the manufacturer of the Ergonauta I encoder.

References

Balsalobre-Fernández, C., Muñoz-López, M., Marchante, D., & García-Ramos, A. (2021). Repetitions in Reserve and Rate of Perceived Exertion Increase the Prediction Capabilities of the Load-Velocity Relationship. *Journal of strength and conditioning research*, *35*(3), 724–730. https://doi.org/10.1519/JSC.0000000000002818

Bjarnason-Wehrens, B., Mayer-Berger, W., Meister, E. R., Baum, K., Hambrecht, R., Gielen, S., & German Federation for Cardiovascular Prevention and Rehabilitation (2004). Recommendations for resistance exercise in cardiac rehabilitation. Recommendations of the German Federation for Cardiovascular Prevention and Rehabilitation. *European journal of cardiovascular prevention and rehabilitation: official journal of the European Society of Cardiology, Working Groups on Epidemiology & Prevention and Cardiac Rehabilitation and Exercise Physiology*, *11*(4), 352–361. https://doi.org/10.1097/01.hjr.0000137692.36013.27

Borg, G. (2000). *Borg scales for pain and perceived exertion* [in portuguese]. Manole

Conceição, F., Fernandes, J., Lewis, M., Gonzaléz-Badillo, J. J., & Jimenéz-Reyes, P. (2016). Movement velocity as a measure of exercise intensity in three lower limb exercises. *Journal of sports sciences*, *34*(12), 1099–1106. https://doi.org/10.1080/02640414.2015.1090010

Galiano, C., Pareja-Blanco, F., Hidalgo de Mora, J., & Sáez de Villarreal, E. (2022). Low-Velocity Loss Induces Similar Strength Gains to Moderate-Velocity Loss During Resistance Training. Journal of strength and conditioning research, *36*(2), 340–345.

González-Badillo, J. J., & Sánchez-Medina, L. (2010). Movement velocity as a measure of loading intensity in resistance training. *International journal of sports medicine*, *31*(5), 347–352. https://doi.org/10.1055/s-0030-1248333

González-Badillo, J. J., Marques, M. C., & Sánchez-Medina, L. (2011). The importance of movement velocity as a measure to control resistance training intensity. *Journal of human kinetics*, *29A*, 15–19. https://doi.org/10.2478/v10078-011-0053-6

González-Badillo, J. J., Rodríguez-Rosell, D., Sánchez-Medina, L., Ribas, J., López-López, C., Mora-Custodio, R., Yañez-García, J. M., & Pareja-Blanco, F. (2016). Short-term Recovery Following Resistance Exercise Leading or not to Failure. *International journal of sports medicine*, *37*(4), 295–304. https://doi.org/10.1055/s-0035-1564254

Hackett, D. A., Cobley, S. P., & Halaki, M. (2018). Estimation of Repetitions to Failure for Monitoring Resistance Exercise Intensity: Building a Case for Application. *Journal of strength and conditioning research*, *32*(5), 1352–1359. https://doi.org/10.1519/JSC.0000000000002419

Halperin, I., Malleron, T., Har-Nir, I., Androulakis-Korakakis, P., Wolf, M., Fisher, J., & Steele, J. (2022). Accuracy in Predicting Repetitions to Task Failure in Resistance Exercise: A Scoping Review and Exploratory Meta-analysis. *Sports medicine (Auckland, N.Z.)*, *52*(2), 377–390. https://doi.org/10.1007/s40279-021-01559-x

Izquierdo, M., Ibañez, J., González-Badillo, J. J., Häkkinen, K., Ratamess, N. A., Kraemer, W. J., French, D. N., Eslava, J., Altadill, A., Asiain, X., & Gorostiaga, E. M. (2006). Differential effects of strength training leading to failure versus not to failure on hormonal responses, strength, and muscle power gains. *Journal of applied physiology (Bethesda, Md. : 1985)*, *100*(5), 1647–1656. https://doi.org/10.1152/japplphysiol.01400.2005

Külkamp, W. (2017). *Monitoring resistance exercises at self-selected velocity: proposed method for quantifying training intensity* [Unpublished doctoral thesis] [in portuguese]. Santa Catarina State University

Külkamp, W., Feunteun, Y., & Junior, N. B. (2021a). Concurrent validity and reliability of self-selected movement velocity for resistance training monitoring in close grip pull-down and knee extension. *Science & Sports*, 36(6), 460-469. https://doi.org/10.1016/j.scispo.2020.06.012

Külkamp, W., Rosa-Junior, J. L., Ache-Dias, J., & Carminatti, L. J. (2021b). An effective, low-cost method to improve the movement velocity measurement of a smartphone app during the bench press exercise. *Proceedings of the Institution of Mechanical Engineers, Part P: Journal of Sports Engineering and Technology*. Ahead of print https://doi.org/10.1177/17543371211058089

Külkamp, W., Bishop, C., Kons, R., Antunes, L., Carmo, E. C., Hizume-Kunzler, D., Dal Pupo, J. (2023). Concurrent Validity and Technological Error-Based Reliability of a Novel Device for Velocity-Based Training. *Measurement in Physical Education and Exercise Science.* DOI: 10.1080/1091367X.2023.2207570

Lachance, P.F., & Hortobágyi, T. (1994). Influence of Cadence on Muscular Performance During Push-up and Pull-up Exercise. *Journal of Strength and Conditioning Research, 8*, 76–79.

Landis, J. R., & Koch, G. G. (1977). The measurement of observer agreement for categorical data. *Biometrics*, *33*(1), 159–174.

Mukaka M. M. (2012). Statistics corner: A guide to appropriate use of correlation coefficient in medical research. *Malawi medical journal : the journal of Medical Association of Malawi*, *24*(3), 69–71.

Nóbrega, S. R., Barroso, R., Ugrinowitsch, C., da Costa, J. L. F., Alvarez, I. F., Barcelos, C., & Libardi, C. A. (2018). Self-selected vs. Fixed Repetition Duration: Effects on Number of Repetitions and Muscle Activation in Resistance-Trained Men. *Journal of strength and conditioning research*, *32*(9), 2419–2424. https://doi.org/10.1519/JSC.0000000000002493

Pareja-Blanco, F., Rodríguez-Rosell, D., Sánchez-Medina, L., Ribas-Serna, J., López-López, C., Mora-Custodio, R., Yáñez-García, J. M., & González-Badillo, J. J. (2017a). Acute and delayed response to resistance exercise leading or not leading to muscle failure. *Clinical physiology and functional imaging*, *37*(6), 630–639. https://doi.org/10.1111/cpf.12348

Pritchett, R. C., Green J. M., Wickwire, P. J., Kovacs, M. S. (2009). Acute and session RPE responses during RT: Bouts to failure at 60% and 90% of 1RM. *South African Journal of Sports Medicine*, *21*(1), 232-26.

Robertson, R. J., Goss, F. L., Rutkowski, J., Lenz, B., Dixon, C., Timmer, J., Frazee, K., Dube, J., & Andreacci, J. (2003). Concurrent validation of the OMNI perceived exertion scale for resistance exercise. *Medicine and science in sports* *and exercise*, *35*(2), 333–341. https://doi.org/10.1249/01.MSS.0000048831.15016.2A

Sánchez-Medina, L., & González-Badillo, J. J. (2011). Velocity loss as an indicator of neuromuscular fatigue during resistance training. *Medicine and science in sports and exercise*, *43*(9), 1725–1734. https://doi.org/10.1249/MSS.0b013e318213f880

Sánchez-Medina, L., Pallarés, J. G., Pérez, C. E., Morán-Navarro, R., & González-Badillo, J. J. (2017). Estimation of Relative Load From Bar Velocity in the Full Back Squat Exercise. *Sports medicine international open*, *1*(2), E80–E88. https://doi.org/10.1055/s-0043-102933

Scott, B. R., Duthie, G. M., Thornton, H. R., & Dascombe, B. J. (2016). Training Monitoring for Resistance Exercise: Theory and Applications. *Sports medicine (Auckland, N.Z.)*, *46*(5), 687–698. https://doi.org/10.1007/s40279-015-0454-0

Shimano, T., Kraemer, W. J., Spiering, B. A., Volek, J. S., Hatfield, D. L., Silvestre, R., Vingren, J. L., Fragala, M. S., Maresh, C. M., Fleck, S. J., Newton, R. U., Spreuwenberg, L. P., & Häkkinen, K. (2006). Relationship between the number of repetitions and selected percentages of one repetition maximum in free weight exercises in trained and untrained men. *Journal of strength and conditioning research*, *20*(4), 819–823. https://doi.org/10.1519/R-18195.1

Tiggemann, C. L., Pinto, R. S., Kruel, L. F. M. (2010). A Percepção de Esforço no Treinamento de Força. *Revista Brasileira de Medicina do Esporte*, *16*(4), 301-309. https://doi.org/10.1590/S1517-86922010000400014

Torrejón, A., Balsalobre-Fernández, C., Haff, G. G., & García-Ramos, A. (2019). The load-velocity profile differs more between men and women than between individuals with different strength levels. *Sports biomechanics*, *18*(3), 245–255. https://doi.org/10.1080/14763141.2018.1433872

Weakley, J., Mann, B., Banyard, H., McLaren, S., Scott, T., Garcia-Ramos, A. (2021). Velocity-based training: From theory to application. *Strength and Conditioning Journal*, *43*(2), 31-49. doi: 10.1519/SSC.0000000000000560

Williams, M. A., Haskell, W. L., Ades, P. A., Amsterdam, E. A., Bittner, V., Franklin, B. A., Gulanick, M., Laing, S. T., Stewart, K. J. (2007). Resistance exercise in individuals with and without cardiovascular disease: 2007 update: a scientific statement from the American Heart Association Council on Clinical Cardiology and Council on Nutrition, Physical Activity, and Metabolism. *Circulation*, *116*(5), 572–584. https://doi.org/10.1161/CIRCULATIONAHA.107.185214

ORIGINAL SCIENTIFIC PAPER

Agreement in Knee Flexion and Hip Extension Range of Motion Assessment between Digital Goniometer and Video-based Motion Tracking Technology

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Abstract

Precise range of motion (ROM) measurements are critical for diagnosing musculoskeletal impairments, planning treatment strategies and monitoring rehabilitation progress. This study compares the reliability and accuracy of ROM measurements using the EasyAngle electronic goniometer device and the Kemtai pose estimation video-based motion tracking software. Participants performed hip extension and knee flexion movements, with measurements taken by two examiners using both tools. The results show that both EasyAngle and Kemtai provide high inter-repetition reliability for knee flexion (ICC 0.93 and. 0.91) and hip extension (ICC 0.96 and 0.93). Kemtai generally overestimated ROM compared to EasyAngle, with relative agreement ranging from poor to good (ICC = 0.71 for knee flexion, ICC = 0.66 for hip extension). Future development and research should focus on refining digital tools like Kemtai to enhance their accuracy and reliability. Given its low cost and ease of use, Kemtai could be a useful tool for clinical practice.

Keywords: *pose estimation, flexibility, goniometry, reliability, application*

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Introduction

The assessment of range of motion (ROM) is essential in both clinical and sports settings, as it provides critical insights into joint function, flexibility, and overall musculoskeletal health. Accurate ROM measurements are crucial for diagnosing impairments, planning interventions, and monitoring rehabilitation progress (Akizuki et al., 2016). Various methods have been developed to measure ROM, including traditional goniometry, digital inclinometers and advanced pose estimation software (Al-Amri et al., 2017; Jovanovic et al., 2024; Hancock et al., 2018; Saiki et al., 2023). Traditional goniometry, which uses a goniometer with arms, is one of the most common methods for measuring ROM. Studies have demonstrated that traditional goniometry can be highly reliable when performed by trained practitioners (Watkins et al., 1991; Brosseau et al., 2001). However, that goniometry can be

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time-consuming and susceptible to variability between different evaluators (Nussbaumer et al., 2010).

In recent years, digital devices such as the EasyAngle have been introduced to enhance the accuracy and reliability of ROM measurements. The EasyAngle is an affordable digital goniometer designed to provide quick and precise measurements of joint angles. Previous studies, including Duffy et al. (2024), have confirmed EasyAngle's reliability across different joints, with Svensson et al. (2019) specifically demonstrating its validity and reliability. With advancements in technology, pose estimation software like Kemtai can be used as a novel method for assessing ROM (Jovanovic et al., 2024). This software utilizes computer vision and artificial intelligence to estimate joint angles and track movements, offering a non-invasive and user-friendly alternative to traditional methods.

The aim of this study is to compare the reliability and accuracy of ROM measurements obtained using the EasyAngle device with those obtained through the pose estimation software Kemtai. By evaluating these two methods, we aim to determine the feasibility and practicality of integrating advanced digital tools in routine clinical assessments.

Methods

Participants

The sample included 23 subjects (12 women, 11 men; age = 22.1 ± 2.9 years). The participants, who were physiotherapy students, were recruited through social media, email, and personal networks as a convenience sample. Exclusion criteria included reporting any knee or hip pain, lack of full range of motion, or previous lower limb injury. Informed consent was obtained from all participants prior to the experiment, which was approved by the ethics board of the Academy of Applied Studies Belgrade, College of Health Sciences (approval number 01-264/4).

Study design

In this cross-sectional study predefined measurement protocol required participants to actively perform hip extension and knee flexion movements. Measurements were alternately taken using the EasyAngle goniometer and the Kemtai software installed on an Apple iPhone 12 mini mobile phone (Apple Inc., Cupertino, California, USA). Kemtai is an AI-powered fitness platform that uses computer vision technology to provide real-time feedback and guidance on exercise form. The Kemtai software analyzes movements by tracking changes in the location of anatomical landmarks based on motion pattern data contained within the system. For the purpose of the research, we used an adjusted version of software (version 4) that measures range of motion.

Measurement procedures

Measurements were performed on a therapy table, with participants in prone position. Each participant underwent two sets of measurements, alternating between each device. The Kemtai measurements were captured using the mobile phone camera mounted on a tripod (1.5 m in height) positioned 0.7 m 70 cm from the participant. Each set included measurements taken with the EasyAngle goniometer (Figure 1) and the Kemtai application (Figure 2), performed by two experienced physiotherapists who were blinded to the results during measurement. The participants were in prone position for all measurements and same leg was measured each time during procedure. Participant was instructed to perform movement in slow manner and to hold little bit at the end of motion so physiotherapist could perform measurements. First, active knee joint flexion was measured using the EasyAngle goniometer by one examiner, followed by

Figure 1. Measurements with EasyAngle digital inclinometer

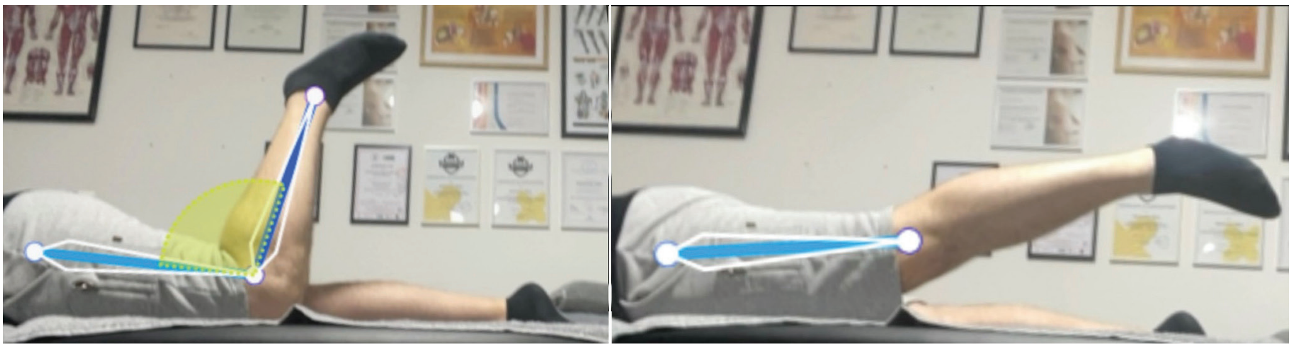

Figure 2. Snapshots of video-based motion tracking analysis done with Kemtai software.

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the same motion being measured using the Kemtai software. This identical procedure was then repeated by a second examiner on the same motion. Then, active hip joint extension was measured in the same manner and order. A third examiner was responsible for recording the values and managing the computer.

Statistical analysis

The data are presented as means ± standard deviations. The reliability between the repetitions for the same device was evaluated with intra-class correlation coefficient (ICC; single measures, absolute agreement). We considered ICC values <0.5 to be indicative of poor reliability, values between 0.5 and 0.75 to indicate moderate reliability, values between 0.75 and 0.9 to indicate good reliability, and values greater than 0.9 to indicate excellent reliability. Additionally, absolute reliability was assessed by calculating the typical error (TE). The agreement between the devices were assessed with ICC, TE and paired-sample t-test with mean difference and 95 % confidence intervals (CI) included. All analyses were carried out using SPSS statistical software (version 25.0, IBM: Armonk, NY, USA).

Results

Reliability

Table 1 contains descriptive statistics and inter-repetition reliability analyses. For knee flexion assessed with EasyAngle, the ICC was 0.93 (95% CI: 0.83–0.97), with a TE of 2.15° (95% CI: 1.66–3.04). For Kemtai, the ICC was 0.91 (95% CI: 0.79–0.96), with a TE of 2.45° (95% CI: 1.89–3.46). Hip extension measured wtih EasyAngle showed and ICC of 0.96 (95% CI: 0.90–0.98), with a TE of 1.83° (95% CI: 1.42–2.60). For Kemtai, the ICC was 0.93 (95% CI: 0.85–0.97), with a TE of 2.41° (95% CI: 1.87–3.42).

Table 1. Descriptive statistics and inter-repetition reliability.

Outcome measure	Repetition 1		Repetition 2		Reliability					
	Mean	SD	Mean	SD	ICC	95% CI		TE	95% CI	
Knee Flexion – EasyAngle (°)	119.74	7.88	119.43	7.10	0.93	0.83	0.97	2.15	1.66	3.04
Knee Flexion – Kemtai (°)	129.83	7.36	130.22	7.98	0.91	0.79	0.96	2.45	1.89	3.46
Hip Extension – EasyAngle (°)	22.57	8.00	23.78	8.98	0.96	0.90	0.98	1.83	1.42	2.60
Hip Extension - Kemtai(°)	31.26	8.44	31.00	9.52	0.93	0.85	0.97	2.41	1.87	3.42

Note. SD: Standard Deviation; ICC: Intraclass Correlation Coefficient; CI: Confidence Interval; TE: Typical Error;

Agreement

The agreement analysis is shown in Table 2. The mean values of knee flexion ROM for EasyAngle and Kemtai were 119.59° (SD = 7.35) and 130.02° (SD = 7.48), respectively. There was a statistically significant difference between the two methods ($p < 0.001$), with mean difference of 10.43° (95% CI: 7.91–12.96; relative difference = 8.6 %). The relative agreement was poor to good, with an ICC of 0.71 (95% CI: 0.42–0.86). For hip extension, the mean values for EasyAngle and Kemtai were 23.17° (SD = 8.41) and 31.13° (SD = 8.83), respectively. There was a statistically significant difference between the two methods ($p < 0.001$) with a mean difference of 7.96° (95% CI: 4.80–11.11; relative difference = 36.6%. The relative agreement was poor to good, with an ICC of 0.66 (95% CI: 0.35–0.84). In summary, both knee flexion and hip extension measurements showed a significant difference between EasyAngle and Kemtai, with the estimation for the relative agreement ranging from poor to good.

Table 2. Agreement between EasyAngle and Kemtai.

Outcome variable	Easy Angle		Kemtai		Difference			Relative agreement		
	Mean	SD	Mean	SD	Mean	95% CI		ICC	95% CI	
Knee flexion (°)	119.59	7.35	130.02	7.48	10.43	7.91	12.96	0.71	0.42	0.86
Hip extension (°)	23.17	8.41	31.13	8.83	7.96	4.80	11.11	0.66	0.35	0.84

Note: SD: Standard Deviation; ICC: Intraclass Correlation Coefficient; CI: Confidence Interval;

Discussion

This study compared ROM measurement reliability between the EasyAngle device and Kemtai software. EasyAngle showed high ICC values (knee flexion: 0.93, hip extension: 0.96) with low typical errors (knee flexion: 2.15°, hip extension: 1.83°), while Kemtai also demonstrated good reliability (knee flexion: ICC 0.91, hip extension: ICC 0.93) with slightly higher typical errors (knee flexion: 2.45°, hip extension: 2.41°), indicating both tools provide consistent and reliable measurements.

These findings are consistent with previous research showing the reliability of digital tools and inertial measurement units for clinical movement analysis (Al-Amri et al., 2017; Keogh et al., 2019). The slightly higher ICC values for EasyAngle suggest it may offer marginally better reliability compared to Kemtai, particularly for hip extension. The typical errors (TE) for both devices are within acceptable ranges, with EasyAngle showing slightly lower TE values than Kemtai, indicating higher precision. These results align with studies by Watkins et al. (2001) and Brosseau et al. (2001), which found high reliability for goniometry assessment and emphasize the importance of precision in ROM measurements. Also, results from some previous studies (Hancock et al., 2018; Kiatkulanusorn et al., 2023; Pantouveris et al., 2024) indicate the effectiveness of digital goniometers in providing reliable data, and to enhance that, it is often advised to use the average of ratings from two or more raters (Perkins, Wyatt, & Bartko, 2000). Overall, the study demonstrates that both EasyAngle and Kemtai are reliable tools for assessing knee flexion and hip extension, however, the agreement between the devices is not sufficient for them to be used interchangeably.

The study also compared knee flexion and hip extension measurements using EasyAngle and Kemtai software. Kemtai consistently measured higher angles than EasyAngle for both knee flexion (mean difference 10.43°) and hip extension (mean difference 7.96°). While there was moderate consistency between the methods (ICC = 0.71 for knee flexion, ICC = 0.66 for hip extension), significant differences were noted, suggesting potential overestimation by Kemtai.

These differences could be attributed to several factors. First, the methodology of Kemtai, which relies on computer vision and pose estimation algorithms, may interpret joint angles differently than the direct measurement approach of EasyAngle, which is a goniometer. The overestimation by Kemtai could be due to the pose estimation software's interpretation of anatomical landmarks and movement patterns like in a similar study (Horsak et al., 2024; Wren et al., 2023), which might not always align perfectly with manual goniometric measurements. The timing and conditions of measurements are crucial in biomechanical studies, as they can significantly impact the accuracy and consistency of the data. Since our goniometric measurements and video analysis are conducted at different times, even slight differences in posture or movement can result in variations in the recorded angles (Nussbaumer et al., 2010). Furthermore, the poor to good relative agreement (ICC values) suggests that while there is some consistency between the two methods, the discrepancies are significant enough to warrant caution. Clinicians and researchers should be aware of these differences and consider them when choosing a measurement tool for specific applications. The significant differences and moderate consistency between the two methods underscore the need for further research to refine and calibrate digital measurement tools like Kemtai. To make the process easier and more accurate during measurements, we could suggest that individuals wear form-fitting clothing like yoga pants or underwear. Such efforts could enhance their accuracy and reliability, making them more comparable to traditional goniometric methods. Additionally, understanding the contexts in which each tool performs best can guide their application in clinical and research settings. It is important to said that both assessors conducted their measurements independently and were kept unaware of each other's results, thereby reducing the potential for bias and ensuring that their assessments did not influence one another.

Some limitations of the study need to be acknowledged. During the measurement of extension ROM, we did not fixate the pelvis because the camera used by the software tends to recognize the person performing the fixation as another object. This can interfere with the accurate identification of joints, leading to measurement errors. As a result, we observed somewhat larger extension ROM values with both devices. This issue highlights a limitation in the accuracy of our measurements due to the lack of pelvic stabilization, which is crucial for obtaining precise and reliable joint angle assessments (Nussbaumer et al., 2010). Also, the lack of simultaneity during measurements may have impacted the reproducibility of the measurements which could also lead to variability in the arithmetic means. Additionally, the study did not extensively address inter-rater variability, focused primarily on static rather than dynamic measurements, and involved a relatively small and homogeneous sample size, limiting generalizability. Further research should address these issues, refine digital tools, and validate their use in diverse clinical settings.

Conclusion

This study demonstrates that both EasyAngle and Kemtai provide high reliability for measuring knee flexion and hip extension. However, significant differences were found between the mean values, with Kemtai generally overestimating compared to EasyAngle. The relative agreement ranged from poor to good, indicating moderate consistency but some discrepancies. Despite these differences, Kemtai could still be used solely for assessment purposes, especially given its non-invasive nature and ease of use. These findings emphasize the importance of selecting the appropriate measurement tool based on specific requirements and suggest the need for further refinement of digital tools like Kemtai to enhance their accuracy and reliability. Future research should focus on standardizing digital measurement methodologies to improve their clinical application.

Author contributions

Nenad Nedović, Stevan Jovanović and Žiga Kozinc conceptualized the idea. All authors worked on obtaining and analyzing the data and worked on finalizing the manuscript.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Ethics approval

The study was approved by the ethics board of the Academy of Applied Studies Belgrade, College of Health Sciences (approval number 01-264/4) and was conducted in accordance with the Declaration of Helsinki.

References

Akizuki, K., Yamaguchi, K., Morita, Y., & Ohashi, Y. (2016). The effect of proficiency level on measurement error of range of motion. Journal of physical therapy science, 28(9), 2644–2651.

Al-Amri, M., Nicholas, K., Button, K., Sparkes, V., Sheeran, L., & Davies, J. L. (2017). Inertial measurement units for clinical movement analysis: Reliability and concurrent validity. Sensors, 17(7), 1412.

Brosseau, L., Balmer, S., Tousignant, M., O'Sullivan, J. P., Goudreault, C., & Goudreault, M. (2001). Intra- and intertester reliability and criterion validity of the parallelogram and universal goniometers for active knee flexion in healthy subjects. Physiotherapy Research International, 6(4), 211-228.

Duffy, E., Wells, M., Miller, A., Tondra, M., & Doty, A. (2024). Reliability of the EasyAngle for Assessing Hip Range of Motion in Healthy Children. International Journal of Sports Physical Therapy, 19(1), 1484-1493.

Hancock, G. E., Hepworth, T., & Wembridge, K. (2018). Accuracy and reliability of knee goniometry methods. Journal of Experimental Orthopaedics, 5, 46.

DOI 10.26773/mjssm.24090x

Horsak, B., Prock, K., Krondorfer, P., Siragy, T., Simonlehner, M., & Dumphart, B. (2024). Inter-trial variability is higher in 3D markerless compared to marker-based motion capture: Implications for data post-processing and analysis. Journal of Biomechanics, 166, 112049.

Jovanović, S., Nedović, N., Vujičić, D., & Teovanović, P. (2024). Reliability and validity of measuring shoulder joint flexion using digital and standard goniometric methods. Fizička kultura. Advance online publication.

Keogh, J. W. L., Cox, A., Anderson, S., Liew, B., Olsen, A., Schram, B., et al. (2019). Reliability and validity of clinically accessible smartphone applications to measure joint range of motion: A systematic review. PLoS ONE, 14(5), e0215806.

Kiatkulanusorn, S., Luangpon, N., Srijunto, W., Watechagit, S., Pitchayadejanant, K., Kuharat, S., Bég, O. A., & Suato, B. P. (2023). Analysis of the concurrent validity and reliability of five common clinical goniometric devices. Scientific reports, 13(1), 20931.

Nussbaumer, S., Leunig, M., Glatthorn, J. F., Stauffacher, S., Gerber, H., & Maffiuletti, N. A. (2010). Validity and test-retest reliability of manual goniometers for measuring passive hip range of motion in femoroacetabular impingement patients. BMC Musculoskeletal Disorders, 11, 194.

Pantouveris, M., Kotsifaki, R., & Whiteley, R. (2024). Inclinometers and Apps Are Better than Goniometers, Measuring Knee Extension Range of Motion in Anterior Cruciate Ligament Patients: Reliability and Minimal Detectable Change for the Three Devices. The journal of knee surgery, 10.1055/a-2321-0516. Advance online publication.

Perkins, D. O., Wyatt, R. J., & Bartko, J. J. (2000). Penny-wise and pound- foolish: The impact of measurement error on sample size requirements in clinical trials. Biological Psychiatry, 47(8), 762–766.

Saiki, Y., Kabata, T., Ojima, T., Kajino, Y., Kubo, N., & Tsuchiya, H. (2023). Reliability and validity of pose estimation algorithm for measurement of knee range of motion after total knee arthroplasty. Bone & Joint Research, 12(5), 313-320.

Svensson, M., Lind, V., & Löfgren Harringe, M. (2019). Measurement of knee joint range of motion with a digital goniometer: A reliability study. Physiotherapy Research International, 24, e1765.

Watkins, M. A., Riddle, D. L., Lamb, R. L., & Personius, W. J. (1991). Reliability of goniometric measurements and visual estimates of knee range of motion obtained in a clinical setting. Physical therapy, 71(2), 90–97.

Wren, T. A., Isakov, P., & Rethlefsen, S. A. (2023). Comparison of kinematics between Theia markerless and conventional marker-based gait analysis in clinical patients. Gait & Posture, 104, 9-14

ORIGINAL SCIENTIFIC PAPER

Analyzing the effects of competitive fatigue on body composition and functional capacities of youth elite handball players

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Abstract

Handball demands intense movements like rapid direction changes and physical contact. Consecutive competitions expose player fatigue and weaknesses due to the sport's exhaustive nature. Therefore, the aims of this study are two-fold: (i) to investigate the impact of competitive fatigue on the body composition of youth elite handball players, and (ii) to analyze the impact of concentrated competition on their functional capacity performance. Seventeen young male handball players (age: 16.2 years, height; 177.8 cm, body mass: 73.0 kg) were assessed twenty-four hours before (TM1) and after the competitive period (TM2) in body composition, static strength, lower- and upper-body explosive strength, speed, agility, balance, and flexibility indicators. A Wilcoxon Signed Rank Test was conducted to assess differences in body composition and functional capacities assessment between TM1 and TM2. Regarding results, body mass significantly increased in TM2 ($p < 0.01$), while increases in waist circumference and body fat percentage were not statistically significant. Functional capacity assessments revealed a significant decline in jumping performance (CMJ and SJ; $p \leq 0.01$). Speed and agility assessments showed worse performance in TM2, significantly increasing 30 m sprint time ($p \leq 0.01$). Balance indicators showed no significant differences, with mixed results in performance across different conditions. In sum, evaluating vertical jumps and long-distance maximum speed (i.e., 30 meters) could be valid tests for measuring and controlling fatigue in young elite handball players. Future research should regularly monitor young handballers after the competition to analyze the entire fatigue recovery process.

Keywords: *team sports, adolescents, physical fitness, vertical jumps, sprinting*

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Introduction

In handball, players must continuously perform movements with maximum or submaximal effort without having time to fully recover in between (Petruzela et al., 2023). Since teams are not allowed to purposefully slow down the game by delaying or holding onto the ball without moving forward or trying to get a goal opportunity, handball players must frequently perform rapid direction changes, repeated accelerations, physical contact with other players, leaps, and shoots during competition (Kale & Akdoğan, 2020). During the competition, players must repeatedly perform high-intensity activity, followed by brief periods of low-intensity activity to quickly recover (Wagner et al., 2019). According to previous research, optimizing high-intensity actions and recovery depends on the strength and power capacities of both upper and lower limb muscles (Hermassi et al., 2017). Consequently, players' physical attributes seem to impact their match performance (Leuciuc et al., 2022). Moreover, the literature has reported that proper training control for evaluating physical fitness is crucial to minimize fatigue and the risk of injury during competition while optimizing players' performance (Tyshchenko et al., 2019). Besides functional capacities, age, body composition, technical skills, and tactical awareness are relevant variables for handball players' performance (Molina-López et al., 2020).

In the meantime, fatigue is noticeable when a player can no longer sustain the required level of effort, whether in training or competition (Marcora et al., 2009). As a result, physical and physiological components have been studied in the past years, suspecting that fatigue may significantly and negatively impact players' performance (Silva et al., 2018). The speed of actions (Coutinho et al., 2018) decreases the effectiveness of technical skills performance, such as passing and shooting (Mohr et al., 2003). Indeed, long-term and short-term fatigue influence players' performances (Wu et al., 2019), which may be enhanced during competition with a busy fixture calendar. The short recovery periods between matches seem to impact functional capacity performance, particularly sprinting and jumping abilities (Alba-Jiménez et al., 2022). Simultaneously, insufficient recovery periods are related to increased injury risk (Jones et al., 2017). Although the competitive and training intensity of professional players is naturally more demanding than that of young players, 3 days with 3 games exposes the aforementioned concerns.

However, to our knowledge, research regarding the effects of consecutive competition days on elite youth handball players' body composition and functional capacities is still lacking. This information is of interest to players and coaching staff to deploy managing strategies during competition to avoid the detrimental impact of fatigue and to provide adequate training programs according to competition demands. Therefore, the aims of this study were twofold: (i) to investigate the impact of competitive fatigue on the body composition of youth elite handball players, and (ii) to analyze the impact of a 3-day concentrated competition on players' functional capacity performance.

Materials and Methods

Participants

Seventeen male adolescent handball players aged 16.2 ± 1.1 years (height: 177.8 ± 7.5 cm, body mass: 73.0 ± 12.1 kg) participated in this study. All these players compete in regional competitions weekly and only compete at the national level once a year based on a concentration system (i.e., three games in 3 days).

Study design

The study was conducted during the season 2021/2022. Players were evaluated the day before the beginning of the national concentrated competition (TM1) and the day after the return from that same competition (TM2). All players were assessed in one morning, from 8:00 a.m. to 11:00 a.m., with a break between assessments. The timeline of the study design is displayed in table 1. All the protocols were conducted in a physical performance laboratory by trained staff from the research team. The field tests were conducted in a covered area appropriate for them and monitored by trained research team staff. The study protocol was approved by the Faculty of Human Kinetics Ethics Committee (CEIFMH N°22/2022) and followed the Declaration of Helsinki. Participation was voluntary, and informed consent was signed before data collection.

Body composition

Height was measured to the nearest 0.01 cm using a stadiometer (SECA 213, Hamburg, Germany). Body composition was evaluated using a hand-to-foot bioelectrical impedance analysis (InBody 770, Cerritos, CA, USA) during the early morning while participants were fasting. Participants were barefoot and only wearing their underwear. On the platform, their feet were placed on the defined spots, and their arms were placed nearly 45º from their trunk until the assessment was concluded. The waist circumference assessment was performed just above the iliac crest using a non-elastic measurement tape. The participants were standing position with arms hanging freely.

Static strength

The dominant and non-dominant handgrip was used to evaluate static strength. The protocol included three alternated trials for each arm using a hand dynamometer (Jamar Plus+, Chicago, IL, USA). Participants were standing and asked to hold a dynamometer in one hand, laterally to their trunk, with the elbow at 90º. Participants squeezed the dynamometer as hard as possible from this position for about two seconds. If the dynamometer touched the participant's body, the assessment was repeated. The rest interval between trials was 60 seconds, and the best score of the three trials was retained for analysis.

Upper-body explosive strength

The 3-kg medicine ball throw was used to assess upper-body explosive strength. All subjects began with a familiarization session. A brief description of the optimal technique was given, suggesting a release angle to achieve a maximum throw distance . The test consisted of standing with the feet parallel to each other and throwing the heavy ball as far as possible with both hands behind the head (throw-in), using an explosive forward movement . Each player made three repetitions, and the best performance was considered for evaluation.

Lower-body explosive strength

The countermovement jump (CMJ) and the squat jump (SJ) were used to evaluate the vertical jumping capacity . Participants performed four data collection trials 30 seconds apart. Although indications endorse a 1-minute passive rest between jumps to ensure muscular recovery , the issue is not consensual in the literature. In our study, due to time restrictions, we considered a rest period of 30 seconds between each jump. Some studies have presented shorter recovery times, such as 20 s and

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30 s between each repetition . The data were collected using the Optojump Next (Microgate, Bolzano, Italy) system of analysis. Participants were encouraged to jump to maximum height during testing. After the protocol explanation, participants were allowed three experimental trials to ensure correct execution.

For the CMJ, participants began standing, with feet placed hip-width to shoulder-width apart. Participants dropped into nearly 90° of knee flexion from this position, followed by a maximal-effort vertical jump. To avoid the influence of arm swing, the hands remained on the hips for the entire movement For the SJ, the participants started in a squat position of approximately 90° knee flexion, followed by a maximal-effort vertical jump. The participants reset to the starting position after each jump.

The Three-Jump Test (3JT) began from an upright standing position, with both feet flat. Participants tried to cover as much distance as possible with three forward jumps, alternating left, right, left or right, left, right, according to the sequence of supports they normally use to execute a handball suspension throw. The distance covered was measured to the nearest 1 cm using a tape measure.

Linear speed

Participants performed maximal sprints at 5-, 10- and 35-m. Sprint time was recorded in seconds using Witty-Gate photocells (Microgate, Bolzano, Italy), and the best of two trials was retained for analysis. Participants recovered between sprints by walking back to the start line for 2 min between trials.

Non-reactive agility

Non-reactive agility was evaluated through the t-test. The t-test is a 4-directional agility and body control test that assesses the ability to change direction rapidly while maintaining balance and without losing speed. Participants sprinted 9.14 m straight, then shuffled 4.75 m to the left side. Next, participants shuffled to the right side 9.14 m and immediately shuffled 4.75 m back. Finally, participants run backwards until they pass the starting point. Test time was recorded in seconds using Witty-Gate photocells (Microgate, Bolzano, Italy).

Flexibility

Sit and reach tests were used to assess flexibility . The protocol used a sit-and-reach trunk flexibility box (32.4 cm high and 53.3 cm long) with a 23 cm heel line mark. Participants sat barefoot before the box, with the knee fully extended and the heel placed against the box. Then, participants were asked to put their hands on each other, palms down, and push forward the measuring cycle. The forward position was repeated twice, and the third forward stretch was held for 3 s, corresponding to the test score. First, the test was conducted unilaterally (right and left leg) and then bilaterally. Two trials were performed, and the best score was used for analysis.

Balance

Balance was assessed using the Biodex Balance System SD (Biodex, Shirley, NY, USA). Before each testing, the equipment was adjusted to the participant's height. Participants were allowed to practice with the protocols through a single training session to guarantee the protocols' understanding and minimize learning effects during the testing phase. The rest interval between testing sessions was set at 60 seconds.

The protocol was performed in an unilateral stance with participants barefoot for bilateral comparison. During the assessment, the overall stability index (OSI), anteroposterior stability index (APSI), and mediolateral stability index (MLSI) were measured under four levels of platform stability for 20 s. Level 4 was the most stable, and level 1 was the most unstable. The indexes' scores show the deviation from the horizontal position; therefore, lower scores indicate better balance .

Statistics

Descriptive statistics are presented as means ± standard deviation. All data were checked for normality using the Shapiro-Wilk test. A Wilcoxon Signed Rank Test was conducted to assess differences in body composition and functional capacities before (TM1) and after competition (TM2). The effect size (r) was calculated by dividing the z value by the square root of N and interpreted using Cohen criteria as follows: $0.1 > r < 0.3$ (small), $0.3 > r < 0.5$ (medium), and ≥ 0.5 (large). All analyses were performed using IBM SPSS Statistics software 28.0 (SPSS Inc., Chicago, IL, USA). The significance level was set at 0.05.

Results

Figure 1 illustrates an overview of the percentage changes in the studied variables between pre-competitive (TM1) and post-competitive (TM2) assessments. Overall, the results show that in all the body composition variables, on

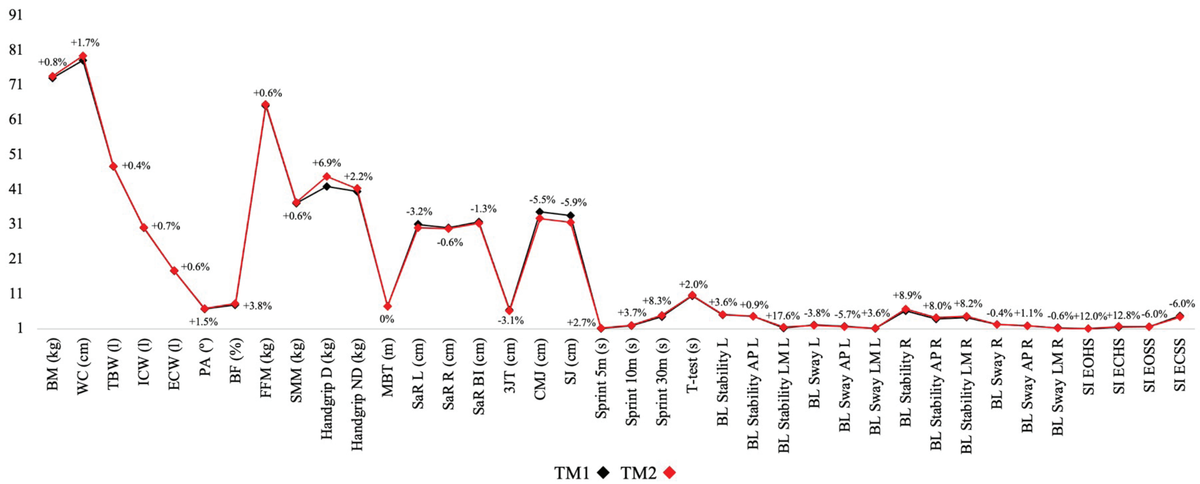

Figure 1. Overview of percentage changes in variables between pre-competitive assessments (TM1) and post-competitive assessments (TM2)

average, there was an increase of between 0.4% and 3.8%. Regarding to the functional capacities assessments, the results of the handgrip with both limbs showed improvements of between 2.2% and 6.9%. On the other hand, in the physical tests of flexibility and vertical and horizontal jumps, the results were worse after the competitive period, with lower percentages of between 0.6% and 5.9%. In addition, the players showed higher average results in the linear sprints (5m, 10m, and 30m) and t-test, between 2% and 8.3%. It should be noted that these values represent worse results since these are speed and agility tests in which a shorter time corresponds to a better performance. Finally, in the balance variables, it was possible to observe that 10 of the 16 indices increased their oscillation, which shows a worse average index after the competitive period, with negative values between 0.9% and 17.6%.

Table 2 presents descriptive statistics for body composition and the results of the comparison between TM1 and

Table 1. Timeline of the study design

Pre-Competitive Assessments (Day before competition)	National Competition (Duration of three days)	Post-Competition Assessments (Day after competition)
Body composition	Day 1: Match at 8 P.M.	Body composition
Functional capacities	Day 2: Match at 4 P.M.	Functional capacities
Balance	Day 3: match at 1 P.M.	Balance

Table 2. Descriptive statistics for body composition variables and results of the comparison between pre-competitive assessments (TM1) and post-competitive assessments (TM2)

Variable	TM1	TM2	Wilcoxon Signed Rank Test	
	Mean ± SD	Mean ± SD	z	p
CA (years)	16.2 ± 1.1			
Height (cm)	177.8 ± 7.5			
Body mass (kg)	73.0 ± 12.1	73.6 ± 12.2	2.665	≤ 0.01
Waist circumference (cm)	78.1 ± 6.9	79.4 ± 6.6	1.870	0.06
TBW (l)	47.6 ± 6.6	47.8 ± 6.7	0.700	0.48
ICW (l)	30.0 ± 4.1	30.2 ± 4.2	1.481	0.14
ECW (l)	17.6 ± 2.5	17.7 ± 2.6	0.000	1.0
Phase angle (º)	6.7 ± 0.6	6.8 ± 0.6	1.262	0.21
Body fat percentage (%)	7.9 ± 4.4	8.2 ± 4.4	1.198	0.23
Fat-free mass (kg)	65.1 ± 9.1	65.5 ± 9.3	1.068	0.29
Skeletal muscle mass (kg)	37.1 ± 5.4	37.3 ± 5.4	1.340	0.18

CA: chronological age; TBW: total body water; ICW: intracellular water; ECW: extracellular water.

Table 3. Descriptive statistics for functional capacities and results comparison between pre-competitive assessments (TM1) and post-competitive assessments (TM2)

Variable	TM1	TM2	Wilcoxon Signed Rank Test	
	Mean ± SD	Mean ± SD	z	p
Handgrip dominant side (kg)	41.9 ± 7.9	44.8 ± 7.1	1.917	0.06
Handgrip non-dominant side (kg)	40.4 ± 7.1	41.3 ± 6.0	0.308	0.76
Medicine ball throw (m)	7.5 ± 1.7	7.5 ± 1.5	0.315	0.75
Sit and reach left (cm)	31.0 ± 7.3	30.0 ± 6.9	1.136	0.26
Sit and reach right (cm)	30.0 ± 7.4	29.8 ± 6.9	0.402	0.69
Sit and reach bilateral (cm)	31.7 ± 7.2	31.3 ± 7.3	0.750	0.45
3JT (cm)	6.4 ± 0.5	6.2 ± 0.8	1.578	0.12
CMJ height (cm)	34.6 ± 6.4	32.7 ± 4.8	2.486	≤ 0.01
SJ height (cm)	33.6 ± 6.3	31.6 ± 5.0	2.415	0.02*
5 m linear sprint (s)	1.13 ± 0.09	1.16 ± 0.11	0.909	0.36
10 m linear sprint (s)	1.88 ± 0.09	1.95 ± 0.16	1.506	0.13
30 m linear sprint (s)	4.47 ± 0.21	4.84 ± 0.73	3.386	≤ 0.01
T-test (s)	10.46 ± 0.62	10.67 ± 0.85	0.355	0.72

3JT: three-jump throw; CMJ: countermovement jump; SJ: squat jump.

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TM2. Regarding significant differences found when comparing both moments, body mass was significantly higher in TM2 compared to TM1 (z = 2.665, p < 0.01, large effect size). Also, waist circumference (z = 1.870, p = 0.06) and body fat percentage (z = 1.198, p = 0.23) were higher in TM2 than in TM1, however, the differences were not significant. In the remaining variables, no significant differences were found between assessment moments.

Table 3 shows descriptive statistics for functional capacities and the comparison results between TM1 and TM2. Overall, players presented higher scores for the handgrip strength in TM2 (dominant limb: z = 1.917, p = 0.06; non-dominant limb: z = 0.308, p = 0.76). In contrast, significantly lower performance levels were observed in the jumping assessments in TM2 compared to TM1 (CMJ: z = 2.486, p = ≤ 0.01, large effect size; SJ: z = 2.145, p = 0.02, large effect size). Additionally, higher scores for speed and agility tests were registered in TM2, indicating worse performance. However, statistically significant differences were only found in the 30 m linear sprint time (z = 3.386, p = ≤ 0.01, large effect size).

Table 4 resumes descriptive statistics for balance indicators and compares the results between TM1 and TM2. Overall, no statistically significant differences were detected between moments. The results vary between better and worse balance scores at TM2. The players showed higher scores in the stability lateromedial left and right (z = 1.207, p = 0.23 and z = 0.970, p = 0.33, respectively), corresponding to decreased performance at TM2. Besides, values attained with eyes open and closed in the hard surface condition were higher at TM2, indicating worse performance. In contrast, scores observed with eyes open and closed in the soft surface condition were lower at TM2, indicating better balance ability.

Table 4. Descriptive statistics for balance variables and comparison of the results between pre-competitive assessments (TM1) and post-competitive assessments (TM2)

Variable	TM1	TM2	Wilcoxon Signed Rank Test	
	Mean ± SD	Mean ± SD	z	p
BL Stability Overall Left	4.94 ± 3.07	5.12 ± 2.70	0.213	0.83
BL Stability Ant Post Left	4.55 ± 3.22	4.59 ± 3.01	0.213	0.83
BL Stability Lat Med Left	1.25 ± 0.63	1.47 ± 0.68	1.207	0.23
BL Sway Overall Left	2.09 ± 0.56	2.01 ± 0.50	0.402	0.69
BL Sway Ant Post Left	1.74 ± 0.61	1.64 ± 0.46	0.118	0.91
BL Sway Lat Med Left	1.10 ± 0.30	1.14 ± 0.32	0.497	0.62
BL Stability Overall Right	6.16 ± 2.79	6.71 ± 2.67	1.018	0.31
BL Stability Ant Post Right	3.87 ± 2.55	4.18 ± 2.70	0.118	0.91
BL Stability Lat Med Right	4.27 ± 2.06	4.62 ± 2.02	0.970	0.33
BL Sway Overall Right	2.28 ± 0.72	2.27 ± 0.67	0.497	0.62
BL Sway Ant Post Right	1.88 ± 0.63	1.90 ± 0.69	0.213	0.83
BL Sway Lat Med Right	1.27 ± 0.44	1.20 ± 0.25	0.355	0.72
SI EOHS	0.92 ± 0.33	1.03 ± 0.37	0.710	0.48
SI ECHS	1.48 ± 0.52	1.67 ± 0.63	1.302	0.19
SI EOSS	1.58 ± 0.53	1.57 ± 0.38	0.118	0.91
SI ECSS	4.70 ± 1.00	4.41 ± 1.22	1.231	0.22

BL: balance; Ant Post: anteroposterior; Lat Med: lateromedial: SI EOHS: sway index eyes open hard surface; SI ECHS: sway index eyes closed hard surface; SI EOSS: sway index eyes open soft surface; SI ECSS: sway index eyes closed soft surface.

Discussion

The present study aimed to investigate the impact of competitive fatigue from a concentrated competition on body composition and functional capacities of youth elite handball players. The results indicated that the evaluation of vertical jumps and the long-distance maximum speed test (i.e., 30 meters) are valid tests for measuring and controlling fatigue in young elite handball players after three consecutive days of competition. In addition, the results also showed that the regeneration process of the variables analyzed in terms of body composition is quickly completed in this specific context.

Impact of Competitive Fatigue on Body Composition

Regarding body composition, no significant differences were observed in overall variables, except for body mass. However, the other variables considered for analysis (i.e., waist circumference, total body water, intracellular water, extracellular water, body fat percentage, fat-free mass, and skeletal muscle mass) increased their values, although without statistical significance. Indeed, the literature reinforces that there may be an association between an increase in the above-mentioned variables and a significant increase in body mass (Martins et al., 2022). First of all, it's important to note that the average daily weight change is around two kilograms. Therefore, a statistically significant variation of an average of 600 grams may not be clinically significant regarding the biological structures of the players in the sample. Yet, body composition is vital since being physically prepared for competition has been reported as probably the main element reducing players' susceptibility to fatigue following handball matches (Ronglan et al., 2006). Players might thus benefit from more targeted high-intensity exercises like sprinting, leaping, and more intense eccentric exercises, reducing minor muscle ruptures following high-intensity activity (Harper et al., 2019).

Evaluation of Functional Capacities: Jumping and Sprinting

Regarding functional capacities, on average, the players significantly increased their lower-body explosive strength (countermovement jump and squat jump) from TM1 to TM2. Worldwide, researchers and coaching staffs have relied on the countermovement jump and squat jump to assess players' lower-body explosive strength levels (Asimakidis et al., 2024; França et al., 2022; Molina-López et al., 2020). As expected due to the fatigue effect, players decreased their performance in both vertical jumping tasks. According to the literature, high-intensity actions (i.e., sprints, jumps, and changes of directions) are related to lower-body strength capacity (Hermassi et al., 2017), which might be affected by fatigue levels accumulated due to game demands and congested calendars (Alba-Jiménez et al., 2022). When objectively interpreting the outcomes of our study, a key breakthrough in our research was the precise demonstration that evaluating vertical jumps can serve as a reliable metric for monitoring fatigue control in handball, particularly among young elite players.

Meanwhile, the results of the present study indicate decreases in linear sprints and changes in direction performance between TM1 and TM2. However, results were only statistically significant in the 30 m linear sprint. In that specific speed test, there was an increase of nearly 0.37 seconds in the total running time, corresponding to a decreased performance. Interestingly, the time spent in the 5 m and 10 m linear sprints, and t-test have also increased after the competitive period, which should also be related to accumulated fatigue. Recent investigations have shown that restoring the sprint and vertical jump measurements requires 24 to 72 hours of recovery time to their pre-competitive levels of neuromuscular function (Thomas et al., 2018). After a tough competition, this function decline may extend for up to four days (McLean et al., 2010). In general, these studies highlight the value of personalized monitoring processes in team sports to deploy adequate intervention programs to avoid the detrimental effects of fatigue (Alba-Jiménez et al., 2022).

Fatigue Effects on Balance Performance

Finally, although an overall performance decrease from TM1 to TM2 was observed in balance variables, the differences were not statistically significant. To the best of our knowledge, the research on the influence of competitive fatigue on young handballers' balance indices is limited. However, the literature has underlined the need to integrate dynamic balance processes throughout training sessions. In football, it has been suggested that fatigue affects players' functional stability during match play (Greig & Walker-Johnson, 2007). Elite football players experience fatigue in the final 15 min of each half, which is related to deficits in postural balance during that particular match timeframe (Mohr et al., 2005). As a result, diminished postural stability may help explain why injuries happen around the conclusion of each half of the game (Brito et al., 2012). Indeed, introducing balance content throughout training sessions may increase movement effectiveness and reduce the risk of injury (Daneshjoo et al., 2022).

Study Limitations

Despite its scientific validity, the present study has some limitations that should be mentioned. First, the lack of longitudinal assessment limits comparing the results to pre- and post-competition testing sessions. Collecting longitudinal data would allow a more extensive analysis of the players' baseline characteristics and the short-term effects of congestive competitions on body composition and functional capacities. Furthermore, the fact that each player's playing time was not one of the variables controlled and taken into account does not allow us to differentiate in body and physical terms between players with a higher competitive load and those with a lower competitive load. Even though the influence of competitive fatigue in young handballers is still a scarce topic in the literature. Still, this study reports novelty findings in exploring vertical jump evaluations as a reliable fatigue monitor and control measurement that can be applied in youth elite handballers.

Conclusions

This study demonstrate the validity of using vertical jumps as a measure of fatigue after a concentrated competition in young handball players. In addition, it was also shown that body composition variables were regenerated quickly after the competitive period. These results are essential for technical staff to understand the type of preparation for these demanding periods of competition and the type of assessments they could use to measure their young players' fatigue. It is also essential to retain these findings and consider them for the prevention and recovery processes of sports injuries and the period of return to competition. Future studies should follow and evaluate the groups evaluated more regularly, especially after the competition, so that it is possible to monitor the recovery process after competitive fatigue.

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Declaration of Interest Statement

The authors declare no conflict of interest.

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Institutional Review Board Statement

This study was conducted according to the guidelines of the Declaration of Helsinki and approved by the Ethics Committee of the Faculty of Human Kinetics, (CEIFMH Nº22/2022), and followed the ethical standards of the Declaration of Helsinki for Medical Research in Humans (2013) and the Oviedo Convention (1997).

Informed Consent Statement

Informed consent was obtained from all subjects involved in the study. Written informed consent has been obtained from all players to publish this paper.

Data Availability Statement

The data presented in this study are available upon request from the corresponding author.

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References

Alba-Jiménez, C., Moreno-Doutres, D., & Peña, J. (2022). Trends assessing neuromuscular fatigue in team sports: a narrative review. *Sports*, *10*(3), 33.

Asimakidis, N. D., Mukandi, I. N., Beato, M., Bishop, C., & Turner, A. N. (2024). Assessment of strength and power capacities in elite male soccer: a systematic review of test protocols used in practice and research. *Sports medicine*, 1-38.

Brito, J., Fontes, I., Ribeiro, F., Raposo, A., Krustrup, P., & Rebelo, A. (2012). Postural stability decreases in elite young soccer players after a competitive soccer match. *Physical therapy in sport*, *13*(3), 175-179.

Coutinho, D., Gonçalves, B., Wong, D. P., Travassos, B., Coutts, A. J., & Sampaio, J. (2018). Exploring the effects of mental and muscular fatigue in soccer players' performance. *Human movement science*, *58*, 287-296.

Daneshjoo, A., Hoseinpour, A., Sadeghi, H., Kalantari, A., & Behm, D. G. (2022). The effect of a handball warm-up program on dynamic balance among elite adolescent handball players. *Sports*, *10*(2), 18.

França, C., Gouveia, É., Caldeira, R., Marques, A., Martins, J., Lopes, H., Henriques, R., & Ihle, A. (2022). Speed and Agility Predictors among Adolescent Male Football Players. *International Journal of Environmental Research and Public Health*, *19*(5), 2856.

Greig, M., & Walker-Johnson, C. (2007). The influence of soccer-specific fatigue on functional stability. *Physical therapy in sport*, *8*(4), 185-190.

Harper, D. J., Carling, C., & Kiely, J. (2019). High-intensity acceleration and deceleration demands in elite team sports competitive match play: a systematic review and meta-analysis of observational studies. *Sports medicine*, *49*(12), 1923-1947.

Hermassi, S., Schwesig, R., Wollny, R., Fieseler, G., van den Tillaar, R., Fernandez-Fernandez, J., Shephard, R. J., & Chelly, M.-S. (2017). Shuttle versus straight repeated-sprint ability tests and their relationship to anthropometrics and explosive muscular performance in elite handball players. *The Journal of Sports Medicine and Physical Fitness*, *58*(11), 1625-1634.

Jones, C. M., Griffiths, P. C., & Mellalieu, S. D. (2017). Training load and fatigue marker associations with injury and illness: a systematic review of longitudinal studies. *Sports medicine*, *47*, 943-974.

Kale, M., & Akdoğan, E. (2020). Relationships between body composition and anaerobic performance parameters in female handball players. *Physical education of students*, *24*(5), 265-270.

Leuciuc, F. V., Petrariu, I., Pricop, G., Rohozneanu, D. M., & Popovici, I. M. (2022). Toward an Anthropometric Pattern in Elite Male Handball. *International Journal of Environmental Research and Public Health*, *19*(5), 2839.

Marcora, S. M., Staiano, W., & Manning, V. (2009). Mental fatigue impairs physical performance in humans. *Journal of applied physiology*.

Martins, F., França, C., Henriques, R., Ihle, A., Przednowek, K., Marques, A., Lopes, H., Sarmento, H., & Gouveia, É. R. (2022). Body composition variations between injured and non-injured professional soccer players. *Scientific Reports*, *12*(1), 20779.

McLean, B. D., Coutts, A. J., Kelly, V., McGuigan, M. R., & Cormack, S. J. (2010). Neuromuscular, endocrine, and perceptual fatigue responses during different length between-match microcycles in professional rugby league players. *International Journal of Sports Physiology and Performance*, *5*(3), 367-383.

Mohr, M., Krustrup, P., & Bangsbo, J. (2003). Match performance of high-standard soccer players with special reference to development of fatigue. *Journal of sports sciences*, *21*(7), 519-528.

Mohr, M., Krustrup, P., & Bangsbo, J. (2005). Fatigue in soccer: a brief review. *Journal of sports sciences*, *23*(6), 593-599.

Molina-López, J., Barea Zarzuela, I., Sáez-Padilla, J., Tornero-Quiñones, I., & Planells, E. (2020). Mediation effect of age category on the relationship between body composition and the physical fitness profile in youth handball players. *International Journal of Environmental Research and Public Health*, *17*(7), 2350.

Petruzela, J., Papla, M., & Stastny, P. (2023). Conditioning Strategies for Improving Handball Throwing Velocity: A Systematic Review and Meta-Analyses. *Journal of human kinetics*, *87*, 189.

Ronglan, L., Raastad, T., & Børgesen, A. (2006). Neuromuscular fatigue and recovery in elite female handball players. *Scandinavian journal of medicine & science in sports*, *16*(4), 267-273.

Silva, J. R., Rumpf, M., Hertzog, M., Castagna, C., Farooq, A., Girard, O., & Hader, K. (2018). Acute and residual soccer match-related fatigue: a systematic review and meta-analysis. *Sports medicine*, *48*, 539-583.

Thomas, K., Brownstein, C., Dent, J., Parker, P., Goodall, S., & Howatson, G. (2018). Neuromuscular fatigue and recovery after heavy resistance, jump, and sprint training. *Medicine & Science in sports & exercise*, *50*(12), 2526-2535.

Tyshchenko, V., Cherednichenko, I., & Lytvynenko, O. (2019). The concept of building control for certain components of the system for training handball players. *Journal of Physical Education and Sport*, *19*, 1380-1385.

Wagner, H., Sperl, B., Bell, J. W., & Von Duvillard, S. P. (2019). Testing specific physical performance in male team handball players and the relationship to general tests in team sports. *The Journal of Strength & Conditioning Research*, *33*(4), 1056-1064.

Wu, P. P.-Y., Sterkenburg, N., Everett, K., Chapman, D. W., White, N., & Mengersen, K. (2019). Predicting fatigue using countermovement jump force-time signatures: PCA can distinguish neuromuscular versus metabolic fatigue. *PloS one*, *14*(7), e0219295.

ORIGINAL SCIENTIFIC PAPER

Analysis of Tactical-Technical Attack Performance Factors: A Case Study of a Professional Women's Handball Team

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Abstract

Game analysis based on tactical-technical sports performance provides important information for coaches to periodize and evaluate team processes more accurately. The aim of this study was to analyze the probabilities of success in offensive situations by a Brazilian professional women's handball team. The method used was a quantitative, descriptive and case study approach, which was a professional women's handball team with national and international achievements. Data collection was based on the Handball Observation System, which allowed a total of 726 game actions to be evaluated from the two target competitions (world and national), 143 for the Women's Super Globe and 583 for the national handball league. The data was analyzed using the Lince program, which helps with video analysis (games from different sports), optimizing data verification, and the SPSS 23.0 software, using multinomial regression. The results showed that the team had 10.538 more probabilities of scoring when using basic tactical means, compared to 1-on-1 actions (CR = 1.061) and complex tactical means (CR = 1). The offensive organization showed greater probabilities (OR = 1.668) of scoring with the full team, in attacks from the central area of the court of less than 9 meters (OR = 1.917) and with shots between 21 and 40 minutes (OR = 1.393). There were also 7.968 more chances for the opposing goalkeeper to make a save when the team attacked with basic tactical means and 2.562 more chances for him to save the shot between 21 and 40 minutes.

Keywords: *performance analysis, handball, sport*

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Introduction

The analysis of tactical-technical sports performance provides important information for coaches to periodize and evaluate team processes accurately. Performance analysis is associated with evaluating the players' individual and collective performance and its use is a determining factor in improving the skills and capabilities offered by sports, as well as the entire context of the players' training process (Collet et al., 2011; Porath et al., 2016; Lamas & Morales, 2022).

The analysis of actions in team and individual sports has

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grown exponentially in recent years, with several authors (Grehaigne et al., 1997; Lamas & Morales, 2022) have addressed the contextualization of match observation, performance analysis and game analysis. The analysis of possible information about the team and players can generate potential data to support the coaches' and managers' decisions, both in the tactical and technical training and in the physical one. This fact is linked to the players' performance level, which in a way allows coaches to modify the development of training sessions and tasks around the specificity of each player or the team in general (Pollard & Reep 1997; Oslin et al., 1998; Menezes & Reis 2010; Saad et al., 2013).

Performance analysis seeks to provide information that shows the coach the aspects/problems that deserve more attention (technical, tactical, physical or psychological) so that they can be solved during the sports training process (Greco & Benda, 1998; Prudente et al., 2004; Saad et al., 2013). It is also worth noting that, although complex, the task of analyzing a match can help identify potentialities or weaknesses, either in one's own team or in the opponent (Matias & Greco, 2009; Salles et al., 2017).

Specifically in handball, there are studies that provide data on tactical organization patterns (Santos, 2012), analysis of the handball game based on the coaches' opinion (Menezes et al., 2015) and the verification of play patterns, according to some type of specific position of a given player (Rodríguez & Anguera, 2018). Other studies look at the analysis of actions that differentiate winning teams from losing ones (Paula et al., 2020), as well as analyses that show some type of specific match actions, such as 2-2 disputes, numerical superiority and offensive actions (Sousa et al., 2014; Lozano et al., 2015; Lozano et al., 2016; Prudente et al., 2017; Amatria et al., 2020).

Generally speaking, the studies listed have focused on the coaches' perspective of certain situations that take place in a match (superiority, 2-2 situations, offensive actions, etc.), with the main conclusions being that the play patterns that develop offensive actions through the center, with basic tactical means, from between 6 and 9 meters, and that present a solid defensive balance during the matches with use of counter-attacks, were more successful in terms of team performance.

However, there is a need to broaden the analysis from the perspective of a team's attack since, in this way, certain play movements and patterns can be more reliably understood, bearing in mind that, although the game has the attack-defense duality, in order to achieve the objective proposed in handball, it is necessary to develop attack actions that overcome the opponent's defense.

In this context, it is necessary to have a more specific view of the performance process, taking into account the offensive aspects as the guiding principles of the game, as it is from the decision-making developed by the players that the match sequence takes place. In view of this, the research aims at advancing discussions around the process of analyzing tactical-technical performance factors that assess attack actions in handball. Therefore, the objective of this study was to analyze the probabilities for success in attack situations for a Brazilian professional women's handball team.

Method

This research is classified as an applied study with a quantitative approach, with a descriptive objective and based on a case study (Ato et al., 2013).

Data analysis

To analyze the tactical-technical performance factors, the Lince program was first used to analyze the videos of the target competitions (World Cup and National Handball League), which were then exported to an Excel spreadsheet. Subsequently, the IBM SPSS® 23.0 for Windows software was employed to perform the multinomial regression, adopting a 5% significance level to interpret the results. Thus, the study dependent variable corresponded to the match actions characterized as method: tactical means, offensive organization, campogram and attack time. The independent variables were the finishing parameters, specifically goal and save by the goalkeeper.

Inter- and intra-rater statistical analyses were performed, which were developed using the Kappa test, which aims to determine agreement between two or more groups, seeking consistency in the results. The inter-rater analysis of the tactical-technical performance factor analysis form obtained an agreement index between the values of 0.81 and 1, thus presenting an 'almost perfect' agreement, according to Landis and Koch (1977). The intra-rater analysis process was also carried out, which was developed by the doctoral student, who analyzed three games in a period of one week, leaving a gap of 15 days for analysis, to subsequently analyze the same sessions again. As in the inter-rater validation, the process of verifying the agreement index was between 0.81 and 1, also obtaining an 'almost perfect' result (LANDIS; KOCH, 1977).

Data collection

Initially, the identification forms for the coaches and players involved in the research process were filled in. The National Women's Handball League matches were filmed. The first phase was played using a group format (home and away matches), with the top teams in their respective groups competing in the final phase, concentrated over a five-day period. The process to collect information from the team's matches took place using a camera and a tripod. The equipment was positioned in the stands in the center of the court, with the possibility of turning the camera to the right or left in order to follow the ball movements (attack, defense and counter-attack).

The data from the IHF Women's Super Globe (Club World Cup) were taken from digital platforms where the matches are available (YouTube and Facebook of the team under study). The competition format was elimination and concentrated over a 4-day period, starting with the quarter-finals on day one, semi-finals on day two, and 3rd and 4th place play-offs and the final match on day four.

The information from the footage of the games was transcribed according to the Handball Observation System classification, where it was possible to analyze the tactical-technical performance factors of 726 match actions: 143 for the Women's Super Globe and 583 for the National League.

Research context and participants

The study participants were the coaches and players of an elite women's handball team from Brazil. The team was chosen on a non-probability-intentional basis (Guimarães, 2012), taking into account its prominence on the national handball scene, which is relevant when it comes to important achievements, as the team has already been three-time Brazilian handball champion, South American

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champion, champion of the Brazilian university games, champion of the Brazilian handball cup and ten-time champion of the Santa Catarina open, as well as reaching the third place in the 2019 World Championship. In addition to these collective results, the team is notable for the number of players called up to the Brazilian national teams in the youth and adult categories, with the athlete who won the adult women's handball world championship in 2013 standing out.

Instruments

At a first instance, identification forms were used for the coaches and players, in order to obtain the specific characteristics of the research participants. In addition, the Handball Observation System (Prudente et al., 2004) was used to analyze tactical-technical performance factors, with the premise of evaluating both the offensive and defensive aspects of the team.

For this research, it was decided to only use the attack contexts, as it is during this process that the main performance variables take place and we can obtain patterns for analyzing how and in what way the team organizes itself during matches. It was therefore necessary to group some of the instrument's variables in an attempt to provide a better understanding of the results based on the verification of matches in the Club World Cup and National League competitions. Specifically, the instrument was organized as follows:

- Finishing: goal, save by the goalkeeper;
- Method: counter-attack and organized attack;
- Tactical means: one-on-one, basic (breaking passes, pass and go, successive penetrations), complex (crosses, interchanges, blocking, entry of winger or playmaker as second pivot, rehearsed plays, etc.);
- Offensive organization: complete (six or seven players on the court for the attack) and incomplete (less than six players for the attack);
- Attack field: side field, center field -9 meters and center field +9 meters;
- Time: playing time up to 20 minutes, from 21 to 40 minutes, and from 41 to 60 minutes.

Results

Table 1 shows the Odds Ratios (ORs) of successful shots, according to the tactical-technical performance factors of the team under study. It was found that the team had 10.538 more probabilities of scoring when using basic tactical means, when compared to one-on-one actions (OR = 1.061) and complex tactical means (OR = 1).

Table 1. Odds Ratios of scoring or save by the goalkeeper, according to tactical-technical performance factors

Variables				OR 95% Confidence Interval	
Finishing - Goal		Sig.	OR	Lower limit	Upper limit
Method	Counter-attack	0.128	0.085	0.004	2.026
	Organized attack	.	1	.	.
Tactical means	One on one	0.867	1.061	0.503	2.239
	Basic	0.000*	10.538	2.941	37.758
	Complex	.	1	.	.
Offensive organization	Complete	0.353	1.668	0.567	4.907
	Incomplete	.	1	.	.
Offensive campogram	Side field	0.993	0.996	0.416	2.382
	Center field -9m	0.065	1.917	0.960	3.827
	Center field +9m	.	1	.	.
Time	Up to 20 minutes	0.947	1.023	0.532	1.966
	From 20 to 40 minutes	0.349	1.393	0.697	2.786
	From 40 to 60 minutes	.	1	.	.
Finishing – Save by the goalkeeper		Sig.	OR	Lower limit	Upper limit
Method	Counter-attack	0.605	0.480	0.030	7.739
	Organized attack	.	1	.	.
Tactical means	One on one	0.496	1.349	0.570	3.196
	Basic	0.003*	7.968	2.058	30.845
	Complex	.	1	.	.
Offensive organization	Complete	0.102	3.994	0.759	21.014
	Incomplete	.	1	.	.
Offensive campogram	Side field	0.449	0.705	0.255	1.946
	Center field -9m	0.686	1.178	0.532	2.608
	Center field +9m	.	1	.	.
Time	Up to 20 minutes	0.162	1.750	0.798	3.839
	From 21 to 40 minutes	0.023*	2.562	1.139	5.761
	From 41 to 60 minutes	.	1	.	.

With regard to the opposing goalkeeper defense OR, 7.968 more probabilities were found for the opposing goalkeeper when the team attacked with basic tactical means, when compared to one-on-one actions and complex tactical means. There were 2.562 more probabilities of the opposing goalkeeper saving the shots between the times of 21 to 40 minutes, when compared to 0 to 20 minutes (1.750) and 41 to 60 minutes (1).

Discussion

The objective of this study was to analyze the probabilities success the attack actions of a professional Brazilian women's handball team. The data obtained revealed that the team under study made both successes and errors when using the same tactical means (basic) and attack time in the same period (from 21 to 40 minutes). In this scenario, as the priority adopted by the team was to attack using basic tactical means to break through the opponent's defensive system, the success ORs using this performance factor also corresponded to the OR of the errors, as in both attack processes (goal or save by the goalkeeper), the variables stood out for shots. A similar situation was found in attack time, where the team predominantly hit and missed at playing times between 21 and 40 minutes. This can be explained by the fact that the team had a higher volume of actions during this time of the matches when compared to the initial (up to 20 minutes) and final (41 minutes to 60 minutes) phases.

These findings reinforce the evidence found with youth handball teams (Spanish championship - Martín & Guerrero, 2009) and adult handball teams (World Championship, European Championship, Olympic Games – Lozano et al., 2016 and EHF Champions League - Vaz et al., 2023). These research studies found that the most used tactical means were those considered basic, whereas more complex actions were only used in the first attack sequence.

The studies by Lozano et al., (2016) and Vaz et al. (2023) also found that the teams tried to finish their actions between 6 and 9 meters from the goal, as they found greater success probabilities in finishing from that space when compared to shots from the side field and from distances greater than 9 meters from the goal. On the other hand, a study by Almeida et al. (2020), with men's teams from the 2007-2019 world championships, discovered that the Top 8 teams developed more successful actions from 9 m and from the extremes, with the latter increasing over the years. In a way, the greater success odds at the end of an offensive action from situations considered to be simpler can be related to the complexity degree of the combined plays, as this more elaborate process can usually lead to errors at the time of its deployment, making it more difficult to finish the play with a goal (Souza et al., 2014).

When tactical behavior is analyzed during a formal match, many elements should be taken into account, and the main analysis index must have a direct link to who is on the court. In this sense, a study by Rodríguez and Anguera (2018), which analyzed the behavior of a Spanish adult team through the two central players, found that when one of them was on the court, the team was more dynamic, whereas when the other central player was playing, the team became more paced and organized. In this study, the main factor contributing to this difference in the team's attack behavior was organization of the attacks by different tactical means. This is similar to the findings of the current study, as the team had more probabilities of scoring when using basic tactical means.

As for the offensive construction process of the team under study, no differences were observed between the OR of the play method (counter-attack: OR = 0.085; organized attack: OR = 1) in development of the actions during the matches. In this sense, it stands out that the team attacked primarily in organized offensive actions, refraining from playing at speed even when they were numerically equal, inferior or superior. This finding differs from the information found in the study by Amatria et al. (2020) with teams taking part in the 2016 World Cup, which showed that the teams' main attack action, especially when they were outnumbered, was unstructured/standardized counter-attack.

Vaz et al. (2023) also considered that winning teams maintain a stable pattern of counter-attack actions during development of a match, as well as that they follow a trend of organized attacks. This situation shows how important counter-attack is for planning a match in handball and reinforces the need for a team to develop, improve and execute more offensive transition actions against its opponents in order to surprise them while they are returning to defense.

Studies such as the one by Hernández et al. (2010) have emphasized how important counter-attack is in handball, as they observed that counter-attack actions are more effective at scoring goals than positional play actions. From this perspective, Lozano and Camerino (2012) also emphasized that counter-attack is the most effective offensive situation when faced with any type of opposing defense. Finally, a study by Paula et al. (2020), which observed World Championship matches between 2007 and 2017 to detect discriminating variables between winners and losers, found that teams prioritized successful defensive behaviors and resorting to counter-attack situations.

In general, the results of the team studied based on the ORs and the tactical-technical performance factors are similar to the findings of other studies in the literature consulted. However, the data also revealed the need for the team to improve and develop counter-attack offensive transition actions when they recover the ball, given that some studies have shown the benefits of this option for achieving success in offensive actions.

This reinforces the important role of performance analysis in helping coaches and the technical committee of a team to develop training tasks based on the guiding parameters indicated. In addition, this type of analysis can help authenticate the practical experiences players have during training and formal matches (Teoldo et al., 2015).

Conclusion

The objective of this study was to analyze the probabilities the success in attack situations for a professional Brazilian women's handball team. According to the evidence found, it was noticed that the tactical-technical performance factors that contributed to the team's success in attack were, in particular: 1- Actions of basic tactical means; 2- Shots taken within 9 m from the goal; 3- Playing time between 21 and 40 minutes.

The study has the potential to analyze tactical-technical performance factors in high-level competitions such as the Club World Cup and the National League. In this sense, it can collaborate with the academic and scientific community by presenting results on the process of analyzing performance in two significant competitions contested by a team with recognized success in Brazilian women's handball. An important

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contribution to the professional handball coaching community is that the findings shed light on the offensive construction process of an elite team's game. This opens new perspectives for designing the sports training process and analyzing performance during the season, given that this type of research is still scarce at the national level.

The main limitation of this study concerns the absence of complementary qualitative data, as semi-structured interviews with the coaching staff, for example, might better contextualize the data obtained and justify the tactical-technical options adopted by the team under study.

It is recommended that future research studies use the qualitative approach be used to complement the analysis, allowing the coaching staff's playing philosophy to be identified in greater detail, as well as other relevant data on decision-making regarding structuring of the team's training and playing model. The qualitative analysis of the match actions can thus provide more comprehensive information on the tactical-technical performance of the team and its opponents, which can render the sports teaching-learning-training process more robust and contextualized to individual and collective needs and potentialities.

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References

Almeida, A. G., Merlin, M., Pinto, A., Torres, R. S., & Cunha, S. A. (2020). Performance-level indicators of male elite handball teams. *International Journal of Performance Analysis in Sport, 20*(1), 1-9. https://doi.org/10.1080/24748668.2019.

Amatria, M., Lapresa, D., Martín Santos, C., & Pérez Túrpin, J. A. (2020). Offensive effectiveness in the female elite handball in numerical superiority situations. *Revista Internacional de Medicina y Ciencias de la Actividad Física y el Deporte, 20*(78), 227-242. https://doi.org/10.15366/rimcafd2020.78.003.

Ato, M., López, J. J., & Benavente, A. (2013). Un sistema de clasificación de los diseños de investigación en psicología. *Anales de psicología, 29*(3) (octubre), 1038-1059. http://dx.doi.org/10.6018/analesps.29.3.17851.

Castelo, J. (2009). *Soccer: Dynamic Organization of the Game*. 3. ed. Lisbon, Portugal: Faculty of Human Motricity.

Collet, C., Nascimento, J. V., Ramos, V., & Stefanello, J. M. F. (2011). Construction and validation of an instrument to evaluate technical-tactical performance in volleyball. *Revista Brasileira de Cineantropometria e Desempenho Humano, 13*(1), 43-51. https://doi.org/10.1590/1980-0037.2011v13n1p43.

Galatti, L. R., Reverdito, R. S., Scaglia, A. J., Paes, R. R., & Seoane, A. M. (2014). Pedagogy of sport: tension in science and the teaching of team sports games. *Revista da Educação Física, 25*(1), 153-162. https://doi.org/10.4025/reveducfis.v25i1.21088.

Galatti, L. R., Paes, R. R., Collet, C., & Seoane, A. M. (2018). Contemporary sport: perspectives for understanding the phenomenon. *Corpoconsciência, 22*(3), 115-127. https://doi.org/10.4025/reveducfis.v25i1.21088.

Greco, P. J., & Benda, R. N. (1998). *Universal sports initiation: from motor learning to technical training*. Belo Horizonte, Brazil: Editora UFMG.

Grehaigne, J. F., & Godbout, P. (1997). Performance assessment in team sports. *Journal of Teaching in Physical Education, 16*(4), 500-516. https://doi.org/10.1123/jtpe.16.4.500.

Guimarães, P. R. B. (2012). *Quantitative statistical methods*. rev. ed. Curitiba, Brazil: IESDE Brasil.

Hernández, J. M., Rodríguez, A. J., Hernández, J., Álvarez, P. A., Jiménez, F., &

Hernández, I. M. (2010). Análisis del juego de ataque en balonmano femenino. *Ágora, para la Educación Física y el Deporte, 12*(3), 257-272.

Lamas, L., & Morales, J. C. P. (2022). Integration between performance analysis and teaching-learning in team sports. *Revista Brasileira de Ciências do Esporte, 44*(01), 1-8. https://doi.org/10.1590/rbce.44.e010121.

Landis, J. R., Koch, G. The Measurement of Observer Agreement for Categorical Data. *International Biometric Society*. (1977). Washington, 33(1), 159-174.

DOI: 10.2307/2529310.

Lozano, D., & Camerino, O. (2012). Eficacia de los sistemas ofensivos en balonmano. *Apunts. Educación Física y Deportes, 108*(2), 70-81. https://dx.doi.org/10.5672/apunts.2014-0983.es.(2012/2).108.08.

Lozano, D. J., Camerino, O., & Hileno, R. (2015). Análisis del comportamiento táctico ofensivo en momentos críticos de juego en el alto rendimiento en balonmano: Un estudio Mixed Methods. *Cuadernos de Psicología del Deporte, 16*(1), 151-160.

Lozano, D. J., Camerino, O., & Hileno, R. (2016). Interacción dinámica ofensiva en balonmano de alto rendimiento. *Apunts. Educación Física y Deportes, 3*(125), 90-110. https://doi.org/10.5672/apunts.2014-0983.es.(2016/3).125.08.

Machado, G. V., Galatti, L. R., & Paes, R. R. (2014). Pedagogy of sport and the cultural-historical framework: interlocution between theory and practice. *Pensar a Prática, 17*(2), 414-430. https://doi.org/10.5216/rpp.v17i2.24459.

Martín, R. S., & Guerrero, J. P. (2009). Análisis de la Eficacia en Ataque en Balonmano: influencia del establecimiento de objetivos. *Apunts. Educación Física y Deportes, 2*(96), 111-112.

Matias, C. J. A. S., & Greco, P. J. (2009). Game analysis in team sports games: the example of volleyball. *Pensar à Prática, 12*(3), 1-16. https://doi.org/10.5216/rpp.v12i3.6726.

Menezes, R. P., & Reis, H. H. B. (2010). Analysis of the handball game as a tool for its technical-tactical understanding. *Motriz, 16*(2), 458-67. https://doi.org/10.5016/1980-6574.2010v16n2p458.

Menezes, R. P., Morato, M. P., & Reis, H. H. B. (2015). Analysis of the handball game from the perspective of experienced coaches: offensive categories of analysis. *Revista da Educação Física/UEM, 26*(1), 11-20. https://doi.org/10.4025/reveducfis.v26i1.24306.

Oslin, J. L., Mitchell, S. A., & Griffin, L. L. (1998). The Game Performance Assessment Instrument (GPAI): development and preliminary validation. *Journal of Teaching in Physical Education, 17*(2), 231-243. https://doi.org/10.1123/jtpe.17.2.231.

Paula, L. V., Costa, F. E., Ferreira, R. M., Menezes, R. P., Werneck, F. Z., Coelho, E. F., & Greco, P. J. (2020). Analysis of discriminatory game variables between winners and losers in women's handball world championships from

2007 to 2017. *Kinesiology, 52*(1), 54-63. https://doi.org/10.26582/k.52.1.6.

Pollard, R., & Reep, C. (1997). Measuring the Effectiveness of Playing Strategies at Soccer. *Journal of the Royal Statistical Society Series D (The Statistician), 46*(4), 541-550. https://doi.org/10.1111/1467-9884.00108.

Porath, M., Collet, C., Milistetd, M., Salles, W. N., & Nascimento, J. V. (2016). Technical-Tactical Performance Level of Volleyball Teams in Training Grades. *Motricidade, 12*(2), 08-17. https://doi.org/10.6063/motricidade.6012.

Prudente, J., Garganta, J., & Anguera, M. (2004). Design and validation of an observation system in handball. *Revista Portuguesa de Cinências do Desporto, 4*(3), 49-65. https://doi.org/10.6018/cpd.382331.

Prudente, J., Sousa, D., Sequeira, P., López-López, J. A., & Hernández-Mendo, A. (2017). Analyzing the influence of playing time and partial score on the tactical behavior in the duel 2 vs 2 in the offensive process in handball, using the polar coordinates technique. *Anales de Psicología 33*(3), 515-529. https://doi.org/10.6018/analesps.33.3.271071.

Rodríguez, J. F., & Anguera, M. T. (2018). Game Pattern in Handball According to the Player who Occupies the Center Back Position. *Apunts. Educación Física y Deportes, 4*(134), 110-123. https://doi.org/10.5672/apunts.2014-0983.es.(2018/4).134.08.

Salles, W. N., Collet, C., Porath, M., Milistetd, M., & Nascimento, J. V. (2017). Factors associated with effectiveness in the performance of technical-tactical actions in volleyball. *Revista Brasileira de Cineantropometria & Desempenho Humano, 19*(1), 74-83. https://doi.org/10.1590/1980-0037.2017v19n1p74.

Santos, L. R. (2012). Game analysis and observation in handball: from numbers to training. In Greco, J. P., & Romero, J. J. F (Eds.), *Manual de handebol: da iniciação ao alto nível* (287-297). São Paulo, Brazil: Phorte.

Sousa, D., Prudente, J., Sequeira, P., López-López, J. A., & Hernández-Mendo, A. (2012). Análisis de las situaciones de juego 2vs2 en el campeonato europeo masculino de balonmano 2012: Aplicación de la técnica de coordenadas polares. *Cuadernos de Psicología del Deporte, 15*(1), 181-194. http://dx.doi.org/10.4321/S1578-84232015000100018.

Teoldo, I., Guilherme, J., & Garganta, J. (2015). *For a soccer played with ideas: conception, training and evaluation of the tactical performance of players and teams.* Curitiba, Brazil: Appris.

Vaz, V., Ferrari, W., Sarmento, H., Couceiro, M., Souza, T., & Dias, G. (2023). Handball offensive analysis: comparative evolution of linear tendency lines between finalist teams in the EHF CL. *Applied Sciences, 13*, 1-13. https://doi.org/10.3390/app13031366.

Guidelines for Authors

Revised Maj 2021

*** Please use the bookmark function to navigate within the guidelines. ***

When preparing the final version of the manuscripts, either NEW or REVISED authors should strictly follow the guidelines. Manuscripts departing substantially from the guidelines will be returned to the authors for revision or, rejected.

1. UNIFORM REQUIREMENTS

1.1. Overview

The *Montenegrin Journal of Sports Science and Medicine* (MJSSM) applies the Creative Commons Attribution (CC BY) license to articles and other works it publishes.

There is no charge for submissions and no page charge for accepted manuscripts. However, if the manuscript contains graphics in color, note that printing in color is charged.

MJSSM adopts a double-blind approach for peer reviewing in which the reviewer's name is always concealed from the submitting authors as well as the author(s)'s name from the selected reviewers.

MJSSM honors a six-weeks for an initial decision of manuscript submission.

Authors should submit the manuscripts as one Microsoft Word (.doc) file.

Manuscripts must be provided either in standard UK or US English. English standard should be consistent throughout the manuscripts.

Format the manuscript in A4 paper size; margins are 1 inch or 2.5 cm all around. Type the whole manuscript double-spaced, justified alignment.

Use Times New Roman font, size eleven (11) point.

Number (Arabic numerals) the pages consecutively (centering at the bottom of each page), beginning with the title page as page 1 and ending with the Figure legend page.

Include line numbers (continuous) for the convenience of the reviewers.

Apart from chapter headings and sub-headings avoid any kind of formatting in the main text of the manuscripts.

1.2. Type & Length

MJSSM publishes following types of papers:

Original scientific papers are the results of empirically- or theoretically-based scientific research, which employ scientific methods, and which report experimental or observational aspects of sports science and medicine, such as all clinical aspects of exercise, health, and sport; exercise physiology and biophysical investigation of sports performance; sport biomechanics; sports nutrition; rehabilitation, physiotherapy; sports psychology; sport pedagogy, sport history, sport philosophy, sport sociology, sport management; and all aspects of scientific support of the sports coaches from the natural, social and humanistic side. Descriptive analyses or data inferences should include rigorous methodological structure as well as sound theory. Your manuscript should include the following sections: Introduction, Methods, Results, and Discussion.

☑Open Submissions ☑Indexed ☑Peer Reviewed

Original scientific papers should be:

- Up to 3000 words (excluding title, abstract, tables/figures, figure legends, Acknowledgements, Conflict of Interest, and References);
- A structured abstract of less than 250 words;
- Maximum number of references is 30;
- Maximum combined total of 6 Tables/Figures.

Review papers should provide concise in-depth reviews of both established and new areas, based on a critical examination of the literature, analyzing the various approaches to a specific topic in all aspects of sports science and medicine, such as all clinical aspects of exercise, health, and sport; exercise physiology and biophysical investigation of sports performance; sport biomechanics; sports nutrition; rehabilitation, physiotherapy; sports psychology; sport pedagogy, sport history, sport philosophy, sport sociology, sport management; and all aspects of scientific support of the sports coaches from the natural, social and humanistic side.

☑Open Submissions ☑Indexed ☑Peer Reviewed

Review papers should be:

- Up to 6000 words (excluding title, abstract, tables/figures, figure legends, Acknowledgements, Conflict of Interest, and References);
- A structured abstract of less than 250 words;
- Maximum number of references is 100.

Editorials are written or commissioned by the editors, but suggestions for possible topics and authors are welcome. It could be peer reviewed by two reviewers who may be external or by the Editorial Board.

☐Open Submissions ☑Indexed ☑Peer Reviewed

Editorials should be:

- Up to 1000 words (excluding title, abstract, tables/figures, figure legends, Acknowledgements, Conflict of Interest, and References);
- A structured abstract of less than 250 words;
- Maximum number of references is 10.

Short reports of experimental work, new methods, or a preliminary report can be accepted as two page papers. Your manuscript should include the following sections: Introduction, Methods, Results, and Discussion.

☑Open Submissions ☑Indexed ☑Peer Reviewed

Short reports should be:

- Up to 1500 words (excluding title, abstract, tables/figures, figure legends, Acknowledgements, Conflict of Interest, and References);
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- Maximum number of references is 15.

Peer review - fair review provides authors who feel their paper has been unfairly rejected (at any journal) the opportunity to share reviewer comments, explain their concerns, and have their paper reviewed for possible publication in MJSSM.

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Peer review - fair review should be:

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- Maximum number of references is 15.

Invited papers and award papers include invited papers from authors with outstanding scientific credentials. Nomination of invited authors is at the discretion of the MJSSM editorial board. MJSSM also publishes award papers selected by the scientific committee of the MSA annual conference.

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Invited papers and award papers should be:

- Up to 3000 words (excluding title, abstract, tables/figures, figure legends, Acknowledgements, Conflict of Interest, and References);
- A structured abstract of less than 250 words;
- Maximum number of references is 30;
- Maximum combined total of 6 Tables/Figures.

Meeting Abstracts contain conference abstracts of the sports science papers presented at the MSA annual conference and MSA-sponsored meetings. This publication offers a first look into the current research in the field of Sports Science.

☐Open Submissions ☑Indexed ☐Peer Reviewed

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- Restricted to 250 words (including title, authors and institutions) and must include the following separate sections: [1] purpose; [2] methods; [3] results; [4] conclusion;
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✓ FAMILY NAME-fig1.tiff – (Figure 1)

1.4. Peer Review Process

An original manuscript submitted for publication will be submitted to the review process as long as it fits the following criteria:

- The study was not previously published, nor has been submitted simultaneously for consideration of publication elsewhere;
- All persons listed as authors approved its submission to MJSSM;
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- The author signs a formal statement that the submitted manuscript complies with the directions and guidelines of MJSSM.

The editors-in-chief, executive editor and associate editors will make a preliminary analysis regarding the appropriateness, quality, originality and written style/grammar of the submitted manuscript. The editors reserve the right to request additional information, corrections, and guideline compliance before they submit the manuscript to the ad-hoc review process.

MJSSM uses ad-hoc reviewers, who volunteer to analyze the merit of the study. Typically, one or two expert reviewers are consulted in a double-blind process. Authors are notified by e-mail when their submission has been accepted (or rejected). Minor changes in the text may be made at the discretion of the editors-in-chief, executive editor and/or associate editors. Changes can include spelling and grammar in the chosen language, written style, journal citations, and reference guidelines. The author is notified of changes via email. The final version is available to the author for his or her approval before it is published.

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2. MANUSCRIPT STRUCTURE

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The first page of the manuscripts should be the title page, containing: title, type of publication, running head, authors, affiliations, corresponding author, and manuscript information. *See* example:

Transfer of Learning on a Spatial Memory Task between the Blind and Sighted People Spatial Memory among Blind and Sighted

Original Scientific Paper

Transfer of learning on a spatial memory task

Selcuk Akpinar[1], Stevo Popović[1,2], Sadettin Kirazci[1]

[1]Middle East Technical University, Physical Education and Sports Department, Ankara, Turkey
[2]University of Montenegro, Faculty for Sport and Physical Education, Niksic, Montenegro

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Narodne omladine bb, 84000 Niksic, Montenegro
E-mail: stevop@ac.me

Word count: 2,980

Abstract word count: 236

Number of Tables: 3

Number of Figures: 3

2.1.1. Title

Title should be short and informative and the recommended length is no more than 20 words. The title should be in Title Case, written in uppercase and lowercase letters (initial uppercase for all words except articles, conjunctions, short prepositions no longer than four letters etc.) so that first letters of the words in the title are capitalized. Exceptions are words like: "and", "or", "between" etc. The word following a colon (:) or a hyphen (-) in the title is always capitalized.

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Authors should suggest the type of their submission.

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The form of an author's name is first name, middle initial(s), and last name. In one line list all authors with full names separated by a comma (and space). Avoid any abbreviations of academic or professional titles. If authors belong to different institutions, following a family name of the author there should be a number in superscript designating affiliation.

2.1.5. Affiliations

Affiliation consists of the name of an institution, department, city, country/territory(in this order) to which the author(s) belong and to which the presented / submitted work should be attributed. List all affiliations (each in a separate line) in the order corresponding to the list of authors. Affiliations must be written in English, so carefully check the official English translation of the names of institutions and departments.

Only if there is more than one affiliation, should a number be given to each affiliation in order of appearance. This number should be written in superscript at the beginning of the line, separated from corresponding affiliation with a space. This number should also be put after corresponding name of the author, in superscript with no space in between.

If an author belongs to more than one institution, all corresponding superscript digits, separated with a comma with no space in between, should be present behind the family name of this author.

In case all authors belong to the same institution affiliation numbering is not needed.

Whenever possible expand your authors' affiliations with departments, or some other, specific and lower levels of organization.

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Corresponding author's name with full postal address in English and e-mail address should appear, after the affiliations. It is preferred that submitted address is institutional and not private. Corresponding author's name should include only initials of the first and middle names separated by a full stop (and a space) and the last name. Postal address should be written in the following line in sentence case. Parts of the address should be separated by a comma instead of a line break. E-mail (if possible) should be placed in the line following the postal address. Author should clearly state whether or not the e- mail should be published.

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All authors are required to provide word count (excluding title page, abstract, tables/figures, figure legends, Acknowledgements, Conflict of Interest, and References), the Abstract word count, the number of Tables, and the number of Figures.

2.2. Abstract

The second page of the manuscripts should be the abstract and key words. It should be placed on second page of the manuscripts after the standard title written in upper and lower case letters, bold.

Since abstract is independent part of your paper, all abbreviations used in the abstract should also be explained in it. If an abbreviation is used, the term should always be first written in full with the abbreviation in parentheses immediately after it. Abstract should not have any special headings (e.g., Aim, Results…).

Authors should provide up to six key words that capture the main topics of the article. Terms from the Medical Subject Headings (MeSH) list of Index Medicus are recommended to be used.

Key words should be placed on the second page of the manuscript right below the abstract, written in italic. Separate each key word by a comma (and a space). Do not put a full stop after the last key word. *See example:*

Abstract

Results of the analysis of…
Key words: spatial memory, blind, transfer of learning, feedback

2.3. Main Chapters

Starting from the third page of the manuscripts, it should be the main chapters. Depending on the type of publication main manuscript chapters may vary. The general outline is: Introduction, Methods, Results, Discussion, Acknowledgements (optional), Conflict of Interest (optional), and Title and Abstract in Montenegrin (only for the authors from former Yugoslavia, excluding Macedonians and Slovenes). However, this scheme may not be suitable for reviews or publications from some areas and authors should then adjust their chapters accordingly but use the general outline as much as possible.

2.3.1. Headings

Main chapter headings: written in bold and in Title Case. *See* example:
- ✓ **Methods**

Sub-headings: written in italic and in normal sentence case. Do not put a full stop or any other sign at the end of the title. Do not create more than one level of sub-heading. *See* example:

- ✓ *Table position of the research football team*

2.3.2 Ethics

When reporting experiments on human subjects, there must be a declaration of Ethics compliance. Inclusion of a statement such as follow in Methods section will be understood by the Editor as authors' affirmation of compliance: "This study was approved in advance by [name of committee and/or its institutional sponsor]. Each participant voluntarily provided written informed consent before participating." Authors that fail to submit an Ethics statement will be asked to resubmit the manuscripts, which may delay publication.

2.3.3 Statistics reporting

MJSSM encourages authors to report precise p-values. When possible, quantify findings and present them with appropriate indicators of measurement error or uncertainty (such as confidence intervals). Use normal text (i.e., non-capitalized, non-italic) for statistical term "p".

2.3.4. 'Acknowledgements' and 'Conflict of Interest' (optional)

All contributors who do not meet the criteria for authorship should be listed in the 'Acknowledgements' section. If applicable, in 'Conflict of Interest' section, authors must clearly disclose any grants, financial or material supports, or any sort of technical assistances from an institution, organization, group or an individual that might be perceived as leading to a conflict of interest.

2.4. References

References should be placed on a new page after the standard title written in upper and lower case letters, bold.

All information needed for each type of must be present as specified in guidelines. Authors are solely responsible for accuracy of each reference. Use authoritative source for information such as Web of Science, Medline, or PubMed to check the validity of citations.

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MJSSM adheres to the American Psychological Association 7th Edition reference style. Check the Publication Manual of the American Psychological Association (2019), Seventh Edition that is the official source for APA Style, to ensure the manuscripts conform to this reference style. Authors using EndNote® to organize the references must convert the citations and bibliography to plain text before submission.

2.4.2. Examples for Reference citations

One work by one author

- ✓ In one study (Reilly, 1997), soccer players…
- ✓ In the study by Reilly (1997), soccer players…
- ✓ In 1997, Reilly's study of soccer players…

Works by two authors

- ✓ Duffield and Marino (2007) studied…
- ✓ In one study (Duffield & Marino, 2007), soccer players…
- ✓ In 2007, Duffield and Marino's study of soccer players…

Works by three or more authors: cite only the name of the first author followed by et al. and the year

- ✓ Bangsbo et al. (2008) stated that…
- ✓ In one study (Bangsbo et al., 2008), soccer players…

Works by organization as an author: cite the source, just as you would an individual person

- ✓ According to the American Psychological Association (2000)…
- ✓ In the APA Manual (American Psychological Association, 2003), it is explained…

Two or more works in the same parenthetical citation: citation of two or more works in the same parentheses should be listed in the order they appear in the reference list (i.e., alphabetically); separated by a semi-colon

- ✓ Several studies (Bangsbo et al., 2008; Duffield & Marino, 2007; Reilly, 1997) suggest that…

2.4.3. Examples for Reference list

Works by one author
Borg, G. (1998). *Borg's perceived exertion and pain scales*: Human Kinetics.

Works by two authors
Duffield, R., & Marino, F. E. (2007). *Effects of pre-cooling procedures on intermittent-sprint exercise performance in warm conditions. European Journal of Applied Physiology, 100*(6), 727–735. https://doi.org/10.1007/s00421-007-0468-x

Works by three to twenty authors
Nepocatych, S., Balilionis, G., & O'Neal, E. K. (2017). Analysis of dietary intake and body composition of female athletes over a competitive season. *Montenegrin Journal of Sports Science and Medicine, 6*(2), 57–65. https://doi.org/10.26773/mjssm.2017.09.008

Works by more than twenty authors
Krustrup, P., Mohr, M., Amstrup, T., Rysgaard, T., Johansen, J., Steensberg, A.,… Bangsbo, J. (2003). The yo-yo intermittent recovery test: physiological response, reliability, and validity. *Medicine & Science in Sports & Exercise, 35*(4), 697–705. https://doi.org/10.1249/01.mss.0000058441.94520.32

Works by group of authors
NCD-RisC. (2017). Worldwide trends in body-mass index, underweight, overweight, and obesity from 1975 to 2016: a pooled analysis of 2416 population-based measurement studies in 128.9 million children, adolescents, and adults. *Lancet*, 390(10113), 2627-2642. https://doi.org/10.1016/s0140-6736(17)32129-3

Works by unknown authors
Merriam-Webster's collegiate dictionary (11th ed.). (2003). Merriam-Webster.

Journal article (print)
Scruton, R. (1996). The eclipse of listening. *The New Criterion, 15*(3), 5–13.

Journal article (electronic)
Aarnivala, H., Pokka, T., Soininen, R., Mottonen, M., Harila-Saari, A., & Niinimaki, R. (2020). Trends in age- and sex-adjusted body mass index and the prevalence of malnutrition in children with cancer over 42 months after diagnosis: a single-center cohort study. *European Journal of Pediatrics,* 179(1), 91-98. https://doi.org/10.1007/s00431-019-03482-w

Thesis and dissertation
Pyun, D. Y. (2006). *The proposed model of attitude toward advertising through sport*. [Unpublished Doctoral Dissertation]. The Florida State University.

Book
Borg, G. (1998). *Borg's perceived exertion and pain scales*: Human Kinetics.

Chapter of a book
Armstrong, D. (2019). Malory and character. In M. G. Leitch & C. J. Rushton (Eds.), *A new companion to Malory* (pp. 144-163). D. S. Brewer.

Reference to a Facebook profile
Little River Canyon National Preserve (n.d.). *Home* [Facebook page]. Facebook. Retrieved January 12, 2020 from https://www.facebook.com/lirinps/

2.5. Tables

All tables should be included in the main manuscript file, each on a separate page right after the Reference section.

Tables should be presented as standard MS Word tables.

Number (Arabic) tables consecutively in the order of their first citation in the text.

Tables and table headings should be completely intelligible without reference to the text. Give each column a short or abbreviated heading. Authors should place explanatory matter in footnotes, not in the heading. All abbreviations appearing in a table and not considered standard must be explained in a footnote of that table. Avoid any shading or coloring in your tables and be sure that each table is cited in the text.

If you use data from another published or unpublished source, it is the authors' responsibility to obtain permission and acknowledge them fully.

2.5.1. Table heading

Table heading should be written above the table, in Title Case, and without a full stop at the end of the heading. Do not use suffix letters (e.g., Table 1a, 1b, 1c); instead, combine the related tables. *See* example:

- ✓ **Table 1.** Repeated Sprint Time Following Ingestion of Carbohydrate-Electrolyte Beverage

2.5.2. Table sub-heading

All text appearing in tables should be written beginning only with first letter of the first word in all capitals, i.e., all words for variable names, column headings etc. in tables should start with the first letter in all capitals. Avoid any formatting (e.g., bold, italic, underline) in tables.

2.5.3. Table footnotes

Table footnotes should be written below the table.

General notes explain, qualify or provide information about the table as a whole. Put explanations of abbreviations, symbols, etc. here. General notes are designated by the word Note (italicized) followed by a period.

- ✓ *Note.* CI: confidence interval; Con: control group; CE: carbohydrate-electrolyte group.

Specific notes explain, qualify or provide information about a particular column, row, or individual entry. To indicate specific notes, use superscript lowercase letters (e.g. [a, b, c]), and order the superscripts from left to right, top to bottom. Each table's first footnote must be the superscript [a].

- ✓ [a]One participant was diagnosed with heat illness and n = 19.[b]n =20.

Probability notes provide the reader with the results of the texts for statistical significance. Probability notes must be indicated with consecutive use of the following symbols: * † ‡ § ¶ || etc.

- ✓ *P<0.05,†p<0.01.

2.5.4. Table citation

In the text, tables should be cited as full words. *See* example:

- ✓ Table 1 (first letter in all capitals and no full stop)
- ✓ ...as shown in Tables 1 and 3. (citing more tables at once)
- ✓ ...result has shown (Tables 1-3) that... (citing more tables at once)
- ✓ ....in our results (Tables 1, 2 and 5)... (citing more tables at once)

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Figures and figure legends should be completely intelligible without reference to the text.

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Figures should not contain footnotes. All information, including explanations of abbreviations must be present in figure legends. Figure legends should be written bellow the figure, in sentence case. *See* example:

- ✓ **Figure 1.** Changes in accuracy of instep football kick measured before and after fatigued. SR – resting state, SF – state of fatigue, *p>0.01, †p>0.05.

2.6.2. Figure citation

All graphic materials should be referred to as Figures in the text. Figures are cited in the text as full words. *See* example:

- ✓ Figure 1
- × figure 1
- × Figure 1.
- ✓ ….exhibit greater variance than the year before (Figure 2). Therefore…
- ✓ ….as shown in Figures 1 and 3. (citing more figures at once)
- ✓ ….result has shown (Figures 1-3) that... (citing more figures at once)
- ✓ ….in our results (Figures 1, 2 and 5)... (citing more figures at once)

2.6.3. Sub-figures

If there is a figure divided in several sub-figures, each sub-figure should be marked with a small letter, starting with a, b, c etc. The letter should be marked for each subfigure in a logical and consistent way. *See* example:

- ✓ Figure 1a
- ✓ …in Figures 1a and b we can…
- ✓ …data represent (Figures 1a-d)…

2.7. Scientific Terminology

All units of measures should conform to the International System of Units (SI).

Measurements of length, height, weight, and volume should be reported in metric units (meter, kilogram, or liter) or their decimal multiples.

Decimal places in English language are separated with a full stop and not with a comma. Thousands are separated with a comma.

Percentage	Degrees	All other units of measure	Ratios	Decimal numbers
✓ 10%	✓ 10º	✓ 10 kg	✓ 12:2	✓ 0.056
× 10 %	× 10 º	× 10kg	× 12 : 2	× .056

Signs should be placed immediately preceding the relevant number.		
✓ 45±3.4	✓ p<0.01	✓ males >30 years of age
× 45 ± 3.4	× p < 0.01	× males > 30 years of age

2.8. Latin Names

Latin names of species, families etc. should be written in italics (even in titles). If you mention Latin names in your abstract they should be written in non-italic since the rest of the text in abstract is in italic. The first time the name of a species appears in the text both genus and species must be present; later on in the text it is possible to use genus abbreviations. *See* example:

- ✓ First time appearing: *musculus biceps brachii*
- ✓ Abbreviated: *m. biceps brachii*

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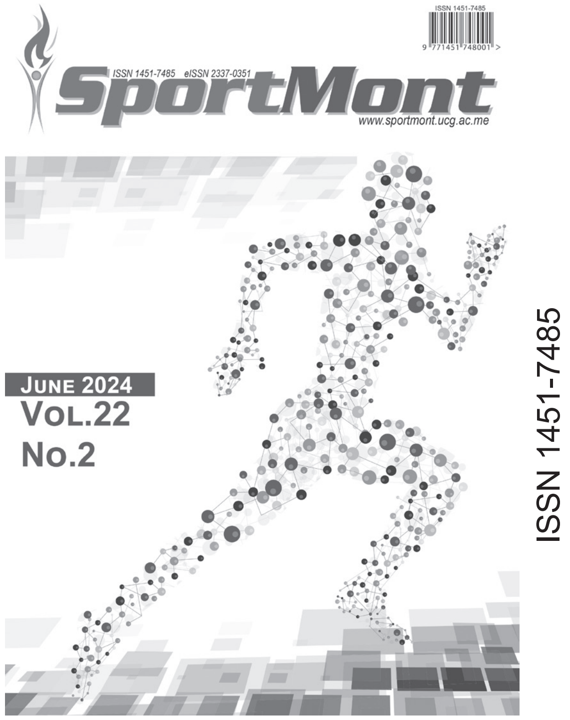

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CRNOGORSKA SPORTSKA AKADEMIJA • MONTENEGRIN SPORTS ACADEMY •

MONTENEGRIN SPORTS ACADEMY

Founded in 2003 in Podgorica (Montenegro), the Montenegrin Sports Academy (MSA) is a sports scientific society dedicated to the collection, generation and dissemination of scientific knowledge at the Montenegrin level and beyond.

The Montenegrin Sports Academy (MSA) is the leading association of sports scientists at the Montenegrin level, which maintains extensive co-operation with the corresponding associations from abroad. The purpose of the MSA is the promotion of science and research, with special attention to sports science across Montenegro and beyond. Its topics include motivation, attitudes, values and responses, adaptation, performance and health aspects of people engaged in physical activity and the relation of physical activity and lifestyle to health, prevention and aging. These topics are investigated on an interdisciplinary basis and they bring together scientists from all areas of sports science, such as adapted physical activity, biochemistry, biomechanics, chronic disease and exercise, coaching and performance, doping, education, engineering and technology, environmental physiology, ethics, exercise and health, exercise, lifestyle and fitness, gender in sports, growth and development, human performance and aging, management and sports law, molecular biology and genetics, motor control and learning, muscle mechanics and neuromuscular control, muscle metabolism and hemodynamics, nutrition and exercise, overtraining, physiology, physiotherapy, rehabilitation, sports history, sports medicine, sports pedagogy, sports philosophy, sports psychology, sports sociology, training and testing.

The MSA is a non-profit organization. It supports Montenegrin institutions, such as the Ministry of Education and Sports, the Ministry of Science and the Montenegrin Olympic Committee, by offering scientific advice and assistance for carrying out coordinated national and European research projects defined by these bodies. In addition, the MSA serves as the most important Montenegrin and regional network of sports scientists from all relevant subdisciplines.

MSA Conference 2025

The main scientific event organized by the Montenegrin Sports Academy (MSA) is the annual conference held in the first week of April.

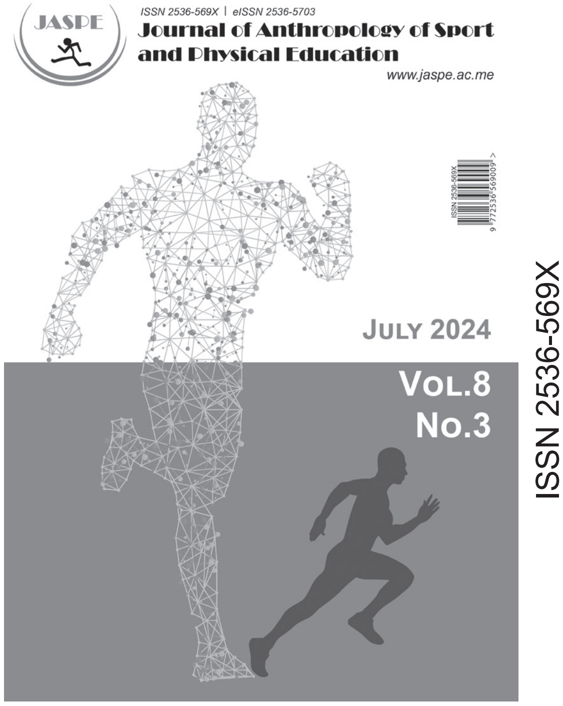
Annual conferences have been organized since the inauguration of the MSA in 2003. Today the MSA conference ranks among the leading sports scientific congresses in the Western Balkans. The conference comprises a range of invited lecturers, oral and poster presentations from multi- and mono-disciplinary areas, as well as various types of workshops. The MSA conference is attended by national, regional and international sports scientists with academic careers. The MSA conference now welcomes up to 200 participants from all over the world.

It is our great pleasure to announce the upcoming 22th Annual Scientific Conference of Montenegrin Sports Academy “Sport, Physical Activity and Health: Contemporary Perspectives” to be held in Dubrovnik, Croatia, from 3 to 6 April, 2025. It is planned to be once again organized by the Montenegrin Sports Academy, in cooperation with the Faculty of Sport and Physical Education, University of Montenegro and other international partner institutions (specified in the partner section).

The conference is focused on very current topics from all areas of sports science and sports medicine including physiology and sports medicine, social sciences and humanities, biomechanics and neuromuscular (see Abstract Submission page for more information).

We do believe that the topics offered to our conference participants will serve as a useful forum for the presentation of the latest research, as well as both for the theoretical and applied insight into the field of sports science and sports medicine disciplines.

Journal of Anthropology of Sport and Physical Education



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JASPE covers all aspects of anthropology of sport and physical education from five major fields of anthropology: cultural, global, biological, linguistic and medical.

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As we continue to increase the quality of our publications across the field, we hope that you will continue to regard MSA journals as authoritative and stimulating sources for your research. We would be delighted to receive your comments and suggestions, mostly due to the reason your proposals are always welcome.

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