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Best practice approaches in women's sports

Edited by
Rubén Maneiro, Mario Amatria, Vasilis Armatas, Claudio Alberto Casal, José Luis Losada and Antonio Ardá Suárez

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Best practice approaches in women's sports

Topic editors
Rubén Maneiro — Pontifical University of Salamanca, Spain
Mario Amatria — Pontifical University of Salamanca, Spain
Vasilis Armatas — National and Kapodistrian University of Athens, Greece
Claudio Alberto Casal — Catholic University of Valencia San Vicente Mártir, Spain
José Luis Losada — University of Barcelona, Spain
Antonio Ardá Suárez — University of A Coruña, Spain

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Editorial: Best practice approaches in women's sports

Rubén Maneiro[1]*, Mario Amatria[1], Vasilis Armatas[2], Claudio A. Casal[3], José Luís Losada[4] and Antonio Ardá[5]

[1]Department of Science of Physical Activity and Sport, Pontifical University of Salamanca, Salamanca, Spain, [2]School of Physical Education and Sport Science, National and Kapodistrian University of Athens, Athens, Greece, [3]Department of Physical Activity and Sport Science, Catholic University of Valencia San Vicente Mártir, Valencia, Spain, [4]Department of Social Psychology and Quantitative Psychology, University of Barcelona, Barcelona, Spain, [5]Department of Physical and Sports Education, University of La Coruña, La Coruña, Spain

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EDITED AND REVIEWED BY
Guy Cheron,
Université Libre de Bruxelles, Belgium

*CORRESPONDENCE
Rubén Maneiro
✉ rubenmaneirodios@gmail.com

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Editorial on the Research Topic
Best practice approaches in women's sports

Introduction

The first scientific articles on women's sport began to be published in the 1980s and their object of research focused on thematic areas such as the physiology and anthropometric values of female players (Iván-Baragaño and Maneiro, 2023).

The measurement of parameters such as height, body fat percentage, maximal oxygen consumption or lactate concentration were the leitmotivs during the 1990s and early 2000s (Kirkendall, 2007). In the last decade of the last century, the number of publications increased slightly, although the total number remained relatively small compared with that of the corresponding publications dealing with men's sport.

According to the PUBMED database, a significant and exponential increase in studies of women's sport has been observed in recent years. More specifically, it can be stated that a larger number of studies have been published in the last decade (2013–2023, $n = 96,882$) than in the entire period since the end of the Second World War (1945–2012, $n = 81,588$).

The present subject of research entitled "*Best practice approaches in women's sports*" was conceived with the aim of providing a forum through which scientists can submit their research studies of women's sport in terms of all its aspects and the full range of categories and types of research. As a result, it can be noted that the topic has had a significant impact, given that eight articles by 52 different authors have been published, with a total number of more than 19,000 visits to the related website and more than 3,000 downloads. This has made it possible to expand and develop the range of information available with regard to both individual sports (four studies presented) and collective sports (four scientific papers presented).

Overview of contributions

The analysis of sporting performance is the subject on which most attention was focused in the studies concerned. This is no coincidence, given the lack of adequately researched scientific literature concerning women's sport in any of its forms and disciplines. In particular, there was a balance among the proposals submitted, since four works dealt with individual sports: jiu-jitsu (Santos et al.); judo (Barreto et al.); pentathlon (Qiao et al.);

and speed skating (Liu et al.). And, on the other hand, another four have addressed collective sports: football (Iván-Baragaño et al.; Zhang et al.; Costa et al.) and volleyball (Slovák et al.).

With regard to martial arts, the paper entitled "*The effects of weight categories on the time-motion analysis of female high-level judo athletes between the 2016 and 2020 Olympic cycles*" analyzed 1,332 high-level judo bouts, concluding that the temporal behavior of the contest changed in nature between Olympic cycles. The study entitled "*Effects of weight divisions in time-motion of female high-level Brazilian Jiu-jitsu combat behaviors*" was also particularly relevant. This study compared continuous high-level female Brazilian Jiu-jitsu maneuvers in terms of time and frequency, taking into consideration weight categories. The main findings showed that the Super Heavyweight category was characterized by a shorter grip time than other weight categories. By contrast, the Rooster category was characterized by longer grip, transition and attack times and frequencies than the Light, Middle and Heavyweight categories.

Another interesting paper focusing on individual sports is entitled "*The effects of 8-week complex training on lower-limb strength and power of Chinese elite female modern pentathlon athletes*". The study aimed to analyse the effects of complex training (CT) on lower limb strength in female modern pentathlon athletes. The study concluded that CT in combination with regular training (RT) gave rise to an improvement in lower-limb strength and power in elite female modern pentathlon athletes.

The latest study focusing on individual sports is entitled "*Construction of Women's All-Around Speed Skating Event Performance Prediction Model and Competition Strategy Analysis Based on Machine Learning Algorithms*". The study aimed to explore the feasibility and effectiveness of machine learning algorithms for predicting women's full speed skating event performance, concluding that the ML algorithm was demonstrated to be a feasible method for predicting women's overall performance in speed skating competitions.

As far as collective sports are concerned, three studies focused on the analysis of football, but from different perspectives. On the one hand, the study entitled "*Future horizons in the analysis of technical-tactical performance in women's football: a mixed methods approach to the analysis of in-depth interviews with professional coaches and players*", conceived with regard to the context of mixed methods, deals with indirect observation applied to interviews with high performance football players and coaches, with the aim of finding variables associated with success. Another work analyzing an aspect of football is "*The effect of the video assistant referee (VAR) on referees' decisions at FIFA Women's World Cups*", which analyses how video refereeing affected refereeing decisions during the FIFA World Cups in 2015 and 2019. Finally, training in women's football was also a subject of analysis within this topic. Specifically, the paper entitled "*Training in women soccer players: a systematic review on training load monitoring*", where they concluded that the training load (TL) during training sessions in women football players is very low, and it is currently very difficult to consider evidence-based practices.

Finally, the study entitled "*External focus of attention enhances arm velocities during volleyball spike in young female players*", analyses the attentional focus during the spike in female volleyball players, finding that a significant benefit was found from the start of the wind-up phase to the acceleration phase (prior to ball-hitting) under external focus conditions.

Author contributions

RM: Writing—original draft, Writing—review & editing. MA: Writing—review & editing. VA: Supervision, Conceptualization, Resources, Writing—review & editing. CC: Supervision, Writing—review & editing. JL: Supervision, Validation, Visualization, Writing—review & editing. AA: Conceptualization, Supervision, Writing—review & editing.

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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References

Iván-Baragaño, I., and Maneiro, R. (2023). Investigación en fútbol femenino: antecedentes, progreso y futuros horizontes. [Research in women's football: background, progress and future horizons]. *Lecturas: Educación Física y Deportes* 28, 127–146. doi: 10.46642/efd.v28i300.3590

Kirkendall, D. T. (2007). Issues in training the female player. *Br. J. Sports Med.* 41, 64–67. doi: 10.1136/bjsm.2007.036970

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ORIGINAL RESEARCH
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Construction of Women's All-Around Speed Skating Event Performance Prediction Model and Competition Strategy Analysis Based on Machine Learning Algorithms

Meng Liu[1†], Yan Chen[1†], Zhenxiang Guo[2], Kaixiang Zhou[1,3], Limingfei Zhou[4], Haoyang Liu[5], Dapeng Bao[6]* and Junhong Zhou[7]*

[1]*Sports Coaching College, Beijing Sport University, Beijing, China,* [2]*Department of Physical Education, Nanjing University of Aeronautics and Astronautics, Nanjing, China,* [3]*College of Sports, Chengdu University of Traditional Chinese Medicine, Chengdu, China,* [4]*School of Strength and Conditioning Training, Beijing Sport University, Beijing, China,* [5]*AI Sports Engineering Lab, School of Sports Engineering, Beijing Sport University, Beijing, China,* [6]*China Institute of Sport and Health Science, Beijing Sport University, Beijing, China,* [7]*Harvard Medical School, Hebrew SeniorLife Hinda and Arthur Marcus Institute for Aging Research, Boston, MA, United States*

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Edited by:
José Luis Losada,
University of Barcelona, Spain

Reviewed by:
Rahim Alhamzawi,
University of Al-Qadisiyah, Iraq
Christer Malm,
Umeå University, Sweden

****Correspondence:***
Haoyang Liu
liuhaoyang@bsu.edu.cn
Dapeng Bao
baodp@bsu.edu.cn

†These authors have contributed equally to this work and share the first authorship

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Introduction: Accurately predicting the competitive performance of elite athletes is an essential prerequisite for formulating competitive strategies. Women's all-around speed skating event consists of four individual subevents, and the competition system is complex and challenging to make accurate predictions on their performance.

Objective: The present study aims to explore the feasibility and effectiveness of machine learning algorithms for predicting the performance of women's all-around speed skating event and provide effective training and competition strategies.

Methods: The data, consisting of 16 seasons of world-class women's all-around speed skating competition results, used in the present study came from the International Skating Union (ISU). According to the competition rules, distinct features are filtered using lasso regression, and a 5,000 m race model and a medal model are built using a fivefold cross-validation method.

Results: The results showed that the support vector machine model was the most stable among the 5,000 m race and the medal models, with the highest AUC (0.86, 0.81, respectively). Furthermore, 3,000 m points are the main characteristic factors that decide whether an athlete can qualify for the final. The 11th lap of the 5,000 m, the second lap of the 500 m, and the fourth lap of the 1,500 m are the main characteristic factors that affect the athlete's ability to win medals.

Conclusion: Compared with logistic regression, random forest, K-nearest neighbor, naive Bayes, neural network, support vector machine is a more viable algorithm to establish the performance prediction model of women's all-around speed skating event; excellent performance in the 3,000 m event can facilitate athletes to advance to the final, and athletes with outstanding performance in the 500 m event are more likely competitive for medals.

Keywords: machine learning, speed skating, performance prediction, elite athletes, model construction

INTRODUCTION

Accurately predicting the performance during the actual competition can help develop training plans and determine optimal strategies for athletes, which is extremely important to winning the competition (Ofoghi et al., 2016; Bunker and Susnjak, 2022). For example, Novak et al. developed a multiple linear regression model and predicted Olympic distance cross-country mountain biking field performance. Then the knowledge obtained from the prediction helped design appropriate training programs for the athletes in this field (Novak et al., 2018). However, studies have shown that the prediction of athletic performance is challenging because of the complicated scoring system and competition rules of the sport [e.g., all-around speed skating event (Ofoghi et al., 2016)], the requirement of the multi-modal coordination of the physiological systems in athletes (Maier et al., 2018) for the performance of the event.

Specifically, women's all-around speed skating event consists of four successive individual subevents, namely the 500, 1,500, 3,000, and 5,000 m races. Only athletes who ranked top eight the scores in the first three events (i.e., 500, 1,500, and 3,000 m) can enter the final 5,000 m competition. The ranking is by calculating the average time of 500 meters for each event (i.e., the number of seconds the athlete costs is the number of points she scores), and the lower the score, the higher the ranking. This unique scoring system thus requires athletes to utilize different strategies of training and competitions for different goals of this event; that is, some may aim at entering in the last 5,000 m round, and then they aim at winning the medals. Therefore, an advanced prediction model is critical for women's all-around speed skating athletes by providing estimated performance in the following rounds for each athlete (Noordhof et al., 2016). Smyth and Willemsen (2020) previously proposed to use a case-based reasoning technique to analyze the competition results of skaters under different external environmental conditions (e.g., altitude) to help athletes adjust the taxiing rhythm in time to achieve the best sports performance. However, this approach is not suitable for all-around speed skating event. The determinants of entering a 5,000 m race and winning a medal may differ, so the athlete cannot obtain appropriate competition and training advice from this prediction method. Therefore, it is highly demanded to develop a novel prediction model for this event, which will ultimately help improve the athletic performance.

This study proposed a novel prediction model based upon machine learning (ML) techniques. The ML is believed to help make better predictions and formulate more reasonable strategies by learning mass data through its algorithms (Maier et al., 2018). It has been widely used in sport sciences, including analyzing injury risk (Karnuta et al., 2020; Huang and Jiang, 2021) and athletic performance (Sarlis and Tjortjis, 2020; Huang and Jiang, 2021). Recently, studies emerged to implement ML to predict sports competition (Blythe and Király, 2016; Kholkine et al., 2021) and the formulation of strategies for competition (Ofoghi et al., 2013b; Tian et al., 2020). However, no studies have focused on predicting the performance use ML of athletes in all-around speed skating.

This study aims to explore the feasibility of using ML to predict the competition performance in all-around speed skating. Six different ML algorithms —support vector machine (SVM), logistic regression (LR), random forest (RF), K-Nearest Neighbor (KNN), naive Bayes (NB), neural network (NN)—was used here to construct a 5,000 m-race model (i.e., to enter the 5,000 m round) and a medal model (i.e., to win the medals). The performance and functionality of these models were then explicitly examined and compared.

MATERIALS AND METHODS

Data Source and Feature Selection

The data for this study are acquired from the International Skating Union (ISU) official website (https://live.isuresults.eu/home), covering a total of 64 world-class women's all-around speed skating competition results in 16 seasons (i.e., 2003/04–2019/20, except for the 2009/10 season). After being counted, the dataset contains 71 features (**Supplementary Table S1**).

First, the competition result data (mm:ss) are converted into data with s as the unit; then, the data are normalized to be limited within the interval [0, 1] to ensure the model converges against the effect of outliers. The data normalization procedure is formularized as:

$$x_i' = \frac{x_i - x_{\min}}{x_{\max} - x_{\min}},\ i = 1, 2, \ldots, n$$

When using ML algorithms for modeling, one needs first to filter out the optimal features to improve the performance of model prediction. If all features are included, it will increase the computational complexity and reduce the model performance. Hence, dimensionality reduction becomes the key to solving the problem. This paper uses the lasso regression method to screen the features of the 5,000 m race and medal models. Lasso regression combines the advantages of both ridge regression and subset selection process so that its computation results reflect the interpretability of subset selection and the stability of ridge regression (Tibshirani, 1996; Hashem et al., 2016; Alhamzawi and Ali, 2018). Lasso regression adds to the minimum sum of squares of errors. Considering the 1-norm constraint on the regression coefficient, the formula can be given as follows:

$$(\alpha, \beta) = \arg\min \sum_{i=1}^{n} (y_i - \alpha_i - X_i\beta)^2 \text{ sbuject to} \|\beta\|_1 < t$$

Add the constraint in the above formula to get the following form:

$$(\alpha, \beta) = \arg\min \sum_{i=1}^{n} (y_i - \alpha_i - X_i\beta)^2 + \lambda \|\beta\|_1$$

where, X_i is the ith group of independent variables, which are row parameters; α and β are regression coefficients, and β is the column parameter, and $\|\beta\|_1$ represents the 1-norm, which is the sum of the absolute values of the elements in the parameters; y_i is the value of the dependent variable of X_i; n is the size of the dataset used for regression modeling; λ and t are the parameters in different forms of lasso regression.

Machine Learning Model Building and Verification

Six instances of the 5,000 m race prediction model and the medal prediction model are established through SVM, RF, LR, KNN, NB, and NN algorithms (**Supplementary Figure S1**); the output of the model is whether the athlete can enter the 5,000 competition or win a medal. The fivefold cross-validation method was used to verify the model's performance. The specific process was splitting the dataset into five groups and assigning them each to an independent folder, four groups used as training data for building the model, and the remaining one used as test data to verify the model's effectiveness. Then, this process was repeated five times, and each of the five verifications was used as the result only once. Then take the average of the five results to get an estimate.

Among the algorithms, SVM adopts the linear kernel function as the primary function (Linear Support Vector Classifier, LSVC), given a set of labels corresponding to the instance, $i = 1,\ldots,l, x_i \in R^P, y_i \in \{-1,+1\}$, which solves an unconstrained loss function optimization problem $\xi(\text{w};,x_i;,y_i)$:

$$\min_{w} = \frac{1}{2} w^T w + C \sum_{i=1}^{l} \xi(w;,x_i;,y_i)$$

The L2-SVM loss function is used in this study:

$$\xi(w;,x_i;,y_i) = \max\left(1 - y_i w^T x_i, 0\right)^2$$

Naive Bayes adopts Gaussian Naive Bayes:

$$P(x_i|y) = \frac{1}{\sqrt{2\pi\sigma_y^2}} \exp\left(-\frac{(x_i - \mu_y)^2}{2\sigma_y^2}\right)$$

where σ_y and μ_y are estimated using maximum likelihood estimation.

Logistic regression uses the L2 penalty logistic regression function:

$$\min_{w,c} \frac{1}{2} w^T w + C \sum_{i=1}^{n} \log\left(\exp\left(-y_i\left(X_i^T w + c\right)\right) + 1\right)$$

The KNN function can be expressed as (Euclidean distance):

$$p_{ij} = \frac{\exp\left(-Lx_i - Lx_j{}^2\right)}{\sum_{k \neq i} \exp-\left(Lx_i - Lx_k{}^2\right)}, \; p_{ii} = 0$$

Uses the Bootstrap method to select n samples from the sample set and generates n classification trees to form a random forest (Breiman, 2001; Austin et al., 2013). The voting result of the classification tree determines the classification prediction result of the new data as expressed by the following formula:

$$f(x) = \arg\max_{Y} \sum_{i=1}^{n} I\left(h_i(X) = Y\right)$$

Where h_i represents the basic model of a single classification tree, Y represents the output variable, and I mean the indicative function.

The neural network model uses Multi-layer perceptron (MLP). A set of training examples $(x_1,y_1),(x_2,y_2),\ldots,(x_n,y_n)$, $x_i \in R^n$ are given in the MLP, $y_i \in \{0,1\}$, one hidden layer and one hidden neuron MLP learning function.

$$f(x) = W_2 g\left(W_1^T x + b_1\right) + b_2$$

with $W_1 \in R^m$, $W_2, b_1, b_2 \in \mathrm{R}$ being the model parameters. W_1 *and* W_2 represent the weights of the input layer and the hidden layer, respectively; b_1 *and* b_2 represent the deviations added to the hidden layer and the output layer, respectively; $g(\cdot): R \rightarrow R$ is the activation function, set by default as the hyperbolic tangent given by:

$$g(z) = \frac{e^z - e^{-z}}{e^z + e^{-z}}$$

For binary classification, $f(x)$ yields an output value between 0 and 1 through the logic function $g(z) = 1/\left(1 + e^{-z}\right)$. Samples are assigned to the positive class if having an output value greater than or equal to the threshold 0.5, else to the negative class.

The algorithm and evaluation are implemented using Scikit-learn based on Python 3 (Pedregosa et al., 2011). In the training process, the main parameters of different instances of the models are adjusted. The grid search method is used to adjust the hyperparameters to find the parameter value corresponding to the highest accuracy provided that the training data exist.

Model Evaluation

Evaluation indicators include the area under the receiver operating characteristic curve (ROC) AUC, accuracy, sensitivity, precision, and balanced F1 score. AUC is used to evaluate the discriminative ability and performance of the model. When the value of AUC is 1, it means that the model is perfect; a value of 0.5 means the deficient performance of a random classifier, i.e., the random classifier does not have any discriminative ability; a value of 0.90–1 means excellent, 0.80–0.90 good, 0.70–0.80 fair, 0.60–0.70 poor, and 0.50–0.60 failure (Bruce et al., 2020). The correct rate is the proportion of the samples judged correctly by the classifier among all samples. The higher the correct rate, the better the classifier; sensitivity is the proportion of all positive examples judged correctly by the classifier, which measures the classifier's ability to recognize positive examples; accuracy represents the proportion of positive examples judged to be positive by the classifier; the F1 score is the weighted average of model accuracy and recall; the maximum of the four indicators is 1, the minimum is 0, and the higher the value, the better the model (Stehman, 1997). Among the results of judgment, TP = true positive, TN = true negative, FP = false positive, FN = false negatives.

$$\text{Accuracy} = \frac{\text{TP} + \text{TN}}{\text{TP} + \text{TN} + \text{FP} + \text{FN}}$$

$$\text{Precision} = \frac{\text{TP}}{\text{TP} + \text{FP}}$$

$$\text{Sensitivity} = \frac{\text{TP}}{\text{TP} + \text{FN}}$$

$$F1 = \frac{2\text{TP}}{2\text{TP} + \text{FP} + \text{FN}}$$

Feature Weight Calculation

The present study quantifies the impact of the included features on model performance by computing weights (Li et al., 2020). To this end, the LSVC model is used in Python 3 Scikit-learn.

RESULTS

Feature Selection Results of Lasso Regression

Feature Inclusion in the 5,000 m Competition Model

Features other than those associated with the 5,000 m race were filtered using Lasso regression analysis to determine the best features to build the model. When λ was equal to 0.051, the model based on the following six features performed best: 3,000 m 1st lap score (3,000 m1), 3,000 m 7th lap score (3,000 m7), 1,500 m 1st lap score (1,500 m1), 3,000 m 8th split timer (3,000 ms8), 1,500 m 2nd split timer (1,500 ms^{2}), and 3,000 m points (3,000 m Points; **Figure 1**).

Feature Inclusion in the Medal Model

Lasso regression analysis was used to screen all features. When λ was equal to 0.0054, the model based on the following 21 features performed best: 500 m 2nd lap score (500 m2), 3,000 m 2nd lap score (3,000 m2), 3,000 m 3rd lap score (3,000 m3), 3,000 m 4th lap score (3,000 m4), 3,000 m 5th lap score (3,000 m5), 3,000 m 7th lap score (3,000 m7), 1,500 m 2nd lap score (1,500 m2), 1,500 m 3rd lap score (1,500 m3), 1,500 m 4th lap score (1,500 m4), 5,000 m 1st lap score (5,000 m1), 5,000 m 2nd lap score (5,000 m2), 5,000 m 4th lap score (5,000 m4), 5,000 m 5th lap score (5,000 m5), 5,000 m 9th lap score (5,000 m9), 5,000 m 11th lap score (5,000 m11), 5,000 m 13th lap score (5,000 m13), 5,000 m 3rd split timer (5,000 ms3), 500 m ranking, 3,000 m ranking, 1,500 m ranking, and 5,000 m ranking (**Figure 2**). In order to facilitate the actual operation, the 500 m ranking, 3,000 m ranking, 1,500 m ranking, and 5,000 m ranking from which features cannot be directly extracted in the test process are excluded, and the remaining 17 features were retained.

Performance Prediction Model Results

Evaluation and Comparison of the 5,000 m Race Model for Women's All-Around Speed Skating Event

According to the plotted ROC curve (**Figure 3**), the AUC values of the six instances of the 5,000 m race model for women's all-around speed skating event established by SVM, RF, LR, KNN, NB, and NN are 0.86, 0.85, 0.85, 0.83, 0.64, and 0.85, respectively. It can be observed that the overall better-performing algorithms are SVM, RF, LR, and NN. SVM had the most balanced classification through a comprehensive comparison of accuracy, sensitivity, and F1 score (**Table 1**).

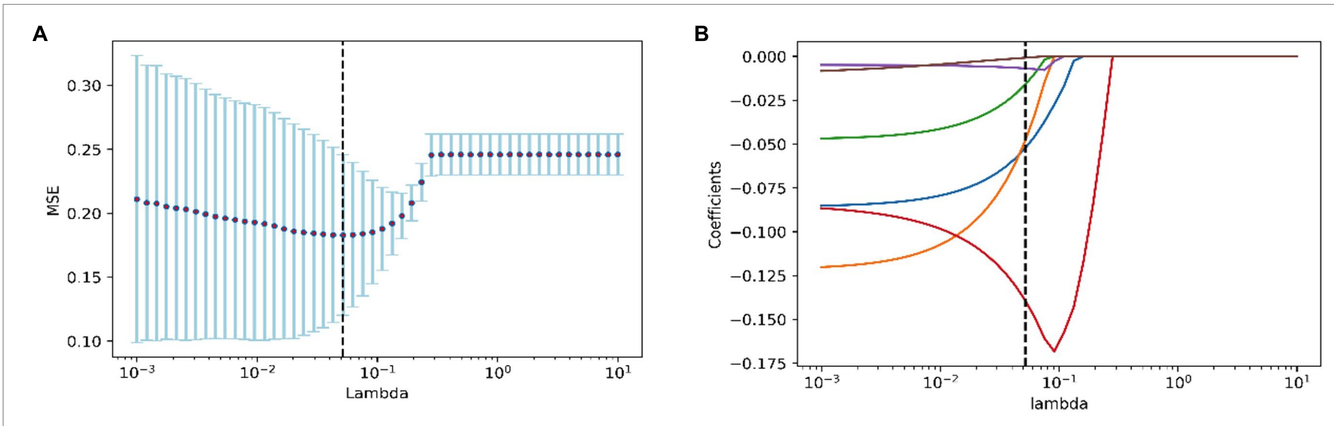

FIGURE 1 | Feature screening of the 5,000 m Race Model. **(A)** The figure of test MSE by lambda value; **(B)** the path diagram of lasso regression coefficients.

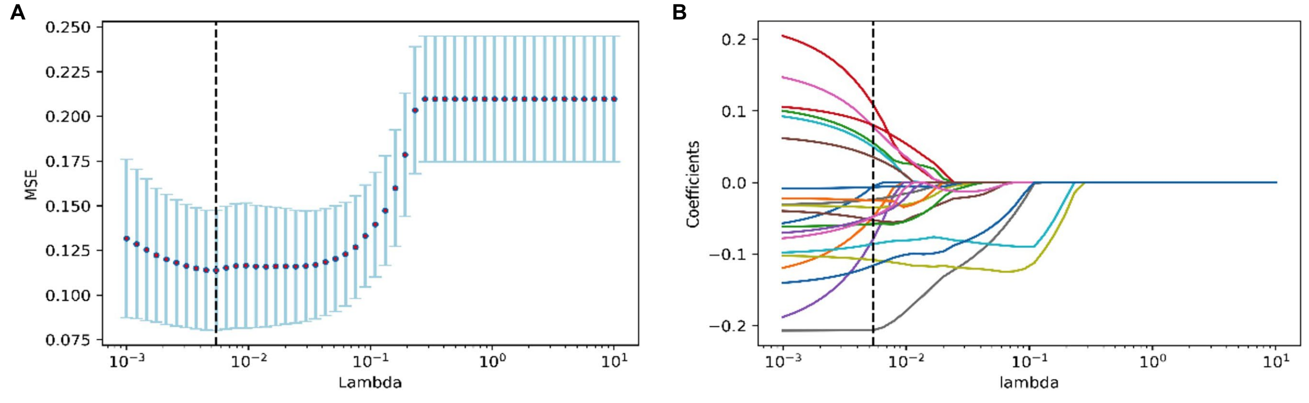

FIGURE 2 | Feature screening of the Medal Model. **(A)** The figure of test MSE by lambda value; **(B)** the path diagram of lasso regression coefficients.

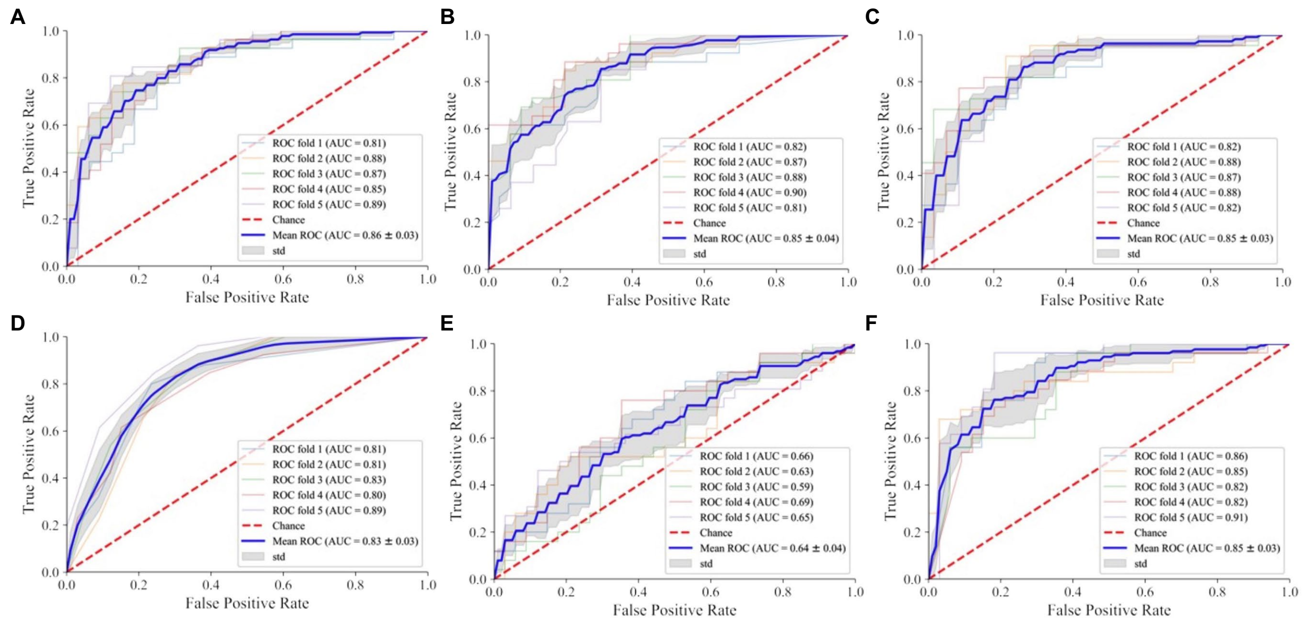

FIGURE 3 | Receiver operating characteristic (ROC) curves of different models in the 5,000 m final of women's all-around speed skating event. **(A)** SVM: support vector machine; **(B)** RF: random forest; **(C)** LR: logistic regression; **(D)** KNN: K-nearest neighbor; **(E)** NB: naive Bayes; **(F)** NN: neural network.

Evaluation and Comparison of the Medal Model

In training the instances of the medal model, the NN-based instance fails due to the excess data size. According to the plotted ROC curve (**Figure 4**), the AUC values of the five medal events for women's all-around speed skating event established by SVM, RF, LR, KNN, and NB are 0.81, 0.73, 0.73, 0.70, and 0.60, respectively. Among these model instances, the SVM instance proves high-performing and is the only instance that demonstrates good stability through a comprehensive comparison of accuracy, sensitivity, and F1 score of the five models (**Table 2**).

Feature Weight Analysis

According to the feature weights calculated by LSVC, the scores of the 3,000 m laps 1st and 7th and the individual points of the 3,000 m are the most critical features that affect whether an athlete can enter the 5,000 m competition (**Figure 5A**). The results of 5,000 m lap 11th, 500 m lap 2nd, and 1,500 m lap 4th are positive characteristics that affect whether athletes can win medals, while the results of 5,000 m laps 9th, 13th and 3,000 m lap 3rd are negative characteristics that affect whether athletes can win medals (**Figure 5B**).

DISCUSSION

This study examined six ML algorithms approaches based upon a real competition database of split times and ranking in women's all-around speed skating athletes. The results have shown that it is feasible to predict the performance ranking by ML algorithms. Through comparison in the performance of the instances of the models built by different algorithms, it has been observed that the SVM-based instance can effectively predict the performance of the women's all-around speed skating event, suggesting that this model would help athletes to set appropriate training programs, improving the quality of their strategic decision-making and competitive performance.

The model for performance prediction in women's all-around speed skating event established through ML can provide more direct suggestions for the training and competition of this event. For instance, coaches and athletes can input the daily test results into the model to obtain the probability of athletes entering the 5,000 m competition or winning medals to help athletes and coaches in training better. This is more generic than Smyth's (Smyth and Willemsen, 2020) use of specific case-based reasoning. The selection of features is the key to building this more general model (Horvat et al., 2020). Research has shown that lasso regression has advantages over traditional Stepwise Regression methods in feature selection (Yarkoni and Westfall, 2017). Applied for feature screening in this study, the lasso regression method is more conducive to eliminating unimportant related features and accurately screening out relatively important ones. Combined with weight calculation, the model can be more accessible and interpretable. In this study, the features of the 5,000 m race model and the medal model are distinct. In deciding whether athletes are eligible for entering the 5,000 m competition, the 3,000 m score has the most relevant features, while in determining whether the final result suffices to win a medal, things are different. Laps 1, 2, 4, 7, 11 at 5,000 m, 5, 7 laps at 3,000 m, lap 2 at 500 m, and before 3,000 m, the speed of the three laps has an important influence on whether the athlete can win a medal. This reminds coaches that the training emphasis of athletes should be highlighted for different competition purposes. If the athlete's goal is to enter the 5,000 m race, she should first develop the long-distance racing ability until scoring high enough in the 3,000 m race for entering the 5,000 m race. However, if the athlete's goal is to win a medal, she should also pay attention to the development of speeding ability. Athletes must not have apparent shortcomings; otherwise, the final ranking will probably be affected by the 500 m score. Athletes with outstanding 500 m scores are easier to win a medal. Moreover, one can notice that the medal winners of laps 9 and 13 of the 5,000 m race do not outspeed the non-winners. This seems to reveal that having faster speed in the first half of the 5,000 m race can be more conducive to good results. Previous studies have reported that active start-up acceleration and forward speed are conducive to achieving better athletic performance (Muehlbauer et al., 2010). This revelation also provides a reference for athletes to formulate competitive strategies. Previous studies have also shown that the decrease in the second half

TABLE 1 | Validity evaluation of different prediction models for the 5,000 m final of women's all-around speed skating event.

ML	Accuracy	Sensitivity	Precision	F1 Score
SVM	0.78 ± 0.03	0.77 ± 0.05	0.73 ± 0.04	0.75 ± 0.03
RF	0.76 ± 0.04	0.81 ± 0.06	0.67 ± 0.03	0.73 ± 0.03
LR	0.77 ± 0.04	0.76 ± 0.05	0.66 ± 0.08	0.70 ± 0.05
KNN	0.72 ± 0.01	0.71 ± 0.11	0.68 ± 0.04	0.69 ± 0.06
NB	0.62 ± 0.01	0.57 ± 0.04	0.66 ± 0.05	0.63 ± 0.04
NN	0.72 ± 0.03	0.65 ± 0.04	0.71 ± 0.04	0.68 ± 0.05

SVM, support vector machine; RF, random forest; LR, logistic regression; KNN, K-nearest neighbor; NB, naive Bayes; NN, neural network.

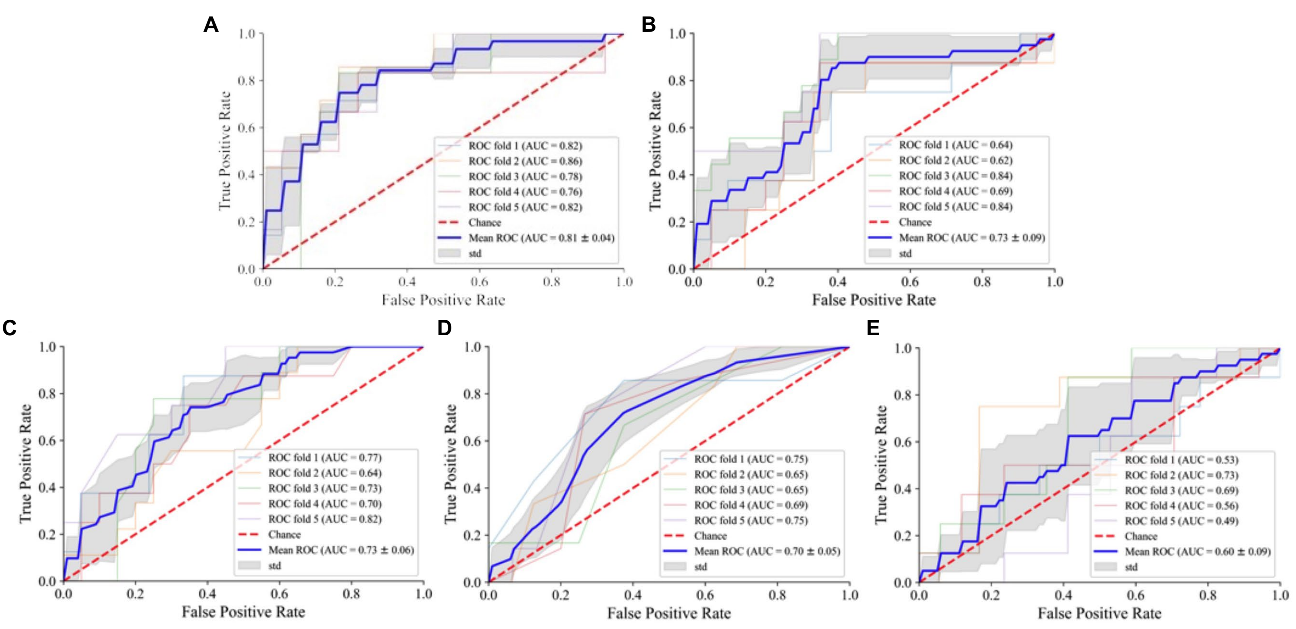

FIGURE 4 | ROC curve of different models of women's speed skating medals. **(A)** SVM: support vector machine; **(B)** RF: random forest; **(C)** LR: logistic regression; **(D)** KNN: K-nearest neighbor; **(E)** NB: naive Bayes.

of the competition speed may increase the push-off angle associated with fatigue (Noordhof et al., 2013). Therefore, improving the technical stability of athletes in a fatigued state is crucial to improving sports performance. This also provides a particular idea for the election of athletes. When all-around speed skaters are elected among women athletes, sufficient attention should be paid to those with excellent aerobic capacity and explosive power.

Since modeling in this study aims to determine the probability of athletes entering the finals and winning medals, six classification algorithms were selected when each model was established. The most commonly used ML algorithms in sports include SVM, RF, LR, KNN, NB, and NN (Horvat et al., 2020). Some of these algorithms have been applied to predict the performance of some events. For example, Ofoghi et al (2013a) used *K*-means combined with traditional statistical methods to model the performance prediction of athlete election after the all-around track cycling competition system was changed, which effectively helped coaches elect athletes and develop the appropriate training plan. The research by Dwyer et al. found that the triathlon performance prediction model based on the NB algorithm is also effective. This model helps coaches and athletes formulate reasonable competitive strategies to optimize athletes' sports performance (Ofoghi et al., 2016). In addition, other researchers have also used different ML algorithms for performance prediction in different events (Richter et al., 2021). In this study, ML proves effective and feasible in predicting the performance ranking in women's all-around speed skating event by learning from past competition data and establishing a viable model. Theoretically, these six models can predict performance, but the comparison has revealed differences in the predicted performance between the prediction models built on different ML algorithms. For the 5,000 m final prediction model, the AUC values of SVM, RF, LR, KNN, and NN are similar. The SVM-based instance model has achieved the best overall performance, while the AUC value of the NB-based instance is only 0.64, and its accuracy, sensitivity, and F1 score are also low (**Table 1**). For the medal model, the SVM-based instance of the medal model has also shown a good performance (**Table 2**), while the NB-based instance has performed relatively poorly, and the NN-based instance has failed.

TABLE 2 | Effectiveness of the prediction models for women's all-around speed skating medal.

ML	Accuracy	Sensitivity	Precision	F1 score
SVM	0.80 ± 0.07	0.71 ± 0.06	0.63 ± 0.04	0.67 ± 0.08
RF	0.73 ± 0.02	0.43 ± 0.08	0.58 ± 0.02	0.49 ± 0.05
LR	0.78 ± 0.06	0.42 ± 0.08	0.8 ± 0.2	0.55 ± 0.08
KNN	0.75 ± 0.07	0.51 ± 0.06	0.63 ± 0.8	0.55 ± 0.8
NB	0.60 ± 0.07	0.59 ± 0.06	0.42 ± 0.08	0.49 ± 0.06

The above differences may be ascribed to the characteristics of different algorithms. Based on conditional probability, the NB algorithm uses Bayes' theorem to calculate the probability by determining the combination of the frequency and the historical data values. It also rests on the assumption of a given output and that the interclass attributes are independent, but this assumption is difficult to hold in practice (Rish, 2001). The same is true in this study. The NN algorithm has very high requirements on data size, which may be the reason for not being able to establish the medal model. The SVM is highly applied in solving relatively small sample predictions and is more sensitive to data. Given the relatively small dataset in this study, the final decision function of SVM has been determined by only a few support vectors. The computational complexity depends on the number of support vectors rather than on the dimensionality of the sample space, and the direct association between the input variables in this study avoids the "curse of dimensionality" in some sense (Shalev-Shwartz et al., 2011). The SVM algorithm is widely used in the domain of sports. For example, the maximum oxygen uptake prediction model established by the SVM algorithm has good prediction accuracy (Abut and Akay, 2015), the gait diagnosis model established by Begg et al. through SVM is also of high applied value (Begg et al., 2005), and the Chinese Super League ranking model built on the SVM algorithm also has high accuracy (Li et al., 2020). From the results of this research, the SVM algorithm is also feasible for performance prediction. The NB algorithm has shown application prospects for predicting the performance of complex events in previous studies, such as all-around track cycling (Ofoghi et al., 2013a), triathlon (Ofoghi et al., 2016), decathlon (Trevor et al., 2002). However, because the NB algorithm assumes that the sample attributes are independent, its effect is not satisfactory when the sample attributes are correlated. In this study, the included features may have a strong correlation, such that the NB algorithm

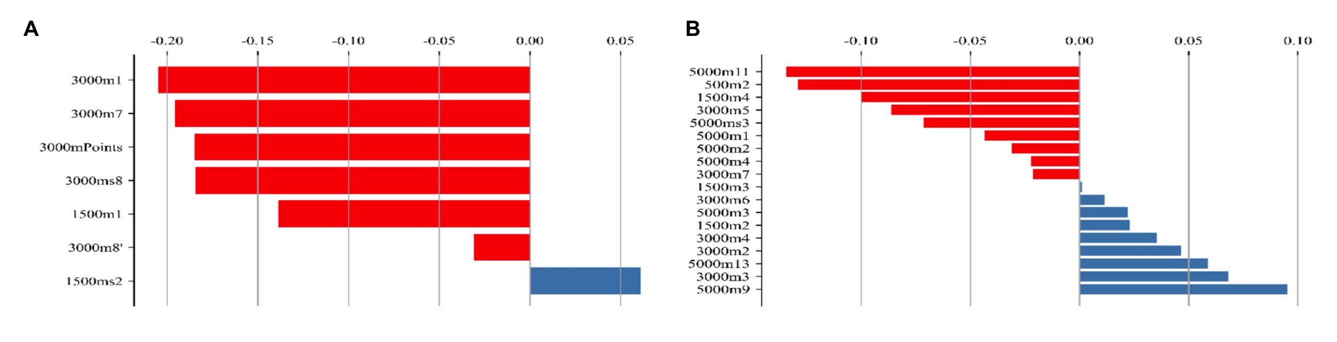

FIGURE 5 | Weight of feature. **(A)** The feature weights of the 5,000 m race model; **(B)** the feature weights of the medal model.

becomes less suitable for the prediction model. NN is considered an excellent ML algorithm, but the model has poor interpretability due to the extremely high data requirements and the "black box" problem. Still, the research results show that NN does not necessarily outperform other ML algorithms in performance prediction (Bunker and Susnjak, 2022).

To sum up, the present work is that it provides information that can be used to predict future performances in women's all-around speed skating with a certain level of accuracy. The mathematical models that form the basis for these predictions were developed from an analysis of historical race data. We believe that our analytical approach is reasonable to be confident about the accuracy of our results. Although we have performed a great deal of work, this study still had some limitations. First, this research has overfitted the available data when using NN to build the medal prediction model due to the relative lack of data. In the future, with the increase in data size, neural networks will be helpful in prediction. Secondly, ignoring the different event settings, this study failed to explore men's all-around speed skating event. Future research can conduct a comparative study between men's and women's events.

CONCLUSION

The ML algorithm has proven feasible in predicting women's all-around speed skating competition performance. The prediction model built on SVM has proven more suitable for predicting women's all-around speed skating competition performance compare with LR, RF, KNN, NB, and NN. Female speed skaters with excellent results in the 3,000 m race are entitled to enter the all-around final, while athletes with outstanding results in the 500 m race are strong competitors for a medal.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding authors.

AUTHOR CONTRIBUTIONS

KZ, DB, ML, and JZ: design and/or conceptualization of the study. KZ, ML, YC, LZ, JZ, and DB: analysis and/or interpretation of the data. KZ, JZ, and DB: drafting and/or revising the manuscript. All authors contributed to the article and approved the submitted version.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2022.915108/full#supplementary-material

REFERENCES

Abut, F., and Akay, M. F. (2015). Machine learning and statistical methods for the prediction of maximal oxygen uptake: recent advances. *Med Devices (Auckl)* 8, 369–379. doi: 10.2147/mder.S57281

Alhamzawi, R., and Ali, H. T. M. (2018). The Bayesian adaptive lasso regression. *Math. Biosci.* 303, 75–82. doi: 10.1016/j.mbs.2018.06.004

Austin, P. C., Tu, J. V., Ho, J. E., Levy, D., and Lee, D. S. (2013). Using methods from the data-mining and machine-learning literature for disease classification and prediction: a case study examining classification of heart failure subtypes. *J. Clin. Epidemiol.* 66, 398–407. doi: 10.1016/j.jclinepi.2012.11.008

Begg, R., and Kamruzzaman, J. J. J. (2005). A machine learning approach for automated recognition of movement patterns using basic, kinetic and kinematic gait data. *J. Biomech.* 38, 401–408. doi: 10.1016/j.jbiomech.2004.05.002

Blythe, D., and Király, F. J. (2016). Prediction and quantification of individual athletic performance of runners. *PLoS One* 11:e0157257. doi: 10.1371/journal.pone.0157257

Breiman, L. (2001). Random forests. *JML* 45, 5–32.

Bruce, P., Bruce, A., and Gedeck, P. (2020). *Practical Statistics for Data Scientists: 50+ Essential Concepts Using R and Python*. Newton, MA: O'Reilly Media.

Bunker, R., and Susnjak, T. (2022). The application of machine learning techniques for predicting results in team sport: a review. *J. Artif. Intell. Res.* 73, 1285–1322. doi: 10.48550/arXiv.1912.11762

Hashem, H., Vinciotti, V., Alhamzawi, R., and Yu, K. (2016). Quantile regression with group lasso for classification. *ADAC* 10, 375–390. doi: 10.1007/s11634-015-0206-x

Horvat, T., Job, J., and Discovery, K. (2020). The use of machine learning in sport outcome prediction: a review. *Wiley Interdiscip. Rev. Data Min. Knowl.* 10:e1380. doi: 10.1002/widm.1380

Huang, C., and Jiang, L. (2021). Data monitoring and sports injury prediction model based on embedded system and machine learning algorithm. *Microprocess. Microsyst.* 81:103654. doi: 10.1016/j.micpro.2020.103654

Karnuta, J. M., Luu, B. C., Haeberle, H. S., Saluan, P. M., Frangiamore, S. J., Stearns, K. L., et al. (2020). Machine learning outperforms regression analysis to predict next-season Major League Baseball player injuries: epidemiology and validation of 13,982 player-years From performance and injury profile trends, 2000-2017. *Orthop. J. Sports Med.* 8:2325967120963046. doi: 10.1177/2325967120963046

Kholkine, L., Servotte, T., de Leeuw, A. W., De Schepper, T., Hellinckx, P., Verdonck, T., et al. (2021). A learn-to-rank approach for predicting road cycling race outcomes. *Front. Sports Act. Living* 3:714107. doi: 10.3389/fspor.2021.714107

Li, Y., Ma, R., Gonçalves, B., Gong, B., Cui, Y., Shen, Y. J. C., et al. (2020). Data-driven team ranking and match performance analysis in Chinese Football Super League. *Chaos Solit. Fractals* 141:110330. doi: 10.1016/j.chaos.2020.110330

Maier, T., Meister, D., Trösch, S., and Wehrlin, J. P. (2018). Predicting biathlon shooting performance using machine learning. *J. Sports Sci.* 36, 2333–2339. doi: 10.1080/02640414.2018.1455261

Muehlbauer, T., Panzer, S., and Schindler, C. (2010). Pacing pattern and speed skating performance in competitive long-distance events. *J. Strength Cond. Res.* 24, 114–119. doi: 10.1519/JSC.0b013e3181c6a04a

Noordhof, D. A., Foster, C., Hoozemans, M. J., and de Koning, J. J. (2013). Changes in speed skating velocity in relation to push-off effectiveness. *Int. J. Sports Physiol. Perform.* 8, 188–194. doi: 10.1123/ijspp.8.2.188

Noordhof, D. A., Mulder, R. C., de Koning, J. J., and Hopkins, W. G. (2016). Race factors affecting performance times in elite long-track speed skating. *Int. J. Sports Physiol. Perform.* 11, 535–542. doi: 10.1123/ijspp.2015-0171

Novak, A. R., Bennett, K. J. M., Fransen, J., and Dascombe, B. J. (2018). A multidimensional approach to performance prediction in Olympic distance cross-country mountain bikers. *J. Sports Sci.* 36, 71–78. doi: 10.1080/02640414.2017.1280611

Ofoghi, B., Zeleznikow, J., Dwyer, D., and Macmahon, C. (2013a). Modelling and analysing track cycling Omnium performances using statistical and machine learning techniques. *J. Sports Sci.* 31, 954–962. doi: 10.1080/02640414.2012.757344

Ofoghi, B., Zeleznikow, J., MacMahon, C., and Dwyer, D. (2013b). Supporting athlete selection and strategic planning in track cycling omnium: a statistical and machine learning approach. *Inf. Sci.* 233, 200–213. doi: 10.1016/j.ins.2012.12.050

Ofoghi, B., Zeleznikow, J., Macmahon, C., Rehula, J., and Dwyer, D. (2016). Performance analysis and prediction in triathlon. *J. Sports Sci.* 34, 607–612. doi: 10.1080/02640414.2015.1065341

Pedregosa, F., Varoquaux, G., Gramfort, A., Michel, V., Thirion, B., Grisel, O., et al. (2011). Scikit-learn: machine learning in Python. *J. Mach. Learn. Res.* 12, 2825–2830. doi: 10.48550/arXiv.1201.0490

Richter, C., O'Reilly, M., and Delahunt, E. (2021). Machine learning in sports science: challenges and opportunities. *Sports Biomech.* 1–7. doi: 10.1080/14763141.2021.1910334

Rish, I. (2001). An empirical study of the naive Bayes classifier. *Int. J. Recent Innov.* 1:127.

Sarlis, V., and Tjortjis, C. J. I. S. (2020). Sports analytics—evaluation of basketball players and team performance. *Inf. Syst.* 93:101562. doi: 10.1016/j.is.2020.101562

Shalev-Shwartz, S., Singer, Y., Srebro, N., and Cotter, A. (2011). Pegasos: primal estimated sub-gradient solver for SVM. *Math. Program.* 127, 3–30. doi: 10.1007/s10107-010-0420-4

Smyth, B., and Willemsen, M. C. (2020). "Predicting the personal-best times of speed skaters using case-based reasoning," in *International Conference on Case-Based Reasoning* (Springer), 112–126.

Stehman, S. (1997). Selecting and interpreting measures of thematic classification accuracy. *Remote Sens. Environ.* 62, 77–89. doi: 10.1016/S0034-4257(97)00083-7

Tian, C., De Silva, V., Caine, M., and Swanson, S. J. A. S. (2020). Use of machine learning to automate the identification of basketball strategies using whole team player tracking data. *Appl. Sci.* 10:24. doi: 10.3390/app10010024

Tibshirani, R. (1996). Regression shrinkage and selection via the lasso. *J. R. Stat. Soc. Series B* 58, 267–288. doi: 10.1111/j.2517-6161.1996.tb02080.x

Trevor, F., Ryan, T., and Cox, D. (2002). An analysis of decathlon data. *J. R. Stat. Soc. Series D* 51, 179–187. doi: 10.1111/1467-9884.00310

Yarkoni, T., and Westfall, J. (2017). Choosing prediction over explanation in psychology: lessons from machine learning. *Perspect. Psychol. Sci.* 12, 1100–1122. doi: 10.1177/1745691617693393

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EDITED BY
José Luis Losada,
University of Barcelona, Spain

REVIEWED BY
Asier Gonzalez-Artetxe,
University of the Basque Country, Spain
Yousri Elghoul,
University of Sfax, Tunisia

*CORRESPONDENCE
Júlio A. Costa
jahdc@hotmail.com

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Training in women soccer players: A systematic review on training load monitoring

Júlio A. Costa[1]*, Vincenzo Rago[2], Pedro Brito[3], Pedro Figueiredo[1,4,5], Ana Sousa[3], Eduardo Abade[1,3] and João Brito[1]

[1]Portugal Football School, Portuguese Football Federation, Oeiras, Portugal, [2]Faculty of Health Sciences and Sports, Universidade Europeia, Lisbon, Portugal, [3]Research Center in Sports Sciences, Health Sciences and Human Development, University of Maia, Maia, Portugal, [4]Research Center in Sports Sciences, Health Sciences and Human Development, Vila Real, Portugal, [5]Centro de Investigação em Desporto, Educação Física, Exercício e Saúde, Universidade Lusófona, Lisbon, Portugal

Objective: The present systematic review aimed to provide an overview of training load (TL), along with their responses, monitoring during training sessions in highly trained and elite adult women soccer players.

Data source: Electronic databases searches (PubMed, Scopus, Web of Science and Ebsco) for relevant studies published in peer-reviewed journals were conducted, and eligibility criteria were based on the PICOS model in accordance with PRISMA guidelines.

Study selection: Studies were considered as follows: (a) highly trained and elite adult (>18 years) women's soccer players; (b) continuous (minimum 1-week duration) TL monitoring in the context of the team routine; (c) TL collected from entire training session. Methodological qualitative assessments and risk of bias criteria were used for judging the studies.

Data extraction: A total of 1,163 studies were identified, and 16 were included. The selected studies were fully screened to extract the population characteristics; the number of players; a type of study design; region where the study was performed; the main findings.

Data synthesis: Accumulated external TL (ETL) during the pre-season was positively correlated to enhanced adaptations in intermittent exercise capacity. Daily ETL was negatively correlated to next-day self-reported fatigue and muscle soreness. Daily internal TL (ITL) was negatively correlated to post-session sleep duration and sleep efficiency. One study showed that higher accumulated player load and total distance were associated with injury.

Conclusion: Information about TL during training sessions in women soccer players is very sparse, and it is currently very difficult to consider evidence-based practices for training sessions in highly trained and elite adult women soccer players. Moreover, the dose–response relationships between TL and training outcome (e.g., fatigue, training adaptations and injuries) need to be further explored to understand the optimal training stimulus to enhance performance outcomes while preserving player health.

KEYWORDS

workload, global positioning systems, heart rate, rating of perceived exertion, female athletes

Introduction

The popularity of women's soccer has markedly increased over the last 10 years (Randell et al., 2021). Alongside, the professionalism has also increased, and current elite players might be exposed to higher training and competitive demands than before, possibly having implications for both performance and health (Datson et al., 2014). However, a recent bibliometric analysis noted that studies investigating elite women soccer players account for just around 15% of all soccer research published (Kirkendall and Krustrup, 2021), while several match- and training-related topics specifically dedicated to women's soccer are still in need of greater attention.

In women's soccer, as well as the male equivalent, it is incumbent that coaches and support staff optimize the health, well-being, and performance of the players. But in contrast to men's soccer, and largely due to the increased female participation, science has struggled to keep pace with the demand for evidence-based studies to inform practice (Okholm Kryger et al., 2021). In a recent narrative review (Randell et al., 2021), it has been reported that the most popular publication topics related to women's soccer are sports medicine, physiological, health and performance outcomes.

Within this context, a better understanding of the training process in elite women soccer players is vital to define appropriate strategies that may contribute to enhance performance, accelerate recovery, and reduce injury risk. Collectively, training responses, fatigue and injury risk can be described as training outcomes. However, the interplay between training load (TL), fatigue and injury risk is still unclear (Jaspers et al., 2017). Moreover, to the best of our knowledge, this information is yet to be reviewed in women soccer players.

Recent systematic reviews conducted in men's and women's soccer describing published TL practices (including data collection and interpretation) revealed that information about women's soccer is very sparse (Rago et al., 2019a,b; Torres-Ronda et al., 2022). These reviews considered methods to collect and interpret TL, such as wearable technology incorporating global positioning systems (GPS) to quantify the external TL (ETL; Rago et al., 2019a; Torres-Ronda et al., 2022), the rating of perceived exertion (RPE) and the session-RPE (s-RPE: perceived intensity multiplied by the exposure time) to subjectively quantify internal TL (ITL; Rago et al., 2019b; Torres-Ronda et al., 2022). Quantified ITL methods (such as heart rate, HR) have also been included.

Therefore, considering the scarce literature and the aforementioned potential advantages associated with a better understanding of training, the present systematic review aimed to provide an overview of ETL and ITL monitoring during training sessions in highly trained and elite adult women soccer players, with a special focus on fatigue, training adaptions and injuries.

Methods

This systematic review was conducted according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines (Page et al., 2021). The protocol was registered at the International Platform of Registered Systematic Review and Meta-analysis Protocols (INPLASY 2021120038).

Eligibility criteria

For the current systematic review, eligibility criteria were based on the PICOS model in accordance to the PRISMA statement (Shamseer et al., 2015) and other systematic reviews published regarding team routines in soccer (Rago et al., 2019a,b; Torres-Ronda et al., 2022); *Study design:* observational; *Participants and setting*: highly trained and elite adult (>18 years) women's soccer players (Mckay et al., 2022) (i.e., players competing at the international leagues/tournaments; players competing in national and/or state leagues/tournaments; individuals on a national team); *Interventions*: continuous TL monitoring during training sessions in the context of the team routine; *Outcomes*: TL collected from entire training session; *Timing*: minimum 1-week duration of training.

Literature search strategy

A systematic search was conducted in PubMed, Scopus, Web of Science and EBSCO combining the following groups of key words in the title, abstract or key words: (women OR female) AND (football OR soccer) AND (elite OR professional OR top-level OR highly trained) AND (load OR intens* OR volume OR training OR monitor* OR quantif* OR speed OR acceleration OR heart rate OR subjective OR rat* OR perce* effort OR exertion) AND (GPS OR "global positioning system" OR LPS OR "local positioning system" OR "time motion" OR physiolog*) AND (fatigue OR adaptations OR performance OR testing OR injury) AND NOT ("American Football" OR "Australian Football" OR AFL). The search was restricted to English peer-reviewed journals from 2000 to April 2022. Then, we further searched the relevant literature using the 'related citations' function of PubMed and by scanning reference lists of each article.

Study selection

All records were exported to EndNote (Clarivate Analytics, Philadelphia, PA, United States) and duplicates were removed by using an automated tool and checked manually. Two authors (JC and PB), independently performed the searches and reviewed the studies. In case of disagreement, inclusion was discussed, and unresolved discrepancies were settled by a third reviewer (JB).

The articles were considered if published on-line regardless of the publication status. To investigate continuous TL monitoring during training sessions, we included articles with a minimum of 1-week duration, respective of sex and study focus (e.g., studies reporting descriptive data of TL without studying its effects were included). Articles were excluded if: the participants (a) were not all highly trained and elite adult women soccer players (e.g., mixed samples including highly trained/elite adult elite and non-highly trained and non-elite players); (b) were aged under 18; (c) were not monitored longitudinally over a minimum of a 1-week duration, or five sessions if the duration was not stated (friendly matches were considered training sessions), to consider continuous monitoring practices (Rago et al., 2019a,b); (d) the articles did not report any TL indicators as described by Halson (2014); single drills were monitored rather than the entire training session, or the article focused on the comparison between a specific drill and match demands; (e) data from training sessions were not reported; and (f) the articles were editorials or reviews. In the event of ambiguity in the title or abstract, the full-text article was checked for verification by two independently authors (JC and PB). The full-text articles of the remaining studies were then downloaded and archived. The references of the selected articles were then screened to identify any potentially relevant articles not identified by the original search. Afterward, the corresponding authors of the selected articles were contacted (via e-mail or social media) requesting missing information. When contacted, the authors were informed about the purpose of the study and no conflict of interest was declared. Information provided by the authors was labeled within the tables.

Data extraction and management

All data on study characteristics and outcomes were extracted from all included studies by one author (PB) and subsequently reviewed by other author (JC).

The selected studies were fully screened to extract the population characteristics (i.e., age and competitive level); number of player's and training sessions; type of study design; region where the study was performed; training period and duration; the monitoring TL method used; and the synthesis of main findings. If reported, TL data and the correlations between TL and training outcomes (fatigue, training adaptations, and injury risk) were also extracted. Only data exclusively related to training sessions have been extracted (i.e., match data have been excluded).

Quality assessment of included studies

Two independent authors (JC and EA) assessed the quality of the included studies. The quality score of each study was based on a 16-item checklist adapted from a previous systematic review in soccer (Sarmento et al., 2018). Publications were evaluated based on: (1) clarity of purpose; (2) relevance of background literature; (3) appropriateness of the study design; (4) study sample; (5) sample size justification; (6) informed consent (if any); (7) outcome measures – reliability; (8) outcome measures – validity; (9) detailed method description; (10) significance of results reporting; (11) analysis methods; (12) practical importance; (13) description of drop-outs (if any); (14) appropriately conclusions; (15) practical implications; (16) study limitations. A binary scale was used to score these items (1 = yes; 0 = no), except for items (6) and (13), which could also be classified as not applicable (n/a). After that, a percentage score was calculated for each study by summing the scores of all items and dividing that by the maximum score the study could achieve. The publications' quality score was classified as: (1) low methodological quality for scores $\leq$ 50%; (2) good methodological quality for scores between 51% and 75%;

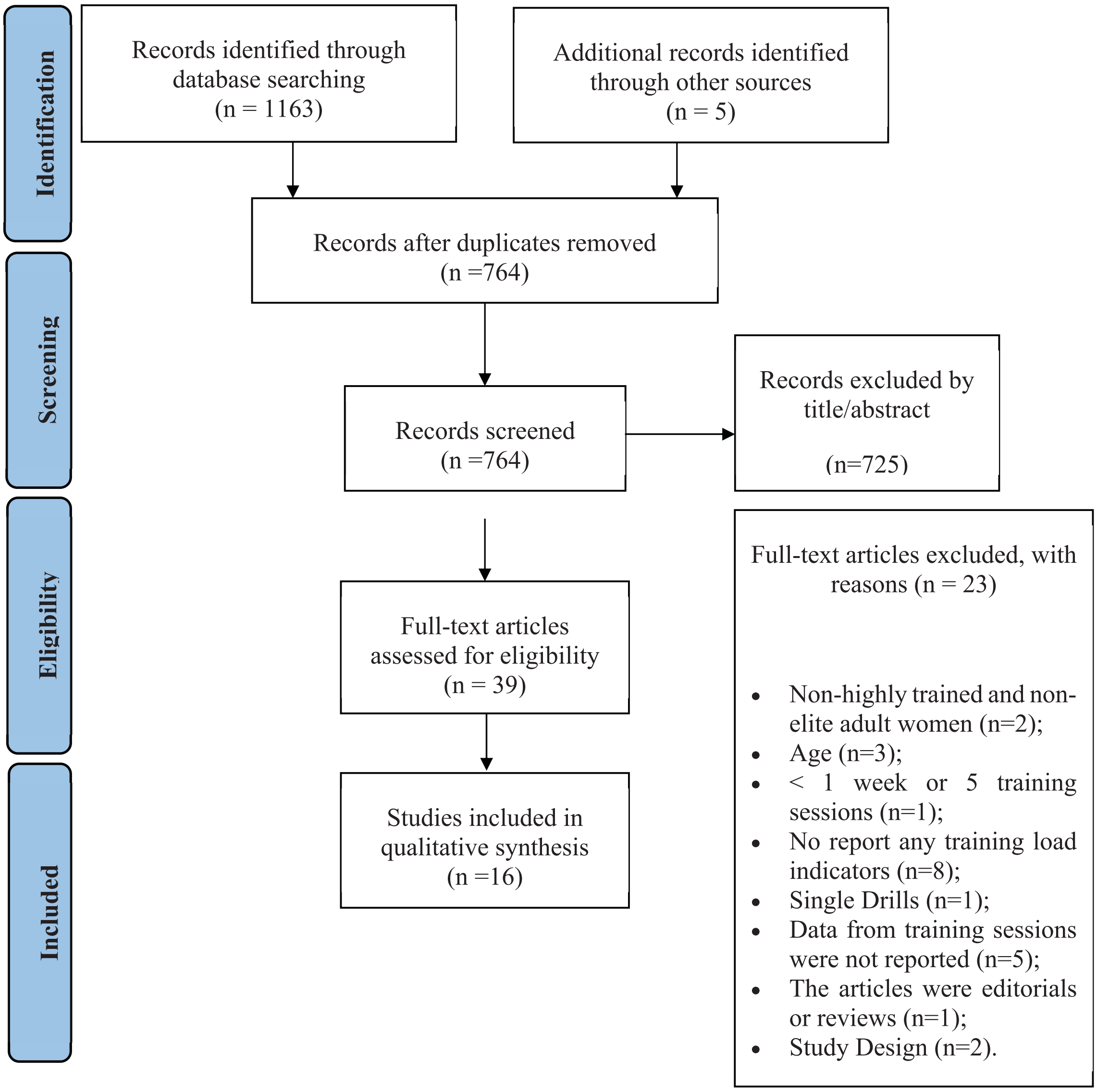

FIGURE 1
Preferred reporting items for systematic reviews and meta-analyses (PRISMA) diagram of the literature search results.

and (3) excellent methodological quality for scores >75% (**Supplementary Table 1**).

Risk of bias

Two independent authors (VR and PB) underwent a calibration exercise, and then assessed the risk of bias of TL monitoring studies in women's soccer (observational designs) using the Risk of Bias Assessment tool for Non-randomized Studies (RoBANS) tool (Kim et al., 2013; **Supplementary Table 2**). Conflicts were resolved through discussion among the pair of reviewers or through consultation with a third reviewer (JB).

Results

Study selection and study characteristics

Initially, *1163* records were identified. After removing duplicates, screening the titles and full texts, 16 original articles met the inclusion criteria (**Figure 1**).

The selected articles were published from January 2000 to April 2022. Thirteen studies were conducted *across* various national leagues at the club level (Mara et al., 2015a,b; Costa et al., 2018a,b, 2019b,c, 2021a,b; Clemente et al., 2019; Douchet et al., 2021; Fernandes et al., 2021;

Romero-Moraleda et al., 2021; Xiao et al., 2021), while three studies were conducted in a National team setting (Scott and Lovell, 2018; Costa et al., 2019a; Doyle et al., 2021). The selected studies were predominantly conducted during periods lasting 1 to 25 weeks (Mara et al., 2015a,b; Costa et al., 2018a, 2019b,c, 2021a,b; Clemente et al., 2019; Douchet et al., 2021; Fernandes et al., 2021; Romero-Moraleda et al., 2021; Xiao et al., 2021) or during international tournaments lasting 10 to 21 days (Scott and Lovell, 2018; Costa et al., 2019a; Doyle et al., 2021). Only one study considered more than one entire season (i.e., three seasons), lasting 15 months (i.e., 5 months each season) (Xiao et al., 2021). A detailed description of the selected studies is reported in **Table 1**.

Quality assessment of the studies

The mean methodological quality score for the 16 selected articles was 93.3%, with two articles achieving the maximum score of 100% (**Table 1**). Among the nine selected studies, the quality score ranged between 86.7 and 100%. All articles achieved an overall rating score of >75% (excellent methodological quality). Potential limitations found were mainly related to the lack of explicit justification for the sample size (criterion 5) and the absence of clear acknowledgment of study limitations (criterion 16).

Risk of bias

The "selection of the participant," "exposure measurement," "blinding outcome assessment" and "incomplete outcome data" were judged as low risk of selection of bias in 100% of the studies (**Figure 2**). For most of the studies (n = 14), the "confounding variables" domain was judged as low risk of selection of bias (87.5%), with two studies being judged as unclear, due to unclarity on the type (i.e., content) of training sessions practiced per week. For most of the studies (n = 14) (87.5%) displayed unclear risk of bias to "selective outcome reporting" domain, because the studies did not clearly describe the exact number of players considered for the respective statistical analyses. No studies were judged with high risk of bias for each domain.

Training load quantification methods

Regarding ETL during training sessions (**Table 2**), eight studies have adopted speed-based intensity zones using arbitrary/fixed thresholds (between 12.2 and 18 km·h^{-1}) (Mara et al., 2015a,b; Clemente et al., 2019; Costa et al., 2019a; Douchet et al., 2021; Doyle et al., 2021; Romero-Moraleda et al., 2021; Xiao et al., 2021), while one study considered individual fitness level (Scott and Lovell, 2018). Two studies reported that players covered greater total distance and high-speed distance (>12.2 km·h^{-1}) during the pre-season compared to early competitive season, and then decreased late in the season (Mara et al., 2015b; Clemente et al., 2019). On the other hand, three studies reported that total distance and high-speed distance (>12.6 km·h^{-1} and >maximal aerobic speed [MAS]) were stable in training sessions during international tournaments, independently of the data reported for official matches (Scott and Lovell, 2018; Costa et al., 2019a; Doyle et al., 2021).

Internal training load was quantified using HR- and RPE-based methods (**Table 2**). Seven studies quantified ITL using HR (Costa et al., 2018a,b, 2019b,c, 2021b; Scott and Lovell, 2018; Douchet et al., 2021). Seven studies individualized physiological responses to exercise relative to HR_{max} obtained by an incremental protocol until exhaustion (Costa et al., 2018a,b, 2019b,c, 2021a,b; Scott and Lovell, 2018). Six studies quantified ITL using RPE (Scott and Lovell, 2018; Costa et al., 2019c; Douchet et al., 2021; Doyle et al., 2021; Fernandes et al., 2021; Romero-Moraleda et al., 2021), while ten studies reported s-RPE (Costa et al., 2018a,b, 2019a,b,c, 2021a,b; Douchet et al., 2021; Doyle et al., 2021; Romero-Moraleda et al., 2021).

Training load and fatigue

The relationship between TL and fatigue has been examined in eight studies (Mara et al., 2015b; Costa et al., 2018a, 2019a,b, 2021b; Scott and Lovell, 2018; Douchet et al., 2021; Fernandes et al., 2021). During a 9-day international tournament, no significant within-subject correlations were observed between post-training night sleep parameters (e.g., total sleep time and sleep efficiency) and ETL metrics (e.g., distance and high-speed distance) (Costa et al., 2019a). On the other hand, small to moderate (r = −0.43 to −0.17) within-subject correlations were observed between ITL (s-RPE and training impulse [TRIMP]) and sleep parameters (sleep duration and efficiency) during a 14-day competitive period (Costa et al., 2021b). Moreover, significant differences in sleep patterns and autonomic nervous activity responses when night training sessions were compared to competitive day matches and rest days, suggesting that the time of day for soccer practice may disrupt sleep patterns and nocturnal autonomic activity (Costa et al., 2018a, 2019b). In addition, Douchet et al. (2021) showed that a week with more accelerations and decelerations were significantly associated (r = 0.94) with increased fatigue as witnessed by the greater RPE and perceived well-being (i.e., Hooper index). Associations were also found between perceived well-being (i.e., stress and fatigue) and s-RPE (r = 0.69) during a 10-week competitive period (Fernandes et al., 2021).

Self-reported measures of fatigue have shown significant associations with ELT (e.g., high-speed

TABLE 1 Studies quantifying training load in highly trained and elite adult women's soccer players over a minimum of 1 week ($n = 16$), and respective quality score.

Reference	Population characteristics (age and level)	Number of players/Sessions /Region	Type of study design	Period/Duration	Monitoring training load method	Synthesis of main findings	Quality score (%)
Clemente et al., 2019	23.6 ± 4.8/National league	89/6–7 training sessions + non-official match/Germany and Portugal	Prospective cohort study	Pre-season/5 weeks	GPS	Small-to-moderate intra-week load variance and no significant changes in weekly load variances based on total distance and sprinting distance. Significant differences were found between training days considering the duration ($p = 0.011$), walking distance ($p = 0.017$), running distance ($p = 0.004$), player's load ($p = 0.040$) and number of sprints ($p = 0.006$).	93.3%
Costa et al., 2018a	21.4 ± 2.1/National league	18/8/Portugal	Single-group longitudinal	Competitive/3 weeks	HR, s-RPE	TRIMP, HR_{mean} and s-RPE varied throughout the week.	93.3%
Costa et al., 2018b	21.5 ± 0.9/National league	11/3/Portugal	Single-group observational	Competitive/1 week	HR, s-RPE	Descriptive values only.	86.7%
Costa et al., 2019a	25.2 ± 3.1/National Team	20/6/Portugal	Single-group observational	Competitive/9 days	GPS, s-RPE	Despite the significant day-to-day variations in TD, HSR and s-RPE, these variables were not correlated to post-session total sleep time, sleep efficiency and lnRMSSD.	93.3%
Costa et al., 2019b	21.6 ± 2.3/National league	17/18/Portugal	Single-group longitudinal	Competitive/6 weeks	HR, s-RPE	TRIMP, HR_{mean} and s-RPE were lower on night training days, and higher during away matches.	93.3%
Costa et al., 2019c	21.4 ± 2.1/National league	17/18/Portugal	Single-group observational	Competitive/6 weeks	HR, s-RPE	s-RPE was largely correlated with TRIMP ($r = 0.74$–0.82).	93.3%
Costa et al., 2021a	21.8 ± 2.6/National league	16/Nr/Portugal	Single-group longitudinal	Pre-season/4 weeks	s-RPE	Players improved aerobic fitness, along with increased 24-h cardiac vagal activity. The relative changes in HF24h and HF index were largely correlated with improvements in the distance covered during the Yo-Yo IR1 ($r = 0.68$ and $r = 0.56$; respectively).	100%
Costa et al., 2021b	20.6 ± 2.3/National league	34/8/Portugal	Single-group longitudinal	Competitive/14 days	HR, s-RPE	s-RPE and TRIMP were slightly to moderately correlated with sleep duration and sleep efficiency ($r = -0.43$ to -0.17) but not with HR variability parameters (lnRMSSD, lnLF, lnHF).	93.3%
Douchet et al., 2021	24.2 ± 2.3/National league	12/6/France	Single-group observational	Competitive/2 weeks	GPS, HR, s-RPE	Total number of accelerations and decelerations were greater during the heavy week than during the low week ($p < 0.001$). The mean HR%, total distance, $m \cdot min^{-1}$, RPE, sRPE and the Hooper Index were significantly greater during the heavy week. There were significant differences ($p < 0.001$) between the start and the end of the heavy week for Sleep, Fatigue, and DOMS.	93.3%
Doyle et al., 2021	24.2 ± 4.4/National Team	18/6/Ireland	Single-group observational	Competitive/1 week	GPS, s-RPE	Training load peaked on MD-5 as all variables significantly increased in comparison to MD-6 and MD-7. A significant decrease in volume and intensity was evident on MD-3 due to reductions on TL ($P = 0.001$, $r = 0.60$), TD ($P = 0.001$, $r = 0.60$), VHSR ($P = 0.001$, $r = 0.61$) and SPD ($P = 0.00$, $r = 0.62$). Significant difference in VHSD, SPD and SP between position on MD-2.	93.3%

(Continued)

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TABLE 1 (Continued)

Reference	Population characteristics (age and level)	Number of players/Sessions /Region	Type of study design	Period/Duration	Monitoring training load method	Synthesis of main findings	Quality score (%)
Mara et al., 2015b	Nr/National league	17/90/Australia	Single-group longitudinal	Pre-season and competitive/18 weeks	GPS	Players covered greater TD and HSD during pre-season compared to early season, and then decreased in late season. TL was not correlated with fatigue, muscle soreness, sleep time, and changes in sprint performance. TD, HSR and accelerations were correlated to changes in Yo-Yo IR2 performance from pre-season to early season (r = 0.55–0.70).	86.7%
Romero-Moraleda et al., 2021	26.5 ± 5.7/National league	18/20/Spain	Single-group longitudinal	Competitive/5 months	GPS, s-RPE	The EL and the IL from official matches were higher compared to training sessions ($p < 0.05$; effect size [ES]:0.6–5.4). The training sessions MD + 1 and MD-2 showed the lowest EL and IL values. During MD, significant differences in EL and IL were noted between playing positions, although not during training sessions.	92.9%
Scott and Lovell, 2018	21.9–39.5/National Team	22/16/Australia	Single-group longitudinal	Competitive/21 days	GPS, HR, RPE	Irrespective of the quantification method adopted for HSD and very HSD (fixed or individualized speed zones), negative small correlations were observed with fatigue and soreness (r = −0.25 to −0.14).	92.9%
Xiao et al., 2021	Nr/National league	65/Nr/United States	Prospective cohort study	Competitive/3 seasons	GPS	There were no significant differences in player load, total distance, or high-speed distance ACWR between injured and non-injured players, regardless of the type of ACWR calculation (EWMA and Simple moving average). The prior 2-week, 3-week, and 4-week accumulated player loads were significantly higher for injured players. Similarly, the prior 2-week, 3-week, and 4-week accumulated total distances were significantly higher for injured players.	100%
Fernandes et al., 2021	24.1 ± 2.7/National league	19/30/Portugal	Single-group longitudinal	Competitive/10 weeks	RPE	Associations were found between Hooper Index categories and s-RPE like stress or fatigue (0.693, $p < 0.01$), stress or DOMS (0.593, $p < 0.01$), stress or s-RPE (0.516, $p < 0.05$) and fatigue or DOMS (0.688, $p < 0.01$). No differences were found in playing position or status when considering in-season IL and perceived well-being variation.	93.3%
Mara et al., 2015a	23–30/National league	8/5/Australia	Single-group observational	Pre-season/1 week	GPS	No differences between match and training days (p = 1.00) in mean total energy expenditure, however, significant differences were found between individual training sessions (p = 0.001–0.035). Significant differences with large effect sizes between friendly match and training sessions were found for total distance and HSD, but not sprinting distance, acceleration count or deceleration count.	93.3%

HR, heart rate; HSD, high-speed distance; lnRMSSD, natural logarithm of square root of the mean of the sum of the squares of differences between adjacent NN intervals; lnLF, natural logarithm of low-frequency; lnHF, natural logarithm of high-frequency; s-RPE, session-rating of perceived exertion; Yo-Yo IR1, Yo-Yo Intermittent Recovery – Level 1; Yo-Yo IR2, Yo-Yo Intermittent Recovery – Level 2; TD, total distance; TL, training load; TRIMP, training impulse; DOMS, delayed onset muscle soreness; SWA, SenseWear Mini Armbands; EL, external load; IL, internal load; MD, match-day; ACWR, acute-to-chronic workload rations; EWMA, exponentially weighted moving averages; Nr, not reported.

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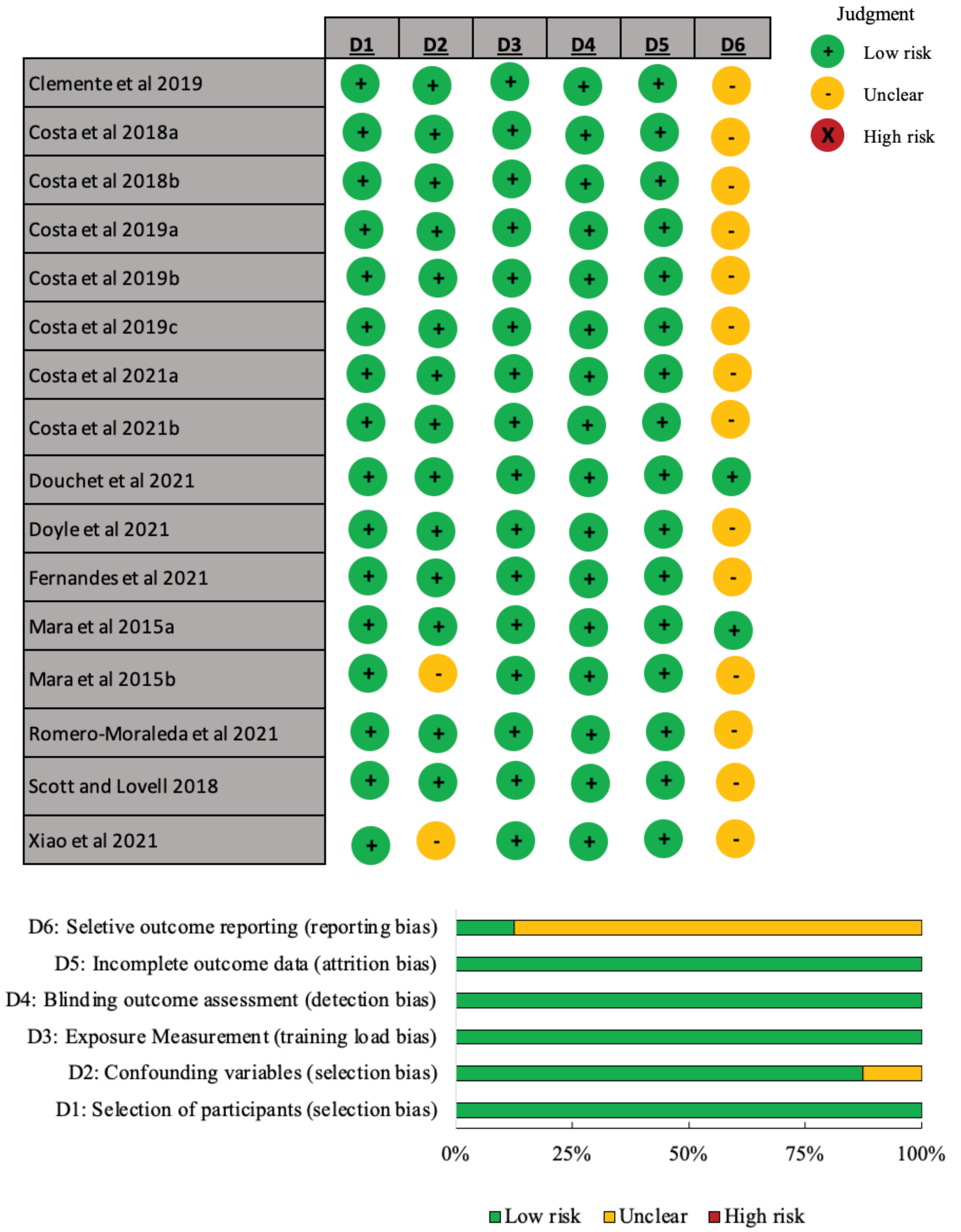

FIGURE 2
Risk of bias judgments for training load monitoring in highly trained and elite adult women's soccer studies through RoBANS.

distance) on the previous day during a tournament (Scott and Lovell, 2018). Scott and Lovell (2018) described that self-reported fatigue and muscle soreness were negatively associated (small magnitude) with high-speed distance covered (r = −0.20) using either fixed (>12.6 km/h^{-1}) or individual thresholds during a 21-day training camp. Finally, Mara et al. (2015b) showed that self-reported fatigue and sleep times were not correlated with the total distance covered >12.6 km·h^{-1}, whereas muscle soreness was negatively correlated (moderate magnitude) with ETL parameters during the pre-season.

TABLE 2 Training load data during training sessions in highly trained and elite adult women soccer players.

Reference	Training load variables	Values	Description
Clemente et al., 2019	TD (m) HSD > 14 km·h^{-1} (m) Sprint distance > 20 km·h^{-1} (m)	3000 to 5000 200 to 400 1000 to 1500	Mean of weekly load (lowest to highest load values) during 5 weeks of the pre-season.
Costa et al., 2018a	HR_{ex} (%HR_{peak}) TRIMP (AU) s-RPE (AU)	70 ± 3 to 75 ± 4 72 ± 18 to 138 ± 29 193 ± 60 to 442 ± 159	Mean ± standard deviations (lowest to highest load values) during 3 weeks of the competitive season.
Costa et al., 2018b	HR_{ex} (bpm) TRIMP (AU) s-RPE (AU)	138 ± 13 to 149 ± 16.8 77 ± 36 to 110 ± 31 281 ± 117 to 369 ± 111	Mean ± standard deviations (lowest to highest load values) during 1 week of the competitive season.
Costa et al., 2019a	TD (m) HSD > 12.6 km·h^{-1} (m) s-RPE (AU)	2201 to 4284 130 to 756 131 to 360	Median (lowest to highest load values) during 9 days of international tournament.
Costa et al., 2019b	HR_{ex} (%HR_{peak}) TRIMP (AU) s-RPE (AU)	74 ± 2 192 ± 21 326 ± 33	Mean ± standard deviations values during 6 weeks of the competitive season.
Costa et al., 2019c	HR_{ex} (bpm) TRIMP (AU) %HR_{peak} Time > 90 of %HR_{peak} (min) s-RPE (AU) RPE (AU)	139 ± 12 211 ± 81 73 ± 6 8 ± 7 338 ± 107 3 ± 2	Mean ± standard deviations values during 6 weeks of the competitive season.
Costa et al., 2021a	s-RPE (AU)	604 ± 70	Mean ± standard deviations value during 4 weeks of pre-season.
Costa et al., 2021b	HR_{ex} (bpm) TRIMP (AU) %HR_{peak} s-RPE (AU)	143 to 147 187 to 189 75 to 77 377 to 411	Mean values during 14 days of the competitive season.
Douchet et al., 2021	TD (m) HSD > 18 km·h^{-1} (m) Number of sprints > 19.4 km·h^{-1}(counts) Accelerations > 2 m·s^{-2} (counts) Decelerations > −2 m·s^{-2} (counts) HR_{ex} (%) s-RPE (AU) RPE (AU)	3870 ± 870; 5090 ± 620 124 ± 61; 155 ± 92 7 ± 3; 7 ± 3 28 ± 12; 56 ± 10 31 ± 12; 61 ± 14 63 ± 6; 67 ± 7 201 ± 47; 357 ± 50 3 ± 1; 5 ± 1	Mean ± standard deviations values during 2 weeks: Low week load (1 week); heavy week load (1 week).
Doyle et al., 2021	TD (m) HSD > 12.6 km·h^{-1} (m) Number of sprints > 19.4 km·h^{-1}(counts) Accelerations > 3 m·s^{-2} (counts) Decelerations > −3 m·s^{-2} (counts) s-RPE (AU) RPE (AU)	3339 to 59335 58 to 389 2 to 14 28 to 56 21 to 46 203 to 721 3 to 7	Median (lowest to highest load values) during 1 week of the competitive season.
Fernandes et al., 2021	RPE (AU)	3 to 6	Mean of weekly load (lowest to highest load values) during 10 weeks of the competitive season.
Mara et al., 2015a	TD (m) HSD > 12.2 km·h^{-1} (m) Sprint distance 19.4 km·h^{-1} (m) Accelerations > 2 m·s^{-2} (counts) Decelerations > −2 m·s^{-2} (counts)	6581 ± 847 880 ± 244 333 ± 107 49 ± 13 18 ± 9	Mean ± standard deviations values during 1 week of the pre-season.
Mara et al., 2015b	TD (m) HSD > 12.6 km·h^{-1} (m) Number of sprints > 19.4 km·h^{-1}(counts) Accelerations > 2 m·s^{-2} (counts) Decelerations > −2 m·s^{-2} (counts)	6646 ± 111; 5437 ± 106 1415 ± 42; 1027 ± 40 27 ± 15; 24 ± 9 56 ± 19; 49 ± 14 22 ± 10; 20 ± 10	Mean ± standard deviations values during 18 weeks: pre-season (6 weeks); competitive season (12 weeks).
Romero-Moraleda et al., 2021	TD (m) HSD > 15 km·h^{-1} (m) Accelerations > 1 m·s^{-2} (counts) Decelerations > −1 m·s^{-2} (counts) s-RPE (AU) RPE (AU)	2496 ± 1639 to 4975 ± 1319 170 ± 214 to 494 ± 248 70 ± 56 to 144 ± 39 17 ± 17 to 38 ± 16 167 ± 134 to 579 ± 139	Mean ± standard deviations (lowest to highest load values) during 5 months of the competitive season.

(Continued)

TABLE 2 (Continued)

Reference	Training load variables	Values	Description
Scott and Lovell, 2018	HSD > 12.6 km·h^{-1} (m) Minutes spent > 80 %HR$_{máx}$ (min) TRIMP (AU) RPE (AU)	250 to 2500 5 to 65 150 to 400 3 to 8	Individual means (lowest to highest load values) during 21 days of the competitive season.
Xiao et al., 2021	TD (m) HSD > 12.9 km·h^{-1} (m)	3662 to 18461 1173 to 4994	Mean accumulated workloads over 4 weeks of the competitive season.

HR, heart rate; HSD, high-speed distance; s-RPE, session-rating of perceived exertion; TD, total distance; TRIMP, training impulse.

Training load and training adaptations

Information of the dose–response relationship between TL and training adaptations in highly trained and elite adult women soccer players is limited to one study (Mara et al., 2015b). Positive correlations were reported between changes in intermittent endurance capacity assessed through performance in the Yo-Yo Intermittent Recovery Test – level 2 after the pre-season (r = 0.70), and accumulated ETL (r = 0.71; r = 0.56, respectively), high-speed distance (>12.6 km·h^{-1}) and accelerations (>2 m·s^{-2}) during the pre-season (Mara et al., 2015b).

Training load and injury

Only one study reported the relationship between TL and injuries (defined as an event that caused the player to miss at least 1 subsequent practice or match and lower extremity injuries) in women soccer players (Xiao et al., 2021), revealing that players that sustained an injury had significantly higher 2-, 3-, and 4-week accumulated TL and total distance covered as compared with injury-free players during the same time frame.

Discussion

In the current systematic review, we confirmed the limited information available about training outcomes in highly trained and elite adult women soccer players, especially in the relationship between TL, training adaptation and injuries (Kirkendall and Krustrup, 2021). Additionally, current monitoring practices in highly trained and elite adult women soccer players are sparse, which underline the need for conducting studies or surveys based on that implemented in men's soccer (Akenhead and Nassis, 2016).

External training load monitoring

Wearable microtechnology incorporating GPS, local positioning systems or triaxial accelerometers have shown good ability to measure ETL based on distance, speed, and accelerations in team sports (Scott et al., 2016; Torres-Ronda et al., 2022). In this context, one key aspect of training prescription is to understand how the individual athlete is coping with the imposed training demands. While the use of individualized intensity zones to quantify ITL (e.g., based on HR_{max} or $HR_{reserve}$) is widely adopted among sports practitioners, especially in men's soccer (Dellal et al., 2012; Akenhead and Nassis, 2016), the use of individualized intensity zones for ETL quantification (based on speed and acceleration) is not fully established, especially in women's soccer. Actually, the individualization of speed-based EL based on testing metrics (e.g., MAS; and maximal sprinting speed, MSS) has received increased attention in adult men (Hunter et al., 2015; Rago et al., 2019c, 2020) and youth soccer (Mendez-Villanueva et al., 2013; Abbott et al., 2018) players, but not in women players. Generally, match-analysis reports in women's soccer described physical match data using two different sprint thresholds, based on either fixed (20 km·h^{-1}) and individualized (90% mean speed obtained from a 20-m sprint test) speed zones (Nakamura et al., 2017). Similar patterns were observed between halves, and playing positions, but fixed speed zones may have likely underestimated the mean duration, distance, and the number of sprint sequences (Nakamura et al., 2017). Additionally, only one study employed individual speed zones based on MAS and MSS, showing that individualizing ETL metrics did not improve the relationship between training load and self-reported fatigue (Scott and Lovell, 2018). In this study (Scott and Lovell, 2018), HSD > 12.6 km·h^{-1} ranged between 250 to 2500 m during 21 days of the competitive season. However, the latter study employed MAS and MSS separately, adopting the following criteria: distance covered >80% MAS, MAS, >50% MSS and 65% MSS (Scott and Lovell, 2018). Moreover, it is important to note the use of 50–65% MSS that could be close to the potential MAS (15–18 km·h^{-1}) in elite athletes (Rago et al., 2020), considering that women soccer players peak approximately at 30–32 km·h^{-1} during a match (Datson et al., 2014, 2017). This assumes a linear relationship between aerobic (MAS) and anaerobic (Li et al., 2019) power that may consequently result in an erroneous interpretation of ETL. In this context, once MAS and MSS have been obtained from incremental and 40-m sprint tests, respectively, suggested by the assessment of anaerobic speed reserve (ASR) (Bundle et al., 2003). The use of ASR rely on the fact that different players with the same MAS, but different sprinting capacity, require different training prescription when exercising at intensities above MAS (Buchheit and Laursen, 2013). However, no information is available regarding ASR-based training load in women's soccer. Similarly, no data are available on the individual training prescriptions based on maximal acceleration capacity in women soccer players. This might be relevant due to the frequent acceleration demands required during soccer training and match play, as well as the variations in acceleration capacity observed throughout different periods of the season (Mara et al., 2015b).

Internal training load monitoring

Internal training load is usually quantified using HR monitors, which generically provide information about the aerobic contribution during exercise (Achten and Jeukendrup, 2003). A potential strength of HR-based methods is the information about aerobic contribution based on the strong relationship with oxygen consumption during exercise, when data are expressed as percentage of HR_{max} or $HR_{reserve}$ (Achten and Jeukendrup, 2003). On the other hand, a potential limitation of HR-based methods is the failure to detect anaerobic-oriented efforts such as sudden sprints or explosive bursts commonly observed during soccer training and match-play (Achten and Jeukendrup, 2003; Dellal et al., 2012). Therefore, an integrated approach encompassing both ETL and ITL is imperative to provide a full picture the exercise demands placed on the athletes. Nonetheless, HR-based variables are sensitive in detecting day-to-day variations in TL in highly trained and elite adult women soccer players under different competitive conditions, such as a domestic league competitive period (Costa et al., 2018a) or an international tournament (Scott and Lovell, 2018).

Beyond the usefulness of HR-based methods, and despite the development of women's soccer, most women's teams worldwide might still have weak budgets compared to that of men's teams to acquire sophisticated equipment, which frequently results in adopting cost-free methods based on the post-training subjective RPE (Costa et al., 2019c). The use of RPE-based methods such as the s-RPE is deemed to be valid in women soccer players based on its large relationship with HR-based methods (e.g., training impulse, Edwards' TL; Costa et al., 2019c). The latter study (Costa et al., 2019c), found an large correlation between s-RPE with TRIMP (r = 0.74–0.82), with TRIMP values ranging from 211 ± 81 AU and s-RPE values from 388 ± 107 AU. However, the connection between RPE-based and ETL parameters is unknown in women soccer players. This would be useful to discriminate between TL parameters, providing practitioners with evidence-based TL metrics to be adopted in their monitoring systems.

Fatigue

Fatigue has been defined as the inability to complete a task that was once achievable within a recent time frame (Pyne and Martin, 2011). Acute (immediately after) and residual (up to 72 h) fatigue may temporarily impair players' readiness to train and compete (Silva et al., 2018). In this context, monitoring TL may be useful to infer about acute and residual fatigue, allowing individual adjustments to training programs, improve well-being, restore physical capacity, and inform about the recovery process (Hader et al., 2019). Generally, women soccer players may need up to 72 h to achieve full neuromuscular recovery after a competitive match (Andersson et al., 2008; Krustrup et al., 2010; Sjokvist et al., 2011). Specifically, sprint performance, countermovement jump (CMJ), and peak torque in knee extension and flexion are reduced after a match (Andersson et al., 2008; Krustrup et al., 2010; Sjokvist et al., 2011). However, changes in neuromuscular function following a match and throughout the recovery period need further elucidation in women's soccer.

Notably, self-reported measures of fatigue are widely accepted among practitioners due to their ease to use and low-cost (Hooper et al., 1995). Indeed, subjective measures have shown acceptable sensitivity and consistency in athletes (Saw et al., 2016). For instance, self-reported measures of fatigue have shown significant associations with GPS-based TL on the previous day during a tournament (Scott and Lovell, 2018). In this study (Scott and Lovell, 2018), irrespective of the quantification method adopted for HSD > 12.6 $km{\cdot}h^{1}$ and very HSD (fixed or individualized speed zones), negative small correlations were observed with fatigue and soreness (r = −0.25 to −0.14). Actually, it seems that self-reported outcomes might be dependent on the training and competitive context, underlining the need to consider studies with more extensive periods (e.g., full or multiple seasons) and over a wide range of fatigue and recovery indicators; specially because there is very limited information about acute and residual fatigue in relation to TL in highly trained and elite adult women soccer players. Findings in men's soccer have shown significant correlations between various indicators of acute and residual fatigue and TL (Thorpe et al., 2017a; Hader et al., 2019). Specifically, non-invasive measures of fatigue such as sitting HR, submaximal HR, CMJ and self-reported questionnaires have shown responsiveness to daily and acute changes in TL over time (Thorpe et al., 2015, 2017b). These measures can be routinely applied to a number of athletes to monitor changes in training status (Buchheit, 2014). Moreover, subjective measures of fatigue can be easily incorporated into the monitoring systems, with the advantage of being cost-free and showing responsiveness to TL (Saw et al., 2016).

Information regarding HR measures during recovery after training sessions or matches in highly trained and elite adult women's soccer has been predominantly conducted during sleep time (Costa et al., 2018a,b, 2019a,b, 2021b). Most players from the same team presented fluctuations in nocturnal cardiac autonomic activity (i.e., coefficient of variation ranging from 2.8 to 9.0%) (Costa et al., 2019a). However, no within-subject associations over time were observed between TL (e.g., s-RPE, TRIMP and distance > 12 km·h^{-1}) and HR parameters during sleep (Costa et al., 2019a, 2021b). The authors (Costa et al., 2019a, 2021b) suggested that the amount of training and match demands (s-RPE ranging between 348 to 690 AU and TRIMP between 191 to 247 AU) prescribed to the players was not high enough to cause meaningful changes in cardiac sympathetic and parasympathetic activities during sleep. Additionally, no evidence is available about resting and submaximal HR in women soccer players, as previously described in men's soccer (Naranjo et al., 2015). However, women soccer players showed significant differences in sleep patterns and autonomic nervous activity responses when night training sessions were compared to competitive day matches and rest days, suggesting that the time of day for soccer practice may disrupt sleep patterns and nocturnal autonomic activity (Costa et al., 2018a, 2019b). For example, during a 9-day international tournament, no significant within-subject correlations were observed between post-training night sleep parameters (sleep time, sleep efficiency and heart rate variability during sleep) and both ETL (i.e., HSD > 12.6 km·h^{1} ranging between 130 to 756 m) and s-RPE (i.e., ranging between 131 to 360 AU) (Costa et al., 2019a). On the other hand, small within-subject correlations were observed between ITL (s-RPE [ranging between 377 to 411 AU] and TRIMP [ranging between 187 to 189 AU]) and sleep parameters (sleep duration and efficiency) during a 14-day competitive period (Costa et al., 2021b). Thus, even under stress imposed by tournament scheduling and training and match loads, the players maintained relatively good consistency in sleep habits to recover from the training sessions and matches.

Training adaptations

Following an acute fatigue phase, it is expected that chronic exposure to TL contributes to benefits in players' fitness levels, resulting in positive health or performance adaptations (Mara et al., 2015b). Thus, understanding changes in physiological and functional capacities of women soccer players is of upmost importance given its meaningful connection with physical performance during a match (Krustrup et al., 2005). Currently, the effectiveness of various training interventions (e.g., interval, resisted sprint, and plyometric training) in women's soccer is well-documented (Datson et al., 2014). However, it is important to note that some coaches could prescribe training programs based on their professional and educational background, with less attention to published training interventions (Rago, 2020). This could be due to the fact that evidence-based analytic drills do not always fit within the technical staff philosophy. In this sense, observational studies considering the exercise prescribed by coaches and the associated training outcomes could aid in understanding the effectiveness of training programs without the need to design intervention studies. For example, employing field performance tests at different seasonal points while simultaneously quantifying TL allows the computation of the relationship between TL and changes in performance (Jaspers et al., 2017). To date, only one study has adopted an observational design based on fitness testing at different seasonal points (i.e., 6 weeks of pre-season and 12 weeks of the competitive season) concerning TL; positive correlations were reported between changes in intermittent endurance capacity and ELT (Mara et al., 2015b). However, the latter study did not consider the individual capacity to adjust TL and only included maximal tests (e.g., jump, sprint, and time-to exhaustion). In this context, non-invasive measures of resting or submaximal HR may aid in detecting training adaptations without having the athletes to perform until exhaustion (Buchheit, 2014; Naranjo et al., 2015; Rago et al., 2019d). Also, different force-time and force-velocity components during the different phases of a jump might be sensitive in detecting training-induced changes (Gathercole et al., 2015). In summary, information regarding the dose–response relationship between TL and training adaptations in highly trained and elite adult women soccer players is limited to one study (Mara et al., 2015b), which did not consider the individual capacity to quantify TL. Thus, further studies are warranted to explore the dose–response relationship that may elicit the desired long-term performance outcomes.

Injuries

It has been reported that players might sustain illnesses or time-loss injuries during the season (Fuller et al., 2006). Injury incidence in women's soccer ranged between 1.2–7.0 injuries per 1,000 training hours, and 12.6–24.0 per 1,000 match hours (Giza et al., 2005; Jacobson and Tegner, 2007; Tegnander et al., 2008; Alahmad et al., 2020). The latter studies were based on descriptive epidemiological information, without inferences computed on injury incidence or risk in relation to training outcomes. Only one study reported information about the relationship between TL and injuries. Xiao et al. (2021) found that higher accumulated player load and total distance covered (values ranging between 3662 to 18461 m) were associated with injury in women soccer players during the same time frame. Thus, it is currently not possible to provide an explanation about training-related factors associated to injury or medical assistance. Alternatively, registering the occurrence of medical assistance (instead of time-loss injuries), as previously described in other team sports, could be of interest (Martinez-Riaza et al., 2017). Indeed, erroneous training progressions could result in delayed muscle soreness (Thorpe et al., 2017a) with an associated search for medical assistance. In general, the connection between training outcomes and injury risk has yet to be explored in women soccer players.

Conclusion

Information about TL in women soccer players is very sparse. Thus, it is very difficult for practitioners to consider evidence-based practices for training sessions beyond solid information available from match-analysis studies. For example, further studies on training contents, loads and adaptations are warranted to design match-like practice sessions and drills for women's soccer. Moreover, the dose–response relationships between TL, fatigue, training adaptions and injuries need to be clarified to understand the optimal training stimulus to enhance performance while preserving players' health. Also, future studies should encompass extensive periods with different seasonal phases (e.g., off-season, pre-season and in-season) and fixtures (e.g., ordinary microcycles, congested periods, national team breaks) with special emphasis on how TL affects training outcomes (e.g., acute fatigue, training adaptations, and injury risk) as previously examined in men's soccer (Jaspers et al., 2017). In addition, as future research, would be imperative to understand the importance of training load prescription and adaptation within youth women's soccer players from different competitive levels, which may help to preventing decrements in performance, or enhancing recovery in women's soccer population.

We have attempted to summarize current TL monitoring during training sessions in women's soccer, which may help to inform the practitioners working with highly trained and elite players, but also identify knowledge gaps and make suggestions for future research. More specifically, from a physical and physiological perspective, future research should use monitoring technology to determine more accurately the physical and physiological demands of training in women soccer players.

Data availability statement

The original contributions presented in this study are included in the article/**Supplementary material**, further inquiries can be directed to the corresponding author.

Author contributions

JC, VR, and JB contributed to the conceptualization and methodology. JC, VR, PB, EA, and JB contributed to the formal analysis and investigation. JC, VR, PB, and EA contributed to the data curation. VR, PF, AS, EA, and JB contributed to the writing—review and editing. JC and JB contributed to the writing—original draft preparation and visualization. JC contributed to the software. JB contributed to the validation, resources, supervision, and project administration. All authors read and agreed to the published version of the manuscript.

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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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Supplementary material

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References

Abbott, W., Brickley, G., and Smeeton, N. J. (2018). An individual approach to monitoring locomotive training load in English Premier League academy soccer players. *Int. J. Sports Sci. Coach.* 13, 421–428.

Achten, J., and Jeukendrup, A. E. (2003). Heart rate monitoring: applications and limitations. *Sports Med.* 33, 517–538.

Akenhead, R., and Nassis, G. P. (2016). Training Load and Player Monitoring in High-Level Football: current Practice and Perceptions. *Int. J. Sports Physiol. Perform.* 11, 587–593. doi: 10.1123/ijspp.2015-0331

Alahmad, T. A., Kearney, P., and Cahalan, R. (2020). Injury in elite women's soccer: a systematic review. *Phys. Sports Med.* 48, 259–265.

Andersson, H., Raastad, T., Nilsson, J., Paulsen, G., Garthe, I., and Kadi, F. (2008). Neuromuscular fatigue and recovery in elite female soccer: effects of active recovery. *Med. Sci. Sports Exerc.* 40, 372–380. doi: 10.1249/mss.0b013e31815b8497

Buchheit, M. (2014). Monitoring training status with HR measures: do all roads lead to Rome? *Front. Physiol.* 5:73. doi: 10.3389/fphys.2014.00073

Buchheit, M., and Laursen, P. (2013). High-intensity interval training, solutions to the programming puzzle: part I: cardiopulmonary emphasis. *Sports Med.* 43, 313–338. doi: 10.1007/s40279-013-0029-x

Bundle, M. W., Hoyt, R. W., and Weyand, P. G. (2003). High-speed running performance: a new approach to assessment and prediction. *J. Appl. Physiol.* 95, 1955–1962. doi: 10.1152/japplphysiol.00921.2002

Clemente, F. M., Seerden, G., and Van Der Linden, C. M. I. (2019). Quantifying the physical loading of five weeks of pre-season training in professional soccer teams from Dutch and Portuguese leagues. *Physiol. Behav.* 209:112588. doi: 10.1016/j.physbeh.2019.112588

Costa, J., Figueiredo, P., Nakamura, F., Rago, V., Rebelo, A., and Brito, J. (2019a). Intra-individual variability of sleep and nocturnal cardiac autonomic activity in elite female soccer players during an international tournament. *PLoS One* 14:1–19. doi: 10.1371/journal.pone.0218635

Costa, J. A., Brito, J., Nakamura, F. Y., Figueiredo, P., Oliveira, E., and Rebelo, A. (2019b). Sleep patterns and nocturnal cardiac autonomic activity in female athletes are affected by the timing of exercise and match location. *Chronobiol. Int.* 36, 360–373. doi: 10.1080/07420528.2018.1545782

Costa, J. A., Brito, J., Nakamura, F. Y., Figueiredo, P., and Rebelo, A. (2019c). Using the rating of perceived exertion and heart rate to quantify training intensity in female soccer players: validity and utility. *J. Strength Cond. Res.* 36, 201–206. doi: 10.1519/JSC.0000000000003407

Costa, J. A., Brito, J., Nakamura, F. Y., Dores, H., and Rebelo, A. (2021a). Associations between 24-h heart rate variability and aerobic fitness in high-level female soccer players. *Scand. J. Med. Sci. Sports* 1, 140–149. doi: 10.1111/sms.14116

Costa, J. A., Figueiredo, P., Nakamura, F. Y., Rebelo, A., and Brito, J. (2021b). Monitoring Individual Sleep and Nocturnal Heart Rate Variability Indices: the Impact of Training and Match Schedule and Load in High-Level Female Soccer Players. *Front. Physiol.* 12:678462. doi: 10.3389/fphys.2021.678462

Costa, J. A., Brito, J., Nakamura, F. Y., Oliveira, E. M., Costa, O. P., and Rebelo, A. N. (2018a). Does Night-Training Load Affect Sleep Patterns and Nocturnal Cardiac Autonomic Activity in High-Level Female Soccer Players? *Int. J. Sports Physiol. Perform.* 14, 779–787. doi: 10.1123/ijspp.2018-0652

Costa, J. A., Brito, J., Nakamura, F. Y., Oliveira, E. M., and Rebelo, A. N. (2018b). Effects of Late-Night Training on "Slow-Wave Sleep Episode" and Hour-by-Hour-Derived Nocturnal Cardiac Autonomic Activity in Female Soccer Players. *Int. J. Sports Physiol. Perform.* 13, 638–644. doi: 10.1123/ijspp.2017-0681

Datson, N., Drust, B., Weston, M., Jarman, I. H., Lisboa, P. J., and Gregson, W. (2017). Match Physical Performance of Elite Female Soccer Players During International Competition. *J. Strength Cond. Res.* 31, 2379–2387.

Datson, N., Hulton, A., Andersson, H., Lewis, T., Weston, M., Drust, B., et al. (2014). Applied physiology of female soccer: an update. *Sports Med.* 44, 1225–1240. doi: 10.1007/s40279-014-0199-1

Dellal, A., Da Silva, C. D., Hill-Haas, S., Wong Del, P., Natali, A. J., De Lima, J. R., et al. (2012). Heart rate monitoring in soccer: interest and limits during competitive match play and training, practical application. *J. Strength Cond. Res.* 26, 2890–2906. doi: 10.1519/JSC.0b013e3182429ac7

Douchet, T., Humbertclaude, A., Cometti, C., Paizis, C., and Babault, N. (2021). Quantifying Accelerations and Decelerations in Elite Women Soccer Players during Regular In-Season Training as an Index of Training Load. *Sports (Basel)* 9:109. doi: 10.3390/sports9080109

Doyle, B., Browne, D., and Horan, D. (2021). Quantification of internal and external training load during a training camp in senior international female footballers. *Sci. Med. Footb.* 6, 7–14. doi: 10.1080/24733938.2021.1886320

Fernandes, R., Brito, J. P., Vieira, L. H. P., Martins, A. D., Clemente, F. M., Nobari, H., et al. (2021). In-Season Internal Load and Wellness Variations in Professional Women Soccer Players: comparisons between Playing Positions and Status. *Int. J. Environ. Res. Public Health* 18:12817. doi: 10.3390/ijerph182312817

Fuller, C. W., Ekstrand, J., Junge, A., Andersen, T. E., Bahr, R., Dvorak, J., et al. (2006). Consensus statement on injury definitions and data collection procedures in studies of football (soccer) injuries. *Brit. J. Sports Med.* 40, 193–201.

Gathercole, R., Sporer, B., Stellingwerff, T., and Sleivert, G. (2015). Alternative countermovement-jump analysis to quantify acute neuromuscular fatigue. *Int. J. Sports Physiol. Perform.* 10, 84–92. doi: 10.1123/ijspp.2013-0413

Giza, E., Mithofer, K., Farrell, L., Zarins, B., and Gill, T. (2005). Injuries in women's professional soccer. *Br. J. Sports Med.* 39, 212–216;discussion212–216.

Hader, K., Rumpf, M. C., Hertzog, M., Kilduff, L. P., Girard, O., and Silva, J. R. (2019). Monitoring the Athlete Match Response: can External Load Variables Predict Post-match Acute and Residual Fatigue in Soccer? A Systematic Review with Meta-analysis. *Sports Med. Open* 5:48. doi: 10.1186/s40798-019-0219-7

Halson, S. L. (2014). Monitoring training load to understand fatigue in athletes. *Sports Med.* 44, S139–S147.

Hooper, S. L., Mackinnon, L. T., Howard, A., Gordon, R. D., and Bachmann, A. W. (1995). Markers for monitoring overtraining and recovery. *Med. Sci. Sports Exerc.* 27, 106–112.

Hunter, F., Bray, J., Towlson, C., Smith, M., Barrett, S., Madden, J., et al. (2015). Individualisation of time-motion analysis: a method comparison and case report series. *Int. J. Sports Med* 36, 41–48. doi: 10.1055/s-0034-1384547

Jacobson, I., and Tegner, Y. (2007). Injuries among Swedish female elite football players: a prospective population study. *Scand. J. Med. Sci. Sports* 17, 84–91. doi: 10.1111/j.1600-0838.2006.00524.x

Jaspers, A., Brink, M. S., Probst, S. G., Frencken, W. G., and Helsen, W. F. (2017). Relationships Between Training Load Indicators and Training Outcomes in Professional Soccer. *Sports Med.* 47, 533–544.

Kim, S. Y., Park, J. E., Lee, Y. J., Seo, H. J., Sheen, S. S., Hahn, S., et al. (2013). Testing a tool for assessing the risk of bias for nonrandomized studies showed moderate reliability and promising validity. *J. Clin. Epidemiol.* 66, 408–414. doi: 10.1016/j.jclinepi.2012.09.016

Kirkendall, D. T., and Krustrup, P. (2021). Studying professional and recreational female footballers: a bibliometric exercise. *Scand. J. Med. Sci. Sports* 1, 12–26. doi: 10.1111/sms.14019

Krustrup, P., Mohr, M., Ellingsgaard, H., and Bangsbo, J. (2005). Physical demands during an elite female soccer game: importance of training status. *Med. Sci. Sports Exerc.* 37, 1242–1248. doi: 10.1249/01.mss.0000170062.73981.94

Krustrup, P., Zebis, M., Jensen, J. M., and Mohr, M. (2010). Game-induced fatigue patterns in elite female soccer. *J. Strength Cond. Res.* 24, 437–441. doi: 10.1519/JSC.0b013e3181c09b79

Li, K., Rudiger, H., and Ziemssen, T. (2019). Spectral Analysis of Heart Rate Variability: time Window Matters. *Front. Neurol.* 10:545.

Mara, J. K., Thompson, K. G., and Pumpa, K. L. (2015a). Assessing the Energy Expenditure of Elite Female Soccer Players: a Preliminary Study. *J. Strength Cond. Res.* 29, 2780–2786. doi: 10.1519/JSC.0000000000000952

Mara, J. K., Thompson, K. G., Pumpa, K. L., and Ball, N. B. (2015b). Periodization and physical performance in elite female soccer players. *Int. J. Sports Physiol. Perform.* 10, 664–669.

Martinez-Riaza, L., Herrero-Gonzalez, H., Lopez-Alcorocho, J. M., Guillen-Garcia, P., and Fernandez-Jaen, T. F. (2017). Epidemiology of injuries in the Spanish national futsal male team: a five-season retrospective study. *BMJ Open Sport Exerc. Med.* 2:e000180. doi: 10.1136/bmjsem-2016-000180

Mckay, A. K. A., Stellingwerff, T., Smith, E. S., Martin, D. T., Mujika, I., Goosey-Tolfrey, V. L., et al. (2022). Defining Training and Performance Caliber: a Participant Classification Framework. *Int. J. Sports Physiol. Perform.* 17, 317–331. doi: 10.1123/ijspp.2021-0451

Mendez-Villanueva, A., Buchheit, M., Simpson, B., and Bourdon, P. C. (2013). Match play intensity distribution in youth soccer. *Int. J. Sports Med.* 34, 101–110.

Nakamura, F. Y., Pereira, L. A., Loturco, I., Rosseti, M., Moura, F. A., and Bradley, P. S. (2017). Repeated-Sprint Sequences During Female Soccer Matches Using Fixed and Individual Speed Thresholds. *J. Strength Cond. Res.* 31, 1802–1810. doi: 10.1519/JSC.0000000000001659

Naranjo, J., De La Cruz, B., Sarabia, E., De Hoyo, M., and Dominguez-Cobo, S. (2015). Heart Rate Variability: a Follow-up in Elite Soccer Players Throughout the Season. *Int. J. Sports Med.* 36, 881–886.

Okholm Kryger, K., Wang, A., Mehta, R., Impellizzeri, F. M., Massey, A., and Mccall, A. (2021). Research on women's football: A scoping review. *Sci. Med. Footb.* 1–10. doi: 10.1080/24733938.2020.1868560 [Epub ahead of print].

Page, M. J., Mckenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., et al. (2021). The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *BMJ* 372, n71.

Pyne, D., and Martin, D. (2011). "Fatigue-insights from individual and team sports," in *Regulation of fatigue in exercise*, ed. F. E. Marino (New York, NY: Nova Science), 177–185.

Rago, V. (2020). Training load monitoring in football: application of field systems in professional male players. *Brit. J. Sports Med.* 2020:102394. doi: 10.1123/ijspp.2021-0126

Rago, V., Brito, J., Figueiredo, P., Costa, J., Barreira, D., Krustrup, P., et al. (2019a). Methods to collect and interpret external training load using microtechnology incorporating GPS in professional football: a systematic review. *Res. Sports Med.* 28, 437–458. doi: 10.1080/15438627.2019.1686703

Rago, V., Brito, J., Figueiredo, P., Costa, J., Krustrup, P., and Rebelo, A. (2019b). Internal training load monitoring in professional football: a systematic review of methods using rating of perceived exertion. *J. Sports Med. Phys. Fitness* 60, 160–171.

Rago, V., Brito, J., Figueiredo, P., Krustrup, P., and Rebelo, A. (2019c). Relationship between External Load and Perceptual Responses to Training in Professional Football: effects of Quantification Method. *Sports (Basel)* 7:68. doi: 10.3390/sports7030068

Rago, V., Krustrup, P., Martín-Acero, R., Rebelo, A., and Mohr, M. (2019d). Training load and submaximal heart rate testing throughout a competitive period in a top-level male football team. *J. Sports Sci.* 38, 1408–1415. doi: 10.1080/02640414.2019.1618534

Rago, V., Brito, J., Figueiredo, P., Krustrup, P., and Rebelo, A. (2020). Application of Individualized Speed Zones to Quantify External Training Load in Professional Soccer. *J. Hum. Kinet.* 72, 279–289. doi: 10.2478/hukin-2019-0113

Randell, R. K., Clifford, T., Drust, B., Moss, S. L., Unnithan, V. B., De Ste Croix, M. B. A., et al. (2021). Physiological Characteristics of Female Soccer Players and Health and Performance Considerations: a Narrative Review. *Sports Med.* 51, 1377–1399. doi: 10.1007/s40279-021-01458-1

Romero-Moraleda, B., Nedergaard, N. J., Morencos, E., Casamichana, D., Ramirez-Campillo, R., and Vanrenterghem, J. (2021). External and internal loads during the competitive season in professional female soccer players according to their playing position: differences between training and competition. *Res. Sports Med.* 29, 449–461. doi: 10.1080/15438627.2021.1895781

Sarmento, H., Clemente, F. M., Araujo, D., Davids, K., Mcrobert, A., and Figueiredo, A. (2018). What Performance Analysts Need to Know About Research Trends in Association Football (2012-2016): a Systematic Review. *Sports Med.* 48, 799–836. doi: 10.1007/s40279-017-0836-6

Saw, A. E., Main, L. C., and Gastin, P. B. (2016). Monitoring the athlete training response: subjective self-reported measures trump commonly used objective measures: a systematic review. *Br. J. Sports Med.* 50, 281–291. doi: 10.1136/bjsports-2015-094758

Scott, D., and Lovell, R. (2018). Individualisation of speed thresholds does not enhance the dose-response determination in football training. *J. Sports Sci.* 36, 1523–1532.

Scott, M., Scott, T. J., and Kelly, V. G. (2016). The Validity and Reliability of Global Positioning Systems in Team Sport: a Brief Review. *J. Strength Cond. Res.* 30, 1470–1490. doi: 10.1519/JSC.0000000000001221

Shamseer, L., Moher, D., Clarke, M., Ghersi, D., Liberati, A., Petticrew, M., et al. (2015). Preferred reporting items for systematic review and meta-analysis protocols (PRISMA-P) 2015: elaboration and explanation. *Bmj* 350:g7647.

Silva, J. R., Rumpf, M. C., Hertzog, M., Castagna, C., Farooq, A., Girard, O., et al. (2018). Acute and Residual Soccer Match-Related Fatigue: a Systematic Review and Meta-analysis. *Sports Med.* 48, 539–583.

Sjokvist, J., Laurent, M. C., Richardson, M., Curtner-Smith, M., Holmberg, H. C., and Bishop, P. A. (2011). Recovery from high-intensity training sessions in female soccer players. *J. Strength Cond. Res.* 25, 1726–1735.

Tegnander, A., Olsen, O. E., Moholdt, T. T., Engebretsen, L., and Bahr, R. (2008). Injuries in Norwegian female elite soccer: a prospective one-season cohort study. *Knee Surg. Sports Traumatol. Arthrosc.* 16, 194–198. doi: 10.1007/s00167-007-0403-z

Thorpe, R. T., Atkinson, G., Drust, B., and Gregson, W. (2017a). Monitoring Fatigue Status in Elite Team-Sport Athletes: implications for Practice. *Int. J. Sports Physiol. Perform.* 12, S227–S234. doi: 10.1123/ijspp.2016-0434

Thorpe, R. T., Strudwick, A. J., Buchheit, M., Atkinson, G., Drust, B., and Gregson, W. (2017b). The Influence of Changes in Acute Training Load on Daily Sensitivity of Morning-Measured Fatigue Variables in Elite Soccer Players. *Int. J. Sports Physiol. Perform.* 12, S2107–S2113. doi: 10.1123/ijspp.2016-0433

Thorpe, R. T., Strudwick, A. J., Buchheit, M., Atkinson, G., Drust, B., and Gregson, W. (2015). Monitoring Fatigue During the In-Season Competitive Phase in Elite Soccer Players. *Int. J. Sports Physiol. Perform.* 10, 958–964. doi: 10.1123/ijspp.2015-0004

Torres-Ronda, L., Beanland, E., Whitehead, S., Sweeting, A., and Clubb, J. (2022). Tracking Systems in Team Sports: a Narrative Review of Applications of the Data and Sport Specific Analysis. *Sports Med. Open* 8:15. doi: 10.1186/s40798-022-00408-z

Xiao, M., Nguyen, J. N., Hwang, C. E., and Abrams, G. D. (2021). Increased Lower Extremity Injury Risk Associated With Player Load and Distance in Collegiate Women's Soccer. *Orthop. J. Sports Med.* 9, 23259671211048248. doi: 10.1177/23259671211048248

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EDITED BY
Rubén Maneiro,
Pontifical University of Salamanca, Spain

REVIEWED BY
Alliance Kubayi,
Tshwane University of Technology, South Africa
Júlio Alejandro Costa,
Portuguese Football Federation, Portugal

*CORRESPONDENCE
Chunman Li
lcmbsu@hotmail.com

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The effect of the video assistant referee (VAR) on referees' decisions at FIFA Women's World Cups

Yeqin Zhang[1], Danyang Li[2], Miguel-Ángel Gómez-Ruano[3], Daniel Memmert[4], Chunman Li[1]* and Ming Fu[5]

[1]China Football College, Beijing Sport University, Beijing, China, [2]School of Psychology, Beijing Sport University, Beijing, China, [3]Faculty of Physical Activity and Sport Sciences (INEF), Polytechnic University of Madrid, Madrid, Spain, [4]Institute of Exercise Training and Sport Informatics, German Sport University Cologne, Cologne, Germany, [5]Institute of Physical Education and Training, Capital University of Physical Education and Sports, Beijing, China

Video assistant referee (VAR) has been implemented in women's football, aiming to improve referees' decision-making, but its impact has not yet been analyzed. This study intended to explore how the VAR affects refereeing decisions at Fédération Internationale de Football Association (FIFA) Women's World Cup competitions. The sample includes all 52 matches played in the 2015 tournament before VAR was introduced and all 52 matches played in the 2019 competition where VAR was deployed. For each match, data on ten variables were collected: first half playing time, second half playing time, total playing time, penalties, offsides, fouls, goals, corner kicks, yellow cards, and red cards. The match variables were compared before and after VAR implementation using a Mann–Whitney U test, a Bayesian analysis, a generalized linear model, and a non-clinical magnitude-based inference. The results demonstrated that after VAR was introduced, playing time during the first half [$p < 0.001$, $BF_{10} = 547.05$, Cohen's $d = 1.06$, 90%CI (0.71, 1.40)], the second half [$p < 0.001$, $BF_{10} = 57.09$, Cohen's $d = 0.91$, 90%CI (0.57, 1.25)], and the entire match [$p < 0.001$, $BF_{10} = 1{,}120.39$, Cohen's $d = 1.33$, 90%CI (0.97, 1.69)] increased significantly with moderate to large effect sizes, while the number of penalties, offsides, and fouls did not vary significantly neither did the number of goals, corner kicks, yellow cards, and red cards. This study has practical implications for professionals in terms of a better understanding of VAR's impact on elite women's football.

KEYWORDS

Women's World Cup, video technology, refereeing decision, playing duration, sports performance

Introduction

The contribution of refereeing decisions to football (soccer) is undeniably important: referees enforce the match's laws and penalize transgressions. On average, referees make 137 observable decisions per match at the international level (Helsen and Bultynck, 2004; Märtins et al., 2022). Any mistake by a referee could impact the match outcome, which is why referees are expected to make the most accurate decisions. However, referees' decision-making process is complex as it entails making instant judgments in fast-paced circumstances involving several players and with limited vision (Lex et al., 2015). In addition, several other factors may also affect referees' decisions, such as perceptual limitations (Oudejans et al., 2000), crowd noise (Unkelbach and Memmert, 2010), fan pressure (Buraimo et al., 2010), match location (Goumas, 2014; Wunderlich et al., 2021), and differences between teams' levels of play (Lago-Peñas and Gómez-López, 2016). Consequently, judgment mistakes and bias in referees' decisions may sometimes seem inevitable.

To fix mistakes and eliminate bias in refereeing decisions, various technical officiating aids have been gradually incorporated into competitive arenas (Collins and Evans, 2012; Kolbinger and Link, 2016; Kolbinger and Lames, 2017). These technologies can be divided into three categories (Kolbinger and Link, 2016): (1) those that enhance perception and assist refereeing decisions (e.g., goal-line technology to identify whether the ball goes over the goal line, Nlandu, 2012); (2) those that substitute human officials for some refereeing decisions (e.g., Hawk-Eye system to determine the ball's bounce point and trajectory, Bal and Dureja, 2012); and (3) those that assist referees in enforcing sports regulations (e.g., vanishing spray to mark the required distance of defending players in football, Kolbinger and Link, 2016). The video assistant referee (VAR), on which this study focuses, is in the first category.

In 2018 the Laws of the Game were amended to include VAR, a match official with independent access to video footage (FIFA, 2019). According to its governing principles, VAR should be used to assist the main referee in reviewing four types of match-changing events where there are "clear and obvious errors" or "serious missed incidents": goal/no goal, penalty/no penalty, direct red card, and mistaken identity. Generally, VAR automatically checks events in any of these four categories using TV camera footage. If the check demonstrates a possible "clear and obvious error" or "serious missed incident" made by the referees, VAR informs the main referee *via* a headset of what the video depicts and recommends that the main referee review or change the original decision. Normally, there are two kinds of reviews: one is called a VAR-only review, which allows the initial decision to be modified based on the information from the VAR, such as an offside incident that occurred prior to a goal; and the other option is referred to as on-field review, which means the main referee can watch the video footage directly on a monitor next to the field of play before making a final decision (Holder et al., 2021; Spitz et al., 2021).

The use of VAR is helpful in reducing critical errors and improving refereeing accuracy in complex and dynamic football match situations. For example, FIFA (2018) revealed that in the 2018 Men's World Cup, the accuracy rate of refereeing decisions was 95.60% when VAR was not employed and 99.35% when VAR was used. Additionally, in a study of 13 men's national leagues, using VAR was found to increase refereeing decision accuracy from 92.1 to 98.3% (Spitz et al., 2021).

In addition to refereeing accuracy, some studies have investigated the effect of VAR on match variables in men's national and international football competitions. Specifically, compared to other match variables (e.g., goals, corner kicks, yellow cards, and red cards), four variables appear to have been affected by the implementation of VAR:

- Match playing time. Whether a football team can succeed depends on how long it can maintain highly competitive performance throughout the entire match (Maneiro et al., 2020). Related research has observed a significant rise in the match playing time since VAR was introduced (Lago-Peñas et al., 2019, 2020; Han et al., 2020; Kubayi et al., 2022). The main cause of increased playing time is the pauses in the match when VAR intervenes. Each time a review is conducted, the match has to be halted. One study revealed median times of 15.0 s for a VAR-only review and 62.0 s for an on-field review (Spitz et al., 2021). Therefore, matches with VAR intervention generally last longer than do matches without VAR.
- Number of penalty kicks. Given the relatively small number of goals scored in many matches, penalty kicks play an important role in a football match (Makaruk et al., 2020). The number of penalties awarded at the 2018 FIFA Men's World Cup, where VAR was used, was higher than at the 2014 Men's World Cup without VAR (Kubayi et al., 2022). This difference is probably explained by VAR's slow-motion playback function, which could detect fouls that might be missed in fast-paced matches.
- Number of offside judgments. Offside decisions are among the most important responsibilities of a referee, with the potential to dramatically change the outcome of a football match (Helsen et al., 2006). Much of the literature has demonstrated a reduced number of offsides following the introduction of VAR (Lago-Peñas et al., 2019, 2020; Han et al., 2020; Kubayi et al., 2022). One explanation is that VAR corrects erroneous offside calls caused by the flash-lag effect, which refers to the human eye's tendency to detect a moving object as spatially prior to its real position (Baldo et al., 2002; Nijhawan, 2002; Helsen et al., 2006).
- Aggregate of fouls. During a football match, over 30% of the referee's observable decisions involve foul play situations (Spitz et al., 2017). Since the implementation of VAR, the number of fouls in football matches has decreased (Lago-Peñas et al., 2019; Han et al., 2020). This could be explained by players being more cautious in their actions, with a minimum of 12 cameras monitoring the whole pitch. Since any minor physical contact, whether deliberate or unintentional, could be clearly captured on video, players' misconduct may be restrained (Han et al., 2020).

While several previous studies indicated that VAR has a remarkable influence on match variables in men's domestic and international football tournaments (e.g., Lago-Peñas et al., 2019; Han et al., 2020; Spitz et al., 2021; Kubayi et al., 2022), there is still limited scientific research on how VAR may affect women's football competitions. In particular, the effect of VAR at the FIFA Women's World Cup, the most significant tournament for women footballers (Geertsema et al., 2021), has not yet been investigated. Despite the fact that women's football has recently experienced a significant rise in popularity (UEFA., 2017), professionalization (Welford, 2015), and receiving attention from sports researchers and practitioners worldwide (Pfister, 2015), two literature reviews about women's football research (Valenti et al., 2018; Okholm Kryger et al., 2021) clearly indicate that women's football and relevant research is still in development relative to their male counterpart. Therefore, any research regarding women's football will be valuable for broadening the understanding of sport and gender and breaking through the gender constraints (Williams and Hess, 2016). In addition, research on women's football is essential and helpful in accelerating the growth of women's football, which is one of the eleven goals of the FIFA vision 2020–2023 Making Football Truly Global (FIFA., 2020). Beyond that, there is one year to go until the 2023 FIFA Women's World Cup, and a more detailed understanding of VAR's influence on FIFA Women's World Cup tournaments can help the professionals (e.g., referees, coaches, players, and managers) to achieve a higher-quality tournament preparation. Thus, this study took a closer look at the response of women's football toward the implementation of VAR by comparing referee-related variables in the 2015 FIFA Women's World Cup without VAR against those in the 2019 tournament with VAR.

In addition, based on previous research on VAR in men's football, the current study aimed to investigate whether there are similar changes in women's football after VAR implementation. Therefore, two kinds of hypotheses were proposed: first, we assume a significant increase in the playing time and the number of penalties while a significant decrease in the number of offsides and fouls after VAR implementation in the FIFA Women's World Cup, just as it occurs in men's football matches; and second, we assume no significant difference in the number of goals, corner kicks, yellow cards and red cards before and after VAR implementation in FIFA Women's World Cups.

Materials and methods

Sample

In the 2015 FIFA Women's World Cup, the total number of matches played was 52, including 36 matches in the group stage and 16 matches in the knockout stage. In the 2019 FIFA Women's World Cup, the match system arrangements were the same, totaling 52 matches consisting of 36 matches in the group stage and 16 matches in the knockout stage. Therefore, all 104 matches from 2015 (no VAR, $n = 52$) and 2019 (VAR, $n = 52$) FIFA Women's World Cup competitions were included in the analysis. The referee-related statistics were compared between the two tournaments.

Procedures

Consistent with previous research (Kubayi et al., 2022), analysis was undertaken on 10 match variables, all inextricably tied to referees' decisions: first half playing time, second half playing time, total playing time, penalties, offsides, fouls, goals, corner kicks, yellow cards, and red cards. Data for the match variables were gathered from the website of FBref (https://fbref.com), which releases publicly available data through a partnership with the software company StatsBomb. StatsBomb is one of the most recognized companies in the football market (PRNewswire, 2019), supplying statistics and analysis for every European football league and international football tournament (StatsBomb, 2022). To verify the reliability of the data set, the first author independently coded three randomly selected football matches using LongoMatch (version 0.20.8, Barcelona, Spain: https://longomatch.com/en/), a custom-notational analysis system. In the present study, Intraclass Correlation Coefficients (ICCs) between the data provided by StatsBomb and the data provided by the leading author coding were the inter-rater reliability (Koo and Li, 2016). ICC values for 10 match variables ranged from 0.938 to 1, representing excellent reliability (Koo and Li, 2016) (for more details, please see Supplementary Material). The current study was approved by the ethics committee of the local university (BSUCFCIRB-10043070).

Statistical analyses

The Kolmogorov–Smirnov test revealed that all the match variables were not normally distributed. Hence, the non-parametric Mann–Whitney U test was run to compare differences between each variable with and without VAR. The threshold for statistical significance was set at $p < 0.05$.

As the limitation of traditional frequentist statistics is dependent on p values (Vandekerckhove et al., 2018; Wagenmakers et al., 2018), the Bayesian statistical paradigm has been proposed as an alternative method of analysis to reduce the dependence on p values (Marsman and Wagenmakers, 2016; Bernards et al., 2017). In this study, a Bayesian Mann–Whitney U test was performed to quantify the relative degree of evidence supporting H_0 (no significant differences before and after VAR implementation) or H_1 (significant differences before and after VAR implementation) through the Bayes factor—BF_{10}. The

TABLE 1 Descriptive statistics and results of Mann–Whitney U test and Bayesian analysis for match variables without VAR (2015) and with VAR (2019).

Variables	No VAR (2015)		VAR (2019)		Z	p-value	BF_{10}	Cohen's d with 90%CI
	M	SD	M	SD				
First half playing time	46.12	1.10	47.37	1.25	−5.134	<0.001	547.05	1.06 (0.71, 1.40)
Second half playing time	48.42	0.78	49.46	1.41	−4.360	<0.001	57.09	0.91 (0.57, 1.25)
Total playing time	94.54	1.41	96.83	1.98	−5.796	<0.001	1120.39	1.33 (0.97, 1.69)
Penalties	0.42	0.72	0.50	0.61	−1.119	0.263	0.27	0.11 (−0.21, 0.44)
Offsides	3.50	2.02	3.90	2.39	−0.810	0.418	0.27	0.18 (−0.14, 0.51)
Fouls	22.85	7.40	22.17	6.77	−0.430	0.667	0.22	−0.09 (−0.42, 0.23)
Goals	2.69	2.02	2.65	1.98	−0.140	0.889	0.23	−0.02 (−0.34, 0.30)
Corner kicks	9.67	3.94	9.13	3.58	−0.529	0.596	0.26	−0.14 (−0.47, 0.18)
Yellow cards	2.13	1.47	2.44	1.38	−1.347	0.178	0.33	0.22 (−0.11, 0.54)
Red cards	0.06	0.24	0.08	0.27	−0.389	0.697	0.27	0.08 (−0.25, 0.40)

M, the mean value of the match variable; SD, the standardized deviation of the match variable; BF, the Bayes factor; CI, the confidence interval.

subscripts "10" in BF_{10} suggest that the model related to H_1 is in the numerator and that the model corresponding to H_0 is in the denominator (Marsman and Wagenmakers, 2016). H_0 would be supported if $BF_{10} \leq 0.33$, whereas H_1 would be supported if $BF_{10} \geq 3.0$ (Lee and Wagenmakers, 2013).

For each match variable, a generalized linear model was fitted. The goodness of fit was assessed using the Bayesian information criterion (BIC) and a 95% confidence interval (CI).

Furthermore, the true effects of VAR application on each match variable were analyzed using non-clinical magnitude-based inference (Hopkins et al., 2009). Differences were determined by computing standardized effect sizes, reported as Cohen's d with 90%CI. The thresholds of effect size for small, moderate, large, very large, and extremely large were 0.2, 0.6, 1.2, 2.0, and 4.0 (Hopkins et al., 2009). The smallest worthwhile change was estimated as 0.2 with standardized units. Unless the 90%CI encompassed both positive and negative values, an effect was regarded as clear. The qualitative likelihood of clear effects was measured on the following scale: <0.5% for *most unlikely*, 0.5–5% for *very unlikely*, 5–25% for *unlikely*, 25–75% for *possibly*, 75–95% for *likely*, 95–99.5% for *very likely*, and > 99.5% for *most likely* (Hopkins et al., 2009).

IBM SPSS statistical software (version 26.0), JASP software (version 0.16.1), and Microsoft Excel (Hopkins, 2007) were used for all statistical analyses.

Results

Descriptive data of the match variables in FIFA Women's World Cup tournaments are summarized in Table 1. Following the implementation of VAR, a significant rise was observed in playing time in the first half ($p < 0.001$, $BF_{10} = 547.05$), the second half ($p < 0.001$, $BF_{10} = 57.09$), and the full match ($p < 0.001$, $BF_{10} = 1120.39$). While the other match indicators did not show a significant change after the intervention of VAR.

The results of the generalized linear model for each match variable are shown in Table 2. VAR implementation resulted in a statistically significant increase in playing time in the first half ($p < 0.001$), the second half ($p < 0.001$), and consequently, the entire match ($p < 0.001$). In contrast, there was no significant change in the other match variables after the intervention of VAR.

The true effects of VAR application on each match variable, as determined by non-clinical magnitude-based inference (Hopkins et al., 2009), are illustrated in Figure 1. The findings reveal that before and after VAR was introduced, only three variables showed clear effects: playing time in the first half [$d = 1.06$, 90%CI (0.71, 1.40)], the second half [$d = 0.91$, 90%CI (0.57, 1.25)], and the entire match [$d = 1.33$, 90%CI (0.97, 1.69)], with *most likely* moderate to large effect sizes. Conversely, the rest of these variables showed an unclear effect as their 90%CIs of Cohen's d results included both positive and negative values.

Discussion

VAR has been introduced progressively into football. As the usage of VAR in women's football has not previously been assessed, this study adds new information to the evidence base on VAR's effects in elite football, particularly in women's football. The main finding is that the playing duration in each match was significantly longer, on average, at the 2019 FIFA Women's World Cup with VAR than at the 2015 tournament without VAR.

Corresponding to our first hypothesis, the amount of time spent on the field increased significantly in both halves and, consequently, for the entire match, following VAR's introduction. These findings are consistent with previous findings for men's football (Lago-Peñas et al., 2019, 2020; Han

TABLE 2 Results of the generalized linear model for each match variable.

Variables	Estimate	95%CI	p-value	BIC
First half playing time	1.250	(0.802, 1.698)	<0.001	340.996
Second half playing time	1.038	(0.606, 1.471)	<0.001	333.564
Total playing time	2.288	(1.635, 2.942)	<0.001	419.376
Penalties	0.077	(−0.178, 0.332)	0.554	223.536
Offsides	0.404	(−0.439, 1.246)	0.347	472.275
Fouls	−0.673	(−3.373, 2.027)	0.625	714.518
Goals	−0.038	(−0.799, 0.722)	0.921	450.933
Corner kicks	−0.538	(−1.970, 0.894)	0.461	582.638
Yellow cards	0.308	(−0.234, 0.850)	0.266	380.601
Red cards	0.019	(−0.077, 0.115)	0.695	21.030

CI, the confidence interval; BIC, the Bayesian information criterion.

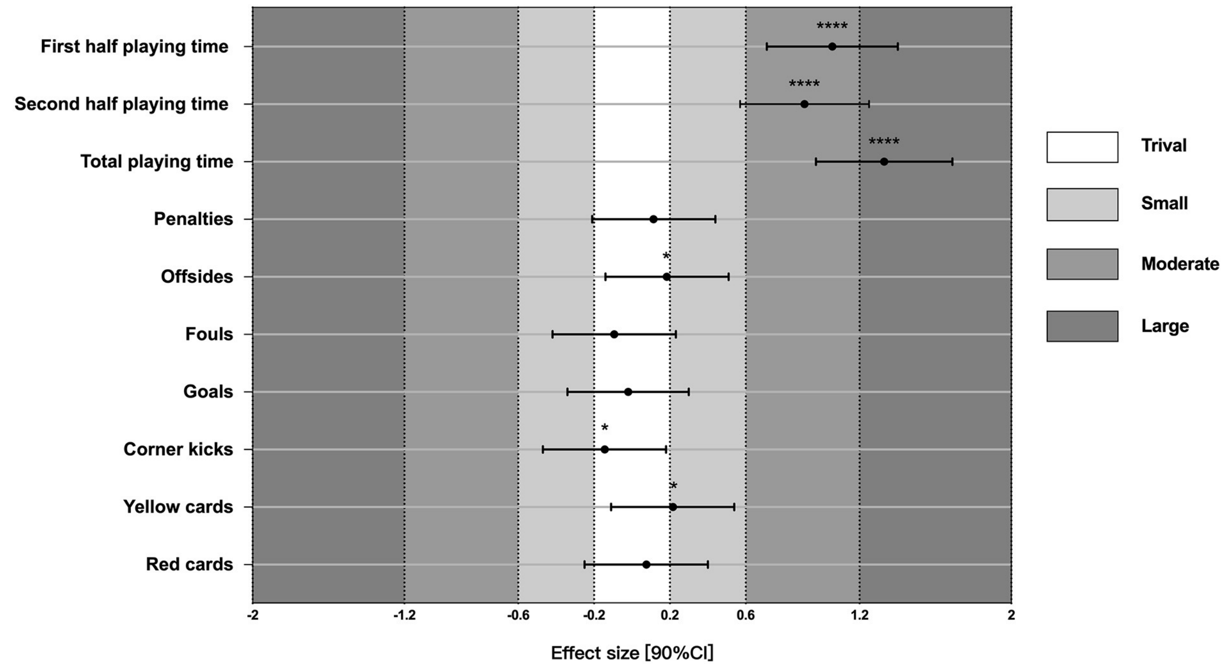

FIGURE 1
Effect sizes of differences in each match variable before and after the introduction of VAR. Asterisks indicate the qualitative likelihood of the magnitude of true effects: **possibly*; *****most likely*; CI, confidence interval.

et al., 2020; Kubayi et al., 2022). Some critics of VAR in football have argued that by halting play to review footage of disputed incidents, the match's flow is broken, and its tempo slowed (Nlandu, 2012; Svantesson, 2014; Scanlon et al., 2022). However, this study finds that the time added to a match by using VAR is not very long in the FIFA Women's World Cup: only around one minute in the first half (46.12 min without VAR vs. 47.37 min with VAR) and the second half (48.42 vs. 49.46 min), respectively, and consequently two minutes in the full match (94.54 vs. 96.83 min). These findings imply that implementing VAR does not dramatically lengthen the duration of a football match, providing support for previous studies (Errekagorri et al., 2020; Lago-Peñas et al., 2020).

Contrary to our first hypothesis, the number of offsides did not significantly change following the implementation of VAR. This result is inconsistent with the considerable decrease in the number of offsides found in men's football after VAR's introduction, both in the FIFA Men's World Cup (Kubayi et al., 2022) and domestic leagues (Lago-Peñas et al., 2019; Han et al., 2020). There are two possible explanations for the inconsistency. The first concerns the flash-lag effect (Nijhawan, 2002), which is often cited to explain errors in offside calls (Helsen et al.,

2006) that VAR can effectively correct. Motion speed influences the flash-lag effect, which tends to be smaller at slower speeds (Shioiri et al., 2010). Generally, women football players have a slower sprint speed than men football players (de Araújo et al., 2020; Haugen et al., 2020), meaning that the flash-lag effect may be less significant in women's football matches than in men's matches. Consequently, after introducing VAR, the reduction in the number of offside calls in women's matches is not as significant as that in men's matches. Second, compared to men's football matches, women's football matches create less favorable patterns of match structure and tend to have fewer penetrative passes (Tenga et al., 2017). As penetrative passes are associated with both scoring opportunities and offside possibilities, fewer penetrative passes in women's football leave less scope for intervention by VAR in correcting offside calls by the assistant referees. These differences may reflect that women's football matches have their own styles of play and idiosyncrasies compared to men's football (Gutierrez and García-López, 2012; Bradley et al., 2014).

Inconsistent with our first hypothesis, this study found that the number of fouls and penalties did not significantly change after VAR was implemented. These results are contrary to previous findings in men's football, where VAR use has resulted in referees awarding fewer free kicks for fouls (Lago-Peñas et al., 2019; Han et al., 2020) and more penalties (Kubayi et al., 2022). The inconsistencies could be attributable to women football players being less aggressive than men football players (Coulomb-Cabagno et al., 2005; Coulomb-Cabagno and Rascle, 2006), manifesting in fewer rule violations, such as illegal tackles, interceptions, and striking of opponents. Consequently, VAR plays a relatively small part in addressing misconduct in women's football matches.

Corresponding to our second hypothesis, a non-significant change in the number of goals, corner kicks, and yellow/red cards was found following the implementation of VAR, which was consistent with previous studies related to men's football (Han et al., 2020; Lago-Peñas et al., 2020). A likely explanation for this is that these variables are generally less affected by referees' visual limitations compared to the judgment of offside; thus, the misjudgment of these variables is relatively rare. Therefore, these indicators did not show considerable change before and after the intervention of VAR in FIFA Women's World Cup tournaments.

There are certain limitations in this study that need to be addressed in future research. First, between the 2015 FIFA Women's World Cup and the 2019 tournament, there were developments in techniques and tactics of modern football that may have influenced the studied match variables. Although this study focused on referee-related indicators that are relatively less sensitive to such developments, future studies of the impact of VAR should also consider how techniques and tactics have evolved. Second, according to Lago-Peñas and Gómez-López (2016), the greater the difference in score between the two teams, the less stoppage time the referee adds to the second half of the match; in close matches, by contrast, added time tends to be longer when a higher-ranking team is trailing than when it is leading. Consequently, the strength differences between opposing teams should also be considered in future research. Lastly, as this study only considered a relatively small number of women's football matches, caution must be exercised in interpreting our findings on the effects of VAR implementation on referees' decisions. Future research should analyze a greater number of women's domestic and international football competitions to test the robustness of this study's findings and increase the statistical power.

Regarding practical applications, this study highlights the importance of examining novel technical refereeing devices in women's international football. The findings may aid football practitioners (e.g., referees, coaches, players, and managers) in amply comprehending how VAR has affected elite women's football and in effectively identifying tactics for improving team performance. VAR does not appear to dramatically affect elite women's football in terms of match duration. Nonetheless, VAR should be improved to minimize disruptions to the matches' flow and rhythm. Furthermore, with the development of modern football, demands on women football players are increasing, for instance, through greater emphasis on high-speed running and sprinting (Griffin et al., 2020), passing accuracy (Soroka and Bergier, 2010), and high levels of anaerobic qualities and aerobic capacity (Turner et al., 2013). These new challenges will reinforce the role of VAR in women's football matches.

Conclusion

This study investigated the influence of VAR on referee-related match variables at FIFA Women's World Cup tournaments. The primary findings were that playing time in the first half, second half, and full match increased significantly but not excessively. These findings indicate that the introduction of VAR has not excessively impacted elite women's football matches. Nonetheless, it is necessary to continue analyzing the effects of this innovative refereeing aid on women's football to verify its effectiveness and assess its applicability.

Data availability statement

Publicly available datasets were analyzed in this study. This data can be found here: https://fbref.com.

Author contributions

YZ and DL contributed to the conception and design of the study, performed the statistical analysis, and wrote the first draft of the manuscript. YZ organized the database. M-ÁG-R, DM, CL, and MF reviewed and revised the manuscript. All authors have made a substantial and direct contribution to the manuscript and approved its final version.

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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.

Publisher's note

Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2022.984367/full#supplementary-material

References

Bal, B., and Dureja, G. (2012). Hawk Eye: a logical innovative technology use in sports for effective decision making. *Sport Sci. Rev.* 21, 107–119. doi: 10.2478/v10237-012-0006-6

Baldo, M. V., Ranvaud, R. D., and Morya, E. (2002). Flag errors in soccer games: the flash-lag effect brought to real life. *Perception* 31, 1205–1210. doi: 10.1068/p3422

Bernards, J. R., Sato, K., Haff, G. G., and Bazyler, C. D. (2017). Current research and statistical practices in sport science and a need for change. *Sports* 5, 87–96. doi: 10.3390/sports5040087

Bradley, P. S., Dellal, A., Mohr, M., Castellano, J., and Wilkie, A. (2014). Gender differences in match performance characteristics of soccer players competing in the UEFA Champions League. *Hum. Mov. Sci.* 33, 159–171. doi: 10.1016/j.humov.2013.07.024

Buraimo, B., Forrest, D., and Simmons, R. (2010). The 12th man? Refereeing bias in English and German soccer. *J. R. Stat. Soc. Ser. A Stat. Soc.* 173, 431–449. doi: 10.1111/j.1467-985X.2009.00604.x

Collins, H., and Evans, R. (2012). Sport-decision aids and the "CSI-effect": why cricket uses Hawk-Eye well and tennis uses it badly. *Public Underst. Sci.* 21, 904–921. doi: 10.1177/0963662511407991

Coulomb-Cabagno, G., and Rascle, O. (2006). Team sports players' observed aggression as a function of gender, competitive level, and sport type. *J. Appl. Soc. Psychol.* 36, 1980–2000. doi: 10.1111/j.0021-9029.2006.00090.x

Coulomb-Cabagno, G., Rascle, O., and Souchon, N. (2005). Players' gender and male referees' decisions about aggression in French soccer: a preliminary study. *Sex Roles* 52, 547–553. doi: 10.1007/s11199-005-3720-z

de Araújo, M. C., Baumgart, C., Jansen, C. T., Freiwald, J., and Hoppe, M. W. (2020). Sex differences in physical capacities of German Bundesliga soccer players. *J. Strength Cond. Res.* 34, 2329–2337. doi: 10.1519/JSC.0000000000002662

Errekagorri, I., Castellano, J., Echeazarra, I., and Lago-Peñas, C. (2020). The effects of the Video Assistant Referee system (VAR) on the playing time, technical-tactical and physical performance in elite soccer. *Int. J. Perform. Anal. Sport* 20, 808–817. doi: 10.1080/24748668.2020.1788350

FIFA (2018). *FIFA World Cup Russia 2018: Refereeing Statistics.* Available online at: https://fifa-backend.pressfire.net/media/newsletter/FWC18-Refereeing-VAR-Report-Statistics-Finals-STATS.pdf

FIFA (2019). *Laws of the Game: Video Assistant Referee (VAR) Protocol.* Zurich: FIFA.

FIFA. (2020). *11 Goals to Make Football Truly Global.* Available online at: https://publications.fifa.com/en/annual-report-2020/the-global-game/the-vision-2020-2023/ (accessed July 12, 2022).

Geertsema, C., Geertsema, L., Farooq, A., Haroy, J., Oester, C., Weber, A., et al. (2021). Injury prevention knowledge, beliefs and strategies in elite female footballers at the FIFA Women's World Cup France 2019. *Br. J. Sports Med.* 55, 801–806. doi: 10.1136/bjsports-2020-103131

Goumas, C. (2014). Home advantage and referee bias in European football. *Eur. J. Sport Sci.* 14, 243–249. doi: 10.1080/17461391.2012.686062

Griffin, J., Larsen, B., Horan, S., Keogh, J., Dodd, K., Andreatta, M., et al. (2020). Women's football: an examination of factors that influence movement patterns. *J. Strength Cond. Res.* 34, 2384–2393. doi: 10.1519/JSC.0000000000003638

Gutierrez, D., and García-López, L. M. (2012). Gender differences in game behaviour in invasion games. *Phys. Educ. Sport Pedagogy* 17, 289–301. doi: 10.1080/17408989.2012.690379

Han, B., Chen, Q., Lago-Peñas, C., Wang, C., and Liu, T. (2020). The influence of the video assistant referee on the Chinese Super League. *Int. J. Sports Sci. Coach.* 15, 662–668. doi: 10.1177/1747954120938984

Haugen, T. A., Breitschadel, F., and Seiler, S. (2020). Sprint mechanical properties in soccer players according to playing standard, position, age and sex. *J. Sports Sci.* 38, 1070–1076. doi: 10.1080/02640414.2020.1741955

Helsen, W., and Bultynck, J. B. (2004). Physical and perceptual-cognitive demands of top-class refereeing in association football. *J. Sports Sci.* 22, 179–189. doi: 10.1080/02640410310001641502

Helsen, W., Gilis, B., and Weston, M. (2006). Errors in judging "offside" in association football: test of the optical error versus the perceptual flash-lag hypothesis. *J. Sports Sci.* 24, 521–528. doi: 10.1080/02640410500298065

Holder, U., Ehrmann, T., and König, A. (2021). Monitoring experts: insights from the introduction of video assistant referee (VAR) in elite football. *J. Bus. Econ.* 92, 285–308. doi: 10.1007/s11573-021-01058-5

Hopkins, W. G. (2007). Understanding statistics by using spreadsheets to generate and analyze samples. *Sport Sci.* 11, 23–37.

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

Kolbinger, O., and Lames, M. (2017). Scientific approaches to technological officiating aids in game sports. *Curr. Issues Sport Sci.* 2, 1–10. doi: 10.15203/ciss_2017.001

Kolbinger, O., and Link, D. (2016). The use of vanishing spray reduces the extent of rule violations in soccer. *SpringerPlus* 5, 1572–1578. doi: 10.1186/s40064-016-3274-2

Koo, T. K., and Li, M. Y. (2016). A guideline of selecting and reporting intraclass correlation coefficients for reliability research. *J. Chiropr. Med.* 15, 155–163. doi: 10.1016/j.jcm.2016.02.012

Kubayi, A., Larkin, P., and Toriola, A. (2022). The impact of video assistant referee (VAR) on match performance variables at men's FIFA World Cup tournaments. *Proc. Inst. Mech. Eng. P J. Sports Eng. Technol.* 236, 187–191. doi: 10.1177/1754337121997581

Lago-Peñas, C., Gómez, M. A., and Pollard, R. (2020). The effect of the Video Assistant Referee on referee's decisions in the Spanish *LaLiga*. *Int. J. Sports Sci. Coach.* 16, 824–829. doi: 10.1177/1747954120980111

Lago-Peñas, C., and Gómez-López, M. (2016). The influence of referee bias on extra time in elite soccer matches. *Percept. Motor Skills* 122, 666–677. doi: 10.1177/0031512516633342

Lago-Peñas, C., Rey, E., and Kalén, A. (2019). How does video assistant referee (VAR) modify the game in elite soccer? *Int. J. Perform. Anal. Sport* 19, 646–653. doi: 10.1080/24748668.2019.1646521

Lee, M. D., and Wagenmakers, E.-J. (2013). *Bayesian Cognitive Modeling: A Practical Course.* Cambridge, UK: Cambridge University Press.

Lex, H., Pizzera, A., Kurtes, M., and Schack, T. (2015). Influence of players' vocalisations on soccer referees' decisions. *Eur. J. Sport Sci.* 15, 424–428. doi: 10.1080/17461391.2014.962620

Makaruk, H., Porter, J. M., Bodasinska, A., and Palmer, S. (2020). Optimizing the penalty kick under external focus of attention and autonomy support instructions. *Eur. J. Sport Sci.* 20, 1378–1386. doi: 10.1080/17461391.2020.1720829

Maneiro, R., Losada, J. L., Casal, C. A., and Arda, A. (2020). The influence of match status on ball possession in high performance women's football. *Front. Psychol.* 11, 487. doi: 10.3389/fpsyg.2020.00487

Marsman, M., and Wagenmakers, E.-J. (2016). Bayesian benefits with JASP. *Eur. J. Dev. Psychol.* 14, 545–555. doi: 10.1080/17405629.2016.1259614

Märtins, J., Westmattelmann, D., and Schewe, G. (2022). Affected but not involved: two-scenario based investigation of individuals' attitude towards decision support systems based on the example of the video assistant referee. *J. Decis. Syst.* 2022, 1–25. doi: 10.1080/12460125.2022.2041274

Nijhawan, R. (2002). Neural delays, visual motion and the flash-lag effect. *Trends Cogn. Sci.* 6, 387–393. doi: 10.1016/S1364-6613(02)01963-0

Nlandu, T. (2012). The fallacies of the assumptions behind the arguments for goal-line technology in soccer. *Sport Ethics Philos.* 6, 451–466. doi: 10.1080/17511321.2012.745896

Okholm Kryger, K., Wang, A., Mehta, R., Impellizzeri, F. M., Massey, A., and McCall, A. (2021). Research on women's football: a scoping review. *Sci. Med. Footb.* 2021, 1–10. doi: 10.1080/24733938.2020.1868560

Oudejans, R. R., Verheijen, R., Bakker, F. C., Gerrits, J. C., Steinbrückner, M., and Beek, P. J. (2000). Errors in judging 'offside' in football. *Nature* 404, 33. doi: 10.1038/35003639

Pfister, G. (2015). Assessing the sociology of sport: on women and football. *Int. Rev. Sport Sociol.* 50, 563–569. doi: 10.1177/1012690214566646

PRNewswire (2019). *StatsBomb, the Most Advanced Analytics Provider in Football, Announces the Full Acquisition of Arqam to Provide More Than Double the Data of Any Other Provider.* Available online at: https://martechseries.com/analytics/statsbomb-advanced-analytics-provider-football-announces-full-acquisition-arqam-provide-double-data-provider/ (accessed July 12, 2022).

Scanlon, C., Griggs, G., and McGillick, C. (2022). 'It's not football anymore': perceptions of the video assistant referee by English premier league football fans. *Soccer Soc.* 2022, 1–13. doi: 10.1080/14660970.2022.2033731

Shioiri, S., Yamamoto, K., Oshida, H., Matsubara, K., and Yaguchi, H. (2010). Measuring attention using flash-lag effect. *J. Vis.* 10, 1–13. doi: 10.1167/10.10.10

Soroka, A., and Bergier, J. (2010). Actions with the ball that determine the effectiveness of play in women's football. *J. Hum. Kinet.* 26, 97–104. doi: 10.2478/v10078-010-0053-y

Spitz, J., Put, K., Wagemans, J., Williams, A. M., and Helsen, W. F. (2017). Does slow motion impact on the perception of foul play in football? *Eur. J. Sport Sci.* 17, 748–756. doi: 10.1080/17461391.2017.1304580

Spitz, J., Wagemans, J., Memmert, D., Williams, A. M., and Helsen, W. F. (2021). Video assistant referees (VAR): the impact of technology on decision making in association football referees. *J. Sports Sci.* 39, 147–153. doi: 10.1080/02640414.2020.1809163

StatsBomb (2022). *DataSoccer*. Available online at: https://statsbomb.com/what-we-do/soccer-data/ (accessed July 12, 2022).

Svantesson, D. J. B. (2014). Could technology resurrect the dignity of the FIFA World Cup refereeing? *Comput. Law Secur. Rev.* 30, 569–573. doi: 10.1016/j.clsr.2014.07.004

Tenga, A., Zubillaga, A., Caro, O., and Fradua, L. (2017). Explorative study on patterns of game structure in male and female matches from elite Spanish soccer. *Int. J. Perform. Anal. Sport* 15, 411–423. doi: 10.1080/24748668.2015.11868802

Turner, E., Munro, A. G., and Comfort, P. (2013). Female soccer: part 1—A needs analysis. *Strength Cond. J.* 35, 51–57. doi: 10.1519/SSC.0b013e318281f689

UEFA. (2017). Women's football across the national associations. *UEFA Rep* 1–93.

Unkelbach, C., and Memmert, D. (2010). Crowd noise as a cue in referee decisions contributes to the home advantage. *J. Sport Exerc. Psychol.* 32, 483–498. doi: 10.1123/jsep.32.4.483

Valenti, M., Scelles, N., and Morrow, S. (2018). Women's football studies: an integrative review. *Sport Bus. Manag.: Int. J.* 8, 511–528. doi: 10.1108/sbm-09-2017-0048

Vandekerckhove, J., Rouder, J. N., and Kruschke, J. K. (2018). Editorial: bayesian methods for advancing psychological science. *Psychon. Bull. Rev.* 25, 1–4. doi: 10.3758/s13423-018-1443-8

Wagenmakers, E. J., Marsman, M., Jamil, T., Ly, A., Verhagen, J., Love, J., et al. (2018). Bayesian inference for psychology. *Part I: theoretical advantages and practical ramifications. Psychon. Bull. Rev.* 25, 35–57. doi: 10.3758/s13423-017-1343-3

Welford, J. (2015). Globalising women's football: Europe, migration and professionalization. *Int. J. Hist. Sport* 32, 726–728. doi: 10.1080/09523367.2015.1004914

Williams, J., and Hess, R. (2016). Women, football and history: international perspectives. *Int. J. Hist. Sport* 32, 2115–2122. doi: 10.1080/09523367.2015.1172877

Wunderlich, F., Weigelt, M., Rein, R., and Memmert, D. (2021). How does spectator presence affect football? Home advantage remains in European top-class football matches played without spectators during the COVID-19 pandemic. *PLoS ONE* 16, e0248590. doi: 10.1371/journal.pone.0248590

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EDITED BY
Rubén Maneiro,
Pontifical University of Salamanca, Spain

REVIEWED BY
Ersan Arslan,
Tokat Gaziosmanpasa University,
Turkey
Francesco Fischetti,
University of Bari Aldo Moro, Italy
Anna Paola Trindade Rocha Pierucci,
Federal University of Rio de Janeiro, Brazil

*CORRESPONDENCE
Limingfei Zhou
zlmf@bsu.edu.cn
Dapeng Bao
baodp@bsu.edu.cn

†These authors have contributed equally to this work

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The effects of 8-week complex training on lower-limb strength and power of Chinese elite female modern pentathlon athletes

Zining Qiao[1†], Zhenxiang Guo[2†], Bin Li[3], Meng Liu[4], Guozhen Miao[5], Limingfei Zhou[1*], Dapeng Bao[6*] and Junhong Zhou[7]

[1]School of Strength and Conditioning Training, Beijing Sport University, Beijing, China, [2]Nanjing University of Aeronautics and Astronautics, Nanjing, China, [3]Cycling and Fencing Sports Administrative Center Under the General Administration of Sport of China, Beijing, China, [4]Sports Coaching College, Beijing Sport University, Beijing, China, [5]Maranatha High School, Pasadena, CA, United States, [6]China Institute of Sport and Health Science, Beijing Sport University, Beijing, China, [7]Harvard Medical School, Hebrew SeniorLife Hinda and Arthur Marcus Institute for Aging Research, Boston, MA, United States

Complex training (CT) is a combination training method that alternates between performing high-load resistance training (RT) and plyometric training within one single session. The study aimed to examine the effects of CT on lower-limb strength and power of elite female modern pentathlon athletes under the new modern pentathlon format and competition rules. Ten female participants (age: 23.55±2.22years, weight: 60.59±3.87kg, height: 169.44±4.57cm, and training experience: 6.90±2.08years) of the national modern pentathlon team completed 8weeks of RT as followed by 8weeks of CT, with 2 weeks of break. Then, the participants conducted 8weeks of CT, which included RT combined with plyometric training (e.g., drop jump and continuous jump). All stages of training were designed by the linear strength training period theories, requiring participants to train twice for the first 4 weeks and three times for the second 4 weeks. The one-repetition maximum (1RM) of squat, isometric mid-thigh pull (IMTP), counter-movement jump (CMJ), squat jump (SJ), pre-stretch augmentation percentage (PSAP), and reaction strength index (RSI) were assessed before and after both RT and CT training. One-way repeated-measure ANOVA models revealed that the 1RM of squat was significantly improved (p<0.001) after RT as compared to pre-RT. No significant improvement in IMTP (p=0.055), CMJ (p=0.194), SJ (p=0.692), PSAP (p=0.087), and RSI (p=0.238) was not observed. After CT, 1RM of squat (p<0.001), IMTP (p<0.035), CMJ (p<0.001), SJ (p<0.008), RSI (p<0.006) were significant improved as compared to pre-RT, post-RT and pre-CT, while significant improvements in PSAP were observed as compared to pre-RT (p=0.003) and pre-CT (p=0.027), but not to post-RT (p=0.156). This pilot study showed the promise of CT following RT to improve lower-limb strength and power in elite female modern pentathlon athletes. The findings are worthwhile to be confirmed in future studies with larger sample size and randomized design.

KEYWORDS

complex training, lower extremity, power, modern pentathlon, female athletes

Introduction

The modern pentathlon consists of fencing, swimming, equestrian, and a combined event of shooting and cross country running (i.e., laser-run), requiring skilled technique and multiple physical fitness (Le Meur et al., 2010). Lower-limb strength and power are one of the most important contributors to the performance of modern pentathlon (Chirico et al., 2019). Ko et al. (2021) observed that, for example, lower-limb strength and power (e.g., the average strength of flexor muscle and extensor muscle, squat, and sergeant jump) is the most relevant predictor of overall modern pentathlon performance, especially in the fencing, swimming, and laser-run.

Additionally, the International Union of Modern Pentathlon (UIPM) recently has published the new modern pentathlon format and competition rules for 2022–2024, which shortened the distance of laser-run event (from 4 × 800 m to 5 × 600 m), and adopted the short course of swimming (from 50 m to 25 m; Union Internationale de Pentathlon Moderne, 2022). Compared to old rules, these newly-established rules require athletes to have greater lower-limb strength and power to complete the short-distance competition (Hanon and Thomas, 2011; Berryman et al., 2018). These rule changes further highlight the importance of lower-limb strength and power for the competition performance in modern pentathlon, which may thus serve as the appropriate target for strategies aiming to improve combined performance of modern pentathlon athletes.

One such strategy is resistance training (RT), including basic strength training (e.g., squat, split squat, deadlift, etc.). Previous studies found that RT can improve strength performance (e.g., one-repetition maximum [1RM] of squat) in athletes of different sports, such as swimming (Crowley et al., 2017), 800-m running (Bachero-Mena et al., 2021), and fencing (Turner et al., 2014). However, a recent study had shown that RT enhanced muscle hypertrophy but not strength in trained men due to a certain threshold of RT, over which further training in RT was not advantageous and might only delay recovery from exercises for resistance trained-individual (e.g., elite athletes; Schoenfeld et al., 2019). Thereby, these may necessitate RT protocol to combine other training methods to augment its benefits. Complex training (CT) is a combination training method that alternates between performing high-load RT and plyometric training within one single session. The CT can elicit a post-activation potentiation (PAP) response to induce more power in the subsequent plyometric training for athletes (Carter and Greenwood, 2014; Clemente et al., 2021), by stimulating high-order motor unit recruitment and excitability, increasing phosphorylation of the myosin light chain, and changes in limb stiffness (Tillin and Bishop, 2009; Blagrove et al., 2019). Using CT can induce significant improvement of neuromuscular adaptation (MacDonald et al., 2012), and strength and power of muscle (Berriel et al., 2022; Liu et al., 2022). In addition, this CT can simultaneously enhance multiple aspects contributing to running performance, such as running economy and maximal running speed (Blagrove et al., 2019; Li et al., 2019). Taken together, CT may be of great promise to benefit the athletic performance of female modern pentathlon athletes by simultaneously augmenting their lower-limb strength and power, which, however, have not been examined.

This pilot study thus aims to examine if an 8-week CT following RT can augment the lower-limb strength and power in a group of elite female modern pentathlon athletes. Specifically, we hypothesize that the CT protocol would induce a significant increase in athletic performance pertaining to lower-limb strength and power that cannot be enhanced using RT.

Materials and methods

Participants

Ten elite female modern pentathlon participants volunteered to participate in this study (Table 1). The inclusion criteria were as follows: (1) Participants who were preparing for the 19th Asian Games Hangzhou 2022; (2) participants who were proficient in resistance and plyometric training techniques; and (3) the ability and willingness to complete 16-week training programs of tests and intervention. The exclusion criteria were as follows: (1) Participants suffered from severe lower-body injuries related to anterior cruciate ligament, hamstring, meniscus, and ankle, or any medical and orthopedic problems during the last 3 years and (2) unable to execute plyometric exercises. Before data collection, the participants were informed about the benefits and possible risks associated with the study, and the participants provided written informed consent to participate. The participants were on the same routine of diet without taking additional nutritional supplement and had caffeine-free beverages during the whole study period. The study protocol was approved by the Beijing Sport University Institutional Research Commission (approval number: 2022132H), and all procedures were conducted in accordance with the Declaration of Helsinki.

Procedures

The participants first completed the RT for 8 weeks and then the CT for 8 weeks. Table 2 shows the details description and

TABLE 1 The demographic information of the participants.

	Age (years)	Height (cm)	Weight (kg)	Training experience (years)	BMI	Body fat (%)
Participants ($N = 10$)	23.55 ± 2.22	169.44 ± 4.57	60.59 ± 3.87	6.90 ± 2.08	20.80 ± 0.99	23.16 ± 2.32

TABLE 2 Resistance training and plyometric training program.

Phase	Period	RT (week 1–8)	CT (week 10–18)
Phase 1	1 week	65%1RM × 15RM × 6–8 groups × 60 s	(65%1RM × 15RM^{S} + 3-5RM^{P}) × 6–8 groups × 60 s
Phase 2	3 weeks	70–85%1RM × 6-12RM × 6 ~ 8 groups × 90 s	(70–85%1RM × 6 ~ 12RM^{S} + 5-10RM^{P}) × 6–8 group × 90 s
Phase 3	4 weeks	80–100%1RM × 1-8RM × 6–8 groups × 180–240 s	(80–100%1RM × 1-8RM^{S} + 5-10RM^{P}) × 6–8 groups × 18–240 s

RM, maximum repetitions; % 1RM, percentage of 1RM maximum load intensity; S, regular strength training; P, plyometric exercises.

progression of RT and CT programs. Between RT and CT, a 2-week resting period was given. According to the liner strength training periods principles, three phases in each training program were completed: phase 1 of 1 week aimed to improve the anatomical adaptations of muscles, phase 2 of 3 weeks aimed to enhance the hypertrophy of muscles, and phase 3 of 4 weeks was to improve maximal strength and power. Participants were required to train twice in phase 1 and phase 2, and three times for phase 3 with a 48 ~ 72 h of recovery between each training session. Traditional mainly focuses on structural exercises of large muscle groups (e.g., squat, deadlift, and hip thrust). The load arrangement of single strength training session adopts linear periodization load (e.g., pyramid training method) to develop nerve function and strength of lower extremities.

During each session, participants received consistent instructions from certified strength and conditioning coaches on proper techniques for resistance and plyometric exercises. All the protocols were designed and supervised by study personnel, who is an experienced researcher in strength and conditioning, and a fitness trainer.

Test program

Before and immediately after RT (within 3 days after week 8) and CT (within 3 days after week 18), the 1RM of squat, isometric mid-thigh pull (IMTP), counter-movement jump (CMJ), squat jump (SJ), pre-stretch augmentation percentage (PSAP), and reaction strength index (RSI) were assessed. All testing sessions were preceded by a standardized warm-up with included stretching and dynamic movements. There was an interval of 5 min between each test. Before each testing session, participants finished standardized warm-up for 15 min, including 5 min dynamic stretch, 8 min movement integration, and 2 min neural activation.

1RM of squat test

Lower-limb strength was assessed with a 1RM squat as reported by previous studies (Keiner et al., 2013; Jurado-Castro et al., 2022). The maximal load of the parallel back-squat exercise (1RM) was determined using procedures outlined by National Strength and Conditioning Association (NSCA; Miller, 2012). The movement for the parallel back-squat exercise was performed as described above for the squat training. As a squat-exercise warm-up before 1RM measurement, the participates performed 4 sets of squat exercises with (a) 20 kg for 10 repetitions, (b) 50% estimated 1RM for 5 repetitions, (c) 75% estimated 1RM for 3 repetitions, and (d) 90% estimated 1RM for 1 repetition to ensure maximal effort. For determination of workload, the estimated 1RM was used from the participants' recruitment sessions before participation in this study. Then, they tried the estimated 100% 1RM, and the load was increased by 5–10 kg until failure. The 1RM was determined by 6 attempts. They were provided with 3 min of rest between sets, which was considered to be sufficient.

IMTP test

The IMTP test was used to assess the isometric strength of lower limb (Farney et al., 2020). The mid-thigh position was determined for each participant before testing by marking the midpoint distance between the knee and hip joints. Each participant was instructed to assume their preferred deadlift position by self-selecting their hip and knee angles. The height of the barbell was adjusted up or down to make sure it was in contact with the mid-thigh. The participants were allowed to use either overhand, mixed, or hook grip. Participants were instructed to pull upward on the barbell as hard and as fast as possible and to continue their maximal effort for 6 s. All participants were instructed to relax before the command "GO!" to avoid the precontraction. The force-time curve for each trial was recorded by a force plate (Kistler 9281CA, KISTLER, Winterthur, Switzerland) with a sample rate of 1,000 Hz (Comfort et al., 2015). Peak force was defined as the highest force achieved during the 6-s isometric test minus the participant's body weight in Newtons. Additionally, force outputs at 30, 50, 90, 100, 150, 200, and 250 ms from the initiation of the pull were determined for each trial.

Vertical jump test

The vertical jump was used as a performance test to assess lower-limb power, including the height of CMJ and SJ (Nonnato et al., 2022). Series of SJs and CMJs were performed on a force platform three times (Kistler 9281CA, KISTLER, Winterthur, Switzerland). Participants were asked to jump three times and the higher height of a jump from each series was used for analysis. Take-off was strictly monitored by allowing no preliminary steps or movements. The force platform accurately recorded take-off and landing time and this allowed for the assessment of the duration of the flight phase and hence the calculation of CMJ and SJ height using the equation proposed by Bosco (Bosco et al., 1983).

PSAP and RSI test

PSAP and RSI were used to indirectly examine the ability of an athlete to use the stretch-shortening cycle (SSC) to improve their jump height and peak power during a vertical jump, which was often used as an indicator of lower-limb power performance (Suchomel et al., 2016). Indices from the jump data were PSAP and were calculated as follows:

$$\text{PSAP} = \frac{\text{CMJ height} - \text{SJ height}}{\text{SJ height}} \times 100\%$$

RSI was measured by using a drop jump, performed starting from a standing position, with the hands placed on the hips. Participants stepped off the box with one foot, landing with two feet simultaneously on the force plate. As contact was made with the force plate participants immediately performed a vertical jump. The drop jumps (DJ) were carried out at heights of 45 cm. Participants were given three trials at each height with the best trial being used for analysis. RSI was calculated by dividing jump height (mm) by contact time (ms) (Barker et al., 2018).

$$\text{RSI} = \frac{\text{DJ height}}{\text{Ground contact time}}$$

Statistical analyses

Experimental data were processed by IBM SPSS statistical software package (version 25.0, IBM, Chicago, IL, United States). Data were presented as means ± standard deviation (SD) and 95%CI. The level of significance was set at $p < 0.05$ for all tests. The normality of data distribution was confirmed by using the Shapiro–Wilk test, and those not normally distributed were confirmed by using the non-parametric Friedman test. To examine the effects of exercise training (i.e., RT and CT) on the performance of lower-limb strength and power, we performed one-way repeated-measure ANOVA. The dependent variables for each model were 1RM squat, IMTP, CMJ, SJ, PSAP, and RSI. The model factor was the time (pre- and post-intervention of week 1–8 and week 10–18). The absolute value of each test result was used to calculate the effect size (ES) for the within-group comparisons, represented as Cohen's d. It was interpreted according to the following thresholds: <0.2 as trivial, 0.2–0.6 as small, 0.6–1.2 as moderate, 1.2–2.0 as large, and >2.0 as very large (Hopkins et al., 2009).

Results

All participants completed all the training sessions and assessments, and their data were included in the analysis. All the data were normally distributed. Table 1 presents the demographic information of the participants (age: 23.55 ± 2.22 years; height: 169.44 ± 4.57 cm; weight: 60.59 ± 3.87 kg; training experience: 6.90 ± 2.08 years; BMI: 20.80 ± 0.99; body fat: 23.16 ± 2.32%).

The one-way repeated-measure ANOVA models showed in the Table 3 that: (1) The 1RM of squat was significantly improved ($p < 0.001$) after RT as compared to pre-RT. Such significant improvements were not observed in IMTP ($p = 0.055$), CMJ ($p = 0.194$), SJ ($p = 0.692$), PSAP ($p = 0.087$), and RSI ($p = 0.238$); and (2) after CT, 1RM of squat ($p < 0.001$), IMTP ($p < 0.035$), CMJ ($p < 0.001$), SJ ($p < 0.008$), and RSI ($p < 0.006$) were significantly improved as compared to pre-RT, post-RT, and pre-CT (Figure 1). Additionally, significant improvements in PSAP after CT were observed as compared to pre-RT ($p = 0.003$) and pre-CT ($p = 0.027$), but not to post-RT ($p = 0.156$).

Discussion

This pilot study showed that CT following RT only can enhance lower-limb strength and power in elite female modern pentathlon athletes (as assessed by 1RM squat, IMTP, CMJ, SJ, and RSI), suggesting that this type of intervention would be an appropriate strategy to help maximize such functions in athletes of modern pentathlon, and ultimately help improve their performance, especially under the newly-established competition rules.

We observed that 1RM of squat was improved after completing both RT and CT, and after CT, the IMTP was significantly improved. Squat and IMTP mainly reflect lower-limb strength for quadriceps femoris and hamstring, which are linked to the performance of modern pentathlon athletes (Ko et al., 2021). The traditional RT focuses only on isometric contraction with slow velocity, and the conversion time between eccentric contraction and concentric contraction becomes longer. On the other hand, according to the principle of the force-velocity curve, the CT training protocol adopted larger-load (above 75% 1RM) exercises to enhance the strength-speed part of the curve, and used lower-load (below 50% 1RM) exercises to promote the maximum velocity part of the curve (Haff and Nimphius, 2012). CT intervention can simultaneously implement resistance exercises with larger-load and plyometric exercises with quicker velocity to improve multiple abilities of the entire force-velocity curve including strength-speed, peak power, speed-strength, and maximum velocity (Zatsiorsky et al., 2020;

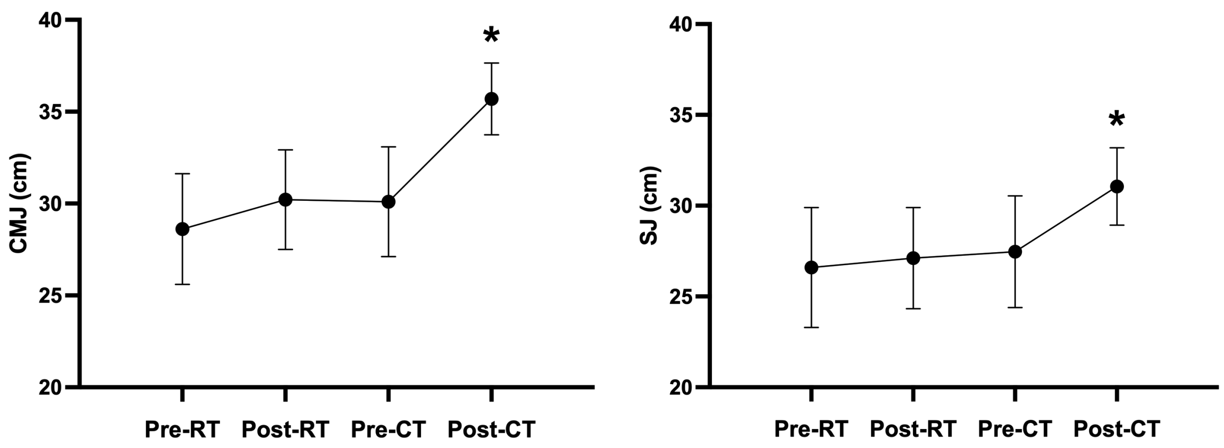

FIGURE 1
The assessment results of CMJ and SJ after CT intervention compared to all pre- and post-intervention. *Statistically significant difference as compared to all the other pre- and post-interventions, $p<0.05$.

TABLE 3 The assessment results for week 1–8 (RT) and week 10–18 (CT).

	Week 1–8 (RT) mean difference with 95% of confidence intervals				Week 10–18 (CT) mean difference with 95% of confidence intervals			
Variable	Pre-RT	Post-RT	Mean Differences	Cohen's d	Pre-CT	Post-CT	Mean Differences	Cohen's d
1RM Squat (kg)	70.40 ± 5.34 (67.1, 73.7)	81.10 ± 3.93 (78.7, 83.5)	10.70 ± 4.63	2.28	76.30 ± 4.22 (73.7, 78.9)	92.50 ± 4.77 (89.5, 95.5)*	16.2 ± 2.90	3.60
IMTP (kg)	189.12 ± 15.88 (179, 199)	202.67 ± 13.24 (194, 211)	13.56 ± 8.65	0.93	191.90 ± 14.33 (183, 201)	217.61 ± 17.38 (207, 228)*	25.71 ± 7.58	1.61
CMJ (cm)	28.62 ± 3.02 (26.7, 30.5)	30.22 ± 2.71 (28.5, 31.9)	1.60 ± 0.69	0.56	30.10 ± 2.99 (28.2, 32.0)	35.70 ± 1.95 (34.5, 36.9)*	5.60 ± 1.80	2.22
SJ (cm)	26.60 ± 3.30 (24.6, 28.6)	27.11 ± 2.79 (25.4,28.8)	0.51 ± 1.23	0.17	27.47 ± 3.08 (25.6, 29.4)	31.06 ± 2.13 (29.7, 32.4)*	3.59 ± 2.63	1.36
PSAP (%)	7.16 ± 4.11 (4.61, 9.71)	10.33 ± 3.44 (6.77, 10.80)	3.17 ± 4.62	0.84	8.79 ± 3.25 (8.19, 12.50)	12.93 ± 5.05 (9.80, 16.10)	4.14 ± 6.28	0.97
RSI	1.10 ± 0.24 (0.95, 1.25)	1.23 ± 0.20 (1.10, 1.35)	0.13 ± 0.06	0.59	1.21 ± 0.30 (1.03, 1.40)	1.54 ± 0.20 (1.42, 1.66)*	0.32 ± 0.20	1.29

*Statistically significant difference as compared to all the other pre- and post-interventions, $p<0.05$.
1RM, one repetition of maximum; IMTP, isometric mid-thigh pull; CMJ, counter-movement jump; SJ, squat jump; PSAP, pre-stretch augmentation percentage; RSI, reaction strength index.

Weakley et al., 2021). It may thus induce significantly greater improvements specifically in 1RM of squat and IMTP by targeting quadriceps femoris and hamstring. These results suggested potential benefits from CT for lower-limb strength.

Significant improvements in CMJ, SJ, and RSI after completing CT, but not after RT, were observed. The CMJ and SJ reflect lower-limb power, associated with strength and speed performance (Jadczak et al., 2019). Previous studies showed that flight time and jump height mainly reflected lower-limb power, among which RSI was extremely important and an indicator of how efficiently athletes perform the SSC (Barker et al., 2018; Jeffreys et al., 2019). The results here suggest that CT can augment such efficiency of muscle action *via* plyometric exercises. Additionally, high-load RT in CT targets phosphorylation of the regulatory light chains, potentiated H-reflex response, and pennation angle of the muscle fibers to active more motor unit (Tillin and Bishop, 2009). However, no significant improvements in PSAP as induced by CT were observed. Suchomel et al. observed that PSAP may show vastly different results when comparing elite athlete ability and RSI will provide more information about how athletes use the SSC as compared with PSAP because of the incorporation of a timing component (e.g., ground contact time; Suchomel et al., 2016). Due to complicated factors of lower-limb power, more comprehensive assessments of power by characterizing multiple aspects of power are thus needed to future explore how the underlying physiological characteristics (e.g., electromyogram) affect power.

Several limitations of this pilot study should be noted. First, only 10 elite female participants were included, and the design of the study was not randomized with a control group. This is because we recruit athletes from the national team, and their daily training routine cannot be changed, we thus cannot implement randomization or control type of training for them. This limitation may thus raise potential issues of placebo or practice effects. Specifically, though many of the observed improvements in the performance can only be observed after completing CT, not RT, the contribution from RT still cannot be ignored, and such improvements might be related to the time effect (i.e., repeated training) instead of the unique benefits from CT. Future studies consisting of larger sample of participants (matched number of male and female) and using the design of randomization by including a control group are thus highly demanded to confirm the findings of our study. Second, studies with longer-term follow-up assessments using different CT protocols are needed to future determine the length that the benefits of CT can sustain, as well as the appropriate intensity and number of sessions of CT to maximize its benefits. Third, assessments that are linked to the performance of modern pentathlon athletes (e.g., the results of laser-run, swimming, and fencing) have not been used here; future studies are thus needed to determine the effects of CT on the match performance of modern pentathlon. Third, in this pilot study, though we asked participants to keep their ordinary daily nutritional intake without taking additional nutritional supplements or caffeine drinks, we did not record/track the daily nutritional intake participants, which may have potential impact on their performance. It is worthwhile to include this important information in the analysis of future studies Nevertheless, this pilot and non-randomized study provided preliminary evidence that CT might significantly augment lower-limb strength and power in elite modern pentathlon athletes.

Data availability statement

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

Ethics statement

The studies involving human participants were reviewed and approved by the study protocol was approved by the Beijing Sport University Institutional Research Commission (approval number: 2022132H). The patients/participants provided their written informed consent to participate in this study.

Author contributions

ZQ, ZG, ML, LZ, and DB: research concept and study design. ZQ, ZG, LZ, and JZ: literature review, writing of the manuscript, and writing—original draft preparation. BL, ML, and DB: conceptualization and methodology. ML, LZ, and DB: formal analysis, investigation, and resources. ZQ, ZG, BL, and LZ: data collection, data analysis and interpretation, and statistical analyses. ZQ, ZG, LZ, DB, and JZ: writing—review and editing. All authors have read and agreed to the published version of the manuscript.

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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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References

Bachero-Mena, B., Pareja-Blanco, F., and González-Badillo, J. J. (2021). Effects of resistance training on physical performance in high-level 800-meter athletes: a comparison between high-speed resistance training and circuit training. *J. Strength Cond. Res.* 35, 1905–1915. doi: 10.1519/jsc.0000000000003066

Barker, L. A., Harry, J. R., and Mercer, J. A. (2018). Relationships between countermovement jump ground reaction forces and jump height, reactive strength index, and jump time. *J. Strength Cond. Res.* 32, 248–254. doi: 10.1519/JSC.0000000000002160

Berriel, G. P., Cardoso, A. S., Costa, R. R., Rosa, R. G., Oliveira, H. B., Kruel, L. F. M., et al. (2022). Does complex training enhance vertical jump performance and muscle power in elite male volleyball players? *Int. J. Sports Physiol. Perform.* 17, 586–593. doi: 10.1123/ijspp.2021-0187

Berryman, N., Mujika, I., Arvisais, D., Roubeix, M., Binet, C., and Bosquet, L. (2018). Strength training for middle- and long-distance performance: a meta-analysis. *Int. J. Sports Physiol. Perform.* 13, 57–64. doi: 10.1123/ijspp.2017-0032

Blagrove, R. C., Howatson, G., and Hayes, P. R. (2019). Use of loaded conditioning activities to potentiate middle- and long-distance performance: a narrative review and practical applications. *J. Strength Cond. Res.* 33, 2288–2297. doi: 10.1519/jsc.0000000000002456

Bosco, C., Luhtanen, P., and Komi, P. V. (1983). A simple method for measurement of mechanical power in jumping. *Eur. J. Appl. Physiol. Occup. Physiol.* 50, 273–282. doi: 10.1007/BF00422166

Carter, J., and Greenwood, M. (2014). Complex training reexamined: review and recommendations to improve strength and power. *Strength Cond. J.* 36, 11–19. doi: 10.1519/SSC.0000000000000036

Chirico, A., Fegatelli, D., Galli, F., Mallia, L., Alivernini, F., Cordone, S., et al. (2019). A study of quiet eye's phenomenon in the shooting section of "laser run" of modern pentathlon. *J. Cell. Physiol.* 234, 9247–9254. doi: 10.1002/jcp.27604

Clemente, F. M., Afonso, J., and Sarmento, H. (2021). Small-sided games: an umbrella review of systematic reviews and meta-analyses. *PLoS One* 16:e0247067. doi: 10.1371/journal.pone.0247067

Comfort, P., Jones, P. A., Mcmahon, J. J., and Newton, R. (2015). Effect of knee and trunk angle on kinetic variables during the isometric midthigh pull: test-retest reliability. *Int. J. Sports Physiol. Perform.* 10, 58–63. doi: 10.1123/ijspp.2014-0077

Crowley, E., Harrison, A. J., and Lyons, M. (2017). The impact of resistance training on swimming performance: a systematic review. *Sports Med.* 47, 2285–2307. doi: 10.1007/s40279-017-0730-2

Farney, T. M., MacLellan, M. J., Hearon, C. M., Johannsen, N. M., and Nelson, A. G. (2020). The effect of aspartate and sodium bicarbonate supplementation on muscle contractile properties among trained men. *J. Strength Cond. Res.* 34, 763–770. doi: 10.1519/JSC.0000000000002692

Haff, G. G., and Nimphius, S. (2012). Training principles for power. *Strength Cond. J.* 34, 2–12. doi: 10.1519/SSC.0b013e31826db467

Hanon, C., and Thomas, C. (2011). Effects of optimal pacing strategies for 400-, 800-, and 1500-m races on the VO2 response. *J. Sports Sci.* 29, 905–912. doi: 10.1080/02640414.2011.562232

Hopkins, W., Marshall, S., Batterham, A., and Hanin, J. (2009). Progressive statistics for studies in sports medicine and exercise science. *Med. Sci. Sports Exerc.* 41, 3–12. doi: 10.1249/MSS.0b013e31818cb278

Jadczak, Ł., Wieczorek, A., Grześkowiak, M., Wieczorek, J., and Łochyński, D. (2019). Jumping height does not increase in well trained volleyball players after transcutaneous spinal direct current stimulation. *Front. Physiol.* 10:1479. doi: 10.3389/fphys.2019.01479

Jeffreys, M. A., Croix, M. B. D. S., Lloyd, R. S., Oliver, J. L., and Hughes, J. D. (2019). The effect of varying plyometric volume on stretch-shortening cycle capability in collegiate male rugby players. *J. Strength Cond. Res.* 33, 139–145. doi: 10.1519/JSC.0000000000001907

Jurado-Castro, J. M., Campos-Perez, J., Ranchal-Sanchez, A., Durán-López, N., and Domínguez, R. (2022). Acute effects of beetroot juice supplements on lower-body strength in female athletes: double-blind crossover randomized trial. *Sports Health*. doi: 10.1177/19417381221083590 [Epub ahead of print]

Keiner, M., Sander, A., Wirth, K., Caruso, O., Immesberger, P., and Zawieja, M. (2013). Strength performance in youth: trainability of adolescents and children in the back and front squats. *J. Strength Cond. Res.* 27, 357–362. doi: 10.1519/JSC.0b013e3182576fbf

Ko, B.-G., Cho, E.-H., Chae, J.-S., and Lee, J.-H. (2021). Relative contribution among physical fitness factors contributing to the performance of modern pentathlon. *Int. J. Environ. Res. Public Health* 18:4880. doi: 10.3390/ijerph18094880

Le Meur, Y., Hausswirth, C., Abbiss, C., Baup, Y., and Dorel, S. (2010). Performance factors in the new combined event of modern pentathlon. *J. Sports Sci.* 28, 1111–1116. doi: 10.1080/02640414.2010.497816

Li, F., Wang, R., Newton, R. U., Sutton, D., Shi, Y., and Ding, H. (2019). Effects of complex training versus heavy resistance training on neuromuscular adaptation, running economy and 5-km performance in well-trained distance runners. *PeerJ* 7:e6787. doi: 10.7717/peerj.6787

Liu, M., Zhou, K., Li, B., Guo, Z., Chen, Y., Miao, G., et al. (2022). Effect of 12 weeks of complex training on occupational activities, strength, and power in professional firefighters. *Front. Physiol.* 13:962546. doi: 10.3389/fphys.2022.962546

MacDonald, C. J., Lamont, H. S., and Garner, J. C. (2012). A comparison of the effects of 6 weeks of traditional resistance training, plyometric training, and complex training on measures of strength and anthropometrics. *J. Strength Cond. Res.* 26, 422–431. doi: 10.1519/JSC.0b013e318220df79

Miller, T. A. (2012). *NSCA's Guide to Tests and Assessments*. Champaign, Illinois, Canada: Human Kinetics.

Nonnato, A., Hulton, A. T., Brownlee, T. E., and Beato, M. (2022). The effect of a single session of plyometric training per week on fitness parameters in professional female soccer players: a randomized controlled trial. *J. Strength Cond. Res.* 36, 1046–1052. doi: 10.1519/JSC.0000000000003591

Schoenfeld, B. J., Contreras, B., Krieger, J., Grgic, J., Delcastillo, K., Belliard, R., et al. (2019). Resistance training volume enhances muscle hypertrophy but not strength in trained men. *Med. Sci. Sports Exerc.* 51, 94–103. doi: 10.1249/mss.0000000000001764

Suchomel, T. J., Sole, C. J., and Stone, M. H. (2016). Comparison of methods that assess lower-body stretch-shortening cycle utilization. *J. Strength Cond. Res.* 30, 547–554. doi: 10.1519/JSC.0000000000001100

Tillin, N. A., and Bishop, D. (2009). Factors modulating post-activation potentiation and its effect on performance of subsequent explosive activities. *Sports Med.* 39, 147–166. doi: 10.2165/00007256-200939020-00004

Turner, A., James, N., Dimitriou, L., Greenhalgh, A., Moody, J., Fulcher, D., et al. (2014). Determinants of olympic fencing performance and implications for strength and conditioning training. *J. Strength Cond. Res.* 28, 3001–3011. doi: 10.1519/jsc.0000000000000478

Union Internationale de Pentathlon Moderne (2022). UIPM Competition Rules and Regulations (Current). Available at: https://www.uipmworld.org/sites/default/files/uipm_normal_3_1.pdf (Accessed Febuary 01, 2022)

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

Zatsiorsky, V. M., Kraemer, W. J., and Fry, A. C. (2020). *Science and Practice of Strength Training*. Champaign, Illinois, Canada: Human Kinetics.

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EDITED BY
José Luis Losada,
University of Barcelona,
Spain

REVIEWED BY
Mario S. Staller,
University of Applied Sciences for Police and Public Administration in North Rhine-Westphalia,
Germany
Jozef Simenko,
University of Hertfordshire,
United Kingdom

*CORRESPONDENCE
Ciro Jose Brito
cirojbrito@gmail.com

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The effects of weight categories on the time-motion analysis of female high-level judo athletes between the 2016 and 2020 Olympic cycles

Lindsei Brabec Mota Barreto[1], Bianca Miarka[2], Roberto Jerônimo dos Santos Silva[3], Nicola Luigi Bragazzi[4], Maamer Slimani[5], Hela Znazen[6], Dani Alexis Sorbazo Soto[7], Esteban Ariel Aedo-Muñoz[8] and Ciro Jose Brito[1]*

[1]Department of Physical Education, Federal University of Juiz de Fora, Campus Governador Valadares, Governador Valadares, Brazil, [2]Department of Physical Education, Laboratory of Psychophysiology and Performance in Sports & Bouts, Postgraduate Program in Physical Education, School of Physical Education and Sport, Federal University of Rio de Janeiro, Rio de Janeiro, Brazil, [3]Department of Physical Education, Federal University of Sergipe, Aracaju, Brazil, [4]Laboratory for Industrial and Applied Mathematics (LIAM), Department of Mathematics and Statistics, York University, Toronto, ON, Canada, [5]Department of Neuroscience, Rehabilitation, Ophthalmology, Genetics, Child and Maternal Health, Faculty of Medical and Pharmaceutical Sciences, University of Genoa, Genoa, Italy, [6]Department of Physical Education and Sport, College of Education, Taif University, Taif, Saudi Arabia, [7]Escuela de Kinesiología, Facultad de Salud, Magister en Ciencias la Actividad Física y Deportes Aplicadas al Entrenamiento Rehabilitación y Reintegro Deportivo, Universidad Santo Tomás, Puerto Montt, Chile, [8]Universidad Metropolitana de Ciencias de la Educación, Santiago, Chile

This study compared the time of female judo combat phases in international competitions between two Olympic cycles (2016; 2020) according to weight divisions (48kg=132; 52kg=72; 57kg=109; 63kg=96; 70kg=69; 78kg=106; >78kg=82; total=666 combats/cycle). The behaviors of 1,332 high-level female judo combats were randomly observed over two Olympic cycles (2016=666; 2020=666) from the top 20 athletes in the world ranking by weight division. We performed time-motion analysis according to the combat phase and sequential judo actions (approach, gripping, attack, defense, groundwork, pause, and effort: pause ratio) considering the moment when the combat ended (Regular time=RT; Golden score=GS). The weight division groups were compared between Olympic cycles (2016; 2020), and $p < 0.05$ was defined as significant. The main results showed that 2020 athletes spent less time in the gripping (p=0.005), attack ($p < 0.001$), defense ($p < 0.001$), groundwork (p<0.001) and pause (p=0.002) phases than 2016 athletes. However, compared by the end-of-combat, 2020 female athletes spent less time in all combat phases for RT combats ($p < 0.001$), and more time in the approach phase for GS combats ($p < 0.05$) than in 2016. The 2016 weight divisions showed a higher diversity in the effort: pause ratio (2.5:1–3.4:1), whereas the 2020 weight divisions had values closer to each other (2.8,1–3:1). Analyzing each weight division separately and by the end-of-combat, the main results showed that ($p < 0.05$): 48, 63, 70, and 78kg reduced the time in almost every phase of RT combat (except for: 63kg=gripping and attack; 70kg=approach and groundwork; 78kg=approach); 48 and 57kg increased the groundwork time in GS combats whereas 78kg decreased; 52kg and 78kg increased the GS approach time. The temporal behavior of the combats changed between the Olympic cycles with different rules. These data must be considered to understand the characteristics of each group and to prescribe specialized training in female judo.

KEYWORDS

martial arts, match analysis, time and motion studies, task performance and analysis, gender

Introduction

Notational analysis allows us to understand how competitive actions are developed in a combat sport (Miarka et al., 2022). This technical analysis allows the most effective actions applied by fighters to be identified (Miarka et al., 2016; Brito et al., 2017), differentiating the time and frequency dedicated to each action that can lead the athlete to achieve victory (Barreto et al., 2021). When the coach has access to accurate information about the weight division in which his athlete competes, an efficient and contextualized training plan can be prepared so that the training load is adequate to the athlete's competitive demand (Miarka et al., 2016, 2020; Brito et al., 2017, 2020). To create more specific and, consequently, more efficient judo training, each temporal phase of combat should be known (Segedi et al., 2014; Sterkowicz-Przybycien et al., 2017); these phases can be classified into approach, gripping, attack, defense, groundwork and pause (Miarka et al., 2011, 2014). The technical-tactical behavior of athletes has been described by studies that temporally characterized the combat phases to identify behaviors that can predict the best sports performance (Kajmovic and Radjo, 2014; Miarka et al., 2014, 2016).

However, continuous rule changes made by the International Judo Federation might have caused changes in the configuration of these temporal phases. In 2015, female judo combat time was reduced from 5 to 4 min, and in 2017–2018, the Yuko score was abolished, the number of penalties (*Shido*) decreased from 4 to 3 (International Judo Federation, 2017a), and the winner was no longer determined at the end of the combat or by the Golden Score (International Judo Federation, 2017b). Due to these changes in the rules, some researchers have attempted to measure the effect of these changes on the behavior of athletes during judo combat (Calmet et al., 2017a,b; Ceylan and Balci, 2017; Barreto et al., 2021, 2022a). To this end, Ceylan and Balci (2017) compared the 2016 and 2017 Paris Grand Slam tournaments; they observed that changing the rules increased the frequency of *Wazari* (half a point) in male and female judokas and decreased the frequency of *Shido* in male judokas. Moreover, they verified that the current rules increase the frequency of combats decided in the GS for male athletes.

Between the 2016 (Rio de Janeiro) and 2021 (Tokyo) Olympic games, rule changes were implemented in 2017, 2018 and 2020 (Barreto et al., 2022b). However, to the best of our knowledge, no technical-tactical analysis studies were carried out in female judo that compared whether these changes in rules resulted in differences in the behavior of athletes. Given the importance of this knowledge for the development of more up-to-date training, new studies analyzing the technical-tactical behavior of fighters in the current rules are interesting (Barreto et al., 2021, 2022a), especially in female judo competition. In this context, the objective of this study was to analyze the temporal phases of international female judo combat in two Olympic cycles (2016 vs. 2020) with different rules by weight division. The data from this study can be useful for judo coaches to plan training considering the temporal demand of each judo combat phase by weight division. We hypothesized that the rule changes affect the combat time dedicated to each combat phase.

Materials and methods

Sample

The present study analyzed 1,332 combat videos of female judo from two Olympic cycles (2016 vs. 2020) distributed in identical numbers by weight division (48 kg = 132; 52 kg = 72; 57 kg = 109; 63 kg = 96; 70 kg = 69; 78 kg = 106; ˃78 kg = 82; total = 666 combats/cycle). The athletes analyzed were among the top 20 of each weight division in the World Ranking (ranking of May 30, 2016; March 16, 2020). The 2016 cycle combats were collected after the 2015 rule change (years 2015 and 2016), so the regular combat time was 4 min. The 2020 cycle combats took place before the interruption of events due to the COVID-19 pandemic (years 2019 and 2020, until January 25, 2020). In the first 2 years of an Olympic cycle in which there is a rule change, athletes need a phase of adaptation to this new context. Therefore, in the 2016 and 2020 cycles, we collected combats from the last 2 years (considering that athletes would already be familiar with the new rules).

The combat videos had a minimum quality of 480/60 pixels, a panoramic view of the entire competition area and were available for public access on the virtual YouTube channel of the International Judo Federation and the Olympic Committee (available in https://www.youtube.com/channel/UCTl3QQTvqHFjurroKxexy2Q; https://www.youtube.com/c/judo/videos); therefore, obtaining informed consent from the athletes was not necessary. The number of combats analyzed per Olympic cycle was determined from the collection of all combats found from the 2016 cycle from the top 20 athletes of each weight division in the World Ranking, since for this period there were fewer videos available on the internet compared to the 2020 cycle. Thus, the combats were analyzed in identical amounts per Olympic cycle, according to sex and weight division.

The combats were from the following international judo competitions: 26 Grand Prix (Almaty 2016; Antalaya 2019; Budapest 2015, 2016, 2019; Dusseldorf 2015, 2016; Havana 2016; Hohhot 2019; Jeju 2015; Marrakech 2019; Montreal 2019; Qingdao 2015, 2016; Samsun 2015, 2016; Tashkent 2016, 2019; Tbilisi 2015, 2016, 2019; Tel Aviv 2019, 2020; Ulaanbaatar 2016; Zagreb 2016, 2019); 11 Grand Slam (Abu Dhabi 2015, 2016, 2019; Baku 2015, 2016, 2019; Paris 2016; Tokyo 2015, 2016; Tyumen 2015, 2016); 2 World Championship (Astana 2015; Tokyo 2019); and the Rio 2016 Olympic Games. The distribution of combats by competition between the 2016 and 2020 cycles was not the same (Grand Prix: 2016 cycle = 16, 2020 cycle = 10; Grand Slam: 2016 cycle = 9, 2020 cycle = 2, Olympic Games: only in the 2016 cycle; World Championship: 1 for both cycles). This distribution is due to the existence of combats available on the internet (in full) of the 20 best ranked athletes in each weight division, in each cycle. Data from the 2020 Olympics was not collected because it was postponed due to the covid-19 pandemic, it taking place in 2021 (outside the period of the last 2 years of an Olympic cycle, inclusion criteria for combat videos).

Procedures

We used a validated analysis protocol for judo (Miarka et al., 2011, 2015), which divided the judo combats into approach (combat beginning by the *hajime* command until the grip on the opponent's uniform—*judogi* grip), grip (characterized by the minimum permanence of 1 s of grip on the *judogi*), attack (performing techniques falling), groundwork (movements with at least three body parts on the ground) and pause phases (interruption of the combat by the referee; Miarka et al., 2011, 2014, 2015).

To analyze the videos, we used the Frami® software and the media player VLC 3.0.4 to make the video compatible with this software (Miarka et al., 2011, 2015). In this study, the time spent in each combat phase was established by weight division, by Olympic cycle (2016 vs. 2020), and by moment of combat end [regular time (RT) or golden score (GS)]. We also calculated the effort: pause ratio by dividing the sum of time spent in action phases by the pause time.

The videos were analyzed by a judo expert (˃ 25 years of Judo, black 2nd Dan degree, national competitive experience) who was trained to use the Frami® and the analysis protocol for 12 h. The use of the judo analysis protocol was demonstrated to be objective when performed by experts with a minimum degree of brown (1st Kyu) and at least 7 h of training in Frami (Miarka et al., 2011; Ando et al., 2016). In fact, the reliability of the analysis was verified (20 judo combats reanalyzed 1 week later), and agreement was "excellent" for all combat phases (intraclass correlation coefficient = 0.95; 0.99; confidence interval = 0.88; 1).

Statistical analysis

For the statistical analysis, we used the SPSS software (version 20.0; SPSS, Inc., Chicago, IL, United States) with a significance level of $p \leq 0.05$. The reliability of the use of the video analysis protocol was calculated with the intraclass correlation coefficient test and confidence interval, as the data are quantitative. In the descriptive analysis of the temporal data of each judo combat phase (in seconds), we used the mean, standard deviation and interval. Kolmogorov–Smirnov test was used to verify the normality of the data. According to the normality check for each variable, we use Student's t test for independent samples or Mann–Whitney *U* test to analyze the data by the Olympic cycle and by weight division. The effect size was calculated and classified considering: ≤0.1 = small effect; 0.11–0.3 = mean effect; 0.31–0.5 = great effect.

Results

Table 1 shows the time of each phase of female judo combat by Olympic cycle (2016 vs. 2020) and by weight division. Athletes from 2020 cycle spent less time in the gripping ($U = 202229.5$; $p = 0.005$; $r = -0.008$), attack ($U = 191004.5$; $p < 0.001$; $r = -0.12$), defense ($U = 192011.5$; $p < 0.001$; $r = -0.12$), groundwork ($U = 195862.5$; $p < 0.001$; $r = -0.08$) and pause ($U = 200080.5$; $p = 0.002$; $r = -0.08$) phases than athletes from 2016 cycle. In the analysis by weight division, whereas the effort/pause ratio varied in the 2016 cycle (2.5:1–3.4:1), since the lowest effort/pause ratio was at 63 kg (2.5:1) and the highest was at 52 kg (3.4:1), these values were similar between divisions in the 2020 cycle (2.8:1–3:1).

In addition, the following situations significantly differed between the Olympic cycles, and 2020 cycle athletes: from 48 kg spent less time for the attack ($U = 6,608$; $p = 0.001$; $r = -0.21$), defense ($U = 7,196$; $p = 0.014$; $r = -0.15$) and pause ($U = 7404.5$; $p = 0.035$; $r = -0.13$) phases; from 52 kg spent less time in the gripping phase ($U = 2080$; $p = 0.041$; $r = -0.17$); from 57 kg spent more time in the groundwork phase ($t_{(216)} = -2.733$; $p = 0.007$; $r = -0.18$); from 63 kg spent less time in the defense phase ($U = 3,762$; $p = 0.027$; $r = -0.16$); from 70 kg spent less time in the gripping ($U = 1,692$; $p = 0.003$; $r = -0.25$) and attack ($t_{(136)} = 2.219$; $p = 0.028$; $r = 0.19$) phases; from 78 kg spent less time in the groundwork phase ($U = 3813.5$; $p < 0.001$; $r = -0.28$); from ˃ 78 kg spent less time in the gripping ($t_{(162)} = 2.365$; $p = 0.019$; $r = 0.18$), attack ($U = 2,558$; $p = 0.008$; $r = 0.21$) and groundwork phase ($t_{(162)} = 3.681$; $p < 0.001$; r = 0.28; Table 1).

Table 2 shows the time phases, by weight division, from combats finished in RT (2016 cycle = 91%; 2020 cycle = 79.6% of the combats) or GS (2016 cycle = 9%; 2020 cycle = 20.4% of the combats) in each Olympic cycle. In combat trials that continued

TABLE 1 Time of combat phases of female judo in the 2016 and 2020 Olympic cycles (n =1,332).

Weight divisions (Combats per cycle)	Combat phases time (seconds) (mean ± standard deviation/interval)							Effort:pause ratio
	Approach	Gripping	Attack	Defense	Groundwork	Pause		
2016 cycle	All categories (n = 666)	69 ± 38.2/250	76.2 ± 42.9/289[#]	4.7 ± 4.2/29*	4.6 ± 4.4/32*	49.9 ± 31/207*	73.3 ± 54.4/345[$]	2.7:1
	48 kg (n = 132)	86.3 ± 39.1/227	63.4 ± 30.6/143	6.3 ± 5.2/29[&]	6 ± 5.5/32[ω]	64.1 ± 25.7/137	83.3 ± 47.5/215[§]	2.7:1
	52 kg (n = 72)	68.8 ± 35.2/139	72.2 ± 38.7/156[⁎]	4.7 ± 3.9/21	4.3 ± 3.7/17	57.6 ± 35/159	61.1 ± 38.6/178	3.4:1
	57 kg (n = 109)	70.8 ± 43/250	80.6 ± 48/289	4.3 ± 3.9/19	4.3 ± 3.9/17	43.4 ± 32/151[α]	65.6 ± 46/188	3.1:1
	63 kg (n = 96)	66.9 ± 32.9/137	67.1 ± 38.4/169	4.8 ± 4.1/19	5.1 ± 4.5/22[¢]	51.9 ± 31.8/138	78.8 ± 55/278	2.5:1
	70 kg (n = 69)	67.1 ± 42.7/182[µ]	74 ± 40.7/189[◘]	4.4 ± 4.1/21	4.5 ± 4.3/23	46.4 ± 30/122	72.6 ± 66/339	2.7:1
	78 kg (n = 106)	57.9 ± 27.4/116	91.3 ± 40.8/164	4.3 ± 4.2/20	4.3 ± 4.3/23	44.4 ± 33/122*	76.4 ± 49/224	2.6:1
	˃78 kg (n = 82)	57.6 ± 37.2/215[∞]	87.4 ± 55.9/251[ʒ]	3 ± 2.4/10	2.7 ± 2.6/12	36.5 ± 18.3/82*	68.6 ± 75.8/345	2.7:1
2020 cycle	All categories (n = 666)	72.8 ± 51.4/309	72.2 ± 50.2/321[#]	3.6 ± 3.3/23*	3.6 ± 3.7/25*	45 ± 34.1/186*	69.3 ± 60.9/314[$]	2.8:1
	48 kg (n = 132)	86.8 ± 55.3/259	70.2 ± 44.4/201	4.4 ± 3.9/17[&]	4.5 ± 4.2/22[ω]	59.7 ± 38.6/183	81.3 ± 70.9/270[§]	2.8:1
	52 kg (n = 72)	84.4 ± 65.1/283	62 ± 46.6/252[⁎]	3.7 ± 2.9/17	3.8 ± 3.5/16	51.3 ± 33.1/143	69.7 ± 55.7/246	2.9: 1
	57 kg (n = 109)	83.4 ± 61/309	78.2 ± 55.5/223	3.8 ± 3.8/23	3.8 ± 4.1/25	55.8 ± 35.2/174[α]	78.4 ± 67.9/314	2.9: 1
	63 kg (n = 96)	71.4 ± 46.4/247	70.9 ± 46.9/243	4.2 ± 3.8/19	3.8 ± 4.1/22[¢]	45.3 ± 27.2/126	71.1 ± 60.9/307	2.8: 1
	70 kg (n = 69)	57.5 ± 35.8/155[µ]	55.9 ± 45.7/205[◘]	3.1 ± 2.7/13	3.2 ± 3.7/22	43.1 ± 37.4/183	54.9 ± 48.4/186	3: 1
	78 kg (n = 106)	66.7 ± 42.6/217	89.2 ± 60.9/317	3.5 ± 2.7/12	3.4 ± 2.9/14	27.7 ± 23.6/108*	67.4 ± 57.2/258	2.8: 1
	˃ 78 kg (n = 82)	48.2 ± 25.7/130[∞]	69.4 ± 40/154[ʒ]	2.1 ± 2.2/10	2.4 ± 2.5/11	25.3 ± 20.8/119*	49.8 ± 44.1/204	3: 1

Significant difference between 2016 vs. 2020 cycle: *p<0.001; [&]p = 0.001; [$]$p$ = 0.002; [µ]p = 0.003; [#]p = 0.005; [α]p = 0.007; [ʒ]p = 0.008; [ω]p = 0.014; [∞]p = 0.019; [¢]p = 0.027; [◘]p = 0.028; [§]p = 0.035; [⁎]p = 0.041.

until RT, 2020 athletes spent less time in all combat phases than 2016 athletes (approach: $U = 134{,}434$; $r = -0.13$; gripping: $U = 124894.5$; $r = -0.18$; attack: $U = 126{,}715$; $r = -0.17$; defense: $U = 125168.5$; $r = -0.18$; groundwork: $U = 126{,}674$; $r = -0.17$; pause: $U = 122{,}365$; $r = -0.19$; $p < 0.001$ for all). In combats ended in the GS, the 2020 athletes spent more time in the approach phase ($t_{(194)} = -2.233$; $p = 0.027$; $r = 0.16$) than 2016 athletes.

In the analysis by weight division of RT combats, there were situations that differed significantly between the Olympic cycles, and 2020 cycle athletes: from 48 kg spent less time in all phases (approach: $t_{(209)} = 3.841$; $p < 0.001$; r = 0.27; gripping: $t_{(209)} = 2.246$; $p = 0.026$; $r = 0.16$; attack: $t_{(209)} = 5.138$; $p<0.001$; $r = 0.33$; defense: $t_{(209)} = 3.855$; $p < 0.001$; $r = 0.26$; groundwork: $t_{(209)} = 4.860$; $p < 0.001$; $r = 0.32$; pause: $t_{(209)} = 4.001$; $p < 0.001$; $r = 0.29$); from 52 kg spent less time in the gripping ($U = 1{,}198$; $p = 0.003$; $r = -0.28$) and attack ($t_{(117)} = 2.379$; $p = 0.019$; $r = 0.21$) phases; from 63 kg spent less time in the approach ($t_{(164)} = 2.619$; $p = 0.01$; $r = 0.2$), defense ($U = 2350.5$; $p = 0.001$; $r = -0.27$), groundwork ($t_{(164)} = 2.801$; $p = 0.006$; $r = 0.16$) and pause ($t_{(164)} = 2.979$; $p = 0.003$; $r = 0.19$) phases; from 70 kg spent less time in the gripping ($U = 973$; $p < 0.001$; $r = -0.38$), attack ($t_{(116)} = 2.317$; $p = 0.023$; $r = 0.21$), defense ($t_{(116)} = 2.839$; $p = 0.006$; $r = 0.25$) and pause ($t_{(116)} = 2.589$; $p = 0.011$; $r = 0.23$) phases; from 78 kg spent less time in the gripping ($t_{(182)} = 4.139$; $p<0.001$; $r = 0.29$), attack ($t_{(182)} = 2.55$; $p = 0.012$; $r = 0.17$), defense ($U = 3399.5$; $p = 0.031$; $r = -0.16$), groundwork ($t_{(182)} = 4.157$; $p<0.001$; $r = 0.29$), and pause ($t_{(182)} = 4.219$; $p<0.001$; $r = 0.29$) phases; from ˃78 kg spent less time in the attack ($U = 2{,}453$; p = 0.02; $r = -0.19$) and groundwork ($t_{(156)} = 3.347$; p = 0.001; $r = 0.29$) phases (Table 2).

Although the effort/pause ratio varied by weight division in both cycles, the values in 2020 were closer between weight divisions. In 2016, combats that ended in RT had the lowest value in the 63 kg class (2.5:1) and the highest value in the 52 kg class (3.5:1). In the 2020 cycle, the lowest effort/pause ratio was in the ˃ 78 kg division (2.9:1), and the highest ratio was in the 48, 52, and 70 kg divisions (3.3:1; Table 2).

In the analysis by weight division of GS combats, there were situations that differed significantly between the Olympic cycles, and 2020 cycle athletes: from 48 kg spent more time in the gripping ($t_{(52)} = -3.778$; $p<0.001$; $r = 0.47$) and groundwork ($t_{(52)} = -2.390$; $p = 0.021$; $r = 0.23$) phases; from 52 kg spent more time in the approach ($t_{(23)} = -2.774$; p = 0.012; $r = 0.41$) phase; from 57 kg spent more time in the groundwork ($U = 87$; $p = 0.016$; $r = -0.40$) phase; from 78 kg spent more time in the approach ($t_{(26)} = -2.539$; $p = 0.017$; $r = 0.17$) and less time in the groundwork ($t_{(26)} = 5.234$; p = 0.031; $r = 0.89$) phases. The weight division ˃78 kg only had 1 occurrence of GS in the 2020 cycle and 5 occurrences in the 2016 cycle, which made the statistical analysis between the cycles unfeasible (Table 2).

In addition, in the 2016 cycle, combats that ended in the GS had the lowest value in the 70 and ˃ 78 kg classes (1.8:1) and the highest value in the 52 kg division (3:1). In the 2020 cycle, the lowest effort/pause ratios were in the 48 kg and 63 kg divisions (2.4:1) and the highest ratio was in the ˃ 78 kg division (3.5:1; referring to 1 combat time; Table 2).

TABLE 2 Time of combat phases of female judo, separating the combats by ending moment, between the 2016 and 2020 Olympic cycles (n =1,332).

Weight divisions (Combats per cycle)		Combat phases time (seconds) (mean ± standard deviation)												Effort: pause ratio	
		Approach		Gripping		Attack		Defense		Groundwork		Pause			
		RT	GS	RT	GS	RT	GS	RT	GS	RT	GS	RT	GS	RT	GS
2016 cycle	All categories (n = 666)	63.7 ± 32.2*	123.3 ± 49.9[#]	72.2 ± 39.2*	116.2 ± 56.5	4.4 ± 4.1*	7.6 ± 4.8	4.3 ± 4.2*	7.2 ± 4.8	47.4 ± 28.9*	75.5 ± 39.2	66.2 ± 48.6*	145.3 ± 57.7	2.9:1	2.3/1
	48 kg (n = 132)	78.2 ± 149.7*	149.7 ± 48.1	62.7 ± 30.9[Ч]	68.6 ± 28.7*	6 ± 5*	8.6 ± 6.2	5.7 ± 5.4*	8.3 ± 6	62.4 ± 26.2*	78.1 ± 16.3[ω]	76.1 ± 44.4*	139.7 ± 30.5	2.8: 1	2.2:1
	52 kg (n = 72)	61.4 ± 30.3	121.1 ± 19.6[$]	66.3 ± 35.8[β]	114.2 ± 33.1	4.2 ± 3.4[Ξ]	8.4 ± 4.9	3.7 ± 3.1	8.3 ± 5.1	52.5 ± 32.4	93.6 ± 33	53.3 ± 32.3	115.7 ± 35.8	3.5:1	3:1
	57 kg (n = 109)	63.2 ± 33.5	119 ± 62.7	70.8 ± 38.4	141.8 ± 57.4	3.8 ± 3.8	7.4 ± 3.8	3.8 ± 3.8	7.1 ± 3.1	40 ± 27.8	64.6 ± 47.1[Ж]	53.5 ± 34.2	141 ± 39.1	3.4:1	2.4:1
	63 kg (n = 96)	64.8 ± 32[Ω]	104.5 ± 26.6	63.3 ± 35.1	136.6 ± 30.3	4.7 ± 4	8.2 ± 4.4	5 ± 4.4[μ]	7.2 ± 5.9	52.1 ± 31.9[◘]	48.3 ± 32.3	75.9 ± 53.5[β]	132.6 ± 60.2	2.5:1	2.3:1
	70 kg (n = 69)	59.5 ± 37.3	124.7 ± 38.1	69 ± 36.6*	112.2 ± 52	4 ± 3.7[α]	7.8 ± 5.7	4 ± 3.9[◘]	8.3 ± 5.3	42.8 ± 28.6	74 ± 27.7	57.8 ± 44.2[∞]	185.1 ± 96.1	3.1:1	1.8:1
	78 kg (n = 106)	58.1 ± 27.8	51.4 ± 12.8[€]	90.8 ± 41*	108.1 ± 32.4	4.3 ± 4.2[$]	3.1 ± 2.7	4.3 ± 4.3[&]	3.4 ± 3.4	41 ± 26.2*	159.7 ± 40.5[&]	75.1 ± 48.7*	120.2 ± 44.9	2.6:1	2.7:1
	>78 kg (n = 82)	53.5 ± 31.6	120.3 ± 61.1	81.6 ± 48.4	176.1 ± 91.1	2.8 ± 2.3[Ł]	6.2 ± 1.9	2.7 ± 2.7	3.2 ± 1.5	35.9 ± 18.5[μ]	46.7 ± 10.5	60.5 ± 67.9	192.9 ± 91.1	2.9:1	1.8:1
2020 cycle	All categories (n = 666)	55 ± 30.5*	142.5 ± 57.2[#]	57.2 ± 36.4*	130.9 ± 54	2.8 ± 2.5*	6.7 ± 4.3	2.8 ± 2.7*	7.1 ± 4.9	37.4 ± 28.1*	74.9 ± 39.1	49.8 ± 42.5*	146 ± 61.7	3.1:1	2.5:1
	48 kg (n = 132)	61.6 ± 33.3*	149 ± 49.3	52.9 ± 31.6[Ч]	113.1 ± 40.8*	3.1 ± 2.8*	7.6 ± 4.2	3.2 ± 3.2*	7.6 ± 4.8	44.6 ± 26.7*	97.2 ± 38.3[Ł]	50.8 ± 47.1*	156.8 ± 63.2	3.3:1	2.4:1
	52 kg (n = 72)	58.7 ± 32.1	174.4 ± 72.2[$]	46.6 ± 28.6 [β]	115.8 ± 57.6	3 ± 2[Ξ]	6.2 ± 4.1	2.6 ± 2.2	8.2 ± 3.9	45.2 ± 32.4	72.5 ± 27.2	47.2 ± 29.6	148.4 ± 54.7	3.3:1	2.5:1
	57 kg (n = 109)	62.8 ± 36.1	164.9 ± 71.5	60.2 ± 39.1	149.7 ± 53.6	2.7 ± 2.5	7.9 ± 5	2.9 ± 2.8	7.3 ± 6.1	47.1 ± 28.7	90.1 ± 38.1[Ж]	57.1 ± 47.1	162.6 ± 73.1	3.1:1	2.6:1
	63 kg (n = 96)	53 ± 26.1 [Ω]	137 ± 43.8	57.4 ± 36.5	119 ± 49.3	3.4 ± 3	6.9 ± 4.8	2.7 ± 2.9[μ]	7.7 ± 5.3	39.8 ± 24.9[◘]	64.9 ± 26.1	52.5 ± 46.3[β]	137.7 ± 61.2	3:1	2.4:1
	70 kg (n = 69)	47 ± 25.2	107.3 ± 37.4	41.4 ± 30.7*	124.4 ± 43.4	2.7 ± 2.3[α]	5.1 ± 3.6	2.4 ± 2.1[◘]	7 ± 6.3	34.6 ± 30.5	83.8 ± 41.6	38.9 ± 34.1[∞]	131 ± 29.8	3.3:1	2.5:1
	78 kg (n = 106)	51.3 ± 28.5	116.3 ± 43.4[€]	66.4 ± 37.9*	163.2 ± 63	3.1 ± 2.2[$]	4.9 ± 3.4	2.8 ± 2.5[&]	5.1 ± 3.3	25.3 ± 24.7*	35.8 ± 18.1[&]	48 ± 38.5*	130.3 ± 63.1	3.1:1	2.5:1
	>78 kg (n = 82)[1]	47.7 ± 25.4	87.9 ± 0	68.3 ± 38.9	159.8 ± 0	2 ± 2.1[Ł]	6.5 ± 0	2.3 ± 2.6	3.9 ± 0	25.3 ± 20.9[μ]	21.2 ± 0	49.4 ± 44.3	78.8 ± 0	2.9:1	3.5:1

RT, regular time; GS, golden score. [1]At 78 kg division from 2020 cycle, there was only one GS combat, which made statistical analysis unfeasible. Significant difference between 2016 vs. 2020 cycle: [*]$p < 0.001$; [μ]$p = 0.001$; [β]$p = 0.003$; [◘]$p = 0.006$; [Ω]$p = 0.01$; [∞]$p = 0.011$; [$]$p = 0.012$; [Ж]$p = 0.016$; [€]$p = 0.017$; [Ξ]$p = 0.019$; [Ł]$p = 0.02$; [ω]$p = 0.021$; [α]$p = 0.023$; [Ч]$p = 0.026$; [#]$p = 0.027$; [&]$p = 0.031$.

Discussion

This study compared the time of female judo combat phases in international competitions between the 2016 and 2020 Olympic cycles by weight division and by moment at the end of combat. For a more organized discussion of the results, we have divided the findings into two subchapters: (a) time of combat phases; (b) time of combat phases by end moment.

Time of the combat phases

Our main results showed that, despite the official combat time for female judo being 4 min in both Olympic cycles analyzed, athletes from the 2020 cycle spent less time in the gripping, attack, defense, groundwork, and pause phases than athletes in the 2016 cycle, resulting in a reduction in the offensive phases of combat. Although a slight increase in the effort: pause ratio was observed between Olympic cycles, the analysis by weight division in 2016 showed great diversity in the effort: pause ratio (↓value: 63 kg; ↑value: 52 kg), whereas the effort: pause ratio was similar between weight divisions in the 2020 cycle, with a reduction in the value for some categories (52 and 57 kg) and an increase in the value for the other weight divisions (Table 1). These data show that specific analyses by weight are important for a better understanding of the time demand of combat agents.

Some similarities characterized and differentiated the temporal demands between weight divisions. In both Olympic cycles, the 48 kg athletes had the longest approach, attack, defense, groundwork and pause times, despite they had spent less time in the attack, defense and pause phases in the 2020 Olympic cycle compared to the 2016 (Table 1). Athletes with lower body mass are generally more agile and quick in their movements and need to spend more time in the approach phase to perform an efficient grip and apply immediate attack techniques; consequently, defending against the opponent is difficult (Kashiwagura and Franchini, 2022). Moreover, the approach and groundwork phases can be used to manage combat time and avoid opponent attacks after obtaining a score. In line with our results, analyses of athletes from international competitions in 2011–2012 showed that lighter divisions spent more time in the approach and groundwork phases than heavier divisions. Adam et al. (2013) found that the 2012 Olympic champion of the 48 kg division showed greater versatility in the application of techniques than other weight divisions (attack versatility index: 48 kg = 32; 52 kg = 26; 70 kg = 10; ˃78 kg = 16).

Conversely, the 78 kg athletes had the longest gripping time in both Olympic cycles and they had a time reduction only in the groundwork phase between Olympic cycles (Table 1). Athletes with a higher body mass strategically spend more time maintaining the grip and positioning their body in the best way to carry out the attack (Courel et al., 2014) because the risk of losing the combat during groundwork is high if the attack is not successful, mainly due to immobilization. In fact, Adam et al. (2013) observed that the groundwork attack efficiency indices were highest for the 63 kg and 78 kg divisions of the 2012 women's Olympic champions (efficiency index: 63 kg = 6 and 78 kg = 5 vs. 48 kg, 52 kg, 57 kg, ˃ 78 kg = 0 and 70 kg = 1.3). In this sense, greater efficiency of attacks in standing combat could explain the reduction in groundwork time in the 2020 cycle, which also occurred for the ˃ 78 kg athletes.

The ˃78 kg athletes had the shortest approach, attack, defense, and groundwork times in both Olympic Cycles. In addition, they spent less time in the gripping, attack and groundwork phases in the 2020 Olympic cycle compared to the 2016 (Table 1). These data demonstrate that the heaviest female weight division spends little time being able to hold the *judogi* and performing offensive actions, irrespective of the rule in force in the Olympic cycle. The reason for this behavior is twofold: athletes either minimize the physical wear and tear caused by the dispute of grips and attack actions, which can be greater because of the movement speed/body mass ratio (Courel et al., 2014; Barreto et al., 2019), or the ˃78 kg attack actions are highly effective. In fact, Ceylan and Balci (2021) analyzed combats from 2018 to 2019 and observed that 5 of the 6 combats in the ˃ 78 kg ended with *Ippon* before the end of the regular time. Thus, the data suggest that the 48, 78, and ˃ 78 kg weight divisions have specific profiles and use different combat strategies.

Time of the combat phases by end moment

When analyzing the total time of the combat phases by weight divisions between Olympic cycles, many temporal similarities persisted between the cycles, as demonstrated in the previous subchapter. However, when we analyzed the combats by the moment they ended (RT vs. GS), we identified with greater clarity the effects that the rule changes had on the female combat time, as there was a reduction in time in all phases of RT combats, an increase in the approach and maintenance of time spent in the other phases of the GS combats (Table 2).

Analyzing by weight division and end-of-combat, we observed that in the 2020 cycle, the 48 kg reduced significantly the time in all phases in the RT combats (Table 2). These results can be explained by the rule changes that occurred between the Olympic cycles. Unlike in the 2016 cycle, as of the 2017 rule change, penalties no longer decide the winner of combats that continue until RT in the event of a tie (Federation, 2013, 2017); therefore, the best strategy in the 2020 cycle was to win as quickly as possible to avoid the GS. Therefore, while in the 2016 cycle the 48 kg spent the most time in the approach phase (both RT and GS), in the 2020 cycle, this time phase was close to the approach time spent by the 52, 57, and 63 kg weight divisions (both RT and GS).

Athletes unable to perform efficient attacks in RT required a GS. The 48 kg increased the GS gripping time in the 2020 cycle (Table 2). These data suggest that 48 kg athletes from 2020 cycle, who were unable to win the combat in regular time, performed defensive actions in the Golden Score, as they spent a lot of time holding the *judogi*, without performing attacks. It is believed that these athletes win the combat on the Golden Score by penalty.

Ceylan et al. (2022), who analyzed 5,111 judo combats from 2018 and 2019 (women = 2,191; men = 2,920), identified that the possibility of a GS was greater in light and middle weight divisions and that the number of penalties increased this possibility.

In the 2020 cycle, almost all weight divisions reduced the time spent in the RT attack phase (except 57 kg and 63 kg), the 52 kg and 78 kg increased the time spent in the GS approach phase, and the GS period for the attack and defense phases did not change between Olympic cycles for any weight division (Table 2). These results indicate that the athletes who could not win the combat by the RT insisted on the strategy of seeking the opponent's disqualification to win. With the 2018 rule change, only the accumulation of 3 opponents' *Shido* (*Hansokumake*) or the 1st score would result in a victory in GS (International Judo Federation, 2017b), unlike in the 2016 cycle, when the 1st opponent's *Shido* determined the winner (International Judo Federation, 2013).

A limitation of our study is that we did not control the type of decision (combats ending by scoring or disqualification). However, regarding the penalties committed in the 2020 cycle, Balci and Ceylan (2020) analyzed the 2018–2019 senior world judo championships and found that the most committed prohibited actions in combat were non-combativity (common for those who held the grip without making attacks) and avoid grip (common for those who spent a lot of time in the approach phase). Kajmovic et al. (2022) carried out a study that analyzed 2041 penalties committed by female judoka from competitions between 2017 and 2021. They identified that the main penalties were non-combativity (41.6%), avoid grip (16.2%) and false attack (15%). Therefore, it seems that the rule change between cycles did not boost the performance of offensive actions.

Conversely, the groundwork phase may have become relevant to define the GS winner for 48 and 57 kg athletes from 2020 cycle, as these athletes increased the GS groundwork time (Table 2). However, this combat phase could be used either to win combat in a continuous action, or to avoid penalties after an unsuccessful attack. On the other hand, the 78 kg athletes modified the use of the GS groundwork phase between Olympic cycles. While in the 2016 cycle, the 78 kg were the ones who spent the most time in the GS groundwork phase, in the 2020 cycle they spent the shortest time in this phase (Table 2).

In our data collection we did not count the effort cycles, because the initial objective was just to observe if there was a change in the time spent in the combat phases with different rules. To alleviate this limitation, we calculated the effort: pause ratio for each phase (Tables 1 and 2). The effort: pause ratio that we observed was consistent with data from other studies that showed that an average of 11 cycles of effort occur in judo combat, ranging from 20 to 30 s of effort and 10 s of rest (Marcon et al., 2010; Franchini et al., 2013). However, in our data, the 48, 63, 70, and 78 kg divisions reduced the pause time and increased the effort: pause ratio of RT combats in the 2020 cycle compared to the 2016 cycle (Table 2), which suggests fewer combat interruptions in the 2020 cycle and that these athletes won combats in the RT by score. On the other hand, there was no significant difference in the GS pause phase between Olympic cycles.

The analysis of judo combats allows the collection of a large number of variables, and therefore, researchers need to choose which variables will be analyzed to contemplate the writing of an article. Our data showed some changes in the temporal behaviors between cycles for some weight divisions. These results highlight the importance of understanding what happens in each weight division and analyzing the moment of the end of the combat to prepare more specific training sessions according to the athlete's profile, i.e., if the athletes usually finish the combat until RT or combat ends in the GS. However, another limitation of this study is that only the temporal analysis of the combat was performed, that is, data on the actions performed by the athletes in each phase were not collected. It could influence the training planning decisions by judo coaches. Therefore, we suggest that other studies identify the actions (type of approach, grip and techniques) performed by athletes in each Olympic cycle to highlight possible difference in the technical actions performed.

Practical application

We created a table that summarizes the main temporal changes by Olympic cycle found in this study (Table 3) to allow judo coaches to understand and apply the results of this study in practice. Specifically, 2020 athletes spent less time in all combat phases compared to the 2016 cycle for combat that continued until RT, indicating that athletes were able to win combat faster than they did before. In the combats that ended in the GS, the 2020 athletes spent more time in the approach phase than in the 2016 cycle, which suggests that athletes spent time on non-offensive actions and searched for the opposing penalty at the expense of *Ippon*.

When the analysis was stratified by category and end-of-combat, a comparison between the 2020 and 2016 cycles showed the following: (a) the 48 kg reduced the time spent in all phases of combats finished until RT; they increased the gripping time and reduced the groundwork time in the GS combats; (b) The 63, 70, and 78 kg divisions reduced the time spent in almost every phase of RT combat (except for 63 kg = gripping and attack; 70 kg = approach and groundwork; 78 kg = approach). (c) The 78 kg division increased the approach time and reduced the groundwork time in the combats ended in the GS. Thus, our main results showed that performing specific analyses by weight division and separating athletes who usually finish combat in RT from those who usually require GS are important considerations to understand the characteristics of each group.

Conclusion

In general, we found that the athletes from the 2020 cycle reduced the time spent on offensive actions (attack, defense and groundwork) compared to athletes from the 2016 cycle. In addition, the weight divisions in the 2016 cycle presented greater diversity in the values of the effort: pause ratio, whereas these values were similar for athletes of the 2020 cycle. However, we were only able

TABLE 3 Significant changes in female judo combat phases in the 2020 Olympic cycle compared to the 2016cycle ($p \leq 0.05$).

Weight division	Approach	Gripping	Attack	Defense	Groundwork	Pause
All weight divisions	--	↓	↓	↓	↓	↓
48 kg	--	--	↓	↓	--	↓
52 kg	--	↓	--	--	--	--
57 kg	--	--	--	--	↑	--
63 kg	--	--	--	↓	--	--
70 kg	--	↓	↓	--	--	--
78 kg	--	--	--	--	↓	--
˃78 kg	--	↓	↓	--	↓	--
Weight division	Combats ended until the Regular Time					
	Approach	Gripping	Attack	Defense	Groundwork	Pause
All weight divisions	↓	↓	↓	↓	↓	↓
48 kg	↓	↓	↓	↓	↓	↓
52 kg	--	↓	↓	--	--	--
57 kg	--	--	--	--	--	--
63 kg	↓	--	--	↓	↓	↓
70 kg	--	↓	↓	↓	--	↓
78 kg	--	↓	↓	↓	↓	↓
˃78 kg	--	--	↓	--	↓	--
Weight division	Combats ended in the *Golden Score*					
	Approach	Gripping	Attack	Defense	Groundwork	Pause
All weight divisions	↑	--	--	--	--	--
48 kg	--	↑	--	--	↑	--
52 kg	↑	--	--	--	--	--
57 kg	--	--	--	--	↑	--
63 kg	--	--	--	--	--	--
70 kg	--	--	--	--	--	--
78 kg	↑	--	--	--	↓	--
˃78 kg*						

-- kept the average combat time; ↑ increased the average combat time; ↓ decreased the average combat time. * Occurrence of only 1 combat made statistical analysis unfeasible.

to specifically detect how these changes occurred when we analyzed the combats by weight division and end-of-combat time. In summary, the temporal behavior of the combat changed between the Olympic cycles as new rules were implemented.

Data availability statement

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

Author contributions

LBMB, BM, and CJB participated in the research concept, study design, and literature review. LB participated in the data collection. LBMB, RJSS, EAA-M, NLB, NMS, DASS, HZ, BM and CJB participated in the data analysis and interpretation, statistical analyses and writing of the manuscript. All authors contributed to the article and approved the submitted version.

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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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References

Adam, M., Tabakov, S., Blach, L., and Smaruj, M. (2013). Characteristics of the technical-tactical preparation of male and female judo competitors participating in the Olympic games–London 2012. Ido movement for culture. *J. Martial Arts Anthropol.* 13, 75–88. doi: 10.14589/ido.13.2.6

Ando, G. Y. U., Miarka, B., and Pinto, M. M. M. (2016). Avaliação de análise técnico-tática em combates de judô por programa computacional por usuários com diferentes níveis de expertise. *J. Phys. Educ. [online]* 27, 1–13. doi: 10.4025/jphyseduc.v27i1.2718

Balci, S. S., and Ceylan, B. (2020). Penalties in judo: the impact of shido on match durations and results. *Int. J. Perform. Anal. Sport* 20, 659–667. doi: 10.1080/24748668.2020.1775413

Barreto, L. B. M., Aedo-Munoz, E. A., Soto, D. A. S., Miarka, B., and Brito, C. J. (2021). Road to Tokyo Olympic games: do new judo rules change the technical-tactical behaviour of elite male athletes? *Int. J. Perform. Anal. Sport* 21, 1140–1148. doi: 10.1080/24748668.2021.1979839

Barreto, L. B. M., Aedo-Muñoz, E. A., Soto, D. A. S., Miarka, B., and Brito, C. J. (2022a). Has there been a change between combat time in male judo? Analysis of the top 20 athletes by weight division between the 2016-20 Olympic cycles. *Int. J. Perform. Anal. Sport* 22, 541–557. doi: 10.1080/24748668.2022.2086516

Barreto, L. B. M., Aedo-Munoz, E., Soto, D. A. S., Miarka, B., and Brito, C. J. (2022b). Judo combat time, scores, and penalties: review of competition rules changes between 2010 and 2020. *Revista de Artes Marciales Asiáticas* 17, 19–37. doi: 10.18002/rama.v17i1.7122

Barreto, L. B. M., Dal Bello, F., Araujo, R. A., Brito, C. J., Fernandes, J. R., and Miarka, B. (2019). Judo approach and handgrip analysis: determining aspects of world circuit high performance. *J. Phys. Educ. Sport* 19, 413–419. doi: 10.7752/jpes.2019.s2061

Brito, C. J., Aedo-Muñoz, E., and Miarka, B. (2020). Judo performance: Kinanthropometricimportance for technical tactical and biomechanics. *Revista Brasileira de Cineantropometria e Desempenho Humano* 22, 1–7. doi: 10.1590/1980-0037.2020v22e76584

Brito, C. J., Miarka, B., Durana, A. L. D., and Fukuda, D. H. (2017). Home advantage in judo: analysis by the combat phase, penalties and the type of attack. *J. Hum. Kinet.* 57, 213–220. doi: 10.1515/hukin-2017-0062

Calmet, M., Pierantozzi, E., Sterkowicz, S., Challis, B., and Franchini, E. (2017a). Rule change and Olympic judo scores, penalties and match duration. *Int. J. Perform. Anal. Sport* 17, 458–465. doi: 10.1080/24748668.2017.1350489

Calmet, M., Pierantozzi, E., Sterkowicz, S., Takito, M. Y., and Franchini, E. (2017b). Judo rules: searching for a wind of changes. *Int. J. Perform. Anal. Sport* 17, 863–871. doi: 10.1080/24748668.2017.1405612

Ceylan, B., and Balci, S. S. (2017). The impact of new rule changes in judo: a comparison of points and penalties during grand slam Paris between 2016 and 2017. *Int. J. Adv. Sport Manag.* 2, 91–94.

Ceylan, B., and Balci, S. S. (2021). The evaluation of senior world judo championships 2018 and 2019: the effects of sex and weight division on points, penalties, and match duration. *Turkiye Klinikleri J. Sports Sci.* 13, 226–233. doi: 10.5336/sportsci.2020-80066

Ceylan, B., Ozturk, F., and Balci, S. S. (2022). Match duration during high-level judo competitions: Golden score or not? Ido movement for culture. *J. Martial Arts Anthropol.* 22, 21–26. doi: 10.14589/ido.22.1.4

Courel, J., Franchini, E., Femia, P., Stankovic, N., and Escobar-Molina, R. (2014). Effects of Kumi-kata grip laterality and throwing side on attack effectiveness and combat result in elite judo athletes. *Int. J. Perform. Anal. Sport* 14, 138–147. doi: 10.1080/24748668.2014.11868709

Franchini, E., Artioli, G. G., and Brito, C. J. (2013). Judo combat: time-motion analysis and physiology. *Int. J. Perform. Anal. Sport* 13, 624–641. doi: 10.1080/24748668.2013.11868676

International Judo Federation (2013). IJF Refereeing & Competition Rules Modifications for 2013–2016. Details & clarification Mexico City seminar 1/26 & 1/27/13. Available at https://www.teamusa.org/USA-Judo/Features/2013/June/05/2013-IJF-Refereeing-Rules-USA-Judo-Rules-Update. aspx (Accessed on Jan 31, 2022).

International Judo Federation (2017a). Adaptation of the judo refereeing rules for the next 2017–2020 Olympic cycle. Available at: https://78884ca60822a34fb0e6-082b8fd5551e97bc65e327988b444396.ssl.cf3.rackcdn.com/up/2017/04/2017-04-10_adaptation_of_the_r-1492087284.pdf (Accessed Octubre 16, 2022).

International Judo Federation (2017b). Detailed explanation of the IJF judo refereeing rules. Version 26 October 2017 effective from 01 January 2018. Available at: https://78884ca60822a34fb0e6-082b8fd5551e97bc65e327988b444396.ssl.cf3.rackcdn.com/up/2017/11/2017-10-26_Explanatory_guide_o-1509786984.pdf (Accessed Octubre 16, 2022).

Kajmovic, H., Karpljuk, D., Kapo, S., and Simenko, J. (2022). Comparison of individual penalties according to gender and weight categories of elite judo athletes from four world championships. *Biology* 11:1284. doi: 10.3390/biology11091284

Kajmovic, H., and Radjo, I. (2014). A comparison of gripping configuration and throwing techniques efficiency index in judo between male and female judoka during Bosnia and Herzegovina senior state championships. *Int. J. Perform. Anal. Sport* 14, 620–634. doi: 10.1080/24748668.2014.11868747

Kashiwagura, D. B., and Franchini, E. (2022). The grip dispute (kumi-kata) in judo: a scoping review. *Revista de Artes Marciales Asiáticas* 17, 1–18. doi: 10.18002/rama.v17i1.7030

Marcon, G., Franchini, E., Jardim, J. R., and Neto, T. L. B. (2010). Structural analysis of action and time in sports: judo. *J. Quant. Anal. Sports* 6, 1–13. doi: 10.2202/1559-0410.1226

Miarka, B., Branco, B. H. M., Vecchio, F. B. D., Camey, S., and Franchini, E. (2015). Development and validation of a time-motion judo combat model based on the Markovian processes. *Int. J. Perform. Anal. Sport* 15, 315–331. doi: 10.1080/24748668.2015.11868795

Miarka, B., Cury, R., Julianetti, R., Battazza, R., Julio, U. F., Calmet, M., et al. (2014). A comparison of time-motion and technical-tactical variables between age groups of female judo matches. *J. Sports Sci.* 32, 1529–1538. doi: 10.1080/02640414.2014.903335

Miarka, B., Fukuda, H. D., Del Vecchio, F. B., and Franchini, E. (2016). Discriminant analysis of technical-tactical actions in high-level judo athletes. *Int. J. Perform. Anal. Sport* 16, 30–39. doi: 10.1080/24748668.2016.11868868

Miarka, B., Hayashida, C. R., Julio, U. F., Calmet, M., and Franchini, E. (2011). Objectivity of FRAMI-software for judo match analysis. *Int. J. Perform. Anal. Sport* 11, 254–266. doi: 10.1080/24748668.2011.11868546

Miarka, B., Perez, D. I. V., Aedo-Munoz, E., Costa, L. O. F., Barreto, L. B. M., and Brito, C. J. (2022). Technical report on a time-motion analysis of male judo cadets' combats between weight divisions. *Ido Mov. Culture. J. Martial Arts Anthrop.* 22, 9–14. doi: 10.14589/ido.22.1.2

Miarka, B., Valenzuela Pérez, D. I., Aedo-Muñoz, E., Barreto, L. B. M., Fernandes, J. R., and Brito, C. J. (2020). Practical application of time-motion analysis of judo female cadets' combats between weight divisions. *Int. J. Perform. Anal. Sport* 20, 701–708. doi: 10.1080/24748668.2020.1780870

Segedi, I., Sertic, H., Franjic, D., Kustro, N., and Rozac, D. (2014). Analysis of judo match for seniors. *J. Combat Sports Martial Arts* 5, 57–61. doi: 10.5604/20815735.1141976

Sterkowicz-Przybycien, K., Miarka, B., and Fukuda, D. H. (2017). Sex and weight category differences in time-motion analysis of elite judo athletes: implications for assessment and training. *J. Strength Cond. Res.* 31, 817–825. doi: 10.1519/jsc.0000000000001597

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EDITED BY
José Luis Losada,
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Australia
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University of Nevada,
Las Vegas,
United States
David Sherwood,
University of Colorado Boulder,
United States

*CORRESPONDENCE
Lukáš Slovák
✉ lukas.slovak@osu.cz

†These authors have contributed equally to this work

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External focus of attention enhances arm velocities during volleyball spike in young female players

Lukáš Slovák[1*†], Javad Sarvestan[1,2,3†], Takehiro Iwatsuki[4†], David Zahradník[1†], William M. Land[5†] and Reza Abdollahipour[2†]

[1]Human Motion Diagnostic Centre, University of Ostrava, Ostrava, Czechia, [2]Department of Natural Sciences in Kinanthropology, Faculty of Physical Culture, Palacký University Olomouc, Olomouc, Czechia, [3]Translational and Clinical Research Institute, Faculty of Medical Sciences, Newcastle University, Newcastle Upon Tyne, United Kingdom, [4]Department of Kinesiology and Exercise Sciences, University of Hawaiʻi at Hilo, Hilo, HI, United States, [5]Department of Kinesiology, College for Health, Community and Policy, The University of Texas at San Antonio, San Antonio, TX, United States

The aim of this study was to investigate the effect of different volleyball-specific attentional focus instructions on arm velocities of a volleyball spike in young female volleyball players using the Statistical Parametric Mapping method. Twelve young female volleyball players (13.6±0.6years old, 1.8±0.8years of experience in volleyball training) were asked to perform a volleyball spike in a standing position in three different attentional focus conditions including internal focus (IF, i.e., pull back your elbow prior to transfer momentum), external focus, (EF, i.e., imagine cracking a whip to transfer momentum), and control (CON, i.e., no-focus instruction). A Qualisys 3D motion capture-system was used to track reflective markers attached to the arm, forearm, and hand. Consequently, four phases of the volleyball spike including wind-up, cocking, acceleration, and follow-through were analyzed. A one-way repeated-measure ANOVA using one-dimensional statistical parametric mapping (SPM1d) showed that players achieved greater velocities in the hand ($p<0.01$), forearm ($p<0.01$), and arm ($p<0.01$) using the EF instructions from the start of the wind-up phase to the acceleration phase. *Post-hoc* (SPM1d-*t*-tests-paired) analyses indicated significantly greater arm, forearm, and hand velocities during the EF condition, compared to CON ($p<0.01$, $p<0.01$, and $p<0.01$ respectively) and IF ($p<0.01$, $p<0.01$, and $p<0.01$ respectively) conditions. These findings suggest that EF instructions had an immediate impact on increasing volleyball spike velocity from the start of the wind-up phase to the acceleration phase prior to ball contact.

KEYWORDS

focus of attention, volleyball, velocity, external focus of attention, volleyball spike

Introduction

In volleyball, the spike is one of the most effective attacks, with the success rate of volleyball spikes directly linked to the match success rate (Valadés et al., 2016). To better understand the keys to an effective spike, several studies have investigated the underlying biomechanical mechanisms of the volleyball spike (Fuchs et al., 2019; Sarvestan et al., 2020). Results from these studies have revealed that spike velocities, within the entire upper arm mechanism, is a key element to achieving a successful volleyball spike (Valadés et al., 2016; Fuchs et al., 2019). Similar to other upper arm throwing actions, proximal-to-distal sequencing is an important aspect of achieving maximal linear velocities of the segment endpoint, such as hand velocity during the spike (Putnam, 1993).

Proximal-to-distal sequencing in upper arm throwing activities is characterized by an efficient and coordinated sequence of joint motions (generated by muscles), starting from the proximal segments (initiating the movements, e.g., arm) of the chain toward the more distal segments (concluding the movement, e.g., hand; Serrien et al., 2018; Fuchs et al., 2019). The main principle is that each successive segment peaks later and faster compared to the previous segment (Escamilla et al., 1998). That is to say, each segment builds off the acceleration of the previous one. Moreover, higher peak velocities reflect greater neuromuscular activity with greater force generation when the athletes efficiently employ the proximal-to-distal coordination pattern (Wang et al., 2018). Due to variable spatiotemporal conditions, volleyball players are required to rapidly react and execute the volleyball spike as fast as possible (Zwierko et al., 2010; Faity et al., 2022). In addition, the volleyball spike is a multidimensional action that involves four phases consisting of wind-up, cocking, acceleration, and follow-through (Reeser et al., 2010). Velocity at the end of the acceleration phase of the volleyball spike (ball-hitting moment) can be considered as the most important phase with regard to the final transfer of force to the ball. To this end, training that improves optimal biomechanical arm sequencing and velocity is crucial for enhancing volleyball spike performance.

One approach to improving movement performance and efficiency may be found in adopting an external focus of attention during volleyball spike execution. Essentially, an external focus (EF) of attention refers to attention directed toward the effects of one's movement or movement goal (e.g., ball, ball trajectory, instrument, or target). Conversely, an internal focus (IF) of attention refers to attention directed toward one's body movements while performing an action (e.g., movement of an arm or joint). Verbal instructions that promote an external focus of attention have been shown to be more effective than verbal instructions that induce an internal focus of attention. Such findings have been found across a variety of different motor tasks, regardless of age, (dis)ability, and level of expertise (Wulf, 2013; Chua et al., 2021). In particular, an EF has been found to be more effective than an IF for motor tasks where velocity plays a crucial role for optimizing outcome performance (An et al., 2013; Lohse et al., 2014; Halperin et al., 2017; Kershner et al., 2019). For example, An et al. (2013) investigated the golf swing and reported an increased X-factor stretch during the backswing, carry distance, and angular velocities of the pelvis, shoulder, and wrist when adopting an EF (e.g., push against the left side of the ground as you hit the ball) relative to an IF (e.g., transfer your weight to your left foot as you hit the ball) or control (e.g., no-focus instruction) group. In a study on dart-throwing (Lohse et al., 2014), results indicated that an EF relative to an IF of attention improved outcome performance and functional variability as reflected by increased variability in the angles and angular velocity of the shoulder, elbow, and wrist joints of the throwing arm. Investigating a punching task, Halperin et al. (2017) found that "focus on punching the pad as fast and as forcefully as possibly" (EF) compared to "focus on moving your arm as fast and as forcefully as possibly" (IF) increased velocity and punch impact. In a study on a countermovement jump, Kershner et al. (2019) reported an increased mean velocity and squat jump height when participants were asked to "concentrate on pushing away from the ground as explosively as possible" (i.e., EF) versus when they were required to "concentrate on extending your knees and hips as explosively as possible" (i.e., IF). As such, evidence suggests that an EF relative to an IF promotes increased angular velocities in motor tasks where velocity is a critical element for successful performance.

Even though the above-mentioned studies have provided insight regarding the influence of attentional focus on kinematic parameters (e.g., velocity and variability), these studies have tended to consider the spatiotemporal characteristics of the movement as a unified whole (e.g., average velocity; Davids et al., 2003). While this approach produces an overall picture of the advantages of EF relative to an IF, consideration of the moment-to-moment (time-series) movement sequence may provide a more comprehensive picture of the spatiotemporal changes over the course of the movement execution (Davids et al., 2003). In this respect, a method that analyzes time waveforms rather than movement coordination over single time points should be used for monitoring kinematic changes (Bańkosz and Winiarski, 2021) when considering the effects of attentional focus instructions. To this end, Statistical Parametric Mapping (SPM) provides in-depth information about point-by-point (time-series) movement sequences across the entire movement execution (Penny et al., 2011). Indeed, SPM analysis is used for determining the time to peak velocity of tracked trajectories to discern the spatial and temporal changes of the movement, representing movement efficiency (Faity et al., 2022). As such, using a SPM analysis may be particularly useful when attentional focus instructions relate to controlling the process of the movement over the course of movement execution.

Consequently, the aim of the current study was to investigate the effect of attentional focus instructions on the moment-by-moment changes in upper-limbs velocity during the volleyball spike using SPM. In considering upper-limb velocity, a key element was to understand the coordinated proximal-to-distal sequence (or synchronized movement timing) that provides capacities for greater spike velocities. Hence, using an SPM analysis could provide a better indicator of how various attentional focus instructions lead to temporal changes during spike performance. As such, we hypothesized that an EF relative to an IF or control condition would result in higher arm, forearm, and hand velocities from the start of the wind-up phase to the acceleration phase of the volleyball spike. In other words, we hypothesized that the coordination patterns of arm-to-forearm-to-hand velocities (e.g., sequence of velocity generation) would be higher in the period between movement initiation and ball-hitting moment of the volleyball spike while adopting an external focus relative to an internal focus and control condition.

Materials and methods

Participants

Twelve adolescent female volleyball players (age: 13.6 ± 0.6 years, height: 170.1 ± 5.8 cm, weight: 57.6 ± 6.1 kg) were recruited for this study. Previous studies on attentional focus using athletes have produced results with a large effect size (e.g., Bell and Hardy, 2009; Porter and Sims, 2013). As such, we assumed a large effect size when performing an *a priori* power analysis. An *a priori* power analysis with G*Power 3.1 indicated that 12 participants would be sufficient to identify significant differences between conditions in a within-participants design with a power (1−β) of 0.80, a large effect size *f* of 0.4 ($\eta_\rho^2 = 0.14$), the number of measurements = 3, correlation among repeated measures = 0.5, nonsphericity correction e = 1, and an α level of.05 (Faul et al., 2007). Participants had 1.8 ± 0.8 years of volleyball experience, but did not have any specific training on performing the volleyball spike when the ball is fixed and not moving. Participants reported no history of musculoskeletal injuries (i.e., muscle, ligament, and tendon rupture, joint dislocation, and bone fracture) within the past 1 year. Participants were not aware of the specific aim of the study and their legal guardian signed the written informed consent prior to the data collection. *The ethical committee of the Faculty of Education, University of Ostrava, approved this study (Ethic code: 45/2021)*, which is in line with the 1964 Helsinki Declaration and its later amendments.

Apparatus and task

Participants were asked to perform a maximal standing volleyball spike to a stationary ball hanging from the ceiling, similar to Fuchs et al. (2019). The height of the ball was standardized for each participant based on the height from the floor to the middle of the dominant hand when fully extended vertically. During the volleyball spike, participants had both feet in contact with the floor, while the feet position was standardized using tape pasted to the floor. Each volleyball spike was performed in the same direction. Measurement was performed under quiet conditions in the kinematics lab (*Human Diagnostic Centre*) at the University of Ostrava.

To track the kinematics of the volleyball spike, six 12 mm diameter markers and two clusters containing four markers were attached to the dominant upper limb landmarks (head of the third metacarpal, processus styloideus radii and ulnae, epicondylus lateralis and medialis humeri, and lateral part of shoulder) (C-motion, Rockville, MD, United States) (Figure 1). The data reconstruction and marker labeling were conducted using Qualisys Track Manager (Version 2021.1, Sweden) and Visual 3D software (C-Motion, Germantown, Kentucky, KY, United States). The interpolation method was used to fill the missing markers trajectories (not more than 10 frames). To identify the joints and segments, the corresponding static trial markers were used. A total of three segments were modeled (arm, forearm, and hand). Prior to data analysis, each spiking trial was trimmed from the start of the wind-up phase to the end of the follow-through phase, and was analyzed as a whole (Rokito et al., 1998; Sarvestan et al., 2020). Using the entire movement sequence, we identified four phases to allow for better illustration and interpretation of the outcomes and their application for training programs. The wind-up phase started with shoulder abduction and extension and ended with initiating the external shoulder rotation. The cocking phase started with shoulder external rotation and terminated with maximum shoulder external rotation. The acceleration phase started immediately after the cocking phase and finished when the upper

FIGURE 1
Marker placement on the participant dominant arm.

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arm was perpendicular to the trunk. The follow-through phase started with the arm perpendicular to the trunk and ended when the arm rotation was complete. Thereafter, the entire spike performance (trimmed data) was normalized to 100 data points for SPM analysis. Ten motion capture cameras (Oqus, Qualisys, Sweden) were used to record the spatiotemporal 3-dimensional trajectory including velocities of the attached marker and clusters with a sampling frequency of 240 Hz.

Procedure

Prior to data collection, participants were instructed on the measurement process and instructed to focus solely on the assigned attentional instructions when performing the volleyball spike. Following a 10-min dynamic warm-up including stretching exercises and active joint mobility, passive reflective markers and clusters were attached to the dominant upper limb landmarks. Each player performed 3 practice trials of a standing volleyball spike with maximal force. Afterward, all participants performed 5 trials of the volleyball spike across three conditions (EF: external, IF: internal, and CON: control) with a one-min rest interval between the trials and a 3-min rest interval between focus conditions. The descriptive instructions for all participants were as follows: "*The task is to perform a volleyball spike with your dominant hand. The goal is to hit the ball as hard as possible*." The descriptive instructions were provided to all participants to ensure an identical task goal (i.e., hitting the ball) across the different attentional focus conditions. Under the EF condition participants were further instructed to: "*Imagine cracking a whip to transfer momentum!*." To ensure that participants understood the meaning of the external focus instructions, the experimenters asked participants whether they fully understood the meaning of cracking a whip. All participants reported their understanding of the given instructions. During the IF condition, participants were instructed: "*Pull back your elbow prior to transferring momentum!*" and finally, under the CON condition, no additional focus instructions were given. The order of the conditions was counterbalanced to eliminate the possibility of order effects. Attentional focus instructions were provided before each trial. Participants were not provided with performance feedback.

Data analysis

Arm, forearm, and hand velocities were determined from the velocity of the respective modeled segment. Total segment velocity was determined using sum of vector velocities in anterior–posterior, mediolateral, and longitudinal axis and referenced to the lab space. The average moment-by-moment velocities from the normalized time series across the 5 trials for each condition were used for further statistical calculations. Ball velocity was not measured due to the limited space within the laboratory. Prior to data analysis, the Shapiro–Wilk normality test was employed to check the normality of the kinematic data ($p > 0.05$). One-way repeated-measures ANOVAs (SPM1d-ANOVA1RM for time-series analysis) were used to separately compare the arm, forearm, and hand velocities of the volleyball spike performance across the attentional focus conditions: EF, IF, and CON conditions ($\alpha < 0.05$). Where inter-condition differences were highlighted, paired-sample *t*-tests (SPM1d-t-tests-paired, in time-series analysis) using Fisher's least significant difference (since there were no more than three conditions) for *post-hoc* comparisons were performed (Hayter, 1986; Howell, 2010). For the entire analysis, we used the spm1d package (v0.4.3).[1] The Partial Eta Square (η_p^2) values were calculated to interpret effect sizes. $\eta_p^2 = 0.01$ was considered as a small effect size, while $\eta_p^2 = 0.06$ and ≥ 0.14 were considered as moderate and large effect sizes, respectively (Sink and Mvududu, 2010). For the *t*-tests (*post-hoc*), the Cohen's $d \leq 0.02$ was considered as a small effect size, while the Cohen's $d \leq 0.05$ and ≥ 0.08 were considered as moderate and large effect sizes, respectively (Urdan, 2010). Since the SPM was performed for the entire volleyball spike performance, we were unable to report the exact effect size for each percent of the spike performance. We subsequently provided the effect size for each range (Sarvestan et al., 2021). All statistical analyses were conducted using MATLAB (v. 2021b, MathWorks, Inc., Natick, MA, United States).

Results

A Shapiro–Wilk statistical test confirmed the normality of data distribution ($p > 0.05$). The SPM1d-ANOVA1RM depicted a significant difference among focus conditions in arm velocities beginning at movement initiation to 74% of the total movement, i.e., at the wind-up phase, cocking phase, acceleration phase, and after the ball-hitting moment ($F = 6.98$, $p < 0.01$, $\eta_p^2 > 0.14$) (Figure 2). *Post-hoc* analysis (SPM1d-t-tests-paired) showed a significantly greater arm velocity during the EF condition, compared to CON (0 to 75%, $p < 0.01$, $F = 8.12$, $d \geq 0.08$) and IF (0 to 79%, $p < 0.01$, $F = 8.81$, $d \geq 0.08$) conditions. No significant difference was observed between CON and IF conditions.

Similarly, in the forearm velocities, from the start of the wind-up phase to 82% ($p < 0.01$, $F = 5.03$, $\eta_p^2 > 0.14$) of the total movement, participants portrayed greater velocities in EF condition in comparison with CON (0–42 and 48–79%, $p < 0.01$, $F = 7.53$, $d \geq 0.08$) and IF (0–83%, $p < 0.01$, $F = 8.37$, $d \geq 0.08$) conditions. As for the hand velocities, participants reached significantly greater velocities from the start of the wind-up phase to 83% ($p < 0.01$, $F = 9.44$, $\eta_p^2 > 0.14$) of the total movement in the EF condition, compared to CON (0–77%, $p < 0.01$, $F = 6.70$, $d \geq 0.08$) and IF (0–84%, $p < 0.01$, $F = 9.72$, $d \geq 0.08$) conditions.

1 www.spm1d.org

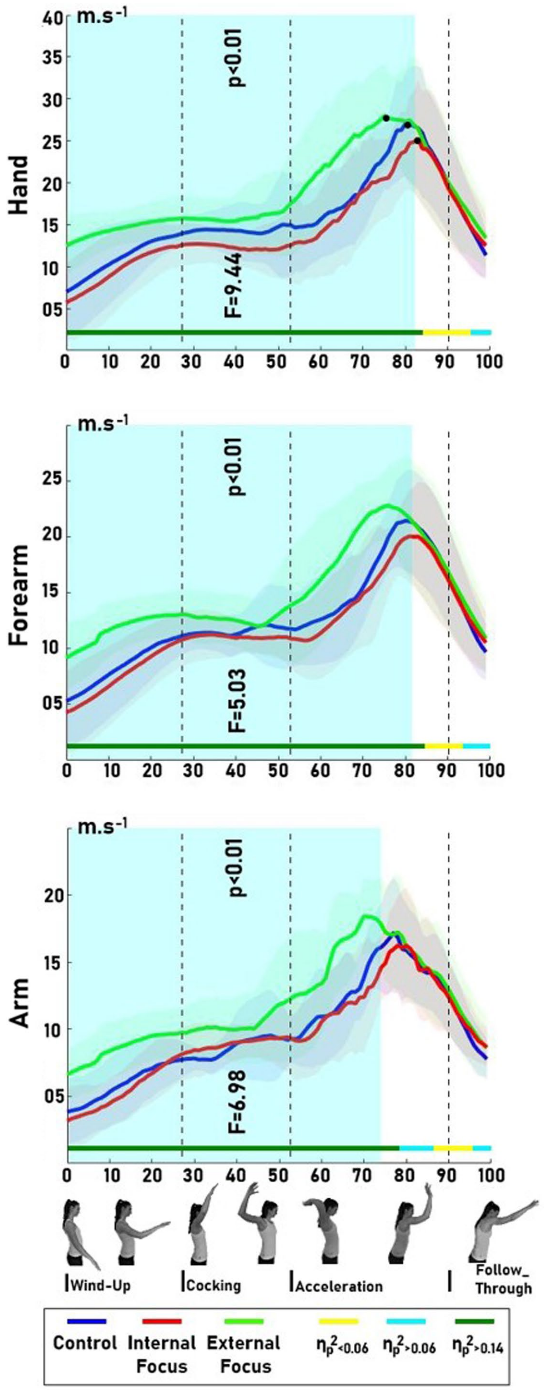

FIGURE 2
The arm, forearm, and hand velocities and their differences among players in three different spiking conditions: EF – external focus of attention (solid green line), IF – internal focus of attention (solid red line), and CON – control (solid blue line). The effect sizes were illustrated in dark green (η_p^2>0.14), cyan (η_p^2>0.06), and yellow (η_p^2<0.06) at the bottom of each graph. The black dots in hand velocities depict the approximate impact moment at each spiking condition. Identification of spike phases (i.e., cocking) is approximate as every player began each phase at a different time point.

Discussion

The present study contributes to the growing body of literature on the effects of attentional focus, and sought to extend this work by examining the spatiotemporal effects of attentional focus for enhancing upper arm segment velocities during volleyball spike performance. Specifically, the purpose of this study was to investigate the influence of different attentional focus instructions on upper-limbs velocities during a volleyball spike using SPM. Our findings support previous research highlighting the beneficial effect of an external focus of attention for motor performance (Wulf, 2013; Chua et al., 2021). Specifically, volleyball spike performance using an EF resulted in achieving significantly greater arm, hand, and forearm velocities than during CON and IF conditions. Moreover, the SPM analyses revealed that athletes reached peak arm, forearm, and hand velocities quicker (sharper curve slope) when performing with an EF. Such changes portray spatial and temporal efficiency within the movement (Faity et al., 2022), and reflect greater force generation (Wang et al., 2018).

The attentional focus instructions used in the current study were derived from biomechanical principles for enhancing arm velocities in volleyball. Specifically, the IF instruction: "*Pull back your elbow prior to transferring momentum!*" was an effort to enhance the stretch-shortening cycle (Dearing, 2018), and the EF instruction: "*Imagine cracking a whip to transfer momentum!*" was an effort to simulate correct proximal-to-distal sequencing of the upper limbs (Serrien et al., 2018). The hand velocity, as the most distal part of upper-limb kinematic sequence during ball-hitting or throwing activities, is considered the most crucial velocity for correlating with projectile (or ball) speed (Wagner et al., 2010, 2011; Lima et al., 2021). It is well known that optimal spiking and throwing techniques are performed by specifically ordered segment timing, including their acceleration and deceleration (Herring and Chapman, 1992; Wagner et al., 2011). Optimal joint movements occur in a proximal-to-distal order beginning with pelvis rotation, trunk rotation, and trunk flexion, followed by shoulder internal rotation, elbow flexion, and wrist and finger flexion (Wagner et al., 2012). Although the current study does not provide additional kinematics variables, (i.e., joint angles), we can suggest optimal progression of segmental motion under the EF instructions because the observed hand velocities reached their highest velocity compared to the other conditions (Serrien et al., 2018). Therefore, one can assume that the proximal-to-distal sequencing under EF was more effective at eliciting a whip-like motion (Herring and Chapman, 1992). That is, the initial segmental motion begins with the forward motion of a proximal segment while more distal segments rotate backward and then forward similar to whipping a whip. Additionally, we found significantly greater arm, forearm, and hand velocities under EF instruction which supports an overall positive effect of externally focused attention. Moreover, adopting the EF instruction in the current study demonstrated that athletes achieved greater arm, forearm, and hand velocity in a relatively shorter period (sharper curve slopes). This conveys greater segmental accelerations in the EF condition, which exhibits more force production by the muscular system (Maffiuletti et al., 2016).

The external focus instructions used in the current study ("imagine cracking a whip") share similarities to instructions using analogies rather than EF instructions that direct attention toward movement effects, such as an implement, target, or a cue. Nonetheless, images and analogies have previously been used to induce an external focus of attention (Wulf et al., 1999, 2002; Lohse and Sherwood, 2011; Singh and Wulf, 2022). In this regard, studies have reported the benefits of an external relative to an internal focus by directing focus of attention to a pendulum-like motion of the club (external) as compared to focusing on the arm (internal) in a golf putting task (Wulf et al., 1999), focusing on an imaginary line (external) as compared to their thighs (internal) in a static wall-sit task (Lohse and Sherwood, 2011), or focusing on a "platform" (external) versus "arm" (internal) in a volleyball pass (Singh and Wulf, 2022). Likewise, Wulf et al. (2002) used images as attentional instructions observing that EF instructions ("hit the ball as if using a whip …") were more effective than IF instructions ("snap your wrist while hitting the ball…") when performing an overhand volleyball serve. Taken together, analogies have been shown to be effective to improve motor performance and learning (Lam et al., 2009a,b), and they could be used to produce the mental images of the movement goal which prevents the negative consequences of an internal focus (McKay et al., 2015; Singh and Wulf, 2022).

It is also important to consider that the IF condition did not demonstrate higher velocities in the forearm or hand at any point during the volleyball spike compared to the CON or EF conditions. This pattern of findings may reflect a disrupted and inharmonious movement pattern caused by the disruption of the automatic control processes resulting from the IF. To this effect, the participants could not properly and efficiently transfer the arm momentum to the distal segments (forearm and hand) and achieve greater spike velocities overall. Overall, participants adopting an internal focus produced similar results as the control condition in which no attentional focus instructions were given. This supports the notion that participants tended to spontaneously focus on their body movements (internal focus of attention), unless they are instructed otherwise (Land et al., 2013; Wulf, 2013). With regard to coaching, such findings reflect how even one or two different words in the attentional focus instruction can significantly change the motor outcome of the athletes (Wulf, 2013). As such, coaches and athletes should base pedagogical and training activities on the empirical results from research on attentional focus which would be beneficial for athletes' performance and learning outcomes.

The current study highlights the benefit of using SPM to identify differences brought about by adopting an external focus of attention. Specifically, SPM was able to detect differences in the mobilization of peak velocities across the different attentional focus conditions. To this extent, findings indicated that an external focus facilitated more effective optimization (temporal pattern of peak velocities) of movement solutions compared to the internal focus or control condition. These findings have particular relevance for advancing theoretical insight and applied application of attentional focus findings. In particular, applying the SPM approach allows researchers to identify at what point within the movement the effect of an external focus impacts movement kinematics. Being able to more exactly identify how movements are being modified *via* adopting an EF has the potential to provide insight into the underlying mechanism of the EF advantage. Moreover, identifying the specific kinematic changes caused by adopting an EF could highlight potential critical elements within the movement, which would be important for guiding the focus of training. In the case of the current study, relatively decreased time to peak arm, forearm, and hand velocities may be an important element to consider during training. As such, more research is needed to explore the benefits and insights uncovered from applying SPM to understanding the advantages of adopting an external focus of attention.

Theoretically, the findings of this study could enrich our knowledge regarding the mechanisms underlying the advantages of an EF relative to an IF during the unfolding of the movement. Particularly, as the goal of the task in the current study was hitting the ball as hard as possible, the relatively earlier time to peak velocity might be an indicator of more effective and efficient coupling between the action and the goal. That is, participants in the EF condition reached the task goal more quickly than during the IF or control conditions, which could be an indicator of a more effective goal-action coupling (Wulf and Lewthwaite, 2016; Abdollahipour et al., 2017, 2022).

Essentially, an EF has been considered as a main contributor to goal-action coupling, which functions to enhance the linkage between the performer's intended movement goal and the activation of one's neuromuscular system (Wulf and Lewthwaite, 2016). Indirect evidence supporting the notion of EF enhancing goal-action coupling has been derived through observation of improved motor performance along with higher cognitive stability (as reflected by a lower number of eye blinks when adopting an EF; Abdollahipour et al., 2022). In another study on the relationship between attentional focus and inattentional blindness, children performed a bowling task while focusing on the path of the ball, their hands, or without focus instructions (Abdollahipour et al., 2017). Unbeknownst to the children, a 3-s video of individuals passing a basketball to each other was projected behind the target area when performing each bowling trial. In the final trial of each attentional focus condition, the same video was presented along with adding the well-known inattentional blindness stimulus showing a "gorilla" turning to face the camera, thumping its chest, and eventually turning away from the camera (Simons and Chabris, 1999). The findings showed that while performance outcome was superior in an EF relative to an IF and no-focus instruction conditions, children in the EF conditions noticed fewer distractive items than in IF and control conditions, indicating more concentration on the task goal. Taken together, the findings of the current study and previous studies (Abdollahipour et al., 2017, 2022) show that an EF may indeed promote an individual's ability to focus on the task at hand or movement goal which suggests enhanced goal-action coupling (Wulf and Lewthwaite, 2016).

It is important to note, that the current study has several limitations. First, we did not provide information about ball speed and accuracy of the performance. Even though a very high correlation ($r = 0.77$) has been found between arm and ball velocities in volleyball spikes (e.g., Lima et al., 2021), it would still be interesting for future research to consider examining the effectiveness of attentional focus instructions on time to reaching peak velocity, ball velocity, and accuracy of performance outcome. Second, despite the fact that the participants were instructed to maximally adopt the attentional focus instructions, this study did not measure the extent to which participants adhered to the attentional focus instructions. Manipulation checks could be used in future research to estimate the amount of adherence to the instructions in internal and external focus conditions, as well as to determine what participants were focusing on during the control condition. Third, in the current study, participants performed the volleyball spike in a standing position in front of a stationary ball hanging from the ceiling. As such, the volleyball spike task could be made more ecological valid in future research. Fourth, it is recognized that in continuous data analysis, a larger sample size may be required (Robinson et al., 2021). Therefore, it is possible that the current study has only been sufficiently powered to detect effects slightly larger than those used in discrete parameter power analysis. Therefore, future research on the attentional focus that considers SPM analysis should use a larger sample size. Finally, while this study aimed to investigate the time-series of arm velocities, additional data analyses (e.g., angles, angular velocities) could provide further in-depth information regarding upper arm proximal-to-distal coordination. However, from a biomechanical point of view, arm velocities are crucial variables determining the spike success rate (Valadés et al., 2016; Fuchs et al., 2019).

Conclusion

This study illustrates the importance that time-series analyses (i.e., SPM) can play in examining changes in motor performance under varied attentional foci. Specifically, a significant benefit was found from the start of the wind-up phase to the acceleration phase (prior to ball-hitting) under the external focus condition, when players produced greater arm, forearm, and hand velocities, compared to internal focus and control (no-focus instruction) conditions. That is, adopting an external focus of attention ("*Imagine cracking a whip to transfer momentum!*") promoted fast, harmonized, and highly coordinated execution of the volleyball spike due to efficiently employing a proximal-to-distal coordination pattern. From a sports training perspective, the external focus instructions used in the current study may be highly applicable for volleyball players to increase velocities in the hitting arm. Lastly, future research should continue to use in-depth online time-series analyses to more precisely investigate the effects of attentional focus instructions on different movement tasks. Such analyses could result in both theoretical and applied insights.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Ethics statement

The studies involving human participants were reviewed and approved by the Institutional Review Board of Faculty of Education, University of Ostrava, ethically approved this study (ethics code of 45/2021). Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin. Written informed consent was obtained from the minor(s)' legal guardian/next of kin for the publication of any potentially identifiable images or data included in this article.

Author contributions

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

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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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References

Abdollahipour, R., Land, W. M., Valtr, L., Banátová, K., and Janura, M. (2022). External focus facilitates cognitive stability and promotes motor performance of an interceptive task in children. *Int. J. Sport Exerc. Psychol.* doi: 10.1080/1612197x.2022.2098356

Abdollahipour, R., Nieto, M. P., Psotta, R., and Wulf, G. (2017). External focus of attention and autonomy support have additive benefits for motor performance in children. *Psychol. Sport Exerc.* 32, 17–24. doi: 10.1016/j.psychsport.2017.05.004

An, J., Wulf, G., and Kim, S. (2013). Increased carry distance and X-factor stretch in golf through an external focus of attention. *J. Mot. Learn. Dev.* 1, 2–11. doi: 10.1123/jmld.1.1.2

Bańkosz, Z., and Winiarski, S. (2021). The application of statistical parametric mapping to evaluate differences in topspin backhand between Chinese and polish female table tennis players. *Appl. Bionics Biomech.* 2021, 1–11. doi: 10.1155/2021/5555874

Bell, J. J., and Hardy, J. (2009). Effects of attentional focus on skilled performance in golf. *J. Appl. Sport Psychol.* 21, 163–177. doi: 10.1080/10413200902795323

Chua, L. K., Jimenez-Diaz, J., Lewthwaite, R., Kim, T., and Wulf, G. (2021). Superiority of external attentional focus for motor performance and learning: systematic reviews and meta-analyses. *Psychol. Bull.* 147, 618–645. doi: 10.1037/bul0000335

Davids, K., Glazier, P., Araújo, D., and Bartlett, R. (2003). Movement systems as dynamical systems. *Sports Med.* 33, 245–260. doi: 10.2165/00007256-200333040-00001

Dearing, J. (2018). *Volleyball Fundamentals, 2nd Edn*. Champaign, Illinois: Human Kinetics.

Escamilla, R. F., Fleisig, G. S., Barrentine, S. W., Zheng, N., and Andrews, J. R. (1998). Kinematic comparisons of throwing different types of baseball pitches. *J. Appl. Biomech.* 14, 1–23. doi: 10.1123/jab.14.1.1

Faity, G., Mottet, D., and Froger, J. (2022). Validity and reliability of Kinect v2 for quantifying upper body kinematics during seated reaching. *Sensors* 22:2735. doi: 10.3390/s22072735

Faul, F., Erdfelder, E., Lang, A. G., and Buchner, A. (2007). G* power 3: a flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behav. Res. Methods* 39, 175–191. doi: 10.3758/bf03193146

Fuchs, P. X., Menzel, H. J. K., Guidotti, F., Bell, J., von Duvillard, S. P., and Wagner, H. (2019). Spike jump biomechanics in male versus female elite volleyball players. *J. Sports Sci.* 37, 2411–2419. doi: 10.1080/02640414.2019.1639437

Halperin, I., Chapman, D. W., Martin, D. T., and Abbiss, C. (2017). The effects of attentional focus instructions on punching velocity and impact forces among trained combat athletes. *J. Sports Sci.* 35, 500–507. doi: 10.1080/02640414.2016.1175651

Hayter, A. J. (1986). The maximum familywise error rate of Fisher's least significant difference test. *J. Am. Stat. Assoc.* 81, 1000–1004. doi: 10.1080/01621459.1986.10478364

Herring, R. M., and Chapman, A. E. (1992). Effects of changes in segmental values and timing of both torque and torque reversal in simulated throws. *J. Biomech.* 25, 1173–1184. doi: 10.1016/0021-9290(92)90073-a

Howell, D. C. (2010). *Statistical Methods for Psychology, 7th Edn*. Belmont, CA: Wadsworth Cengage Learning.

Kershner, A. L., Fry, A. C., and Cabarkapa, D. (2019). Effect of internal volleyball spike. External focus of attention instructions on countermovement jump variables in NCAA division I student-athletes. *J. Strength Cond. Res.* 33, 1467–1473. doi: 10.1519/jsc.0000000000003129

Lam, W. K., Maxwell, J. P., and Masters, R. (2009a). Analogy learning and the performance of motor skills under pressure. *J. Sport Exerc. Psychol.* 31, 337–357. doi: 10.1123/jsep.31.3.337

Lam, W. K., Maxwell, J. P., and Masters, R. S. W. (2009b). Analogy versus explicit learning of a modified basketball shooting task: performance and kinematic outcomes. *J. Sports Sci.* 27, 179–191. doi: 10.1080/02640410802448764

Land, W. M., Tenenbaum, G., Ward, P., and Marquardt, C. (2013). Examination of visual information as a mediator of external focus benefits. *J. Sport Exerc. Psychol.* 35, 250–259. doi: 10.1123/jsep.35.3.250

Lima, R., Afonso, J., Silva, A. F., Silva, R., and Clemente, F. M. (2021). Relationships between ball speed and arm speed during the volleyball serve in youth elite male players, and why statistical significance might be misleading. *Proc. Inst. Mech. Eng. P. J. Sport. Eng. Technol.* 235, 122–130. doi: 10.1177/1754337120971448

Lohse, K. R., and Sherwood, D. E. (2011). Defining the focus of attention: effects of attention on perceived exertion and fatigue. *Front. Psychol.* 2:332. doi: 10.3389/fpsyg.2011.00332

Lohse, K. R., Sherwood, D. E., and Healy, A. F. (2014). On the advantage of an external focus of attention: a benefit to learning or performance? *Hum. Mov. Sci.* 33, 120–134. doi: 10.1016/j.humov.2013.07.022

Maffiuletti, N. A., Aagaard, P., Blazevich, A. J., Folland, J., Tillin, N., and Duchateau, J. (2016). Rate of force development: physiological and methodological considerations. *Eur. J. Appl. Physiol.* 116, 1091–1116. doi: 10.1007/s00421-016-3346-6

McKay, B., Wulf, G., Lewthwaite, R., and Nordin, A. (2015). The self: your own worst enemy? A test of the self-invoking trigger hypothesis. *Q. J. Exp. Psychol.* 68, 1910–1919. doi: 10.1080/17470218.2014.997765

Penny, W. D., Friston, K. J., Ashburner, J. T., Kiebel, S. J., and Nichols, T. E. (Eds.) (2011). *Statistical Parametric Mapping: The Analysis of Functional Brain Images*. Amsterdam: Elsevier.

Porter, J. M., and Sims, B. (2013). Altering focus of attention influences elite athletes sprinting performance. *Int. J. Coach. Sci.* 7, 41–51.

Putnam, C. A. (1993). Sequential motions of body segments in striking and throwing skills: descriptions and explanations. *J. Biomech.* 26, 125–135. doi: 10.1016/0021-9290(93)90084-r

Reeser, J. C., Fleisig, G. S., Bolt, B., and Ruan, M. (2010). Upper limb biomechanics during the volleyball serve and spike. *Sports Health* 2, 368–374. doi: 10.1177/1941738110374624

Robinson, M. A., Vanrenterghem, J., and Pataky, T. C. (2021). Sample size estimation for biomechanical waveforms: current practice, recommendations and a comparison to discrete power analysis. *J. Biomech.* 122:110451. doi: 10.1016/j.jbiomech.2021.110451

Rokito, A. S., Jobe, F. W., Pink, M. M., Perry, J., and Brault, J. (1998). Electromyographic analysis of shoulder function during the volleyball serve and spike. *J. Shoulder Elb. Surg.* 7, 256–263. doi: 10.1016/s1058-2746(98)90054-4

Sarvestan, J., Ataabadi, P. A., Yazdanbakhsh, F., Abbasi, S., Abbasi, A., and Svoboda, Z. (2021). Lower limb joint angles and their variability during uphill walking. *Gait Posture* 90, 434–440. doi: 10.1016/j.gaitpost.2021.09.195

Sarvestan, J., Svoboda, Z., and Linduška, P. (2020). Kinematic differences between successful and faulty spikes in young volleyball players. *J. Sports Sci.* 38, 2314–2320. doi: 10.1080/02640414.2020.1782008

Serrien, B., Goossens, M., and Baeyens, J. P. (2018). Proximal-to-distal sequencing and coordination variability in the volleyball spike of elite youth players: effects of gender and growth. *J. Mot. Learn. Dev.* 6, 250–266. doi: 10.1123/jmld.2017-0049

Simons, D. J., and Chabris, C. F. (1999). Gorillas in our midst: sustained inattentional blindness for dynamic events. *Perception* 28, 1059–1074. doi: 10.1068/p281059

Singh, H., and Wulf, G. (2022). Mind over body: creating an external focus for sport skills. *Eur. J. Sport Sci.* 22, 610–616. doi: 10.1080/17461391.2021.1887367

Sink, C. A., and Mvududu, N. H. (2010). Statistical power, sampling, and effect sizes: three keys to research relevancy. *Couns. Outcome Res. Eval.* 1, 1–18. doi: 10.1177/2150137810373613

Urdan, T. C. (2010). *Statistics in Plain English (3rd Edn)* New York: Routledge.

Valadés, D., Palao, J. M., Aúnsolo, Á., and Ureña, A. (2016). Correlation between ball speed of the spike and the strength condition of a professional women's volleyball team during the season. *Kinesiology* 48, 87–94. doi: 10.26582/k.48.1.7

Wagner, H., Buchecker, M., Von Duvillard, S. P., and Müller, E. (2010). Kinematic description of elite volleyball spike. Low level players in team-handball jump throw. *J. Sports Sci. Med.* 9, 15–23.

Wagner, H., Pfusterschmied, J., von Duvillard, S. P., and Müller, E. (2011). Performance and kinematics of various throwing techniques in team-handball. *J. Sports Sci. Med.* 10, 73–80.

Wagner, H., Pfusterschmied, J., Von Duvillard, S. P., and Müller, E. (2012). Skill-dependent proximal-to-distal sequence in team-handball throwing. *J. Sports Sci.* 30, 21–29. doi: 10.1080/02640414.2011.617773

Wang, S. M., Kuo, L. C., Ouyang, W. C., Hsu, H. M., and Ma, H. I. (2018). Effects of object size and distance on reaching kinematics in patients with schizophrenia. *Hong Kong J. Occup. Ther.* 31, 22–29. doi: 10.1177/1569186118759610

Wulf, G. (2013). Attentional focus and motor learning: a review of 15 years. *Int. Rev. Sport Exerc. Psychol.* 6, 77–104. doi: 10.1080/1750984x.2012.723728

Wulf, G., Lauterbach, B., and Toole, T. (1999). The learning advantages of an external focus of attention in golf. *Res. Q. Exerc. Sport* 70, 120–126. doi: 10.1080/02701367.1999.10608029

Wulf, G., and Lewthwaite, R. (2016). Optimizing performance through intrinsic motivation and attention for learning: the OPTIMAL theory of motor learning. *Psychon. Bull. Rev.* 23, 1382–1414. doi: 10.3758/s13423-015-0999-9

Wulf, G., McConnel, N., Gärtner, M., and Schwarz, A. (2002). Enhancing the learning of sport skills through external-focus feedback. *J. Mot. Behav.* 34, 171–182. doi: 10.1080/00222890209601939

Zwierko, T., Osinski, W., Lubinski, W., Czepita, D., and Florkiewicz, B. (2010). Speed of visual sensorimotor processes and conductivity of visual pathway in volleyball players. *J. Hum. Kinet.* 23, 21–27. doi: 10.2478/v10078-010-0003-8

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EDITED BY
Vasilis Armatas,
National and Kapodistrian University of Athens, Greece

REVIEWED BY
Braulio Branco,
Centro Universitário Cesumar,
Brazil
Wojciech Cynarski,
University of Rzeszow,
Poland

*CORRESPONDENCE
Dany Alexis Sobarzo Soto
✉ danysobarzo@santotomas.cl
Bianca Miarka
✉ miarkasport@hotmail.com

†These authors have contributed equally to this work

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Effects of weight divisions in time-motion of female high-level Brazilian Jiu-jitsu combat behaviors

Marco Antonio Ferreira dos Santos[1†], Dany Alexis Sobarzo Soto[2*†], Michele Andrade de Brito[1,3†], Ciro José Brito[3†], Esteban Aedo-Muñoz[1,4†], Maamer Slimani[5†], Nicola L. Bragazzi[6†], Hela Znazen[7†] and Bianca Miarka[1*†]

[1]Laboratory of Psychophysiology and Performance in Sports and Combats, Postgraduate Program in Physical Education, Federal University of Rio de Janeiro, Rio de Janeiro, Brazil, [2]Escuela de Kinesiología, Facultad de Salud, Universidad Santo Tomás, Puerto Montt, Chile, [3]Postgraduate Program in Physical Education, Federal University of Juiz de Fora, Governador Valadares, Brazil, [4]Departamento de Educación Física, Deportes y Recreación, Facultad de Artes y Educación Física, Universidad Metropolitana de Ciencias de la Educación,Santiago, Chile, [5]Department of Health Sciences (DISSAL), University of Genoa, Genoa, Italy, [6]Department of Mathematics and Statistics, Laboratory for Industrial and Applied Mathematics (LIAM), York University, Toronto, ON, Canada, [7]Department of Physical Education and Sport, College of Education, Taif University, Taif, Saudi Arabia

Coaches and psychologists can use time-motion analysis to elaborate specific interventions for female BJJ athletes, increasing specific training context and reducing unnecessary psychological and physical demands and injuries. Therefore, the present study aimed to analyze high-level BJJ female athletes in the 2020 Pan-American Games by comparing the weight categories on the time-motion analysis. The time-motion analysis (i.e., approach, gripping, attack, defensive actions, transition, mounting, guard, side control, and submissions) of 422 high-level female BJJ combats was divided and compared by weight category as follows: Rooster (n=8), Light Feather (n=18), Feather (n=122), Light (n=84), Middle (n=74), Medium Heavy (n=44), Heavy (n=36), Super Heavy (n=36), using $p \leq 0.05$. The main results indicated that the Super heavyweight category [3.1 (5.8;119.9) s] had a shorter gripping time than other weight categories, $p \leq 0.05$. In contrast, roosters [7.2 (3.5;64.6) s] had longer gripping, transition [14.0 (4.8;29.6) s], and attack time [76.2 (27.7, 93.2)] than the light feather, middlers, and heavier weight categories, $p \leq 0.05$. These findings should be considered for the psychological interventions and training prescription.

KEYWORDS

sports psychology, technical-tactical analysis, task performance and analysis, judo, martial arts

1. Introduction

Female Brazilian Jiu-jitsu (BJJ) practitioners are growing, and the demand for scientific studies generating gender-specific training approaches is needed. An inclusive understanding of the time-motion combat demands of female combat athletes could positively impact the success rate and help in training efficiency (Williams et al., 2019; Ambroży et al., 2021; Pawelec et al., 2022). The performance in grappling combat sports is related to the ability of female or male competitors to execute specific actions at the right moment during each combat phase while quickly adjusting to the continually changing combat context to the following action or phase (Sterkowicz-Przybycień et al., 2017). To the best of our knowledge, no study compared the weight categories of female Brazilian jiu-jitsu athletes in the phases of approach, gripping, attack, defensive actions, and pause. Coaches and psychologists can use the evidence offered here to elaborate specific interventions for female BJJ athletes, increasing specific training contexts and reducing unnecessary psychological and physical demands and injuries (Andreato et al., 2015; Brandt et al., 2021; Santos et al., 2022). Time-motion schemes can be developed that stimulate the acquisition of skills, and at the same time, the athlete has to neutralize opponents' strategies (Miarka et al., 2017b, 2020c, Menescardi et al., 2020).

The time-motion analysis per combat cycle identifies action patterns, often physiological inferences, in the competitive situation of female grappling athletes (Challis et al., 2015; Dudeniene et al., 2017; Soriano et al., 2019; Menescardi et al., 2020). The time-motion analysis can help BJJ coaches and athletes develop specific training for adequately applying the approach, gripping, attack, defense, transition, submission, and all other movements during the combats (Coswig et al., 2018a,b). Investigations with grappling athletes have shown that some of these variables present differentiated frequencies in weight categories (Sterkowicz-Przybycień et al., 2017; Soto et al., 2020a; Dopico-Calvo et al., 2022; Miarka et al., 2022). In a preliminary study, female senior grapplers had longer total combat time, standing combat time, and gripping time than pre-cadet, cadet, and junior athletes (Miarka et al., 2014). Challis et al. (2015) showed work-to-rest ratios of 3:1 blocks off lightweight women's judo matches. Olympic and non-Olympic judo matches by competitive result (winning versus losing) demonstrated differences in decision-making, gripping frequencies, and attack orientations of female athletes (Miarka et al., 2016b). Despite some motor skills similarities between Judo and BJJ, the rules are very different, and no study compared weight categories in the phases of approach, gripping, attack, defensive, groundwork, and pause, verifying the effects of weight categories of female BJJ high-level athletes.

Time-motion analysis identified action and moment patterns of different weight categories in other combat sports studies (Slimani et al., 2017; Soto et al., 2020b; Sciranka et al., 2022). Initially, the authors indicated that the time-motion analysis presents convenient results to the BJJ athletes' training process, suggesting the observation by the coaches of the metabolic components and muscle power. Another study (Del Vecchio et al., 2011) demonstrated the importance of the effort-pause relationship phases in male BJJ matches. Other authors indicated that type of analysis allows observing how athletes tactically use energy systems according to the dynamics of grappling combats (Andreato et al., 2013, 2015; Coswig et al., 2018b; Barreto et al., 2021) classifying their structure in effort-pause, high-intensity, and low-intensity actions during BJJ combat. Conceptually, high-intensity actions occur when the athlete attempts to advance, progress, or evolve with strength or power (Carvalho et al., 2022a). In contrast, low-intensity actions are classified as actions in which movements are performed slowly, with an apparent reduced level of force and power application (Coswig et al., 2018b).

For instance, Coswig et al. (2018a) demonstrate that a male BJJ match has an average of 8.5 high-intensity blocks, 17.9 low-intensity blocks, and eight pause blocks, indicating that the effort-pause ratio is 22:1 and the high-intensity versus low-intensity ratio is of 1:3.5. Authors also indicated that the proportion of effort in a BJJ match is more significant than 90% and that the BJJ athlete spends most of the groundwork phase (Coswig et al., 2018b). Therefore, when investigating the total time of actions, the study results that high-intensity total time is on average 226 s, low intensity is 303 s, with an average pause time of 71 s (Coswig et al., 2018b). This research also showed that concerning high-intensity blocks, the percentage was 37 and 50% for low-intensity blocks, having found 31 high-intensity blocks and 26 low-intensity blocks, generating the effort-pause relationship. 8: 1 and the high and low-intensity ratio at 1:2 (Coswig et al., 2018b).

Andreato et al. (2013) observed in male BJJ combats that the effort time was 296 s, and each block had 117 s of effort, with an effort of 2 blocks. The total time of pauses was 33 s, with an average of 20 s of pauses per block (Andreato et al., 2013). The total high-intensity time was 24 s, with an average of 3 s per high-intensity block, adding up to an average of 8 high-intensity blocks. The total low-intensity effort was 249 s on average, with 25 s on average per block, containing nine blocks and low intensity (Andreato et al., 2013). In a subsequent study, when comparing four bouts of 10 min, the average effort was found in 250 s in the first BJJ fight, with three blocks of effort, 180 s in the second fight, with four blocks of effort, 290 s on average, containing three blocks of effort. In the fourth fight, the authors found 204 s, on average, containing three blocks of effort (Andreato et al., 2015).

Regarding pauses, the result of this study pointed out that in the first combat, the pause was 32 s with two blocks, in the second fight, it got 26 s on average, with three pause blocks, and in the third fight, it found an average of 21 s of pause, with two blocks. In the fourth fight, the average time was 44 s, with two blocks of pauses on average. Finally, the effort-pause ratio was characterized as follows: first fight 8:1, second fight 9:1, third fight 8:1, and fourth fight 6:1 (Andreato et al., 2015).

Female athletes can use the evidence presented here to elaborate on specific BJJ training for each weight category if there are differences between groups (Miarka et al., 2017b; Blach et al., 2021). In addition, strategies can be developed that stimulate skills acquisition and avoid injuries (Santos et al., 2022; Carvalho et al., 2022b). At the same time, the athlete can use this strategy to neutralize the strategy of opponents. Therefore, the present study aimed to analyze high-level BJJ female athletes in the 2020 Pan-American Games by comparing the weight categories on the time-motion analysis (i.e., approach, gripping, attack, defensive actions, transition, mounting, guard, side control, and submissions).

2. Methods

2.1. Sample

The sample number consisted of 422 female match analyses, representing the total number of female fights at the 2020 BJJ Pan American (Kissimmee, Florida, EUA) of the International Brazilian Jiu-Jitsu Federation - BJJF. The sample was divided by weight category as follows: Rooster ($n=8$), Light Feather ($n=18$), Feather ($n=122$), Light ($n=84$), Middle ($n=74$), Medium Heavy ($n=44$), Heavy ($n=36$), Super Heavy ($n=36$) and correlated with time-movement analysis in the phases of approach, grip, transition, guard, lateral control, mount, attack, defensive actions, and movement expressed in seconds.

The sample calculation representing female international combats obtained a 99% confidence level and 1% margin of error, using the equation below (Jill, 2010):

$n = N\,Z^2\,p\,(1-p)\,(N-1)\,e^2 + Z^2\,p\,(1-p).$

The interpretation of each of these elements was made as follows:

n = is the sample size obtained through the calculation;

N = total combats belonging to the championship;

Z = indicated deviation from the acceptable mean value for the confidence level to be reached;

e = is the maximum margin of error that the search allows;

p = is the proportion we want to find in the calculation.

All data used for analysis were taken from a public domain website.[1] As public data, the present study was released from the local Research Ethics Committee following the WMA Declaration of Helsinki.

2.2. Procedures and measurements

The protocol variables of this study were divided into a macro group that allowed the grouping of the techniques used. When classifying a particular technique, the analyst had to inform which group the technique belonged to, then define the technique, and then choose the laterality of the technique's application, as well as inform whether this technique generated points or submission.

The instrument of this study considers the phases of BJJ combat according to a previous protocol of Frami software (Miarka et al., 2011; Barrientos et al., 2021; i.e., approach, gripping, attacks, defense, movement), expanded by the present study (transition, control side, guard, and mounted) taking into account the specifics of BJJ combats.

Approach time: Non-contact displacements, when athletes remain for a few seconds observing the opposing actions without performing any contact action. Or a specific location on the opposing athlete's kimono (Brito et al., 2017; Barreto et al., 2019; Soto et al., 2020b).

Gripping time: When starting a BJJ contact between athletes, the gripping stage is a relevant motor action. It is the ability to perform and maintain the grip (handgrip) in the opponent's kimono (Miarka et al., 2016a; Dal Bello et al., 2019).

Transition time: One of the techniques that appear in the combat's initial moments are the projections or throws, which can result in a score for the athlete who executes efficiently. However, these techniques have lost space for the guard pull. A variety of techniques is used to lead the combat to the ground without the risk of making a throw that can be defended by the opponent (Sterkowicz-Przybycień et al., 2017; Coswig et al., 2018a).

Guard time: A guard is a groundwork position where an athlete wraps his/her/it legs around the opponent, restricting movement and forcing contact, trying to prevent the adversary inside the guard from standing up or escaping (Del Vecchio et al., 2016; Lima et al., 2017).

Side control time: Side control is one of the most frequent positions on the groundwork that allows athletes to control and submit to their opponents (Kirk et al., 2015; Miarka et al., 2020c). It happens when the athlete lays perpendicularly on top of his adversary (Kirk et al., 2015; Miarka et al., 2020c).

Mounting time: This action is a submission where the athlete is on top of his/her/it opponent and facing their head (Kirk et al., 2015). Athletes sit on top of the adversary's torso in a kneeling-like configuration, and his/her/it hips are over his/her/it torso. Athletes' weight should be primarily on the opponent's body to make it difficult for them to move (Kirk et al., 2015).

Attack and Defense Time: The principal techniques grouped in the attack time are sweeps (actions to change position concerning the ground), throws (which occur after the transition time), guard passes, and chokes and locks submissions (Kirk et al., 2015; Coswig et al., 2018a). In addition, defenses happen when any of the athletes defend against the attack, as mentioned above, attempts (Kirk et al., 2015; Miarka et al., 2017a).

Low-intensity movement time: The actions grouped in the low-intensity movement time are activities without progression during the combat or grip adjustment and maintenance of a defensive position, that is, actions that do not contribute to changing the score or the superiority of the athlete over her opponent. Pauses were inserted in this movement context (Del Vecchio et al., 2011; Tornello et al., 2014; Barrientos et al., 2021).

1 https://www.youtube.com/user/ibjjf

2.3. Reliability testing

The reliability measures were observed through intra-observer testing procedures on BJJ time-motion data provided by one expert (i.e., >10 years of experience and with degrees in Physical Education). He analyzes BJJ matches with FRAMI software (Miarka et al., 2011). For intra-observer agreement - expert A analyzed 20 matches of BJJ athletes. Sequentially, expert A performed the intra-observer agreement, with the selection of the 10 BJJ matches (20 performance analyses) in a randomized order before repeating the time-motion analysis.

The reliability of time-motion variables analysis was examined using Cronbach's Alpha Coefficient (CAC). From the frequency distribution for each variable, the following CAC values and strength of agreement classifications were used: Alpha values were described as excellent (0.93–0.94), strong (0.91–0.93), reliable (0.84–0.90), robust (0.81), reasonably high (0.76–0.95), high (0.73–0.95), good (0.71–0.91), relatively high (0.70–0.77), slightly low (0.68), reasonable (0.67–0.87), adequate (0.64–0.85), moderate (0.61–0.65), satisfactory (0.58–0.97), acceptable (0.45–0.98), sufficient (0.45–0.96), not satisfactory (0.4–0.55) and low (0.11). Statistical calculations were made using 22.0 SPSS software, and the significance level was set at $p \leq 0.05$. The index and classification of Alpha values of BJJ time-motion indicators used in the present study are shown in Table 1.

2.4. Statistical analysis

All analyses were conducted using SPSS 22.0 for Windows. Descriptive data are presented as median, mean [25th percentile; 75th percentile] values, and Kruskal Wallis followed by Bonferroni *post hoc*

TABLE 1 The reliability analysis and classification of CAC values of BJJ time-motion indicators.

BJJ combat time	Reliability	Classification	IC (95%) lower/Upper	Value–p
Approach	0.92	Excellent	0.89/0.96	≤0.01
Gripping	0.97	Excellent	0.96/0.99	≤0.01
Transition	0.93	Excellent	0.91/0.96	≤0.01
Guard	0.91	Strong	0.85/0.93	≤0.01
Side Control	0.95	Excellent	0.90/0.96	≤0.01
Mounting	0.89	Reliable	0.83/0.89	≤0.01
Attack	0.96	Excellent	0.89/0.96	≤0.01
Defense	0.98	Excellent	0.92/0.97	≤0.01
Low-intensity movement	0.89	Reliable	0.82/0.91	≤0.01
Total time	0.93	Strong	0.81/0.96	≤0.01

were used to compare time-motion seconds and frequencies between BJJ weight categories and the significance level of $p \leq 0.05$ was used.

3. Results

Table 2 shows the time-motion analysis of the international female BJJ fighters in each combat phase, compared by weight category expressed in seconds.

A significant difference was found in gripping moment ($K = 29.951$; $p \leq 0.001$), transition ($H = 15.943$; $p = 0.026$) and attack time ($K = 14.664$; $p = 0.041$).

Table 3 demonstrates the post-hoc analysis of comparisons between weight divisions, in the combat phases (gripping, transition, and attack) among international female BJJ fighters.

Table 4 indicated the frequency of actions in each combat phase applied by international BJJ fighters in each phase of the combat. Compared according to weight category.

A significant difference in the frequency of techniques, and in the gripping time ($K = 16.092$; $p = 0.024$), transition ($K = 21{,}738$; $p = 0.003$), attack ($K = 15.671$; $p = 0.028$), defense ($K = 24{,}418$; $p \leq 0.001$), movement with low-intensity ($K = 22{,}336$; $p = 0.002$) and in the total number of techniques ($K = 30{,}994$; $p \leq 0.001$).

Table 5 shows a post-hoc analysis of comparisons between action frequencies used in the gripping, transition, attack, defense, and movement with low-intensity phases, according to the weight category used during the combat.

4. Discussion

Findings with time-motion analysis allow a practical application with women because psychologists and coaches can use the results to prepare specific contextual demands of female matches, aiming for the specific category that the BJJ athlete competes (Amtmann, 2012; Coswig et al., 2018a; Brandt et al., 2021; Fernández et al., 2022). In this sense, some studies have specifically investigated time-motion analysis in female combat sports (Tornello et al., 2014; Andreato et al., 2015; Miarka et al., 2017b; Dal Bello et al., 2019). However, the studies have not analyzed the actions separate in the BJJ female weight divisions. The present research pointed out weight categories differences in female high-level BJJ match performance. Findings indicated that the Super heavyweight category had a shorter gripping time than other weight categories. In contrast, roosters had longer gripping, transition, and attack times and frequency than the light feather, middlers, and heavier weight categories.

The approach and gripping times are essential for efficiently applying guard and throw actions during BJJ matches (Coswig et al., 2018b; Williams et al., 2019). Coaches and psychologists consider that taking the initiative during BJJ combats is a factor that puts the athlete at an advantage (Faro et al., 2020; Brandt et al., 2021; Fernández et al., 2022). Grapplers who do not take the initiative with the handgrip tend to present complications dominating the opponent (Challis et al., 2015; Bahmani et al., 2019; Miarka et al., 2020a; Fernandes et al., 2022). Consequently, specific pieces of physical training are designed to approach and grip with speed and in the position that grips the opponent's clothes (Andreato et al., 2015; Diaz-Lara et al., 2016; Ovretveit, 2018). In our study, roosters and super heavies presented critical dependence on gripping time, that specific information about

TABLE 2 Time-motion analysis of the international female BJJ fighters in each combat phase, compared by weight category expressed in seconds.

Category	Approach	Gripping	Transition	Guard	Side control	Mounting	Attack	Defense	Low-intensity movement	Total time
Rooster ($n = 8$)	6.3 (5.2;11.1)	7.2[a] (3.5;64.6)	14.0 (4.8;29.6)	104 (70.3;232.6)	9 (4.7;–)	261 (261;261)	76.2[pq] (27.7;93.2)	30.6 (9.8;60.8)	72.1 (46.4;204.5)	408 (301.7;482)
Light feather ($n = 18$)	9.3 (6.0;14.6)	3.1[a] (6.0;14.6)	1.5[g] (1.2;4.3)	61 (28.0;96.2)	53.9 (31.5;173.1)	47 (15.7;193.6)	64.5[pq] (17.3;111.4)	61.1 (19.9;102)	77.0 (29.6;242.5)	389.3 (305.8;444.9)
Feather ($n = 122$)	6.2 (3.7;11)	4.6[a] (2.7d;13.8)	2.8[ho] (1.6;4.8)	87.5 (38.8;169.9)	37.4 (19.6;66)	57.1 (19.2;128)	38.1[p] (18.3;70)	30.5 (11.3;60.5)	93 (38.2;197.6)	359.6 (226.6;426.1)
Light ($n = 84$)	5.1 (3.0;13.5)	4.1[c] (2.4;8.8)	2.1[hi] (1.3;3.2)	111.8 (32.8;203.8)	60.5 (27.3;114.3)	26.9 (14.7;45.7)	42.7[p] (15.5;4.6)	35.9 (13.8;73.7)	87.4 (25.4;204)	323 (210.3;386.9)
Middle ($n = 74$)	5.6 (2.8;11.1)	5.8[ae] (2.3;13.5)	2.3[mn] (1.6;4.4)	87.7 (41.8;130)	44 (28.9;69.7)	15.9 (11.0;55.6)	32.4[p] (17.2;69)	31.8 (13.8;51.2)	99.7 (40.8;187.4)	335.1 (241.8;417.5)
Medium heavy ($n = 44$)	6.1 (3.1;9.6)	3.3[b] (1.8;8.3)	2.1 (1.6;2.9)	81.6 (22.3;185.5)	34.5 (17.6;51.3)	39.9 (13.4;207.3)	23.9 (7.2;64.7)	25.8 (12.0;102.9)	83.9 (41.1;159.9)	311.2 (89.9;556)
Heavy ($n = 36$)	6.1 (3.7;9.3)	4.5 (1.7f;29)	2.8 (1.7;29.0)	45.1 (18.9;152.3)	81.1 (37.5;136.3)	24.6 (17.3;70.3)	17.2[p] (7.7;42.8)	16.8 (7.6;57.9)	86.0 (21.2;175.6)	314.8 (245.6;373)
Super heavy ($n = 36$)	4.8 (2.9;12.1)	3.1[abcdef] (5.8;119.9)	2.1[j] (1.4;3.5)	91.6 (41.7;145.7)	49.4 (29.3;108.8)	40 (22.1;65.6)	30.1 (14.0;61.4)	25.5 (10.3;43.9)	73.7 (37.8;176.7)	343.0 (287.2;495.5)
H	8.298	29.951	15.943	7.237	12.947	9.038	14.664	7.835	1.29	8.874
P	0.307	0.001	0.026	0.405	0.073	0.250	0.041	0.347	0.989	0.262

p = value of p (significance)/H - statistical test value. [a]Significant difference between light feather and rooster. Feather. middle and super heavy. [b]Significant difference between medium heavy and super heavy tracks. [c]Significant difference between light and super heavy. [d]Significant difference between light and super heavy. [e]Significant difference between middle and super heavy. [f]Significant difference between light and super heavy. [g]Significant difference between light feather and rooster; [h]Significant difference between light and feather. [i]Significant difference between light and rooster; [j]Significant difference between super heavy and rooster. [l]Significant difference between medium heavy and rooster. [m]Significant difference between middle and rooster. [n]Significant difference between heavy and rooster. [o]Significant difference between feather and rooster; [p]Significant difference between heavy and middle. Light. feather. Light feather and rooster; [q]Significant difference between medium heavy and light feather and rooster.

TABLE 3 Time-motion post-hoc analysis of comparisons between weight divisions, used in the combat phases (gripping, transition and attack) among international female BJJ fighters.

Comparisons						
Group	Gripping		Transition		Attack	
	H	*p*	*H*	*p*	*H*	*p*
Light feather × Feather	−59.655	0.024	–	–	–	–
Light feather × Middle	−62.744	0.02	–	–	–	–
Light feather × Heavy	−64.373	0.029	–	–	–	–
Light feather × Rooster	102.286	0.016	112.101	0.002	–	–
Light feather × Super heavy	−132	0.001	–	–	–	–
Medium heavy × Rooster	–	–	102.155	0.003	–	–
Medium heavy × Super heavy	−94.031	0.001	–	–	–	–
Medium heavy × Light feather	–	–	–	–	57.593	0.052
Medium heavy × Rooster	–	–	–	–	85.673	0.034
Light × Rooster	–	–	106.177	0.001	–	–
Light × Feather	–	–	25.869	0.027	–	–
Light × Super heavy	−82.863	0.001	–	–	–	–
Feather × Super heavy	−72.343	0.001	–	–	–	–
Feather × Rooster	–	–	80.308	0.012	–	–
Middle × Super heavy	−69.254	0.001	–	–	–	–
Middle × Rooster	–	–	89.021	0.007	–	–
Heavy × Super heavy	−67.624	0.003	–	–	–	–
Super heavy × Rooster	–	–	104.205	0.004	–	–
Heavy × Rooster	–	–	85.456	0.013	109.536	0.008
Heavy × Middle	–	–	–	–	43.691	0.048
Heavy × Light	–	–	–	–	54.453	0.013
Heavy × Feather	–	–	–	–	55.753	0.007
Heavy × Light feather	–	–	–	–	81.455	0.007

p = value of *p* (significance)/H - statistical test value/Each row tests the null hypothesis where the group 1 and group 2 distributions are equal. Asymptotic (pairwise test) significances are displayed. The significance level is 0.05. Significance values were adjusted by Bonferroni correction for multiple tests.

TABLE 4 Measures of the number of techniques applied by international BJJ fighters in each phase of the combat.

Time measures in combat phases, compared by weight category										
Category	Approach	Gripping	Transition	Guard	Side control	Mounting	Attack	Defense	Low–intensity movement	Total time
Rooster	2 (1;4)	1 (1;2)	3 (1;5[abcd])	5 (2;10)	2 (1;–)	4 (4;4)	5 (3;6[d])	3 (2;5[d])	4 (2;5)	18 (12;30[bce])
Light feather	1 (1;1)	1 (1;1[a])	1 (1;1[a])	3 (2;6)	3 (1;5)	2 (1;2)	3 (2.7)	4 (1;5[de])	2 (1;5[d])	17 (11;22)
Feather	1 (1;2)	1 (1;2[ab])	1 (1;2[bcd])	4 (2;6)	2 (1;4)	1 (1;2)	4 (2;6[bcde])	3 (2;4[de])	4 (2;7[d])	16 (11;22[bcde])
Light	1 (1;2)	1 (1;1[b])	1 (1;1[b])	3 (2;6)	1 (1;3)	1 (1;2)	3 (2;5)	2 (1;3d)	3 (1;6[d])	14 (9;19)
Middle	1 (1;2)	1 (1;2[ab])	1 (1;2[bcd])	3 (2;6)	2 (2;4)	1 (1;2)	4 (6;6[d])	3 (1;5[de])	4 (2;7[de])	18 (12;23[bcde])
Medium heavy	1 (1;1)	1 (1;1)	1 (1;1[c])	4 (1;7)	2 (1;4)	1 (1;2)	3 (1;5)	3 (1;5[d])	4 (2;8[de])	13 (7;20)
Heavy	1 (1;1)	1 (1;2)	1 (1;1[d])	2 (1;3)	3 (1;4)	1 (1;1)	2 (1;5)	2 (2;3)	2 (1;4)	12 (8;15)
Super heavy	1 (1;2)	1 (1;3[abc])	1 (1;1)	2 (1;4)	3 (2;3)	1 (1;2)	3 (1;4[e])	2 (1;3)	2 (2;4)	15 (8;18)
H	10.006	16.092	21.738	13.459	6.014	4.758	15.671	24.418	22.336	30.994
P	0.188	0.024	0.003	0.062	0.538	0.69	0.028	0.001	0.002	0.001

Compared according to weight category. *p* = value of *p* (significance)/H - statistical test value. [a]Significant difference between light feather. Rooster. feather. Middle and super heavy. [b]Significant difference between light. Rooster. feather. Middle and super heavy. [c]significant difference between medium heavy. Rooster. middle and super heavy. [d]significant difference between heavy. Rooster. middle. Feather. light. Medium heavy and light feather. [e]significant difference between super heavy. Feather. middle. Light feather. Medium heavy and rooster.

TABLE 5 Comparison of groups between international BJJ fighters' techniques used in the grip phases.

Groups	Comparison											
	Gripping		Transition		Attack		Defense		Low-intensity movement		Total Time	
	H	*p*	*H*	*p*	*H*	*p*	*H*	*p*	*H*	*p*	*H*	*p*
Light feather – Rooster	–	–	53.15	0.033	–	–	–	–	–	–	–	–
Light feather – Feather	−41.47	0.05	–	–	–	–	–	–	–	–	–	–
Light feather – Middle	−52.082	0.016	–	–	–	–	–	–	–	–	–	–
Light feather – Super Heavy	−56.223	0.016	–	–	–	–	–	–	–	–	–	–
Light – Rooster	–	–	54.875	0.012	–	–	–	–	–	–	91.693	0.042
Light – Feather	27.014	0.035	21.534	0.007	33.803	0.027	–	–	–	–	53.418	0.002
Light – Middle	−37.625	0.006	−23.514	0.012	–	–	–	–	–	–	−60.996	0.002
Light – Super heavy	−41.766	0.009	–	–	–	–	–	–	–	–	–	–
Medium heavy – Rooster	–	–	58.571	0.011	–	–	–	–	–	–	93.642	0.046
Medium heavy – Feather	–	–	25.231	0.016	40.455	0.036	–	–	–	–	55.366	0.01
Medium heavy – Middle	32.903	0.039	27.21	0.019	–	–	–	–	–	–	62.944	0.007
Medium heavy – Super heavy	−37.044	0.04	–	–	–	–	–	–	–	–	–	–
Heavy – Rooster	–	–	63.5	0.007	87.536	0.031	97.535	0.017	–	–	114.59	0.016
Heavy – Middle	–	–	32.139	0.01	47.025	0.032	79.762	0.001	79.609	0.001	83.893	0.001
Heavy – Feather	–	–	30.159	0.008	51.164	0.013	80.559	0.001	76.608	0.001	76.315	0.001
Heavy – Light	–	–	–	–	–	–	63.455	0.003	50.112	0.026	–	–
Heavy – Medium heavy	–	–	–	–	–	–	48.333	0.05	77.984	0.003	–	–
Heavy – Light feather	–	–	–	–	–	–	95.722	0.002	51.286	0.014	–	–
Super heavy – feather	–	–	–	–	43.027	0.049	53.32	0.013	–	–	70.176	0.002
Super heavy – Middle	–	–	–	–	–	–	52.523	0.023	54.286	0.014	77.754	0.002
Super heavy – Light feather	–	–	–	–	–	–	68.483	0.034	–	–	–	–
Super heavy – Medium heavy	–	–	–	–	–	–	–	–	52.661	0.043	–	–
Super heavy – Rooster	–	–	–	–	–	–	–	–	–	–	108.451	0.023

Transition, attack, defense, and the total of techniques according to the weight category used during the combat. p = value of P (significance)/H - statistical test value/Each row tests the null hypothesis where the group 1 and group 2 distributions are equal. Asymptotic (pairwise test) significances are displayed. The significance level is 0.05. Significance values were adjusted by Bonferroni correction for multiple tests.

the gripping is critical for coaches to incorporate into training to adjust and enhance the movements that result in specific tactical acquisition for each weight category (Sterkowicz-Przybycień et al., 2017; Miarka et al., 2020b). In past studies, BJJ high-level athletes presented similar behavior to Olympic judo athletes (Kuvacic et al., 2017; Miarka et al., 2017b; Barreto et al., 2019; Blach et al., 2021), with a lower time of approach and higher frequency of gripping. Our results indicated that differentiated attention should be directed to the rooster category. Since athletes in this category tend to make gripping defensive movements and a higher frequency of attacks, super heavy athletes have shorter gripping time - specific tactics could be elaborated in both categories for female athletes to anticipate the opponent's behaviors. Since rooster and heavyweight athletes have a difference in the frequency and time of gripping moments, for each group of athletes, it would be recommended in the rooster category to pay greater attention to movements that may stop the gripping advantage of the opponents. At the same time, super heavy could increase sequential attacks, trying to induce the opponent to the groundwork combat.

In order to domain the opponent, it is essential to be incisive in the approach. Gripping, choose a gripping variation that allows advantage (i.e., attacks or guard moments) since generally, the female grapplers tend to apply the gripping arrangement that allows biomechanical advantage for the application of their favorite guard position or throws techniques (Dal Bello et al., 2019, Soto et al., 2020a,b). The past author observed that high-level female grappling athletes perform this moment with high speed and a lower amount of movements when compared to beginners and intermediates (Sterkowicz et al., 2016; Reale et al., 2018; Dopico-Calvo et al., 2022). Biomechanical aspects seemed to determine the type and preferred gripping since BJJ female athletes of lighter categories, possibly smaller in stature (Ovretveit, 2018), are the ones who least apply the back and leg gripping (Williams et al., 2019). Other highlighted aspects are the lower gripping and groundwork movement variation in all categories. In a previous study with female judo high-level athletes, Sterkowicz-Przybycień et al. (2017) found that female athletes tend to show single gripping and movement patterns - female grapplers prefer consistency and defensive movements, reducing the possibility of unpredictable adjustments. This fact could be partially confirmed in the present research and maybe the differential in vital phases of the BJJ combat, and that deserves more attention from the coaches and psychologists to make actions more unpredictable.

Reduced Attack times in the medium heavy; heavy groups are supported by the reportedly short timespan of throwing attempts and the ability to defend *via* gripping or counterattacks, similar to high-level judo female athletes (Sterkowicz-Przybycień et al., 2017). The present results established the relationship between skill level and attack velocity or guard establishment in female BJJ matches, where slower standing attacks were found in losing grappling female athletes at non-Olympic events (Miarka et al., 2016b). Furthermore, high-level female grappling athletes have been shown to prefer quick, effective throwing techniques (Sterkowicz et al., 2013), which affects effectiveness during groundwork actions (Miarka et al., 2016b; Williams et al., 2019).

Regarding the defensive combat phase, past findings indicated that female grappling winners at the Olympic Games had more frequent, shorter defensive actions than losers and all athletes in non-Olympic competitions (Miarka et al., 2016b). The observed within-athlete tactical variability in groundwork moment supports previous reports with judo that demonstrated visuomotor adjustments in response to domain attempts in talented grapplers, potentially due to enhanced anticipatory abilities (Dal Bello et al., 2019). During attacking actions, expert judo fighters spent a more significant percentage of their time fixating their gaze on their opponent's lapel and face to detect the actions of their opponents. In contrast, beginners primarily fixated on more peripheral areas of their visual field, such as sleeves, hands, legs, and jacket skirts (Piras et al., 2014). The current study may have exhibited this adaptation by female BJJ weight categories to quickly identify critical moments, such as gripping and transition moments, to groundwork actions (i.e., Guard, Side Control, and Mounted) during competitive actions.

Pause and low-intensity moments are tactical ways to avoid a potential attack. During movements with low-intensity, low-intensity actions could result from attempts to avoid the opponent's control. At the same time, pauses in BJJ are associated with penalties or specific situations (i.e., pause for illegal grip, communication with the referee, penalty for avoiding to fight, pause for injuries, cramps, and others). Furthermore, this seems to be a trend in other grappling fights. In judo, there was a considerable decrease in scores by the punishment at the 2012/2016/2020 Olympics Games (Sterkowicz et al., 2013; Miarka et al., 2016b; Barreto et al., 2019, 2022). Past research indicated 0.44 punishments/min during female judo combats in the 2012 Olympic Games versus 1.26 punishments/min during the 2008 Olympic Games and other international events (ranging from 1.46 to 2.17 punishments/min; Heinisch et al., 2013).

Regarding Guard, Side Control, and Mount moments, no effects of weight categories were observed in these groundwork actions; the reduction of weight dependence in groundwork combat may be responsible for increasing the time distributed to this combat phase in other grappling fights in the last years (Barreto et al., 2021, 2022; Miarka et al., 2022). Unlike present research with female BJJ athletes, the pause time during judo tournaments is likely related to the frequency of Groundwork combat actions because 20% of all attacking attempts have been shown to occur during the transition to or into the Groundwork phase (Heinisch et al., 2013). However, similar to the present results, the higher number of attacks in the transition and groundwork situations results in more techniques being applied (Kirk et al., 2015; Miarka et al., 2016b). Nonetheless, the frequency and duration of the low-intensity moment time allow a women grappler to place the opponent in a susceptible position during Guard, Side Control, and Mount moments.

4.1. Limitations

A possible limitation of BJJ time-motion analysis designated so far is the reliability of the data entry procedure (Avakian et al., 2021; Barrientos et al., 2021) and the present study indicated inter-expert and intra-expert measurement with different classifications index – the reliable, strong, and excellent (r range: 0.89–0.97) ability to reproduce the observed approach, gripping, transition, guard, side control, mounting, attack, defense, movement, and total time analysis. A challenge of the BJJ analysis process is subjectivity, where fast movements notated that have a certain degree of ambiguity may be captured differently by different analysts (Miarka et al., 2020b). Therefore, the observational-descriptive approach limits and extrapolates the present findings, which consist of different actions. Female BJJ athletes may also elicit different demands and physiological responses for specific action and combat phases (Del Vecchio et al., 2011; Sterkowicz-Przybycień et al., 2017).

4.2. Strengths

Objective female BJJ information allows for more evidence-based decisions during combats, reducing those based on speculation. Using evidence to give feedback to female combat athletes helps them to understand what they have done to be effective or ineffective, considering weight divisions. Training theories of grappling athletes stress that training programs should be comprised of three critical phases: preparatory, competition, and transition (Blumenstein et al., 2005). Physical, technical, tactical, and psychological preparations are present in each training phase and consider time-motion BJJ analysis to reproduce contextual demands (Del Vecchio et al., 2011, 2016). During the competition phase, which lasts between 4–8 months, female BJJ athletes should achieve their highest level of performance. Grapplers must pull it all together and reach their peak physically and psychologically (Blumenstein et al., 2005). In line, our results could help with five objectives in the competition phase (Lima et al., 2022): (a) to further improve the combat sport-specific abilities and psychological readiness, (b) to refine the skill level and technique, considering each weight category, (c) to enhance performance at the highest level in female grappling combats, (d) to improve tactics and strategies implemented in BJJ during training and competitions, and (e) to maintain general preparation, according to weight category necessities (Blumenstein et al., 2005).

4.3. Practical applications

The time-motion and behavior characteristics reported in this research, including the effort and pause ratio and the accumulated duration throughout a female BJJ match, provide data that can be used in both manipulations of training variables and periodization design, highlighting the competition phase with contextual training. Using the data provided in this research, BJJ coaches might choose to develop training sessions to improve specific behavior skills and BJJ-specific conditioning. Phase values for an athlete within a given category would guide the selection of sequential BJJ-specific work periods interspersed by "realistic" lower-effort behaviors (i.e., pause, movement, and approach phases) and higher intensities efforts (i.e., gripping, transition, guard, side control, mount, attack, and defense) periods. BJJ-specific work periods by weight category might include gripping, transition, and attack. Those phases are impacted by weight division, with longer gripping, transition, and attack times for roosters. As strength relative to lean body mass tends to be inversely related to body size, the lightest BJJ athletes may exhibit greater muscular endurance and anaerobic power-to-weight ratio (Del Vecchio et al., 2016).

In contrast, light feather, feather, light, and middle categories had longer attack times than heavy athletes. In the heaviest categories, BJJ display the highest body fat percentages and the lowest relative strength compared to other divisions (Del Vecchio et al., 2016). Sterkowicz-Przybycień et al. (2017) showed a higher frequency of specific throwing techniques in male and female lighter-weight judo athletes compared to heavier-weight divisions using a biomechanical approach to classify judo throws. Thus, unique phenotypes and physical qualities among female BJJ athletes in the lowest and highest categories may have precluded potential differences in combat's gripping, transition, and attack phases.

4.4. Conclusion

The pioneering research compared continuous female high-level BJJ actions in time and frequency, considering weight categories. Our principal findings showed that the Super heavyweight category had a shorter gripping time than other weight categories. In contrast, roosters had a longer gripping, transition, and attack times and frequency than the light feather, middlers, and heavier weight categories. In summary, the roosters' category demonstrated more extended actions. There is a trend to equalize middle and lightweight categories in high-intensity actions. Future psychological studies might consider other technical, tactical, and emotional analyses associated with performance.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding authors.

Ethics statement

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. Written informed consent from the [patients/participants OR patients/participants legal guardian/next of kin] was not required to participate in this study in accordance with the national legislation and the institutional requirements.

Author contributions

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

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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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References

Ambroży, T., Rydzik, Ł., Spieszny, M., Chwała, W., Jaszczur-Nowicki, J., Jekiełek, M., et al. (2021). Evaluation of the level of technical and tactical skills and its relationships with aerobic capacity and special fitness in elite Ju-Jitsu athletes. *Int. J. Environ. Res. Public Health* 18:12286. doi: 10.3390/ijerph182312286

Amtmann, J. (2012). Anticipating and training for the worst-case metabolic scenario: a comment on Del Vecchio, Hirata, and Franchini (2011). *Percept. Mot. Skills* 114, 123–124. doi: 10.2466/05.PMS.114.1.123-124

Andreato, L. V., Franchini, E., De Moraes, S. M., Pastório, J. J., Da Silva, D. F., Esteves, J. V., et al. (2013). Physiological and technical-tactical analysis in Brazilian jiu-jitsu competition. *Asian J. Sports Med.* 4, 137–143. doi: 10.5812/asjsm.34496

Andreato, L. V., Julio, U. F., Panissa, V. L., Esteves, J. V., Hardt, F., de Moraes, S. M., et al. (2015). Brazilian jiu-jitsu simulated competition part I: metabolic. Hormonal. Cellular damage. And heart rate responses. *J. Strength Cond. Res.* 29, 2538–2549. doi: 10.1519/JSC.0000000000000918

Avakian, P., Frezza, D. A., Pinho, B. G., Achour, A. J., Aedo-Munoz, E., Perez, D. I. V., et al. (2021). Development and reliability of technical-tactical and time-motion real-time analysis in the world taekwondo grand prix. *Ido Mov. Culture J. Martial Arts Anthrop.* 21, 20–27. doi: 10.14589/ido.21.4.4

Bahmani, M., Bahram, A., Diekfuss, J. A., and Arsham, S. (2019). An expert's mind in action: assessing attentional focus, workload and performance in a dynamic, naturalistic environment. *J. Sports Sci.* 37, 2318–2330. doi: 10.1080/02640414.2019.1631102

Barreto, L. B. M., Aedo-Muñoz, E. A., Soto, D. A. S., Miarka, B., and Brito, C. J. (2021). Road to Tokyo Olympic games: do new judo rules change the technical-tactical behaviour of elite male athletes? *Int. J. Perform. Anal. Sport* 21, 1140–1148. doi: 10.1080/24748668.2021.1979839

Barreto, L. B. M., Aedo-Muñoz, E. A., Soto, D. A. S., Miarka, B., and Brito, C. J. (2022). Has there been a change between combat time in male judo? Analysis of the top 20 athletes by weight division between the 2016-20 Olympic cycles. *Int. J. Perform. Anal. Sport* 22, 541–557. doi: 10.1080/24748668.2022.2086516

Barreto, L. B. M., Bello, F. D., Araujo, R. A., Brito, C. J., Fernandes, J. R., and Miarka, B. (2019). Judo approach and handgrip analysis: determining aspects of world circuit high performance. *J. Phys. Educ. Sport* 19, 413–419. doi: 10.7752/jpes.2019.s2061

Barrientos, C. A. V., Antonietto, D., Rezende Oliveira, C. L., Mota Barreto, L. B., Miarka, B., Aedo-Munoz, E. A., et al. (2021). Frami software protocol for taekwondo: development, reliability and reproducibility. *Ido Mov. Culture J. Martial Arts Anthrop.* 21, 36–46. doi: 10.14589/ido.21.4

Blach, W., Rydzik, L., Blach, L., Cynarski, W. J., Kostrzewa, M., and Ambrozy, T. (2021). Characteristics of technical and tactical preparation of elite judokas during the world championships and Olympic games. *Int. J. Environ. Res. Public Health* 18:5841. doi: 10.3390/ijerph18115841

Brandt, R., Bevilacqua, G. G., Crocetta, T. B., Monteiro, C., Guarnieri, R., Hobold, E., et al. (2021). Comparisons of mood states associated with outcomes achieved by female and male athletes in high-level judo and Brazilian Jiu-Jitsu championships: psychological factors associated with the probability of success. *J. Strength Cond. Res.* 35, 2518–2524. doi: 10.1519/JSC.0000000000003218

Brito, C. J., Miarka, B., de Durana, A. L. D., and Fukuda, D. H. (2017). Home advantage in judo: analysis by the combat phase, penalties and the type of attack. *J. Hum. Kinet.* 57, 213–220. doi: 10.1515/hukin-2017-0062

Carvalho, N. G., Barcellos, L. C., Santos, C. F. M., Andrade, V. M. M., Soto, D. A. S., Aedo-Muñoz, E., et al. (2022a). Analysis of acute responses from cellular injury biomarkers and oxidative stress in Brazilian jiu-jitsu combat. *J. Phys. Educ. Sport* 22, 1327–1332. doi: 10.7752/jpes.2022.05166

Carvalho, N. G., Rego, R. S., Chagas, A., Teixeira, F. G., Antonietto, N. R., Pérez, D. I. V., et al. (2022b). Women Brazilian Jiu-jitsu practitioners showed a higher incidence of concussion: an epidemiological analysis. *Motricidade* 18, 151–155. doi: 10.6063/motricidade.25225

Challis, D., Scruton, A., Cole, M., and Callan, M. (2015). A time-motion analysis of lightweight Women's judo in the 2010 world championships. *Int. J. Sports Sci. Coaching* 10, 479–486. doi: 10.1260/1747-9541.10.2-3.479

Coswig, V. S., Bartel, C., and Del Vecchio, F. B. (2018a). Brazilian jiu-jitsu matches induced similar physiological and technical-tactical responses in *gi* and *nogi* conditions. *Arch. Budo.* 14, 291–301.

Coswig, V. S., Gentil, P., Bueno, J. C. A., Follmer, B., Marques, V. A., and Del Vecchio, F. B. (2018b). Physical fitness predicts technical-tactical and time-motion profile in simulated judo and Brazilian Jiu-Jitsu matches. *PeerJ* 6:e4851. doi: 10.7717/peerj.4851

Dal Bello, F., Aedo-Muñoz, E., Brito, C. J., and Miarka, B. (2019). Performance analysis and probabilities by gender in judo: combat phases, techniques and biomechanical levers. *Facta Univ.* 17:135. doi: 10.22190/FUPES190415015D

Del Vecchio, F. B., Gondim, D. F., and Arruda, A. C. (2016). Functional movement screening performance of Brazilian Jiu-Jitsu athletes from Brazil: differences considering practice time and combat style. *J. Strength Cond. Res.* 30, 2341–2347. doi: 10.1519/JSC.0000000000001324

Del Vecchio, F. B., Hirata, S. M., and Franchini, E. (2011). A review of time-motion analysis and combat development in mixed martial arts matches at regional level tournaments. *Percept. Motor Skills* 112, 639–648. doi: 10.2466/05.25.PMS.112.2.639-648

Diaz-Lara, F. J., Del Coso, J., Garcia, J. M., Portillo, L. J., Areces, F., and Abian-Vicen, J. (2016). Caffeine improves muscular performance in elite Brazilian Jiu-jitsu athletes. *Eur. J. Sport Sci.* 16, 1079–1086. doi: 10.1080/17461391.2016.1143036

Dopico-Calvo, X., Iglesias-Soler, E., Santos, L., Carballeira, E., and Mayo, X. (2022). Analysis of successful behaviors leading to groundwork scoring skills in elite judo athletes. *Int. J. Env. Res. Public Health* 19:3165. doi: 10.3390/ijerph19063165

Faro, H. K. C., Tavares, M. P. M., Gantois, P. M. D., Pereira, D. C., Lima, M. N. M., Lima-Junior, D., et al. (2020). Comparison of competitive anxiety and self-confidence in Brazilian Jiu-Jitsu skills levels: a cross-sectional in-event study. *Ido Mov. Culture J. Martial Arts Anthrop.* 20, 30–39. doi: 10.14589/ido.20.1.4

Fernandes, J. R., Brito, A. M., Brito, C. J., Aedo-Muñoz, E., and Miarka, B. (2022). Technical-tactical actions of fighters specialized in striking, grappling, and mixed combat in the ultimate fighting championship®. *Ido Mov. Culture J. Martial Arts Anthrop.* 22, 23–31. doi: 10.14589/ido.22.2.3

Fernández, M. M., Perez, D. I. V., Aedo-Muñoz, E., Barreto, L. B. M., Brito, C. J., De Brito, M. A., et al. (2022). Emotional intelligence contributes to increased ranking in combat athletes with anxiety disorders. *J. Physic. Educ. Sport* 22, 331–336. doi: 10.7752/jpes.2022.02042

Heinisch, H. D., Oswald, R., Ultsch, D., Bazynski, M., Birod, M., and Büsch, D. (2013). Analyse der Olympischen Spiele 2012 im Judo. *Zeitsch Ang. Training* 19, 121–150.

Kirk, C., Hurst, H. T., and Atkins, S. (2015). Measuring the workload of mixed martial arts using accelerometry, time-motion analysis, and lactate. *Int. J. Perform. Anal. Sport* 15, 359–370. doi: 10.1080/24748668.2015.11868798

Kuvacic, G., Krstulovic, S., and Caput, P. D. (2017). Factors determining success in youth judokas. *J. Hum. Kinet.* 56, 207–217. doi: 10.1515/hukin-2017-0038

Lima, P. O., Lima, A. A., Coelho, A. C., Lima, Y. L., Almeida, G. P., Bezerra, M. A., et al. (2017). Biomechanical differences in Brazilian Jiu-Jitsu athletes: the role of combat style. *Int. J. Sports Phys. Ther.* 12, 67–74.

Lima, C. D., Santos, M. H., Barreto, L. B. M., Brito, M. A., Soto, D. A. S., Miarka, B., et al. (2022). Proposition and validation of a protocol for technical-tactical analysis in boxing matches. *Motricidade* 18, 134–149. doi: 10.6063/motricidade.25215

Menescardi, C., Falco, C., and Estevan, I. (2020). Time motion analysis of cadet taekwondo athletes according to gender and weight category. *Ido Mov. Culture J. Martial Arts Anthrop.* 20, 40–46. doi: 10.14589/ido.20.4.6

Miarka, B., Brito, C. J., Bello, F. D., and Amtmann, J. (2017a). Motor actions and spatiotemporal changes by weight divisions of mixed martial arts: applications for training. *Hum. Mov. Sci.* 55, 73–80. doi: 10.1016/j.humov.2017.07.009

Miarka, B., Carvalho, G. N., Ignacio Valenzuela Perez, D., Aedo-Munoz, E., and Jose Brito, C. (2020a). Comparisons of pacing strategy and technical-tactical behaviors in female mixed martial arts rounds. *Front. Psychol.* 11:548546. doi: 10.3389/fpsyg.2020.548546

Miarka, B., Cury, R., Julianetti, R., Battazza, R., Julio, U. F., Calmet, M., et al. (2014). A comparison of time-motion and technical–tactical variables between age groups of female judo matches. *J. Sports Sci.* 32, 1529–1538. doi: 10.1080/02640414.2014.903335

Miarka, B., Fukuda, D. H., Del Vecchio, F. B., and Franchini, E. (2016a). Discriminant analysis of technical-tactical actions in high-level judo athletes. *Int. J. Perform. Anal. Sport* 16, 30–39. doi: 10.1080/24748668.2016.11868868

Miarka, B., Fukuda, H. D., Heinisch, H.-D., Battazza, R., Del Vecchio, F. B., Camey, S., et al. (2016b). Time-motion analysis and decision making in female judo athletes during victory or defeat at Olympic and non-Olympic events: are combat actions really unpredictable? *Int. J. Perform. Anal. Sport* 16, 442–463. doi: 10.1080/24748668.2016.11868900

Miarka, B., Hayashida, C. R., Julio, U. F., Calmet, M., and Franchini, E. (2011). Objectivity of FRAMI-software for judo match analysis. *Int. J. Perform. Anal. Sport* 11, 254–266. doi: 10.1080/24748668.2011.11868546

Miarka, B., Perez, D. I. V., Aedo-Munoz, E., Barreto, L. B. M., Fernandes, J. R., and Brito, C. J. (2020b). Practical application of time-motion analysis of judo female cadets' combats between weight divisions. *Int. J. Perform. Anal. Sport* 20, 701–708. doi: 10.1080/24748668.2020.1780870

Miarka, B., Perez, D. I. V., Aedo-Munoz, E., da Costa, L. O. F., and Brito, C. J. (2020c). Technical-tactical behaviors analysis of male and female judo cadets' combats. *Front. Psychol.* 11:1389. doi: 10.3389/fpsyg.2020.01389

Miarka, B., Sterkowicz-Przybycien, K., and Fukuda, D. H. (2017b). Evaluation of sex-specific movement patterns in judo using probabilistic neural networks. *Mot. Control.* 21, 390–412. doi: 10.1123/mc.2016-0007

Miarka, B., Valenzuela Perez, D. I., Aedo-Munoz, E., Fernandes da Costa, L. O., Mota Barreto, L. B., and Brito, C. J. (2022). Technical report on a time-motion analysis of male judo cadets' combats between weight divisions. *Ido Mov. Culture J. Martial Arts Anthrop.* 22, 9–14. doi: 10.14589/ido.22.1.2

Ovretveit, K. (2018). Anthropometric and physiological characteristics of Brazilian Jiu-Jitsu athletes. *J. Strength Cond. Res.* 32, 997–1004. doi: 10.1519/JSC.0000000000002471

Pawelec, P., Swider, P., and Yu, J. H. (2022). Topics concerning women practicing fighting systems in the discourse of selected scientific journals – a short bibliometric analysis. *Ido Mov. Culture J. Martial Arts Anthrop.* 22, 58–67. doi: 10.14589/ido.22.1.8

Piras, A., Pierantozzi, E., and Squatrito, S. (2014). Visual search strategy in judo fighters during the execution of the first grip. *Int. J. Sports Sci. Coach.* 9, 185–198. doi: 10.1260/1747-9541.9.1.185

Reale, R., Slater, G., and Burke, L. M. (2018). Weight management practices of Australian Olympic combat sport athletes. *Int. J. Sports Physiol. Perform.* 13, 459–466. doi: 10.1123/ijspp.2016-0553

Santos, M. A. F., Oliveira, L., Antonietto, D. A., Silva, F. N. O., Fernandes, A. M., Teixeira, F. G., et al. (2022). Lower experience increases concussion susceptibility in Brazilian jiu-jitsu practitioners. *Motricidade* 18, 145–150. doi: 10.6063/motricidade.25224

Sciranka, J., Augustovicova, D., and Steanovsky, M. (2022). Time-motion analysis in freestyle wrestling: weight category as a factor in different time-motion structures. *Ido Mov. Culture J. Martial Arts Anthrop.* 22, 1–8. doi: 10.14589/ido.22.1.1

Slimani, M., Chaabene, H., Miarka, B., and Chamari, K. (2017). The activity profile of elite low-kick kickboxing competition. *Int. J. Sports Physiol. Perform.* 12, 182–189. doi: 10.1123/ijspp.2015-0659

Soto, D. A. S., Aedo-Munoz, E., Brito, C. J., Camey, S., and Miarka, B. (2020a). Making decisions and motor actions with technical biomechanical classifications in male judo weight categories. *J. Hum. Kinet.* 72, 241–252. doi: 10.2478/hukin-2019-0110

Soto, D. A. S., Aedo-Munoz, E., Brito, C. J., and Miarka, B. (2020b). Comparisons of motor actions and biomechanical assessments of judo techniques between female weight categories. *J. Hum. Kinet.* 75, 247–255. doi: 10.2478/hukin-2020-0053

Sterkowicz, S., Jaworski, J., Lech, G., Pałka, T., Sterkowicz-Przybycień, K., Bujas, P., et al. (2016). Effect of acute effort on isometric strength and body balance: trained vs Untrained Paradigm. *PLoS One* 11:e0155985. doi: 10.1371/journal.pone.0155985

Sterkowicz, S., Sacripanti, A., and Sterkowicz-Przybycien, K. (2013). Techniques frequently used during London Olympic judo tournaments: a biomechanical approach. *Arch. Budo* 9, 51–58. doi: 10.12659/AOB.883848

Sterkowicz-Przybycień, K., Miarka, B., and Fukuda, D. H. (2017). Sex and weight category differences in time-motion analysis of elite judo athletes: implications for assessment and training. *J. Strength Cond. Res.* 31, 817–825. doi: 10.1519/JSC.0000000000001597

Tornello, F., Capranica, L., Minganti, C., Chiodo, S., Condello, G., and Tessitore, A. (2014). Technical-tactical analysis of youth Olympic taekwondo combat. *J. Strength Cond. Res.* 28, 1151–1157. doi: 10.1519/JSC.0000000000000255

Williams, J., Callaway, A., Gara, M., and Tattersall, P. (2019). Technique utilisation and efficiency in competitive Brazilian Jiu-Jitsu matches at white and blue belts. *Int. J. Perform. Anal. Sport* 19, 353–369. doi: 10.1080/24748668.2019.1611290

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*CORRESPONDENCE
Dany Alexis Sobarzo Soto
✉ danysobarzo@santotomas.cl
Bianca Miarka
✉ miarkasport@hotmail.com

†These authors have contributed equally to this work

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Corrigendum: Effects of weight divisions in time-motion of female high-level Brazilian Jiu-jitsu combat behaviors

Marco Antonio Ferreira dos Santos[1†], Dany Alexis Sobarzo Soto[2*†], Michele Andrade de Brito[1,3†], Ciro José Brito[3†], Esteban Aedo-Muñoz[1,4†], Maamer Slimani[5†], Nicola L. Bragazzi[6†], Hela Znazen[7†] and Bianca Miarka[1*†]

[1]Laboratory of Psychophysiology and Performance in Sports and Combats, Postgraduate Program in Physical Education, Federal University of Rio de Janeiro, Rio de Janeiro, Brazil, [2]Escuela de Kinesiología, Facultad de Salud, Universidad Santo Tomás, Puerto Montt, Chile, [3]Postgraduate Program in Physical Education, Federal University of Juiz de Fora, Governador Valadares, Brazil, [4]Departamento de Educación Física, Deportes y Recreación, Facultad de Artes y Educación Física, Universidad Metropolitana de Ciencias de la Educación, Santiago, Chile, [5]Department of Health Sciences (DISSAL), University of Genoa, Genoa, Italy, [6]Department of Mathematics and Statistics, Laboratory for Industrial and Applied Mathematics (LIAM), York University, Toronto, ON, Canada, [7]Department of Physical Education and Sport, College of Education, Taif University, Taif, Saudi Arabia

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REVIEWED BY
Miguel Pic,
South Ural State University, Russia
João Nunes Prudente,
University of Madeira, Portugal
Daniel Lapresa,
University of La Rioja, Spain

*CORRESPONDENCE
Iyán Iván-Baragaño
✉ iyanivanbaragano@gmail.com

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Future horizons in the analysis of technical-tactical performance in women's football: a mixed methods approach to the analysis of in-depth interviews with professional coaches and players

Iyán Iván-Baragaño[1]*, Antonio Ardá[2], M. Teresa Anguera[3], José Luis Losada[4] and Rubén Maneiro[5]

[1]Faculty of Sport Sciences, Universidad Europea de Madrid, Madrid, Spain, [2]Department of Physical and Sport Education, University of A Coruña, A Coruña, Spain, [3]Faculty of Psychology, Institute of Neurosciences, University of Barcelona, Barcelona, Spain, [4]Department of Social Psychology and Quantitative Psychology, University of Barcelona, Barcelona, Spain, [5]Department of Science of Physical Activity and Sport, Pontifical University of Salamanca, Salamanca, Spain

Introduction: Scientific knowledge about the criteria that determine success in women's football is beginning to develop.

Methods: This study was carried out with the aim of detecting regularities in the offensive success in elite women's football, as well as carrying out an interrelational analysis of linked behaviors, based on in-depth interviews with professional coaches and players. Eight in-depth interviews were conducted with professional Spanish coaches and players. The interviews were analyzed by indirect observation from a process of "quantitizing," through the construction of an indirect observation *ad hoc* instrument. The segmentation of the transcription of the interviews was carried out in textual units, and the creation of a matrix of codes. Two types of analysis were performed: first, a lag sequential analysis (LSA) was performed and, then, a polar coordinates analysis (PCA), which allowed to find, respectively, a wide number of established communicative patterns with offensive performance in women's football, as well as an interrelational map between the established codes.

Results: The results obtained allowed us to suggest a statistically significant association between success in women's football and criteria such as the physical characteristics of a particular player, the individual action space, the duration of the attack, the type of dynamic start, individual and collective technical and tactical aspects, decision making and the type of attack used.

Discussion: Based on these results, the influence of these criteria on performance in women's soccer can be studied in future studies. In addition, with the aim of increasing the validity of these conclusions, new studies on this subject may be carried out following strategies such as the Delphi Method.

KEYWORDS

women's football, observational methodology, performance indicators, in-depth interviews, indirect observation, quantitizing

1. Introduction

Women's football has significantly increased its media impact in recent years. The last FIFA Women's World Cup was seen by 1.12 billion spectators, 106% more than the previous edition (FIFA, 2019a). Currently, approximately 30 million players play football worldwide (FIFA, 2019b). Despite this growth, women's football is in an inferior position compared to its male counterpart (Lago et al., 2021).

In the scientific field, the first article on women's football was published in 1939 (Okholm Kryger et al., 2021). Despite this, the first year in which more than 10 articles on this topic were published was 1997 (Okholm Kryger et al., 2021). Currently, the number of scientific publications on women's football represents approximately a quarter of the total on this sport (Kirkendall, 2020). In addition, most studies have focused on the anatomical and physiological aspects related to the physical performance of the players (Kirkendall and Krustrup, 2021).

With the aim of enhancing the visibility and participation of women footballers, new strategies are needed to promote this sport. In this regard, recent research showed that the performance of women's football teams was higher compared to men's teams in those countries with a higher degree of women's empowerment, better domestic leagues, and a greater number of players (Lago et al., 2021). This study, on the other hand, showed that the GDP *per capita*, the number of men and women on the executive committees, or the existence of a strategy for women's football, were variables that did not modify the difference in performance between male and female teams in the same country in the FIFA Ranking (Lago et al., 2021). Therefore, the competent authorities in the field of sport must focus their efforts in the coming years on two fundamental aspects: (i) increasing the number of women who play football and (ii) improving the sports performance of domestic leagues.

Sports performance in team sports, and football in particular, can only be understood from a multifactorial approach (psychological, sociological, physiological, technical-tactical,…), product of the dynamic interaction between competitors through play actions (Preciado et al., 2019). In relation to technical and tactical performance, research in men's football has provided numerous pieces of evidence in the last two decades (Lago, 2009; Tenga et al., 2010; Lago-Ballesteros et al., 2012; Casal et al., 2017; Sarmento et al., 2018). On the other hand, although knowledge about women's football, from areas such as physiology and medicine has been developing in recent decades (Okholm Kryger et al., 2021), according to Kirkendall and Krustrup (2021) there are only 21 articles published with the topic match analysis, 19 of which have been published in the last decade and 40 articles (35 in the last 10 years) with the topic match performance. This is why it is an issue that must be developed in the near future.

On this subject, some recent studies have tried to provide evidence when it comes to understanding which are the criteria that determine a higher performance during a match in women's football. The influence of the match status criterion on the collective behavior in women's football has recently been demonstrated in set pieces (Lee and Mills, 2021) and ball possessions (Maneiro et al., 2020). Other studies have tried to find out which variables determine the outcome of games in women's football. In relation to this issue, De Jong et al. (2020) observed that the variable that most influenced the outcome of the match was scoring first. For their part, Kubayi and Larkin (2020) found technical differences between the winning and losing teams in the last FIFA Women's World Cup France 2019: the teams that won their matches made more passes, shots, and shots on target per game, in addition to having a higher percentage of ball possession and air duels won, this last variable also demonstrated by De Jong et al. (2020). Tactical differences between winning and losing teams were also found in FIFA Women's World Cup France 2019 (Iván-Baragaño et al., 2022). These authors showed that the teams that won their matches were able to keep possession of the ball for longer on the rival field, as well as to develop a greater number of possessions in the first minutes of the match, characterized by a greater dispute over possession of the ball. On the other hand, an analysis of the FIFA Women's World Cup Canada 2015 showed that the type of start was a criterion that significantly influenced the creation of scoring opportunities (Scanlan et al., 2020), an aspect that agrees with the findings obtained in the FIFA Women's World Cup 2019 (Iván-Baragaño et al., 2021). This last study, in turn, demonstrated a probability of offensive success in ball possessions of 75.2% based on the criteria zone of possession, initial offensive intention, and starting zone (Iván-Baragaño et al., 2021), agreeing with the results obtained by Maneiro et al. (2021) 4 years earlier: these authors demonstrated that the result of ball possessions was significantly conditioned by temporality, initial offensive intention or the number of passes, among other criteria. Technical differences have also been found in the development of the game based on the surface of the playing field (García-Unanue et al., 2020).

Despite the recent growth of scientific knowledge, the available evidence is still scarce. For this reason, it is not possible to know if everything we know about men's football performance can be applied to play in women, taking into account the differences in play between the two sexes (Bradley et al., 2014; Casal et al., 2021; Garnica-Caparrós and Memmert, 2021). Answering this question is considered necessary since it can allow professionals in this sport to apply the knowledge acquired about men's football to their own sports specialty (Okholm Kryger et al., 2021). Based on the above, it can be said that we are still facing a study area with short-term growth potential. Researchers will undoubtedly have to further develop this issue in the coming years. In this sense, the experience and knowledge of female football coaches and players can help guide research problems, and conducting interviews with the real participants and connoisseurs of the sport can be an effective tool, as demonstrated in other areas of knowledge (García-Fariña et al., 2018, 2021; Del Giacco et al., 2020; Alvarado et al., 2021; Nunes et al., 2022). In the coming years, clubs, public bodies, and researchers must direct their efforts toward achieving the following objectives (Nassis et al., 2021): (i) to know the needs of female football coaches and players, (ii) to intensify scientific production on female football, (iii) through the integration of coaches and players in the studies carried out, and (iv) in search of an improvement in sports practice and the performance of female football teams.

For all the above reasons, this study was carried out with the aim of detecting regularities in the offensive success in elite women's football, as well as carrying out an interrelational analysis of linked behaviors, based on in-depth interviews with professional coaches and players. Under this premise, we have tried to integrate the practical knowledge, based on the experience in the field of play, of coaches and players of women's football from the realization of in-depth interviews, together with the theoretical knowledge of experienced researchers in women's football. On the basis of the analysis of the answers and the conclusions that can be obtained from this study, we hoped to be able to orient the accomplishment of future studies that can help to increase the performance of teams and selections in female football.

2. Materials and methods

2.1. Design

To carry out this study, the observational methodology was applied, based on the transcription of in-depth interviews carried out with coaches and players, due to their suitability in the analysis and observation of human behavior in natural and spontaneous contexts (Anguera, 1979). It was a nomothetic design -various units of study-, punctual -a single session, although with intra-sessional follow-up-, and multidimensional -various dimensions, as can be seen in the observation instrument- (Anguera et al., 2011).

Due to the nature of the textual material obtained from audio transcriptions of the verbal behavior of coaches and players, it was necessary to conduct the study through indirect observation (Anguera et al., 2018), which is a modality of observational methodology that focuses on situations where perceptivity is limited (there is no visual perception), and the data was obtained from various sources, mostly of a textual nature. Through liquifying (Anguera, 2020), and from the perspective of mixed methods, it is possible to quantitatively analyze qualitative material (in our study, transcriptions of in-depth interviews), which is perfectly compatible with the logic of observational methodology (Anguera et al., 2020). The use of indirect observation requires overcoming challenges derived from partial perceptivity, which have been attempted to be addressed in this research. We highlight the contribution that it provides in studies in which human communication is of interest as a source of information (García-Fariña et al., 2018, 2021; Del Giacco et al., 2020; Alvarado et al., 2021; Nunes et al., 2022).

2.2. Participants and sample

A total of 8 in-depth interviews were conducted with professional female football coaches and players. The choice of coaches and players was based on the need to obtain information, through personal stories, on a wide and varied professional background (Solstad et al., 2021). Due to the intensive nature (obtaining many cases from each case) of the indirect observation studies, this number of interviews was considered sufficient for this study, as were others (Sarmento et al., 2014, 2020; Iván-Baragaño et al., 2021). The transcript obtained from the interviews conducted consisted of 73,046 words and 2,410 textual units.

The coaches and players interviewed were selected by expert sampling provided that they met the following inclusion criteria: (i) for coaches: being in possession of the UEFA Pro title as a coach and having at least 1 year of experience as a coach in the Spanish First Division and, (ii) for players: having been called by the Spanish women's team and having at least 3 years of experience in the Spanish First Division.

A total of 5 coaches (4 men; 1 woman; 39.2 ± 7.85 years) and 3 players (26.66 ± 5.68 years) were interviewed. Among the coaches, there was the second coach of the Spanish Women's Team, a participant in the FIFA Women's World Cup France 2019, a champion of the Queen's Cup in 2019, a Doctor of Sports Sciences, and a Graduate in Physical Activity and Sport Sciences. Of the 3 players interviewed, two of them were UEFA Women's Champions League champions with their clubs, and one of them was selected by her team to play in the FIFA Women's World Cup France 2019.

2.3. Instruments

2.3.1. Semi-structured interviews

The degree of structuring of the interview allowed for obtaining a valid source of information on the participant's experience (Jackman et al., 2022). Prior to the preparation of the interviews, 5 pilot interviews were conducted with Spanish professional football players. The final in-depth interview consisted of 15 questions and sub-questions and was prepared by an expert committee. Of its three members, two of them had a PhD in Sports Sciences and more than 30 years of experience as researchers in the field between the two, and one of them was a PhD student in Sports Sciences. In addition, the members had a UEFA A or higher qualification at the time of this study.

The interviews conducted were conducted face-to-face, individually, and in an undirected manner. The interviews were conducted in a pre-agreed location near the interviewee's residence. Three interviews were conducted by videoconference, a method currently accepted in this type of study (Edwards et al., 2021). All of them were directed by one of the authors of the study and recorded in audio. The interviews lasted between 36 and 75 min and were transcribed *ad verbatim*.

2.3.2. Indirect observation instrument

The *ad hoc* instrument of indirect observation used in this study was constructed by combining the ascending path (of the responses to the theoretical framework/regulation) and descending path (vice versa) from the responses of the people interviewed. A progressive process of adaptation and specification of the dimensions and sub-dimensions that make up this instrument has been followed.

The final instrument was a combination of field format and category systems since it allowed for an ideal solution to the high complexity of the situation under study (Caprara and Anguera, 2019). It was composed of two dimensions and 28 sub-dimensions. Catalogs of behavior were developed based on certain sub-dimensions, depending on their content and characteristics. These catalogs are open lists that meet the condition of mutual exclusivity. In contrast, category systems were constructed based on other sub-dimensions, supported by theoretical frameworks and fulfilling the requirements of exhaustiveness and mutual exclusivity. For each of the categories and behaviors of the catalogs of the observation instrument, a definition was developed and examples and counterexamples were provided using the answers of the people interviewed. The indirect observation instrument used can be found in Table 1.

2.4. Recording instrument

For the recording and coding of the textual units analyzed, the free software Lince Plus[1] (Soto-Fernández et al., 2021) of great applicability in observational methodology was used (Figure 1).

As our study involved indirect observation, the successive textual units corresponding to each question's responses constituted the respective observation units. These units were diachronically recorded as successive rows (formed by one or several codes, depending on the

1 https://observesport.github.io/lince-plus

TABLE 1 Indirect observation instrument *ad hoc*.

Dimensions	Subdimensions	Categories and behaviors	
Dimension 1. Initial assessment of the question	D11 Degree of agreement	D111 Affirmation or degree of positive agreement	
		D112 Affirmation or degree of positive agreement justified	
		D113 Denial or degree of negative agreement	
		D114 Denial or degree of negative agreement justified	
		D115 Neutral	
		D116 Neutral justified	
	D12 Emotional assessment	D121 Emotional interpretation	
Dimension 2. Justification of the reply	D21 Gender allusions	D211 Refers to women's gender or women's football	
		D212 Refers to male gender or male football	
	D22 Justification based on team, specific position or player	D221 Refers to a team or a set of teams	
		D222 Refers to a specific position	
		D223 Refers to a specific player	
	D23 Justification for the offensive phase	D231 Refers to a quick attack: counterattack or direct attack	
		D232 Refers to a combinative attack or position play	
		D233 Refers to a combination of offensive game models	
	D24 Justification for the system of play	D241 Refers to the system of play	
	D25 Justification for the defensive phase	D251 Refers to the type of marking in the defensive phase	
		D252 Refers to the positioning of a team in the defensive phase	
	D26 Justification for transition	D261 Refers to the offensive transition	
		D262 Refers to the defensive transition	
	D27 Justification for set piece	D271 Refers to set piece actions	
	D28 Justification based on tactical intent	D281 Refers to a team's offensive tactical intent	
		D282 Refers to the defensive tactical intent of a team	
	D29 Technical justification	D291 Offensive technique	D2911 Individual offensive technique
			D2912 Collective offensive technique
		D292 Defensive technique	
	D210 Tactical justification	D2101 Offensive tactic	D21011 Individual offensive tactic
			D21012 Collective offensive tactic
		D2102 Defensive tactic	D21021 Individual defensive tactic
			D21022 Collective defensive tactic
	D211 Strategic justification	D2111 Refers to the strategic plan during a match or a moment of this	
	D212 Justification based on final result	D2121 Refers to the final result of the match (successful/unsuccessful)	
		D2122 Refers to the final result in a championship, league… (best/worst teams)	
		D2123 Refer to the level difference between teams	
		D2124 Refers to an even level between teams	
	D213 Justification based on match status	D2131 Refers to winning	
		D2132 Refers to losing	
		D2133 Refers to tying	
	D214 Spatial justification	D2141 Refers to zoned regulatory space	
		D2142 Refers to effective play space	
		D2143 Refers to the spatial context of interaction	
		D2144 Refers to action space	

(Continued)

TABLE 1 (Continued)

Dimensions	Subdimensions	Categories and behaviors
	D215 Temporary justification	D2151 Refers to the temporality of the action
		D2152 Refers to possession time
		D2153 Refers to the duration of the attack
		D2154 Refers to action time
	D216 Physical/conditional justification	D2161 Refers to the physical characteristics of a particular player
		D2162 Refers to the physical characteristics of a specific position or line
		D2163 Refers to the physical characteristics of a team, set of them or generically to women's or men's football
	D217 Psychological justification	D2171 Refers to psychological aspects
	D218 Justification alluding to the type of start	D2181 Refers to a static startup type
		D2182 Refers to a dynamic startup type
	D219 Justification defensive organization	D2191 Refers to an organized or structured defensive structuring
		D2192 Refers to a disorganized or circumstantial defensive structuring
	D220 Decision making	D2201 Refers to decision making and perception
		D2202 Refers to the perception of the match
	D221 Justification based on the number of players	D2211 Refers to the number of players involved in an action
	D222 Justification based on number of passes and speed	D2221 Refers to the number of passes that are made in an action
		D2222 Refers to the speed of play (touches per player)
	D223 Justification based on knowledge or opinions	D2231 Justifies the answer based on your experience and/or observations as a player or coach
		D2232 Justifies the answer based on your technical-scientific knowledge
		D2233 Refers to what they would like based on their opinion
	D224 Regulatory justification	D2241 Refers to the regulation
		D2242 Refers to competition format
	D225 Quantitative/qualitative justification of superiority or inferiority	D2251 Refers to a superiority of the attacking team
		D2252 Refers to an inferiority of the attacking team
		D2253 Refers to an equality between teams of qualitative, quantitative or positional types
	D226 Comparisons	D2261 Makes comparisons (differentiating) between men's football and women's football
		D2262 Makes comparisons (establishing similarities) between men's football and women's football
		D2263 Makes comparisons between competitions, leagues or categories (temporarily simultaneous)
		D2264 Makes comparisons between different historical moments of women's football
	D227 Other justifications	D2271 Refers to the team that belongs to the coach or player (or to any that have belonged)
		D2272 Refers to football as a collective sport, of common space and cooperation-opposition
		D2273 Refers to other factors without defining what they are
		D2274 Refers to the training of players, technicians or training
	D228 Justification based on the success or outcome of an action	D2281 Linking success in offensive action or in the game in a positive way
		D2282 Linking to success in an offensive action or in the game in a negative way
		D2283 Linking success in offensive action or in the game in a neutral way

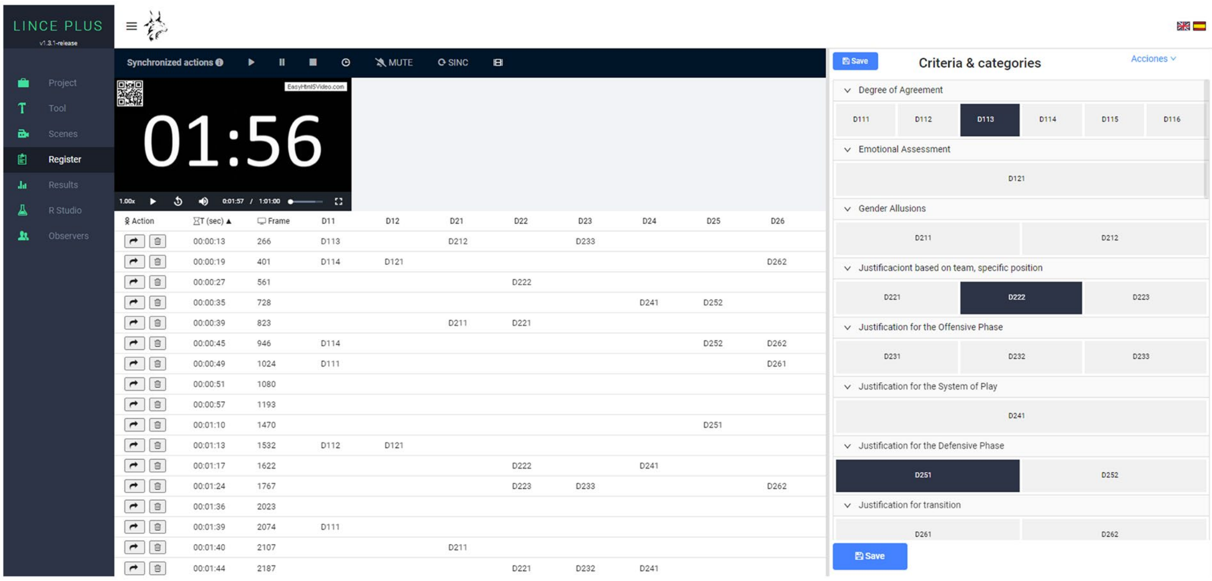

FIGURE 1
Lince Plus software used in this study. Reproduced with permission from Soto-Fernández et al. (2021).

involved sub-dimensions) in the code matrix, which will undergo subsequent analysis.

2.5. Procedure

The interviewees were previously informed of the study carried out and agreed to participate in it. This study was approved by the Ethics Committee of the University of A Coruña (Approval code: CEID-UDC-2019-0024).

Due to the increased risk of inference in the record, indirect observation requires greater caution in data quality control (Anguera, 2020). Therefore, the concordance of the registry was measured by calculating the Cohen (1960), in the intra-observer mode, and yielded a value of 0.708, considered adequate in this study (Landis and Koch, 1977). In addition, consensus agreement (Lapresa et al., 2021) was used as a qualitative method of data quality control among three of the researchers in this study.

Once the recorded interviews were transcribed, they were segmented into textual units under the spelling and syntactic criteria (Krippendorff, 2018). In total, the transcript of the interviews consisted of 73,046 words and 2,410 textual units. These units were recorded and coded by indirect observation, which involved carrying out the "quantitizing" operation (Anguera et al., 2020; Anguera, 2021), starting from the qualitative data of the interview to codify them thanks to the observation instrument, and thus obtaining a matrix of codes (Figure 2) that allowed a subsequent robust quantitative analysis.

2.6. Data analysis

Two types of analysis were carried out in this study, in order to detect the existence of regularities or communicative patterns, on the one hand, and to obtain a map of interrelationships between behaviors, on the other, during the communicative pattern established in the interviews.

First, a lag sequential analysis (LSA) (Bakeman, 1978) was performed to detect the possible existence of patterns of behavior among textual units obtained from interviews about the criteria that determine offensive success in elite women's football. In this analysis, behavior *D2281: Linking success in offensive action or in the game in a positive way* was proposed as the target, which meant that it had the role of initializing the communicative patterns. The rest of the behaviors of the indirect instrument were considered conditioned (which implied knowing if they were part of the communicative patterns analyzed). This target behavior was selected because it represented those allusions made to offensive success in women's football during interviews with coaches and players. Sequential analysis was conducted using the GSEQ software option to differentiate responses corresponding to each question as "units" to preserve intra-response sequentiality without affecting subsequent question responses. From this analysis, used satisfactorily in indirect observation (García-Fariña et al., 2018; Venturella et al., 2019; Del Giacco et al., 2020), the communicative pattern between target behaviors and conditioned behaviors was constructed. Although lags from −5 to +5 were analyzed, in this study, we focused on the results obtained in the −2 to +2, knowing that in higher lags the communicative pattern could become diluted (García-Fariña et al., 2018). Behaviors with a value greater than 1.96 obtained from the adjusted residual values obtained in this analysis were taken as significant ($p < 0.05$).

Second, to obtain a map of interrelationships between behaviors, a polar coordinate analysis (PCA) was carried out for which the target behavior of the sequential analysis was taken as focal, and the same conditioned behaviors. This analysis has been applied in other indirect observation studies in the field of sports (García-Fariña et al., 2018, 2021; Nunes et al., 2022) and other areas (Alcover et al., 2019;

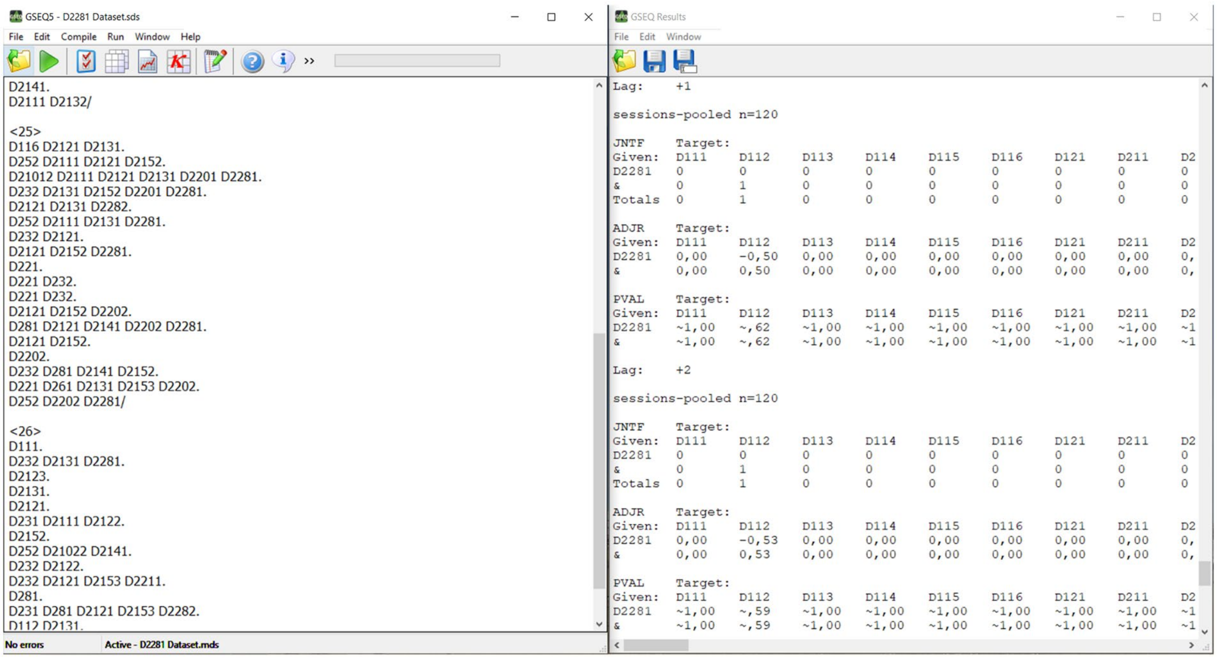

FIGURE 2
Matrix of codes obtained from the transcription of the interviews and lag sequential analysis with the GSEQ5 software. Reproduced with permission from Bakeman and Quera (2011).

Arias-Pujol and Anguera, 2020; Del Giacco et al., 2020; Alvarado et al., 2021). For this analysis, which operates with the adjusted residual values obtained from the lag sequential analysis (LSA), lags −5 to +5 were taken into consideration (Anguera et al., 2018). The lengths and angles of each of the vectors (one for each of the conditioned behaviors) were calculated. These vectors indicate the type of relationship between the focal behavior and each conditioned behavior, and vice versa, as well as the intensity of such relationships. Based on these values, a vector map of the relationships between focal behavior and the rest of the conditioned behaviors was constructed.

The data has been exported using Lince Plus software into a matrix of codes[2] (Soto-Fernández et al., 2021). All analyses were performed with the free program HOISAN (v 2.0)[3] (Hernández-Mendo et al., 2012), with the exception of the calculation of lag 0, carried out using the free software GSEQ5[4] (Bakeman and Quera, 2011).

3. Results

A total of 2,410 textual units were recorded and analyzed in the eight interviews. The behavior taken as target and focal for lag sequential analysis (LSA) and polar coordinate analysis (PCA) respectively was *D2281: Linking success in offensive action or in the game in a positive way.* The other behaviors of the indirect observation instrument were proposed as conditional for both types of analysis.

The results obtained from the lag sequential analysis reflected in Table 2 allowed us to verify how a total of 20 conditioned behaviors of the indirect observation instrument presented a statistically significant association from the value of the adjusted residual. Of the 20 behaviors, only 14 were taken into consideration, as they are related to the performance in women's football. The behaviors were: D223: Refers to a specific player (Lag −2, $Z=2.22$; Lag −1, $Z=2.63$; Lag 0, $Z=4.00$), D232: Refers to a combinative attack or position play (Lag −1, $Z=3.01$; Lag 0, $Z=4.02$), D261: Refers to the offensive transition (Lag 0, $Z=2.28$), D271: Refers to set piece actions (Lag 0, $Z=3.16$; Lag +1, $Z=2.49$), D282: Refers to the defensive tactical intention of a team (Lag −1, $Z=4.06$), D2912: Collective offensive technique (Lag 0, $Z=2.57$), D21011: Individual offensive tactic (Lag −2, $Z=2.15$), D2144: Refers to action space (Lag 0, $Z=2.68$), D2153: Refers to the duration of the attack (Lag 0, $Z=2.00$; Lag +1, $Z=2.57$; Lag +2, $Z=2.11$), D2161: Refers to the physical characteristics of a particular player (Lag−1, $Z=2.55$), D2182: Refers to a dynamic startup type (Lag 0, $Z=6.39$), D2191: Refers to an organized or structured defensive structuring (Lag −2, $Z=2.97$), D2221: Refers to the number of passes that are made in an action (Lag −2, $Z=1.99$), D2242: Refers to competition format (Lag +1, $Z=2.23$; Lag +2, $Z=2.27$).

Only those conditioned behaviors represented in quadrant I (prospective and retrospective activation with focal behavior) of the vector map with a radius equal to or greater than 1.96 were taken into consideration. Therefore, from the results obtained from the polar coordinates analysis (PCA) (Figure 3 and Table 3), a prospective and retrospective association of activation was found between the focal behavior D2281 and the behaviors considered as conditioned, represented in quadrant I of the vector map in eleven (11) conditioned behaviors analyzed in relation to the focal behavior. Of the 11 behaviors that were significant, 8 of them agreed with the results

2 https://observesport.github.io/lince-plus
3 www.menpas.com
4 https://www.mangold-international.com/en/products/software/gseq.html

TABLE 2 Lag sequential analysis results showing the relationship between criteria behavior (*D2281*) and the rest of the conditioned behaviors.

Lag −2	Lag −1	Lag 0	Lag +1	Lag +2
D223	D223	D211	D271	D111
(*Z* = 2.22)	(*Z* = 2.63)	(*Z* = 2.74)	(*Z* = 2,49)	(*Z* = 2,01)
D21011	D232	D223	D2153	D112
(*Z* = 2.15)	(*Z* = 3.01)	(*Z* = 4.00)	(*Z* = 2,57)	(*Z* = 2,59)
D2191	D282	D232	D2242	D114
(*Z* = 2.97)	(*Z* = 4.06)	(*Z* = 4.02)	(*Z* = 2,23)	(*Z* = 2,25)
D2221	D2161	D261	D2271	D2153
(*Z* = 1.99)	(*Z* = 2.55)	(*Z* = 2.28)	(*Z* = 2,75)	(*Z* = 2,11)
		D271		D2242
		(*Z* = 3.16)		(*Z* = 2,27)
		D2912		
		(*Z* = 2.57)		
		D2144		
		(*Z* = 2.68)		
		D2153		
		(*Z* = 2.00)		
		D2182		
		(*Z* = 6.39)		

Results expressed as the value of the adjusted residual obtained for each of the behaviors analyzed.

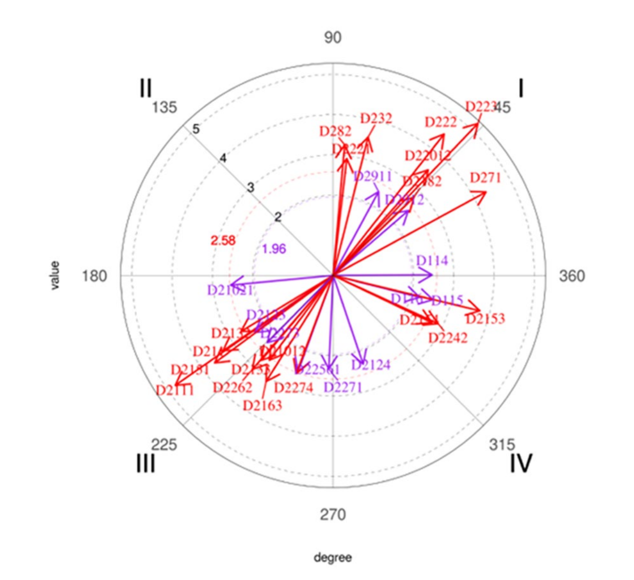

FIGURE 3
Polar coordinate analysis. Focal behavior D2281. Vector map.

obtained from the lag sequential analysis. On the other hand, behaviors D222: Refers to a specific position, D2911: Individual offensive technique and D2201: Refers to decision making and perception, presented significant results for the objective of the study.

The results obtained have made it possible to verify: (i) the existence of a large number of short patterns of behavior from the lag sequential analysis (LSA), as well as, through the application of the polar coordinate analysis (PCA) as a powerful data reduction technique: (ii) a map of interrelationships between behaviors established during the interviews carried out. Based on the interviews carried out, the criteria that, based on the opinions of the interviewees, condition the offensive success in women's football are listed below. The following lines mention those behaviors extracted from the observation instrument that were significant in the analyses carried out, as well as examples extracted from the interviews carried out:

D223: Refers to a specific player (LSA: Lag −2, $Z = 2.22$; Lag −1, $Z = 2.63$; Lag 0, $Z = 4.00$ – PCA: Radius = 5.22, Angle: 46°42′):

Coach 1: *"Speed in women's football is very decisive, Oshoala is a very fast player, if you leave space behind your back, you are dead."*

Player 2: *"In that play the characteristics of the player (the power, the speed) make the action end successfully."*

D232: Refers to a combinative attack or position play (LSA: Lag −1, $Z = 3.01$; Lag 0, $Z = 4.02$ PCA: Radius = 3.55, Angle: 75°84′):

Player 3: *"Successful teams have more ball possession, they keep the ball for more time, they have more passes in the attack. Everything causes physical wear to the unsuccessful team, which in the first part is not visible, but in the second it is."*

Coach 4: *"It is assumed that in a positional attack you perceive how the rival team is positioned and you do it better than in a faster attack, with the disorganized rival team where you have to make decisions in less time."*

D261: Refers to the offensive transition (LSA: Lag 0, $Z = 2.28$):

Player 3: *"In women's football there are many transitions, many quick counterattacks […] and it is very successful."*

Player 2: *"In my opinion […] in women's football more goals are achieved in offensive transitions."*

D271: Refers to set piece actions (LSA: Lag 0, $Z = 3.16$; Lag 1, $Z = 2.49$ – PCA: Radius = 4.33, Angle: 28°66′):

Coach 2: *"We could talk about set pieces as something different, because if we talk about success, normally a team that manages to score in set piece is usually associated with success in a match."*

Player 3: *"There are many goals in corners, fouls, etc. It is very effective. If we do a study of the goals that are scored, there are many games in which you score in set piece."*

D282: Refers to the defensive tactical intent of a team (LSA: Lag−1, $Z = 4.06$ – PCA: Radius = 3.26, Angle = 84°96′):

Player 1: *"I believe that it is a common trend that the best teams are able to: once they lose the ball perform a good pressure after loss and from there re-organize themselves to regain possession in the rival field."*

Player 3: *"In the case of France it usually has more ball possession, it gets higher, so pressure after loss is its best strategy. […] USA is different because it can do the pressure after a loss and may not do it because it feels comfortable running behind it. Both are successful teams and pressure after loss is the strategy because they are the dominating teams […]. It does not make sense that being in a rival field 80 meters from your goal, you go back 50 meters."*

Coach 5: *"I believe that the success, or one of the successes of a team that evidently pressures in the opposite field and steals after loss is that having the opposing team quite far from his goal, they steal near the opposite goal […]. Recovering the ball in that situation allows them to be more successful, be close to the opponent's goal when he recovers […] and be more vertical."*

D2912: Collective offensive technique (LSA: Lag 0, $Z = 2.57$ – ACP: Radius = 2.47, Angle = 40°82′):

Coach 1: *"To get a team that is defensively disorganized out of balance, if you are not able to have a good time, to pass it decisively, to*

TABLE 3 Polar coordinate analysis results showing the relationship between focal behavior (*D2281*) and the rest of the conditioned behaviors.

Code	Quadrant	P. Prosp.	P. Retros.	Radius	Angle
D114	I	2.46	0.01	2.46*	0.31
D115	IV	2.48	−0.6	2.55	346.3
D116	IV	2.15	−0.55	2.22	345.77
D211	III	−2.74	−1.87	3.32	214.4
D222	I	2.75	3.52	4.47*	51.91
D223	I	3.6	3.78	5.22*	46.42
D232	I	0.87	3.44	3.55*	75.84
D271	I	3.8	2.08	4.33*	28.66
D282	I	0.29	3.25	3.26*	84.96
D2911	I	1.13	2.08	2.37*	61.55
D2912	I	1.87	1.61	2.47*	40.82
D21012	III	−1.59	−2.11	2.64	233.05
D21021	III	−2.55	−0.24	2.56	185.41
D2111	III	−3.92	−2.73	4.78	214.86
D2123	III	−1.95	−1.42	2.41	216.08
D2124	IV	0.75	−2.21	2.33	288.68
D2132	III	−2.29	−1.39	2.68	211.33
D2133	III	−1.79	−2.12	2.77	229.78
D2151	III	−2.95	−2.18	3.66	216.46
D2153	IV	3.65	−0.88	3.75	346.43
D2154	IV	2.46	−1.18	2.72	334.4
D2163	III	−1.66	−2.63	3.12	237.72
D2182	I	2.01	1,94	2.79*	44.03
D2201	I	2.36	2.63	3.53*	48.03
D2221	I	0.34	2.91	2.93*	83.33
D2242	IV	2.61	−1.2	2.87	335.31
D2251	III	−0.87	−2.39	2.55	249.97
D2262	III	−2	−2.33	3.08	229.36
D2271	III	−0.11	−2.33	2.33	267.36
D2273	III	−1.64	−1.67	2.34	225.62
D2274	III	−0.92	−2.44	2.61	249.42

P. Prosp, Prospective perspective; P. Retros, Retrospective perspective. *Significant behaviors (Radius > 1.96; $p < 0.05$) of prospective and retrospective activation with the focal behavior (Quadrant I).

know when it is on foot, when it is in space, to get that quality in the pass, it is impossible."

Player 1: *"I believe that having greater efficiency in the pass allows you to have greater control of the ball, more control over the opponent and in the end to be able to move them more so that the spaces are better."*

Coach 4: *"Yes, of course, the key to the attack game is mainly the pass, either in direct game or in combinational game."*

D21011: Individual offensive tactic (LSA: Lag −2, $Z = 2.15$):

Coach 3: *"The teams that are very superior at the end […] end up eliminating players for individual quality, they generate one on ones that end up solving and already the quality of the player generates qualitative superiorities. I think that's where the advantage begins."*

Player 3: *"What makes the differences is the technical and tactical quality of the players, so of course, if you have players who have a higher pass efficiency percentage, your conservation is much safer. Then your attack can be much longer if you decide, and you will be more effective."*

D2144: Refers to action space (LSA: Lag 0, $Z = 2.68$).

Coach 5: *"I think that when a player does not have the ball, what interests me is what I provoke without having the ball: how my position makes the other players, or my companions, can play better, with more time, with more space. How, for example, my extremes and my tip are able to lengthen the rival team to generate spaces to our interiors, to our mid-centers and that is done, obviously with breadth and depth. If we want to have a game of position inside, the position of the far ones in amplitude and depth is fundamental."*

Player 3: *"I think the most talented players make the difference because they do not need that space and that time: their decision making is much faster than the rest, their technical quality makes them* *not need that space because they are going to leave control here, and not there."*

D2153: Refers to the duration of the attack (LSA: Lag 0, $Z = 2.00$; Lag +1, $Z = 2.57$; Lag +2, $Z = 2.11$ – PCA: Radius = 3.75, Angle = 346°43′):

Player 3: *"I can give you the example of USA which I think is a team that feels like defending in its own field and coming out in fast attack, with short possessions […] The current world champion was USA and in the Canadian World Cup it was USA."*

Player 2: *"I think more goals are achieved in offensive transitions."*

D2161: Refers to the physical characteristics of a particular player (LSA: Lag −1, $Z = 2.55$).

Coach 1: *"In elite football, the players who make the difference are the fastest players; they are usually the ones that cause more unbalance on opponents, the most skilled players. That in women's football does not exist so much because of what we have said before: that speed does not exist, in fact, there are 3–4 very fast players and they call attention powerfully because they are very different from the others and they are the ones that make the difference."*

Coach 5: *"In the specific case of Nigeria that has a player like Oshoala that allows you this, well,… nowadays there are more and more players with more power at that level, with more capacity. For example Poland has Pajor who is another player who has a different speed than the rest and allows her team to play that way. Are there more and more styles in women's football in which we can see that the transition is decisive? I think so. Because there are more and more players of this style […] Then it depends a little on the individual characteristics of this type of player. Whether or not you have one on your team allows you to play that way or at some point opt for this game idea."*

D2182: Refers to a dynamic startup type (LSA: Lag 0, $Z = 6.39$ – PCA: Radius = 2.79, Angle = 44°03′):

Player 3: *"I understand that it is more advantageous in dynamic because there is more disorder."*

Coach 5: *"I think that after gaining possession it can be more advantageous, because after stealing possession you get the rival team to be a little more disorganized and if you attack it well it is possible that you can have more advantage in that sense."*

Player 1: *"In the end I believe that the dynamic way is the most advantageous […] Because in the end when you are inside the game the positions are not exact. If you manage to steal the ball, make an interception or appropriation to the team you steal from, it will not be well positioned defensively at that moment."*

D2191: Refers to an organized or structured defensive structuring (LSA: Lag −2, $Z = 2.97$).

Coach 3: *"Static, so to speak, gives us more time for prior organization, and dynamic does not give us time for that prior organization. In the second, we must be faster in organizing ourselves well and a key factor that is very important for me in everything dynamic, which is once again the technical execution and the decision-making capacity. That I think that in feminine football is worse and therefore I think there would be more advantage in static."*

Coach 4: *"In static you can see the options you have to attack, you can perceive them better because it is assumed that in positional attack you contemplate how the rival team is positioned and you can perceive better than perhaps in a faster attack with the disorganized rival team where you have to make the decisions in less time, because this way, it is assumed that you have more time to perceive and decide."*

D2221: Refers to the number of passes that are made in an action (LSA: Lag −2, $Z = 1.99$ – PCA: Radius = 2.93, Angle = 83°33′):

Coach 2: *"In the end the more possession you have in the rival field is better. I think that ball possession in our side of the field is sterile and there are also different studies that reaffirm it; you are not more successful for making more passes in your own side of the field but for making more passes in the opponent's field."*

Coach 3: *"Obviously giving more passes the opponent has to do other things (it has to be adjusted) and if you execute this number of passes well and you are able to turn the opponent, to build an attack passing through different areas, you take to the side to generate "there," you make the opponent close distance between its members to generate in an area,… If all that is well developed I think you can generate certain imbalances that you can then take advantage of."*

Coach 5: *"I believe that a team that bases its attack on the combinational game to perform a greater number of passes will allow it to disorganize the opponent more."*

D2242: Refers to competition format (LSA: Lag +1, $Z = 2.23$; Lag +2, $Z = 2.27$ – PCA: Radius = 2.87, Angle = 335°31′):

Coach 1: *"I think a fundamental aspect of the difference between playing a league and a championship at the end is that you are playing it in a match. So in that game you know that if you put yourself ahead on the scoreboard, you win it, you pass the elimination round and the opposing team is out therefore from that moment you seek to consolidate that put yourself ahead on the scoreboard. This is the moment to be more defensively solid, to maintain more possession of the ball, to try to maintain more possession of the ball without risking it perhaps so much and to propitiate the desperation of the rival and that this desperation of the rival propitiates you to be able to harm him in moments of imbalance. That the opposing team in that wanting to steal possession and in that anxiety for wanting to neutralize the adverse scoreboard can be disorganized and that you can waste it."*

Player 1: *"If you feel very comfortable playing the game and you advance on the scoreboard you can continue to maintain your level of play and you do not need to modify much more unless the opponent goes much more on the attack and you look much more enclosed. Then you have to change your game strategy, you will have to keep the result a little longer by giving the possession to the opponent and trying to find more balls against them. So I think that the factor of how the team is at that time is very important, of whether it is comfortable or not, and especially the minute that it is and that it is a single game, since that conditions you to have to preserve the result much more than if it were a league mode."*

D222: Refers to specific position (PCA: Radius = 4.47, Angle = 51°91′):

Coach 2: *"Many teams in the lower part had a pair of powerful and fast forwards that after stealing possession were only sought after and that they had to manage themselves."*

Player 3: *"If we think about the style of play that has USA (which is a transition team) and it really has very fast players, very strong against, I think that in that sense, at least so far many of the teams that won or that were successful teams in the female category was because they made a difference on a physical level."*

D2911: Individual offensive technique (PCA: Radius = 2.37, Radius = 61°55′):

Player 1: *"In the end successful selections are successful because they have better players, so possession is obviously better because there is a* *different technical-tactical level in those players. I believe that when you have good players and a higher tactical level, because in the end they are players who are in good teams and in good categories, and in the end that makes the team tidy up better tactically. If you have a good tactical disposition and your players are technically better, the possession will be better and you will have more guarantees that the possession will be successful."*

Player 3: *"It is clear that in the end when your players are better in the pass, technically and tactically they are better, that gives you confidence […] and your game model is going to be that."*

D2201: Refers to decision making and perception (PCA: Radius = 3.53, Angle = 48°03′):

Coach 2: *"Football is constant perception and decision making. The less space you have, the less time you have to perceive and make decisions. […] Many times we talk about taking away your space, when really what they are taking away is the time for that decision making. What does that force you to do? To "that thinking before." In such situations we always remember footballers like Xavi Hernández who was always looking everywhere before receiving the ball, so when he received it he already had many more options thought out, many more answers; that's what really gave speed to the game."*

4. Discussion

This study was carried out with the aim of detecting regularities in the offensive success in elite women's football, as well as carrying out an interrelational analysis of linked behaviors, based on in-depth interviews with professional coaches and players. Along these lines, different behaviors linked to offensive success in women's football have been found in the communicative pattern of the interviews carried out.

This study's coaches and players suggested a link between attack type (D232: Refers to a combinative attack or position play – LSA: Lag −1, $Z = 3.01$; Lag 0, $Z = 4.02$ PCA: Radius = 3.55, Angle: 75°84′) and successful possessions in women's football, such as entering the rival area or shooting on goal. In the same way, previous studies confirmed this influence. For example, Scanlan et al. (2020) found that possessions initiated by an interception were more likely to end on score-box possessions at the FIFA Women's World Cup (FWWC) 2015. Similarly, at the FWWC France 2019, possessions that started near the rival goal to advance quickly also reached the rival goal more often (Iván-Baragaño et al., 2021), confirming these findings with the link made in the communicative pattern of the interviewees between offensive transition and success in the attack (D261: Refers to the offensive transition – LSA: Lag 0, $Z = 2.28$). These findings agree with existing literature and could imply that fast attacks, specifically counterattacks, are more effective than positional attacks in women's football. In fact, activation patterns were found in indicators such as the duration of the attack (D2153: Refers to the duration of the attack – LSA: Lag 0, $Z = 2.00$; Lag +1, $Z = 2.57$; Lag +2, $Z = 2.11$ – PCA: Radius = 3.75, Angle = 346°43′) and the dynamic startup type (D2182: Refers to a dynamic startup type – LSA: Lag 0, $Z = 6.39$ – PCA: Radius = 2.79, Angle = 44°03′) which were directly linked to the playing style of the most successful women's football team as follows: "*USA is a team that feels like defending in its own field and coming out in fast attack, with short possessions […] The current world champion was USA and in the Canadian World Cup it was USA.*" In addition, the interviewees mentioned a common but often neglected aspect of football matches: set pieces (D271: Refers to set piece actions LSA: Lag 0, $Z = 3.16$; Lag 1, $Z = 2.49$ – PCA: Radius = 4.33, Angle: 28°66′). As one interviewee said, "if we talk about success, usually a team that scores in set piece is associated with success in a match." Lee and Mills (2021) showed that different variables (e.g., type of ball delivery or the number of players involved) affected the probability of completing these actions through analysis at the FWWC France 2019. Therefore, the interviewees' perceptions seem to agree with the scientific evidence.

On the other hand, responses to interviews suggested a relationship between a player's physical characteristics (D2161: Refers to the physical characteristics of a particular player LSA: Lag −1, $Z = 2.55$) and offensive success. In this line, the lack of scientific evidence does not facilitate the extrapolation of these subjective impressions to the practical field. Nevertheless, some data collected by the official FIFA report on FWWC France 2019 (FIFA, 2019c) seem to indicate that this relationship may exist taking into account that the teams that managed to reach the semi-final round were able to run more meters at high intensity and perform a greater number of sprints per match. Based on these results, we could consider that conditional training is playing (and will play) a fundamental role in the performance of teams in the most important women's football championships. In relation to the individual and collective technical elements, the results of this study (D2912: Collective offensive technique (LSA: Lag 0, $Z = 2.57$) – ACP: Radius = 2.47, Angle = 40°82′); D21011: Individual offensive tactic (LSA: Lag −2, $Z = 2.15$) seem to agree with previous results in which differences in the time of possession in the rival field were evidenced (Iván-Baragaño et al., 2022). In fact, there have been several studies that have analyzed these technical variables and, in particular, the differences between men's football and women's football (Bradley et al., 2014; Casal et al., 2021; Garnica-Caparrós and Memmert, 2021; Pappalardo et al., 2021). In this sense, it could be considered that the improvement of individual technical performance would be a condition that would increase performance and, consequently, the probability of successfully completing offensive actions in women's football.

Finally, reference is made to an aspect discussed during the interviews with the players: the speed of decision-making D2201: Refers to decision-making and perception (PCA: Radius = 3.53, Angle = 48°03′). While it is true that on this subject no research allows us to contrast these opinions strongly, we can agree that the greater the speed in decision-making, the greater the speed in the game and the easier it is to defensively mess up the rival team. In fact, this speed in the game has been compared by Pappalardo et al. (2021) between men's football and women's football, being greater in the case of male players, giving a margin for improvement in the case of women's football and allowing, following the interviewees, to increase the probability of offensive success in women's football teams.

5. Conclusion

In this study, a large number of indicators that can determine offensive success in elite women's football were suggested. Using a novel technique and not often used in the field of sport, significant associations have been found established in the communicative pattern that emerged during the in-depth interviews carried out. Specifically, success in women's football was associated with (i) the conditional characteristics of a player, (ii) offensive transition and the type of dynamic start to ball possession, (iii) set-piece actions, (iv) collective defensive intention, specifically pressure after loss, (v) collective technical performance, (vi) the number of passes, or (vii) decision-making. Many of the indicators mentioned in this study as possible performance indicators in women's football have already been studied in men's football. Despite this, it is still unknown whether the results extracted from studies carried out with a male sample can be extrapolated to the opposite sex. Therefore, the study of future researchers focused on the analysis of match performance in women's football may be oriented toward demonstrating the influence of these criteria on performance in competition.

6. Futures lines of research

In the near future, women's football researchers may propose studies that try to know the influence of the dimensions suggested in this study on success in women's football. In this sense, study aspects such as: (i) the influence of the physical performance of a player or a specific position on the success of a team or selection; (ii) the degree of offensive effectiveness achieved depending on the type of attack used; (iii) the importance of set pieces as decisive actions for the final result of the match; (iv) the degree of association between individual and collective technical-tactical performance and the degree of success achieved by a team in a match or championship; (v) the influence of the competition format on the offensive behavior of the teams; (vi) the modification of the probability of obtaining goal scoring opportunities in the possessions of the ball depending on the number of passes, the type of start, or the defensive tactical intention or; and (vii) the association between the speed of decision-making and the offensive and defensive success of a team or selection will increase the scientific corpus on this subject and, inevitably, increase the performance in matches of teams and selections in elite women's football.

On the other hand, it is seen as crucial that ongoing research expands the understanding and perspectives of specialists in women's football. In this vein, conducting research employing the Delphi Method with coaches and players from various nations might aid in advancing scientific understanding of the most crucial performance indicators in women's soccer.

Data availability statement

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

Author contributions

II-B, MTA, RM, and AA: research concept and study design. II-B, RM, JL, and MTA: literature review and writing of the manuscript—original draft preparation. II-B, MTA, and JL: conceptualization, methodology, data analysis and interpretation, and statistical analysis. MTA, RM, and JL: formal analysis, investigation, and resources. II-B, RM, and AA: data collection. II-B, AA, MTA, JL, and RM: writing—review and editing. All authors have read and agreed to the published version of the manuscript.

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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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References

Alcover, C., Mairena, M. A., Mezzatesta, M., Elias, N., Díez-Juan, M., Balañá, G., et al. (2019). Mixed methods approach to describe social interaction during a group intervention for adolescents with autism Spectrum disorders. *Front. Psychol.* 10:1158. doi: 10.3389/fpsyg.2019.01158

Alvarado, C., Armadans, I., Parada, M. J., and Anguera, M. T. (2021). Unraveling the role of shared vision and trust in constructive conflict management of family firms. An empirical study from a mixed-methods approach. *Front. Psychol.* 12:629730. doi: 10.3389/fpsyg.2021.629730

Anguera, M. T. (1979). Observational typology. *Qual. Quant. Eur. Am. J. Methodol.* 5, 449–484. doi: 10.3390/sports5010020

Anguera, M. T. (2020). "Is it possible to perform liquefying actions in conversational analysis? The detections of structures in indirect observations" in *The temporal structure of multimodal communication. Theory, methods and applications*. eds. L. Hunyadi and I. Szekrényes (Cham: Springer Publishing), 45–67.

Anguera, M. T. (2021). "De la entrevista en profundidad a la observación sistemática: Una pincelada de comunicación multimodal desde los mixed methods [From the in-depth interview to the systematic observation: a brushstroke of multimodal communication from the mixed mthods]" in *Estudios en homenaje a Emigdia Repetto Jiménez*. eds. V. M. Hernández Suárez and J. R. Suárez Robaina (Las Palmas de Gran Canaria: Universidad de Las Palmas de Gran Canaria, Servicio de Publicaciones), 31–55.

Anguera, M. T., Blanco-Villaseñor, A., Hernández Mendo, A., and Losada, J. L. (2011). Diseños observacionales: ajuste y aplicación en psicología del deporte [Observational designs: adjustment and application in sport psychology]. *Cuadernos de Psicología del Deporte* 11, 63–76.

Anguera, M. T., Blanco-Villaseñor, A., Losada, J. L., and Sánchez-Algarra, P. (2020). Integración de elementos cualitativos y cuantitativos en metodología observacional. [Integration of qualitative and quantitative elements in observational methodology].

Ámbitos Revista Internacional de Comunicación 49, 49–70. doi: 10.12795/Ámbitos.2020.i49.04

Anguera, M. T., Portell, M., Chacón-Moscoso, S., and Sanduvete-Chaves, S. (2018). Indirect observation in everyday contexts: concepts and methodological guidelines within a mixed method framework. *Front. Psychol.* 9:13. doi: 10.3389/fpsyg.2018.00013

Arias-Pujol, E., and Anguera, M. T. (2020). A mixed methods framework for psychoanalytic group therapy: from qualitative records to a quantitative approach using T-pattern, lag sequential and polar coordinate analyses. *Front. Psychol.* 11:1922. doi: 10.3389/fpsyg.2020.01922

Bakeman, R. (1978). "Untagling streams of behavior: sequential analysis of observation data" in *Observing behavior*. ed. G. P. Sackett, vol. *2* (Baltimore: University of Park Press), 63–78.

Bakeman, R., and Quera, V.. (2011). *Sequential analysis and observational methods for the behavioural sciences*. Cambridge: Cambdridge University Press.

Bradley, P. S., Dellal, A., Mohr, M., Castellano, J., and Wilkie, A. (2014). Gender differences in match performance of soccer players competing in the UEFA champions league. *Hum. Mov. Sci.* 33, 159–171. doi: 10.1016/j.humov.2013.07.024

Caprara, M., and Anguera, M. T. (2019). "Observación sistemática [Systematic observation]" in *Evaluación Psicològica. Proceso, técnicas y aplicaciones en áreas y contextos [Psychologycal evaluation. Process, techniques and applications in areas and contexts]*. eds. C. Moreno Rosset and I. M. Ramírez Uclés (Madrid: Sanz y Torres), 249–277.

Casal, C. A., Losada, J. L., Maneiro, R., and Ardá, A. (2021). Gender differences in technical-tactical behaviour of La Liga Spanish football teams. *J. Hum. Sport Exerc.* 16, 37–52. doi: 10.14198/jhse.2021.161.04

Casal, C. A., Maneiro, R., Ardá, T., Marí, F. J., and Losada, J. L. (2017). Possession zone as a performance Indicator in football. The game of the best teams. *Front. Psychol.* 8:1176. doi: 10.3389/fpsyg.2017.01176

Cohen, J. (1960). A coefficient of agreement for nominal scales. *Educ. Psychol. Meas.* 20, 37–46. doi: 10.1177/001316446002000104

De Jong, L. M. S., Gastin, P. B., Angelova, M., Bruce, L., and Dwyer, D. B. (2020). Technical determinants of success in profesional women's soccer: a wider range of variables reveals new insights. *PLoS One* 15:e0240992. doi: 10.1371/journal.pone.0240992

Del Giacco, L., Anguera, M. T., and Salcuni, S. (2020). The action of verbal and non-verbal communication in the therapeutic alliance construction: a mixed methods approach to assess the initial interactions with depressed patients. *Front. Psychol.* 11:234. doi: 10.3389/fpsyg.2020.00234

Edwards, C., Molnár, G., and Tod, D. (2021). Searching for ontological security: women's experiences leading to high drive for muscularity. *Qual. Res. Sport Exerc. Health* 14, 609–627. doi: 10.1080/2159676X.2021.1969995

FIFA. (2019a). FIFA Women's World Cup France 2019. Global Broadcast and Audience Report. Available at: https://img.fifa.com/image/upload/rvgxekduqpeo1ptbgcng.pdf

FIFA (2019b). Women's football. Member associations survey report 2019. Available at: https://img.fifa.com/image/upload/nq3ensohyxpuxovcovj0.pdf

FIFA. (2019c). Physical analysis of the FIFA Women's World Cup France 2019. Available at: https://digitalhub.fifa.com/m/4f40a98140d305e2/original/zijqly4oednqa5gffgaz-pdf.pdf

García-Fariña, A., Jiménez-Jiménez, F., and Anguera, M. T. (2018). Observation of communication by physical education teachers: detecting patterns in verbal behaviour. *Front. Psychol.* 9:334. doi: 10.3389/fpsyg.2018.00334

García-Fariña, A., Jiménez-Jiménez, F., and Anguera, M. T. (2021). Do physical education teacher use socioconstructivist communication patterns in their classes? *J. Teach. Phys. Educ.* 41, 301–310. doi: 10.1123/jtpe.2020-0213

García-Unanue, J., Fernandez-Luna, A., Burillo, P., Gallardo, L., Sanchez-Sanchez, J., Manzano-Carrasco, S., et al. (2020). Key performance indicators at FIFA Women's World Cup in different playing surfaces. *PLoS One* 15:e0241385. doi: 10.1371/journal.pone.0241385

Garnica-Caparrós, M., and Memmert, M. (2021). Understanding gender differences in professional European football through machine learning interpretability and match actions data. *Sci. Rep.* 11:10805. doi: 10.1038/s41598-021-90264-w

Hernández-Mendo, A., López, J. A., Castellano Paulis, J., Morales Sánchez, V., and Pastrana Brincones, J. L. (2012). Hoisan 1.2: programa informático para uso en metodología observacional. [Hoisan 1.2: computer program for use in observational methodology]. *Cuadernos de Psicología del Deporte* 12, 55–78. doi: 10.4321/S1578-84232000100006

Iván-Baragaño, I., Maneiro, R., Losada, J. L., and Ardá, A. (2021). Multivariate analysis of the offensive phase in high-performance Women's soccer: a mixed methods study. *Sustainability* 13:6379. doi: 10.3390/su13116379

Iván-Baragaño, I., Maneiro, R., Losada, J. L., and Ardá, A. (2022). Tactical differences between winning and losing teams in elite women's football. *Apunts Educación Física y Deportes* 147, 45–54. doi: 10.5672/apunts.2014-0983.es.(2022/1).147.05

Jackman, P. C., Schweickle, M. J., Goddard, S. G., Vella, S. A., and Swann, C. (2022). The event-focused interview: what is it, why is it useful, and how it used? *Qual. Res. Sport Exerc. Health* 14, 167–180. doi: 10.1080/2159676X.2021.1904442

Kirkendall, D. T. (2020). Evolution of soccer as research topic. *Prog. Cardiovasc. Dis.* 63, 723–729. doi: 10.1016/j.pcad.2020.06.011

Kirkendall, D. T., and Krustrup, P. (2021). Studying professional and recreational female footballers: a bibliometric exercise. *Scand. J. Med. Sci. Sports* 32, 12–26. doi: 10.1111/sms.14019

Krippendorff, K. (2018). *Content analysis. An introduction to its methodology*, *4th*. Los Angeles, CA: SAGE.

Kubayi, A., and Larkin, P. (2020). Technical performance of soccer teams according to match outcome at the 2019 FIFA Women's World Cup. *Int. J. Perform. Anal. Sport* 20, 908–916. doi: 10.1080/24748668.2020.1809320

Lago, C. (2009). The influence of match location, quality of opposition, and match status on possession strategies in professional association football. *J. Sports Sci.* 27, 1463–1469. doi: 10.1080/0264041093131681

Lago, I., Lago-Peñas, S., and Lago-Peñas, C. (2021). Waiting or acting? The gender gap in international football success. *Int. Rev. Sociol. Sport* 57, 1139–1156. doi: 10.1177/10126902211060727

Lago-Ballesteros, J., Lago-Peñas, C., and Rey, E. (2012). The effect of playing tactics and situational variables on achieving score-box possessions in a professional soccer team. *J. Sports Sci.* 30, 1455–1461. doi: 10.1080/02640414.2012.712715

Landis, J. R., and Koch, G. G. (1977). The measurement of observer agreement for categorical data source. *Biometrics* 33, 159–174. doi: 10.2307/2529310

Lapresa, D., Otero, A., Arana, J., Álvarez, I., and Anguera, M. T. (2021). Concordancia consensuada en metodología observacional: efectos del tamaño del grupo en el tiempo y la calidad del registro [Consensual agreement in observational methodology: effects of group size over time and quality of the registry]. *Cuadernos de Psicología del Deporte* 21, 47–58. doi: 10.6018/cpd.467701

Lee, J., and Mills, S. (2021). Analysis of corner kicks at the FIFA Women's World Cup 2019 in relation to match status and team quality. *Int. J. Perform. Anal. Sport* 21, 679–699. doi: 10.1080/24748668.2021.1936408

Maneiro, R., Losada, J. L., Casal, C. A., and Ardá, A. (2020). The influence of match status on ball possession in high performance women's football. *Front. Psychol.* 11:487. doi: 10.3389/fpsyg.2020.00487

Maneiro, R., Losada, J. L., Casal, C. A., and Ardá, A. (2021). Identification of explanatory variables in possession of the ball in high-performance women's football. *Int. J. Environ. Res. Public Health* 18:5922. doi: 10.3390/ijerph18115922

Nassis, G. P., Brito, J., Tomas, R., Heiner-Moller, K., Harder, P., Okholm Kryger, K., et al. (2021). Elite women's football: evolution and changes for the years ahead. *Scand. J. Med. Sci. Sports* 32, 7–11. doi: 10.1111/sms.14094

Nunes, H., Iglesias, X., Del Giacco, L., and Anguera, M. T. (2022). The pick and roll in basketball from deep interviews of elite coaches: a mixed method approach from polar coordinate analysis. *Front. Psychol.* 13:801100. doi: 10.3389/fpsyg.2022.801100

Okholm Kryger, K., Wang, A., Mehta, R., Impellizeri, F. M., Massey, A., and McCall, A. (2021). Research on women's football: a scoping review. *Sci. Med. Football* 6, 549–558. doi: 10.1080/24733938.2020.1868560

Pappalardo, L., Rossi, A., Natilli, M., and Cintia, P. (2021). Explaining the difference between men's and women's football. *PLoS One* 16:e0255407. doi: 10.1371/journal.pone.0255407

Preciado, M., Anguera, M. T., Olarte, M., and Lapresa, D. (2019). Observational studies in male elite football: a systematic mixed study review. *Front. Psychol.* 10:2077. doi: 10.3389/fpsyg.2019.02077

Sarmento, H., Anguera, M. T., Pereira, A., Marques, A., Campaniço, J., and Leitao, J. (2014). Patterns of play in the counterattack of elite football teams – a mixed method approach. *Int. J. Perform. Anal. Sport* 14, 411–427. doi: 10.1080/24748668.2014.11868731

Sarmento, H., Clemente, F. M., Gonçalves, E., Harper, L. D., Dias, D., and Figueiredo, A. (2020). Analysis of the offensive process of AS Monaco profesional soccer team: a mixed-method approach. *Chaos Solutions Fractals* 133:109676. doi: 10.1016/j.chaos.2020.109676

Sarmento, H., Figueiredo, A., Lago-Peñas, C., Milanovic, Z., Barbosa, A., Tadeu, P., et al. (2018). Influence of tactical and situational variables on offensive sequences during elite football matches. *J. Strength Cond. Res.* 32, 2331–2339. doi: 10.1519/JSC.0000000000002147

Scanlan, M., Harms, C., Cochrane Wilkie, J., and Maayah, F. (2020). The creation of goal scoring opportunities at the 2015 women's world cup. *Int. J. Sports Sci. Coachig* 15, 803–808. doi: 10.1177/17447954120942051

Solstad, B. E., Granerud, M., Haraldsen, H. M., Gustafsson, H., and Knight, C. J. (2021). An exploration of reciprocity between female athletes and their coach in elite junior swimming: a shared reality theory perspective. *Qual. Res. Sport Exerc. Health* 14, 545–563. doi: 10.1080/2159676X.2021.1941211

Soto-Fernández, A., Camerino, O., Iglesias, X., Anguera, M. T., and Castañer, M. (2021). LINCE PLUS software for systematic observational studies in sports and health. *Behav. Res. Methods* 54, 1263–1271. doi: 10.3758/s13428-021-01642-1

Tenga, A., Holme, I., Ronglan, L. T., and Bahr, R. (2010). Effect of playing tactics on goal scoring in Norwegian professional soccer. *J. Sports Sci.* 28, 237–244. doi: 10.1080/02640410903502774

Venturella, M., Carbonell, X., Cabré, V., and Arias-Pujol, E. (2019). A psychoanalytical perspective on the co-therapeutic relationship with a group of siblings of children with autism: an observational study of communicative behavior patterns. *Front. Psychol.* 10:1832. doi: 10.3389/fpsyg.2019.01832

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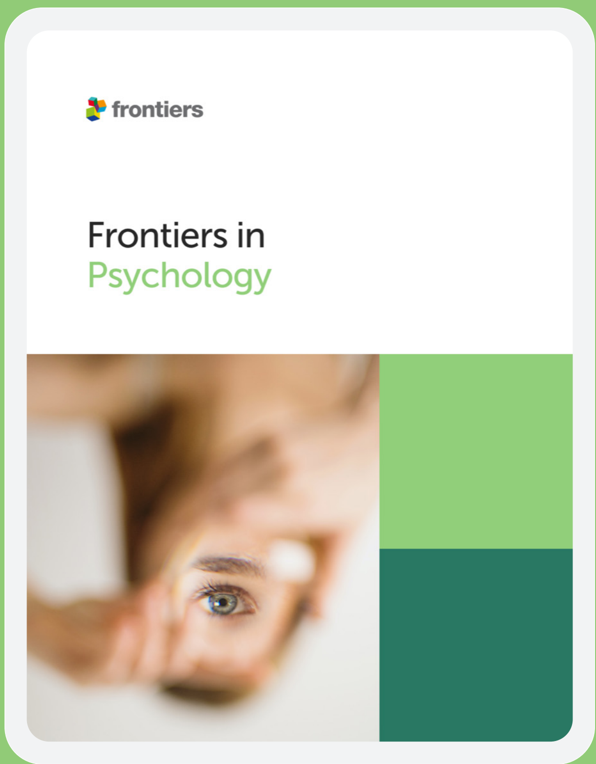

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