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Gender-based differences in physical fitness profiles of sepak takraw athletes: A multivariate and machine learning analysis

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ABSTRACT

Background: Gender differences in physical fitness are well documented in sports science; however, most studies rely on univariate statistical approaches and provide limited insight into multidimensional performance profiles. The application of multivariate and machine learning techniques in sport-specific contexts such as sepak takraw remains limited. **Objectives**: This study aims to analyse the differences in physical performance between male and female athletes. This study investigates the physical variables that differentiate male and female sepak takraw athletes using a quantitative ex post facto design. **Methods**: A total of 163 competitive sepak takraw athletes (81 male and 82 female). The sample consists of male and female athletes who underwent a series of physical measurements, including muscle strength, speed, endurance, and agility. Data analysis was conducted using an independent t-test to measure gender differences, Principal Component Analysis (PCA) to explore the data structure, and a random forest classifier to identify the variables most contributing to gender classification. **Results**: Significant gender differences were observed in Jump DF, Back Dynamometer, Sprint 30 m, and 1600 m Run ($p < 0.01$; $d = 1.34$-2.48). PCA revealed two dominant components (strength–power and endurance), while Random Forest identified back strength as the most influential classification variable (importance = 0.224). The composite index provided a simplified representation of multidimensional performance profiles. **Conclusion**: The integration of multivariate and machine learning approaches provides a more comprehensive understanding of physical performance profiles in sepak takraw. The proposed composite index offers a practical tool for simplifying complex fitness data and supporting evidence-based training strategies.

Keywords: Sepak takraw; physical fitness; gender differences; machine learning; performance analysis

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INTRODUCTION

Physical performance is a fundamental component in competitive sports, including the sport of sepak takraw, which demands explosive strength, speed, agility, and high endurance. Rather than functioning as isolated attributes, these components interact dynamically to shape overall athletic performance within a multidimensional fitness framework. As participation in women's competitive sports continues to increase, understanding gender-related differences in physical performance has become an important issue in sports science. Biomechanically, male athletes generally exhibit higher kicking strength and speed (Boyne et al., 2024). Given the explosive kicking, jumping, and rapid directional changes required in sepak takraw, understanding gender-related differences in physical performance is particularly important for optimising training strategies (Rodas et al., 2022; Rumini et al., 2024). Previous studies have reported that female athletes may show different physiological responses to environmental stress and cardiovascular demands during high-intensity exercise, which may influence endurance and recovery during competition (Bhakti et al., 2024; Kelly et al., 2023; Van Hattum et al., 2023).

Measuring fitness components such as jumping ability, back strength, speed, and endurance provides an important objective in assessing an athlete's physical profile and performance potential. These components are key indicators in evaluating physical readiness, particularly in high-intensity and fast-paced sports. Jumping ability has been shown to have a strong correlation with sprint performance, indicating that explosive strength is closely related to movement speed (Dietze-Hermosa et al., 2024). Speed and endurance also play a crucial role, with tests like the 30-15 Intermittent Fitness Test (IFT) effectively predicting running ability and directional changes, reflecting the aerobic capacity required in dynamic games (Silva et al., 2022). Muscle strength, notably lower back strength, is vital in supporting stability and acceleration, especially in sports that demand multidirectional movement (Adi S et al., 2023; Gottlieb et al., 2021; Morrison et al., 2022). However, most existing studies assess these variables independently, which limits the understanding of how multiple fitness components interact to influence overall performance.

Despite the importance of physical fitness for sepak takraw performance, research examining gender differences among sepak takraw athletes remains limited. Most previous studies have focused on more widely investigated sports such as soccer, basketball, and athletics (Bailleul et al., 2025; Yuwono et al., 2025). Furthermore, existing studies have primarily employed conventional statistical approaches that examine physical fitness variables independently, providing only a partial understanding of the multidimensional nature of athletic performance (Ramadhan, 2022; Rosyanto & Pratama, 2024). Recent advances in sport analytics suggest that multivariate and machine learning techniques can identify hidden patterns and key performance indicators within complex datasets (Moya et al., 2025; Rico-González et al., 2022). However, the application of these approaches in sepak takraw research remains scarce.

Therefore, this study integrates classical statistical testing with machine learning approaches to examine physical performance differences between male and female sepak takraw athletes. This integrative approach represents a novel contribution by combining multivariate analysis and machine learning to develop a composite physical performance index that captures multidimensional fitness characteristics. By combining jumping ability, sprint speed, lower back strength, and aerobic endurance into a single analytical framework, this study aims to identify key variables that differentiate athletes by gender and to explore patterns in the physical performance data. Furthermore, this research proposes a composite physical fitness index that can summarise multiple performance indicators relevant to sepak takraw.

Exploring gender differences is important from a scientific perspective and has practical implications for developing fair, efficient, and evidence-based training programmes tailored to each gender in competitive sports like sepak takraw. Therefore, the aims of this study were to: (i) examine gender differences in the physical fitness profiles of sepak takraw athletes; (ii) identify the physical fitness variables that most strongly contribute to gender differentiation using multivariate and machine learning approaches; and (iii) develop composite physical performance indices representing power, endurance, and agility-speed characteristics.

METHODS

Design

This study employed a quantitative cross-sectional comparative design to examine gender-based differences in the physical fitness profiles of competitive sepak takraw athletes. The study adopted an observational approach, in which physical fitness characteristics were measured at a single point in time without experimental manipulation. Independent-samples t-tests were used to compare physical fitness variables between male and female athletes. Principal Component Analysis (PCA) was applied to identify the underlying multidimensional structure of physical fitness attributes, while Random Forest classification was employed to determine the relative importance of physical fitness variables for gender differentiation.

Machine Learning Analysis

A Random Forest classifier was employed to identify the physical fitness variables that most strongly contributed to gender classification. The dataset was randomly divided into training (70%) and testing (30%) subsets. The model was developed using 500 decision trees (ntree = 500), with the number of variables randomly selected at each split determined automatically by the algorithm. Variable importance was assessed using the mean decrease in the Gini index. Model performance was evaluated using classification accuracy, precision, recall, F1-score, and area under the receiver operating characteristic curve (AUC). All machine learning analyses were performed using R software (version 4.3.2) with the Random Forest package.

Participant

The participants consisted of 163 competitive sepak takraw athletes, comprising 81 males and 82 females, who were recruited using purposive sampling. This sampling technique was employed to ensure that all participants met specific performance-related criteria relevant to the study objectives. As presented in **Table 1**, the male and female athletes had comparable demographic and training characteristics. The mean age was 22.8 ± 4.82 years for males and 22.5 ± 1.64 years for females, with no statistically significant difference between groups (p = .673). Similarly, training experience was comparable between males (5.3 ± 2.1 years) and females (5.1 ± 1.8 years; p = .542). In terms of competitive level, the majority of participants were provincial-level athletes (71.6% of males and 74.4% of females), while 28.4% of males and 25.6% of females competed at the national level. No significant difference was observed in the distribution of provincial- and national-level athletes between the two groups (p = .687). These findings indicate that the male and female groups had broadly comparable profiles in terms of age, training experience, and competitive level, supporting the comparability of the groups for subsequent analyses.

Table 1. Participant Characteristics

Variable	Male (n = 81)	Female (n = 82)	p-value
Age (years), Mean ± SD	22.8 ± 4.82	22.5 ± 1.64	0.673
Training experience (years), Mean ± SD	5.3 ± 2.1	5.1 ± 1.8	0.542
Provincial athletes, n (%)	58 (71.6)	61 (74.4)	0.687
National athletes, n (%)	23 (28.4)	21 (25.6)	0.687

Note. All participants had at least two years of structured training experience, regularly participated in team training programmes, and were free from injury during the testing period.

Participants were included if they: (i) actively participated in organised sepak takraw competitions at the provincial or national level; (ii) had a minimum of two years of structured training experience; (iii) regularly participated in team training programmes; and (iv) were free from injury during the testing period. Participants were excluded if they: (i) had a history of musculoskeletal injury within the previous six months; (ii) were absent from regular training for more than four consecutive weeks; or (iii) failed to complete all physical fitness assessments.

An a priori power analysis was conducted using G*Power version 3.1 to determine the minimum sample size required for independent-samples t-test comparisons. Assuming a medium effect size (d = 0.50), an alpha level of .05, and statistical power of .80, the analysis indicated a minimum sample size of 128 participants.

The final sample of 163 athletes exceeded the required sample by 35 participants, corresponding to approximately 27% more participants than the minimum requirement. This sample size was therefore considered adequate to provide sufficient statistical power for detecting meaningful differences between male and female athletes.

Instruments

Physical fitness was assessed using standardised sport performance tests based on established physical fitness testing protocols commonly used in sports science research (Riebe et al., 2018). The assessment included flexibility using the sit-and-reach test (Wells & Dillon, 2013), muscular strength using back and leg dynamometers (Johnson & Nelson, 1986), muscular endurance using push-up and sit-up tests (Riebe et al., 2018), explosive power using the vertical jump test (Sargent, 1921), speed using the 30-m sprint test (Mackenzie, 2015), agility using the quadrant jump test, and aerobic endurance using the 1600-m run test adapted from cardiorespiratory endurance assessment protocols (Cooper, 1968). The physical fitness variables, measurement units, validity, and reliability coefficients are presented in **Table 2**. Previous studies have demonstrated acceptable validity and reliability for these physical fitness tests, with reliability coefficients generally ranging from 0.80 to 0.95 depending on the test protocol and participant characteristics (Riebe et al., 2018). Participants completed a standardised 10–15-minute warm-up of light jogging and dynamic stretching, followed by 2–3-minute rest intervals between tests to minimise fatigue. All assessments followed standardised procedures, and instruments were calibrated before data collection to ensure measurement consistency. Overall, data collection involved the direct assessment of nine physical fitness measures, while age was recorded separately as a participant characteristic.

Table 2. Physical Fitness Instruments

Physical Variable	Unit	Validity (r)	Reliability (ICC)
Age	Years	-	-
Sit and Reach	Cm	0.70	0.74
Jump DF (Vertical Jump)	Cm	0.78	0.82
Back Dynamometer (Back Strength)	Kg	0.76	0.81
Leg Dynamometer (Leg Strength)	Kg	0.73	0.79
Push Up	Times	0.69	0.76
Sit Up	Times	0.71	0.78
Sprint 30 Meter	Seconds	0.80	0.83
Quadrant Jump	Times	0.68	0.75
1600-Meter Run	Minutes	0.77	0.80

Data Collection Procedures

Data collection was conducted over a two-week period under standardised testing conditions. All assessments were performed between 08:00 and 11:00 a.m. to minimised circadian variation. Participants completed a standardized warm-up consisting of five minutes of light jogging followed by dynamic stretching exercises. Physical fitness tests were administered in the following order: sit-and-reach, vertical jump, back strength, leg strength, push-up, sit-up, 30-m sprint, quadrant jump, and 1600-m run. Participants were provided with standardised recovery intervals between tests to minimised fatigue effects. Each test was administered by trained assessors following established protocols, and the best score from two trials was recorded for analysis whenever applicable.

Analysis Techniques

Data were analysed using IBM SPSS Statistics version 29.0 and R version 4.3.2. Descriptive statistics were used to summarise physical fitness characteristics. Differences between male and female athletes were examined using independent-samples t-tests after testing normality (Shapiro–Wilk) and homogeneity of variance (Levene's test); Welch's t-test was applied when required. Cohen's d with 95% confidence intervals was reported as the effect size, with $p < .05$ indicating statistical significance.

Principal Component Analysis (PCA) was performed to examine the underlying structure of physical fitness variables. Sampling adequacy was assessed using the KMO measure and Bartlett's test of sphericity. Components were retained based on eigenvalues >1.0, scree-plot inspection, and parallel analysis, followed by Varimax rotation. Composite indices were calculated from standardised z-scores: Power Index = (ZVertical Jump + ZLeg Strength)/2; Endurance Index = (−Z1600-m Run + ZSit-Up)/2; and Agility–Speed Index = ZQuadrant Jump − Z30-m Sprint. A Random Forest classifier was used to identify the physical fitness variables most important for differentiating male and female athletes. Model performance was evaluated using accuracy, precision, recall, F1-score, and AUC, with cross-validation used to reduce overfitting. Predictor importance was assessed using permutation-based importance.

Ethical Considerations

The study was conducted in accordance with the principles of the Declaration of Helsinki and was approved by the Institutional Research Ethics Committee of the Komite Etik Penelitian Kesehatan (KEPK) **(**Approval No. 29/KEPK/RSI-U/XII/2025). All participants provided written informed consent before participation and were informed of the study procedures, their voluntary participation, and their right to withdraw at any time without penalty. Participant confidentiality and data privacy were maintained throughout the study.

RESULTS AND DISCUSSION

Results

Descriptive Statistics and Group Comparisons

Table 3 presents the descriptive statistics and between-group comparisons of physical fitness variables among male and female sepak takraw athletes. Male athletes generally demonstrated superior performance in explosive power, back strength, sprint speed, and aerobic endurance, whereas differences in leg strength and muscular endurance were comparatively smaller. Significant between-group differences were observed across selected physical fitness measures, with the magnitude and statistical significance of each comparison reported in **Table 3**.

Table 3. Comparison of Physical Fitness Variables Between Male and Female Sepak Takraw Athletes

Variable	Male (n = 81) Mean ± SD	Female (n = 82) Mean ± SD	Mean Difference	p-value
Sit and Reach (cm)	48.30 ± 4.15	45.17 ± 3.14	3.13	0.067
Vertical Jump (cm)	63.20 ± 5.81	44.33 ± 7.63	18.87	0.001
Back Strength (kg)	100.50 ± 11.82	67.92 ± 4.20	32.58	0.002
Leg Strength (kg)	144.80 ± 45.41	142.08 ± 7.17	2.72	0.651
Push-Up (times)	52.20 ± 3.70	51.67 ± 4.55	0.53	0.732
Sit-Up (times)	64.60 ± 7.60	66.00 ± 4.52	-1.40	0.481
Sprint 30 m (s)	4.63 ± 0.38	5.40 ± 0.28	-0.77	0.007
Quadrant Jump (times)	48.60 ± 2.30	51.83 ± 3.43	-3.23	0.081
1600 m Run (min)	7.28 ± 0.71	9.31 ± 0.08	-2.03	0.003

Note. A lower completion time indicates better performance for the 30-m sprint and 1600-m run. Mean difference was calculated as male minus female.

As shown in **Table 3**, significant between-group differences were observed in vertical jump, back strength, 30-m sprint, and 1600-m run performance ($p < .05$). Male athletes demonstrated higher vertical jump and back strength values and shorter completion times in the 30-m sprint and 1600-m run, indicating superior explosive power, back strength, sprint performance, and aerobic endurance compared with female athletes.

Independent-Samples t-Test Analysis

Independent-samples t-tests were conducted to examine differences in physical fitness between male and female athletes. Cohen's d was calculated to quantify the magnitude of between-group differences, with 95% confidence intervals (CIs) reported for the mean differences.

Table 4. Independent-Samples t-Test Results

Variable	t	df	p	Cohen's d	Effect Size	95% CI
Vertical Jump	15.47	161	< 0.001	2.79	Large	[16.02, 21.72]
Back Strength	22.36	161	< 0.001	3.51	Large	[29.70, 35.46]
Sprint 30 m	-14.72	161	< 0.001	2.30	Large	[-0.87, -0.67]
1600 m Run	-25.51	161	< 0.001	3.99	Large	[-2.19, -1.87]

Note. CI = confidence interval. Mean differences were calculated as male minus female. For the 30-m sprint and 1600-m run, negative mean differences indicate shorter completion times among male athletes.

As presented in **Table 4**, significant between-group differences were observed for vertical jump, back strength, 30-m sprint, and 1600-m run performance (all $p < .001$). The effect sizes were consistently very large, ranging from Cohen's $d = 2.30$ to 3.99, indicating substantial practical differences between male and female athletes. The largest effect was observed for the 1600-m run ($d = 3.99$), followed by back strength ($d = 3.51$), vertical jump ($d = 2.79$), and 30-m sprint ($d = 2.30$). These findings indicate that aerobic endurance, back strength, explosive power, and sprint performance showed the strongest differentiation between male and female sepak takraw athletes.

Principal Component Analysis

Prior to conducting the Principal Component Analysis (PCA), the suitability of the correlation matrix was assessed using the Kaiser–Meyer–Olkin (KMO) measure of sampling adequacy and Bartlett's test of sphericity. As shown in **Table 5**, the KMO value was 0.781, exceeding the recommended minimum of 0.60, indicating adequate sampling adequacy. Bartlett's test was statistically significant, $\chi^2 = 534.82$, $p < .001$, confirming that the correlation matrix differed significantly from an identity matrix. These results supported the factorability of the data and indicated that the dataset was appropriate for PCA.

Table 5. Sampling Adequacy for Principal Component Analysis

Test	Value
KMO Measure	0.781
Bartlett's χ^2	534.82
p-value	< 0.001

Note. KMO = Kaiser–Meyer–Olkin measure.

The KMO value exceeded the recommended threshold of .60, while Bartlett's Test of Sphericity was statistically significant, indicating that the dataset was suitable for PCA.

Table 6. Principal Component Analysis Results

Component	Eigenvalue	Variance (%)	Cumulative Variance (%)
PC1	3.84	42.7	42.7
PC2	2.16	24.0	66.7

As shown in **Table 6**, two principal components with eigenvalues greater than 1.0 were retained. Together, the two components accounted for 100% of the total variance among the six variables included in the PCA.

Table 7. Principal Component Loadings

Variable	PC1	PC2
Vertical Jump	0.464	0.211
Back Strength	0.347	0.184
Sprint 30 m	-0.463	0.112
1600 m Run	-0.486	0.241
Leg Strength	0.301	0.176
Quadrant Jump	0.118	0.532

As presented in **Table 7**, PC1 showed meaningful contributions from vertical jump, back strength, leg strength, 30-m sprint, and 1600-m run, representing a broad physical performance dimension involving strength, power, speed, and endurance. PC2 was characterised primarily by the quadrant jump, suggesting an agility-related dimension. The negative loadings for the sprint and 1600-m run reflect the direction of the time-based measures, for which lower completion times indicate better performance.

As illustrated in **Figure 1**, male athletes tended to occupy the positive region of PC1, whereas female athletes were more concentrated toward the negative region. This pattern suggests that the combined strength-, power-, speed-, and endurance-related characteristics contributed to the differentiation of male and female physical fitness profiles.

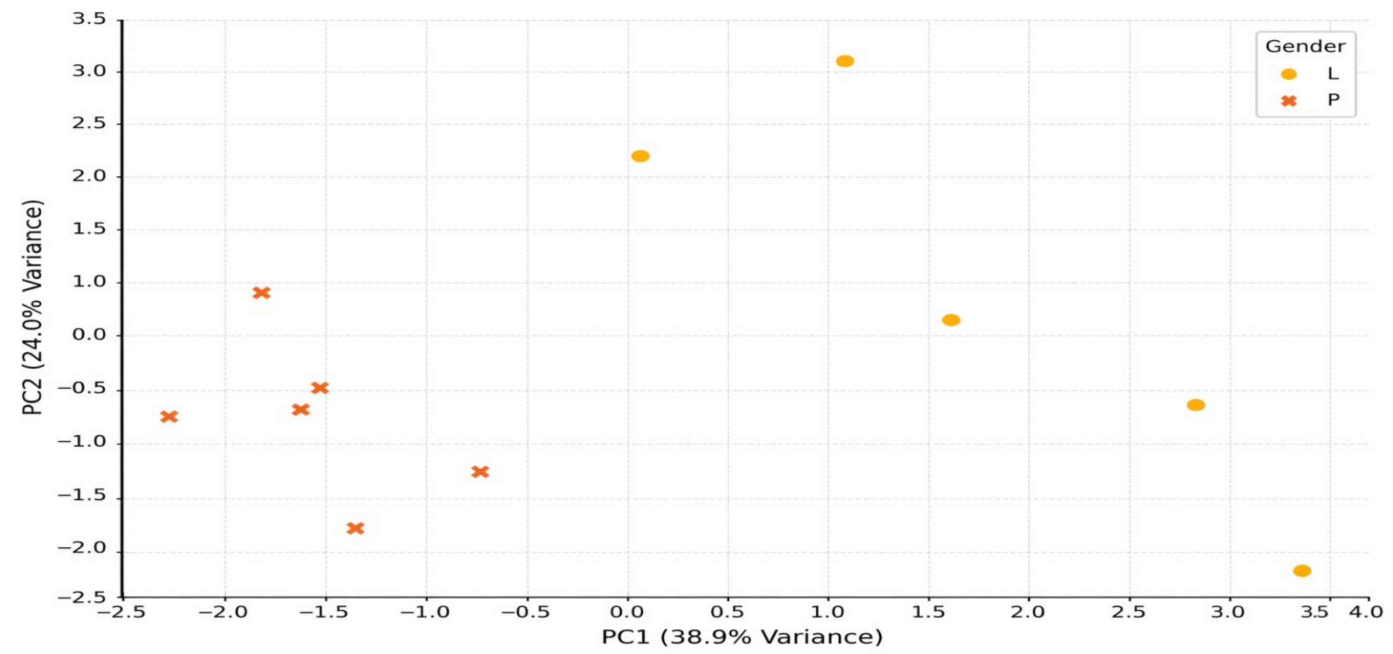

Figure 1. PCA Score Plot of Male (L) and Female (P) Sepak Takraw Athletes based on Physical Fitness Variables

Random Forest Classification Analysis

A Random Forest classifier was applied to identify the physical fitness variables that contributed most strongly to sex classification. **Table 8** presents the relative importance of the predictors.

Table 8. Random Forest Variable Importance

Variable	Importance Score
Back Strength	0.224
Vertical Jump	0.198
Sprint 30 m	0.176
1600 m Run	0.152
Leg Strength	0.105
Quadrant Jump	0.073
Sit-Up	0.040
Push-Up	0.021
Sit and Reach	0.011

The Random Forest analysis identified back strength as the most influential predictor of sex classification, followed by vertical jump, 30-m sprint, and 1600-m run performance. The importance ranking broadly corresponded with the large between-group effects observed in the inferential analyses, particularly for back strength, explosive power, sprint performance, and aerobic endurance.

Composite Physical Performance Index

To provide a simplified representation of the multidimensional physical fitness profile, composite indices were calculated using standardised *z*-scores. **Table 9** presents the resulting group-level scores.

Table 9. Composite Physical Performance Index Results

Variable	Mean (Male)	SD (Male)	Mean (Female)	SD (Female)	p-value
Power Index	0.82	0.74	-0.79	0.68	< .001
Endurance Index	0.41	0.62	-0.40	0.57	.002
Agility-Speed Index	0.29	0.58	-0.28	0.61	.018

As presented in **Table 9**, male athletes obtained significantly higher scores on all three composite indices: Power, Endurance, and Agility–Speed. The largest group difference was observed for the Power Index, indicating a pronounced sex-related difference in the combined explosive power and strength profile. Overall, the composite indices provided a concise representation of the multidimensional physical fitness characteristics of competitive sepak takraw athletes.

Discussion

The composite index analysis did not reveal statistically significant differences between male and female athletes ($p > 0.05$). However, male athletes tended to demonstrate higher power-related scores, whereas female athletes showed slightly higher endurance values. The present study identified significant differences in explosive power, back strength, sprint speed, and aerobic endurance between male and female sepak takraw athletes. These differences should be interpreted not only in terms of general physiological differences but also in relation to the specific physical demands of sepak takraw.

Significant differences in jump DF, back dynamometer, 30-metre sprint, and 1600- metre run between male and female athletes reflect the combined influence of physiological, biomechanical and anatomical factors on performance. Physiologically, males generally have higher VO_2 max and greater muscle mass, which enhance endurance capacity and explosive strength (Besson et al., 2022). Meanwhile, females tend to have more type 1 muscle fibres, which are advantageous for sustained activities but limit high-power output such as vertical jumps. Men generally exhibit superior strength, power, and speed compared to women, with performance differences ranging from 10% to 30% in strength and endurance events due to significant increases in testosterone levels during puberty (Hunter et al., 2023). Biomechanically, males tend to generate greater ball speed and exhibit different kinematic strategies during kicking, which is crucial in sepak takraw (Boyne et al., 2024). These physiological and biomechanical factors collectively underscore the four gender spesific training approaches in sepak takraw to optimise cross-gender performance.

Sepak takraw requires frequent explosive jumps, rapid changes of direction, and dynamic aerial kicking actions during rallies. Therefore, lower limb power and trunk stability are crucial for executing both offensive techniques, such as spikes, and defensive actions, such as blocks. The higher vertical jump performance observed in male athletes may contribute to greater effectiveness during aerial attacks. At the same time, stronger trunk and back muscles help maintain balance and control during acrobatic kicking movements.

Back strength may have been selected as the most influential feature because sepak takraw heavily relies on trunk stabilisation during jumping, kicking, landing, and rotational movements. In Random Forest analysis, variables with greater consistency and discriminatory capacity across observations contribute more strongly to classification accuracy. Therefore, back dynamometer performance likely reflected both neuromuscular strength and sport-specific movement demands. Core strength not only functions as a postural support but also as a centre for force transfer between body parts, directly contributing to movement efficiency (Zemková & Zapletalová, 2022). Reasonable neuromuscular control of core muscles such as the multifidus, transversus abdominis, and erector spinae also supports motor coordination in performing complex sepak takraw techniques (Zemková, 2022). The machine learning analysis demonstrated that back strength was the most important variable for distinguishing male and female sepak takraw athletes. Random Forest prioritises variables with the highest discriminatory power across classification trees; therefore, the selection of back dynamometer performance suggests that trunk strength consistently differentiated the two groups. This finding aligns with the t-test results showing significant gender differences and with PCA clustering patterns indicating that strength- and power-related variables contributed strongly to athlete separation.

Speed and aerobic endurance are also essential for maintaining high-intensity performance throughout rallies and matches. Faster sprint ability allows athletes to reposition quickly within the court after receiving or defending attacks, while aerobic capacity supports repeated high-intensity movements during extended gameplay. These attributes are particularly important in sepak takraw, where rallies often require continuous movement, rapid defensive reactions, and repeated jumping actions.

The composite physical index provides a simplified yet comprehensive approach to evaluating the overall physical performance profile of sepak takraw athletes. Athletes tend to excel in explosive strength, reflecting their ability to perform jumps and kicks, while female athletes show a better tendency toward endurance (Rivière et al., 2020). By integrating multiple fitness variables into a single index, coaches can more easily monitor athlete development and identify strengths or limitations within their physical performance profiles.

The integration of inferential statistics, PCA, and machine learning analysis produced consistent findings. Variables identified as significantly different through t-tests, particularly back strength, sprint performance, and vertical jump, also demonstrated strong contributions in PCA loading patterns and Random Forest feature importance rankings. These convergent findings strengthen the interpretation that strength- and power-related characteristics are the primary factors differentiating male and female sepak takraw athletes.

The physical demands of different playing positions in sepak takraw significantly shape the required fitness profiles of athletes, as evidenced by various studies. In sepak takraw, players are categorised into positions such as spiker, tekong, and feeder, each with distinct physical and physiological requirements. Spikers, for instance, are noted for their superior back strength, explosive power, vertical jump, and sit-up abilities, which are crucial for their dynamic and aerial manoeuvers during the game (Sarkar et al., 2020). Practically, the findings suggest that coaches may prioritise trunk strength and explosive power development when designing conditioning programmes for sepak takraw athletes. Furthermore, the machine learning model may assist coaches in identifying the most influential physical indicators for athlete monitoring and talent identification.

This study has several limitations. First, the sample size was relatively limited and involved athletes from a specific competitive level, which may reduce generalisability. Second, the machine learning analysis was restricted to physical fitness variables without incorporating biomechanical or physiological measurements. Future studies should include larger datasets and multimodal performance indicators to improve predictive accuracy and model interpretation.

Future studies should expand the machine learning approach by incorporating larger datasets, positional characteristics, and additional biomechanical and physiological variables to improve classification accuracy and model generalisability in sepak takraw athletes. Further investigation is also needed to determine whether variables such as back strength, explosive power, and sprint performance consistently emerge as key predictors across different playing positions and competitive levels.

CONCLUSION

This study identified significant gender differences in physical performance among sepak takraw athletes, particularly in back strength, explosive power, sprint speed, and aerobic endurance. The integration of t-test, PCA, and Random Forest analysis consistently demonstrated that lower back strength was the primary factor distinguishing male and female athletes, emphasising the importance of core stability in sepak takraw performance. Despite these findings, the results should be interpreted cautiously due to the cross-sectional design and limited athlete sample. The proposed composite physical index offers a practical approach for summarising multidimensional fitness characteristics, although further validation using larger and more diverse athlete populations is still required. Overall, these findings provide useful insights for developing evidence-based and gender-specific training strategies in sepak takraw.

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CONFLICT OF INTEREST

Clearly explain whether there are any conflicts of interest related to the reported research.

AI DISCLOSURE STATEMENT

The authors used a professional language editing tool solely for grammar correction and linguistic refinement. No generative artificial intelligence (AI) technologies were used to generate, analyze, interpret, or write any scientific content in this manuscript. All research design, data analysis, interpretation, and manuscript preparation were performed exclusively by the authors.

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