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Construction of a physical fitness evaluation index system for excellent female Sanda athletes

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ABSTRACT In this paper, primary, secondary and tertiary indicators are used to construct a physical fitness evaluation system for outstanding female Sanda athletes across three different weight categories: 48-52 kg, 56-65 kg, and 70-75 kg. The data are processed using box plot and standard deviation methods, and an evaluation model is developed by combining the analytic hierarchy process (AHP) with the entropy weight method. Finally, cluster analysis is applied for empirical evaluation. The study findings are as follows: (1) In the evaluation system, the highest-weighted indicators for the lightest category are general agility and specialized speed; for the middle category, specialized speed and 30-second leg raise; and for the heaviest category, 30-second leg raise and lower limb strength. (2) Lower-weight elite female kickboxers excel in speed; higher-weight elite female kickboxers excel in strength; and mid-weight elite female kickboxers excel in both. These indicators, along with a professional analysis of outstanding female Sanda athletes, are beneficial for coaches and athletes to design personalized training programs and competition tactics for fully exploring athletes' potential and enhancing their performances in competitions at different levels.

KEYWORDS: Evaluation indicator system; Box plot method; Standard deviation method; Combined weighting method; Hierarchical clustering method
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Original Article

INTRODUCTION

Physical fitness has always been an indispensable aspect of Sanda (Chinese kickboxing), and research findings (Wang, 2013) indicate that physical fitness accounts for as much as 27% of the entire training phase for Sanda athletes, surpassing the proportions for 'actual combat training' and 'rest'. This highlights the importance of systematic and scientific training in physical fitness, which warrants attention from both coaches and athletes. In fact, since the pilot program in 1979, Sanda training plans have significantly emphasized physical fitness, yet improvements in these plans have been modest, primarily due to mechanistic training approaches, low scientific rigor, and a lack of training equipment. To enhance athletes' physical fitness, the General Administration of Sport of China has introduced the 'National Team Physical Fitness Standards and Evaluation Criteria', aiming to scientifically enhance physical fitness. Subsequent implementations in athlete training have yielded some results, but not significantly. Moreover, inappropriate training methods and unscientific training plans have led to muscle tears, joint wear, and other injuries among some athletes, severely impacting their health and career development. Such situations fail to foster breakthroughs in athletes' performances and may lead to early retirement. This is primarily due to the lack of scientifically effective physical fitness training and guidance in practice, highlighting the urgent need for research on athletes' physical fitness characteristics from both theoretical and practical perspectives to provide theoretical support for the healthy, orderly, and scientific evaluation of Sanda players.

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International research on physical fitness evaluation is extensive, initially focusing on physical fitness, core strength, and other indicators, such as muscle strength, flexibility, body composition, and oxygen consumption (Schwartz *et al*., 2015). This research emphasizes new techniques and methods, analyzing physical fitness characteristics considering individual indicators to assist coaches in athlete selection and training. For instance, some researchers have compared new resistance training with traditional strength training, finding that new methods effectively enhance upper limb strength (Daniel *et al*., 2009). Additionally, balance studies on skateboarders have established relationships between physical activity, physical fitness, and balance, aiding in athlete training and balance improvement (Jeon & Eom, 2021). Domestic research on Sanda athletes' physical fitness evaluation is also abundant and covers topics such as indicator selection, evaluation methods, and empirical studies. For the indicator selection, general physical fitness indicators include 50 m sprint, bench press, squat, 9-minute run endurance (Ye, 2014), while specialized indicators include 1 minute punching, 20 second punching, 1 minute leg whipping, 10 second leg whipping (Yu, 2005; Song, 2018). For combative sports such as Sanda, general physical fitness indicators include speed, strength, endurance, flexibility, and agility (Huo & Wang, 2017), while specialized indicators are based on the characteristics of the sport (Zhou & Han, 2015; Song, 2018). Traditional evaluation methods such as literature reviews and expert interviews are commonly used to evaluate these indicators, with recent scholars incorporating new methods such as fuzzy comprehensive evaluation (Cao *et al*., 2018) and factor analysis (You *et al*., 2019), each with its own strengths and weaknesses, to be chosen based on specific research and data. Researchers have focused primarily on outstanding male Sanda athletes. However, according to the Olympic Charter, a sport must include both male and female categories to be considered for the Olympics. This requires paying increased attention to female Sanda athletes, updating research indicators, introducing new methods, and conducting physical fitness evaluations across different weight categories.

In this study, 96 athletes (including master athletes, first-level athletes, second-level athletes, etc.) were selected across three different weight categories: 48-52 kg, 56-65 kg, and 70-75 kg. A physical fitness evaluation system was constructed for outstanding female Sanda athletes considering aspects of speed, strength, endurance, flexibility, and agility (Long, 2021). Box plot and standard deviation methods were used for data processing, the analytic hierarchy process (AHP) was combined with the entropy weight method for model construction, and the system was empirically evaluated via cluster analysis to provide recommendations for improvement.

METHODS

Flowchart

The investigation in this paper is summarized in the flowchart as shown in Figure 1.

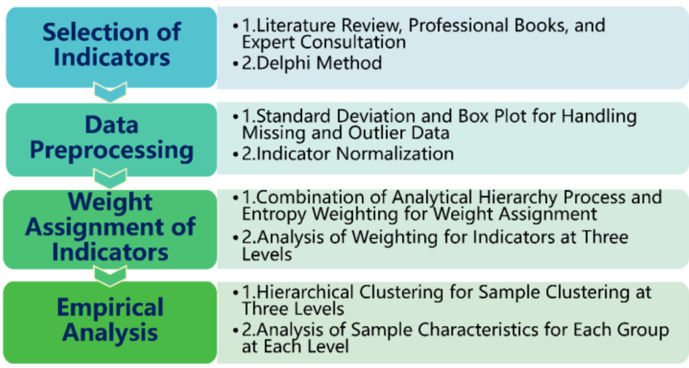

Figure 1. Research flowchart

Participants

Raw data were primarily collected on the physical fitness of 96 outstanding female Sanda athletes across three categories: lightweight (48-52 kg), middleweight (56-65 kg), and heavyweight (70-75 kg). To eliminate subjective factors in the data and ensure authenticity, statistical software such as Python and Stata were utilized for comprehensive data analysis. The mean value of the descriptive data of the participants is provided in Table 1.

Table 1. Mean value of the study subjects

Standard deviation / Characteristic	Lightweight (48-52 kg)	Middleweight (56-65 kg)	Heavyweight (70-75 kg)
Age (years)	21.24±3.20	21.13±2.70	22.92±2.01
Weight (kg)	50.86±1.63	60.09±2.62	72.50±2.50
Years of Training	10.48±2.92	10.69±2.35	11.86±2.14
Years of Professional Training	6.38±2.79	6.04±1.88	7.96±2.05

DESIGN

Women's Sanda, a highly combative competitive sport, requires both aerobic and anaerobic metabolic capabilities. The kinematic characteristics of competition including as rapid starts and sudden stops, agility and speed, the ability to coordinate complex technical movements, and the endurance and strength to sustain prolonged high-intensity confrontations, all impact the athletes' tactical and technical performances (Li, 2004; Luo, 2006; Lu & Jin, 2009; Zhou *et al.*, 2018; Huo & Wang 2017; Yu, 2019; You *et al.*, 2019). First, 23 physical fitness test indicators related to the characteristics of Sanda were selected. Using the Delphi method, 13 experts and coaches subsequently scored these indicators based on their importance over three rounds (Li *et al.*, 2023). A statistical method of averaging three test results was used to identify 19 indicators with coefficients of variation below 15% in all three rounds as necessary test indicators for the project (Table 2).

Table 2. Evaluation indicator system for standing female Sanda Athletes.

Primary Indicator	Secondary Indicator	Tertiary Indicator
Flexibility	Lower Limb Flexibility	Front Splits Straddle Splits
Strength	Lower Limb Strength	Squat Standing Long Jump
	Upper Limb Strength	Bench Press Left Straight Punch Force Right Straight Punch Force
	Specialized Strength	30-Second Plank 30-Second Leg Lifts Sandbag Hold for 30 Seconds
Endurance	General Endurance	800 m Run
	Specialized Endurance	30-Second Left and Right Punches 30-Second Back Kick on Sandbag
Agility	General Agility	8 m x 4 Shuttle Run
	Specialized Agility	15-Second Combination of Two Straight Punches and One Roundhouse Kick
Speed	General Speed	30 m Run 50 m Run
	Specialized Speed	10-Second Punch Count in Place 10-Second Kick Count in Place

DATA ANALYSYS PROCEDURES

Anomaly Data Detection and Processing

In this paper, a combination of box plot and standard deviation methods was employed to initially process the outliers in the data, enhancing the accuracy and reliability of anomaly data detection. The box plot is a statistical approach for outlier treatment. Its fundamental concept involves using the quartiles and interquartile range (IQR) of the data to identify which data points are outliers and then either replacing or excluding these outliers (Williamson *et al*., 1989). The original observational values of the physical fitness data of outstanding female Sanda athletes across three categories were included the analysis. The 25th percentile, 75th percentile, IQR, and lower and upper limits were calculated. Outliers were identified using the threshold of 1.5 times the IQR. Finally, Boolean indexing was used to replace data elements that were below the lower limit or above the upper limit with the median value, effectively replacing outliers with the median. Replacing outliers with the median is an effective, robust, and simple method that helps maintain the central tendency of the data, reduces the negative impact of extreme values, and improves the stability and predictive performance of the model. The box plots of the processed data were subsequently drawn using matplotlib's boxplot function.

The standard deviation is a statistical measure that quantifies the dispersion of a dataset relative to its mean, representing the deviation of each data point from the mean. The standard deviation method is a statistical approach to treating outliers based on the principles of statistics. In this method, data points that significantly deviate from the mean value are identified using the dataset's mean and standard deviation and considered outliers (Leys *et al*., 2013).

$$\sigma = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(x_i - \overline{x})^2} \quad (1)$$

N represents the size of the dataset, $\overline{x}$ denotes the *i*-th data point, and $\overline{x}$ signifies the mean of the dataset.

The specific steps for data preprocessing using a combination of the box plot method and the standard deviation method are as follows:

1) Use the box plot method to identify potential outliers in the dataset and replace these outliers.
2) After processing, employ the standard deviation method for further outlier detection. Identify and label data points whose standardized values are greater than or equal to 3 or less than or equal to -3.

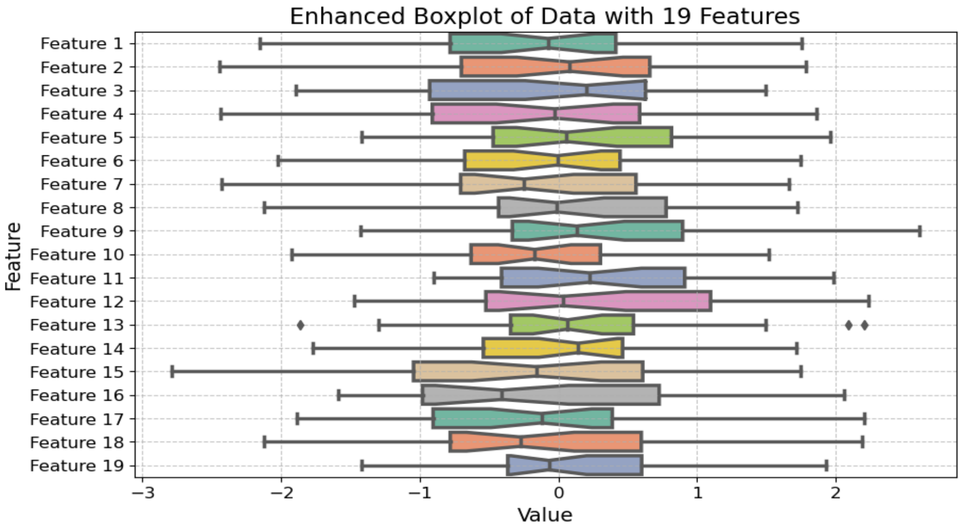

Figure 2. Data preprocessing using the box plot and standard deviation methods

The data preprocessing procedure uses the box plot method, and the standard deviation method is depicted in Figure 2. The data processing criteria is given in Figure 1.

Before the data are preprocessed, thus addressing outliers, the data may contain some extreme values or outliers, which could distort the overall data distribution. After preprocessing, by replacing these outliers (usually with the median as shown in Figure 2), the overall distribution of the data becomes more uniform, reducing the impacts of extreme values. This approach helps yield more reliable and consistent results in further data analysis or modelling.

The data processed with the box plot is more robust because they reduce the impacts of extreme values. This is very important in many statistical analyses, as extreme values can lead to overfitting or biased results. Improving the consistency and reliability of the data increases the suitability of the dataset for statistical analysis and modelling.

Figures 2 and 3 show a dataset with 96 samples and 19 features, illustrating the total sums before and after handling missing values. The bars labelled 'After Imputation' represent the total sum of each feature after processing with an iterative imputer. The Iterative Imputer is an advanced method for handling missing values in a dataset. It is particularly useful when the missing values are distributed across different features, as it can leverage the relationships between features to provide more accurate imputed values. This reflects the overall data distribution after missing values are inputted. The bar graph labelled 'Missing Values' shows the number of missing values in each feature in the original data. This helps identify the features with the most missing data in the dataset. By comparing these two sets of data, one can observe which features are most affected by missing values and how the imputation operation changes the data volume of each feature.

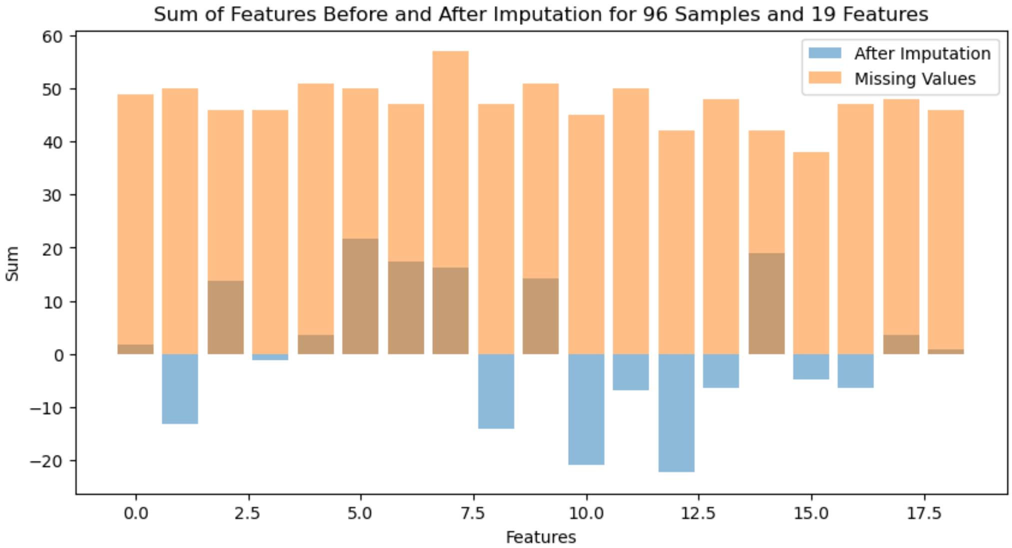

Figure 3. Comparison Chart After Data Preprocessing

Maximization and Normalization of Indicators

In this study, to address the presence of both maximization and minimization indicators in the data, methods of indicator maximization and normalization were adopted before conducting the data analysis. To standardize different types of indicators, non-maximization indicators are transformed into maximization indicators by linearly transforming the original indicators to fit the definition of maximization indicators (Pollesch & Dale, 2016). The specific steps are as follows. Given m number of features indicators and n number of samples, for the i-th indicator and the j-th sample, the maximization indicator is calculated as follows.

1. Determine the minimum value $\min_i$ and maximum value $\max_i$:

$$\min_i = \min_{j=1}^{n} x_{ij}, \tag{2}$$

$$\max_i = \max_{j=1}^{n} x_{ij}. \tag{3}$$

2. Use the following formula to transform indicator x_{ij} into a maximization indicator y_{ij}:

$$y_{ij} = \frac{x_{ij} - \min_i}{\max_i - \min_i}. \tag{4}$$

3. If indicator i needs to be inverted when an indicator is a negative indicator, then use the following formula for conversion:

$$y_{ij} = \frac{\max_i - x_{ij}}{\max_i - \min_i}. \tag{5}$$

4. Repeat steps 2 and 3 until all the indicators have been transformed into maximization indicators.

Through this transformation, the original range of values of the indicators is mapped to the [0,1] interval, with the maximum value corresponding to 1. Thus, by using this new indicator, we can convert all the original indicators into maximization indicators, which facilitates comparison and analysis. In summary, through these methods, we can better understand the characteristics of the dataset after handling missing values and assess the improvements brought by preprocessing (such as box plot treatment). These steps convert all indicators to positive indicators, which is crucial for preparing a high-quality dataset for accurate data analysis and modeling. Especially for the upcoming application of the AHP method, unifying the direction of indicators is a key step to ensure the accuracy of the comparison matrix and enhance the credibility of the analysis results.

AHP Method for Determining Subjective Weights

In this paper, the subjective weights for 19 evaluation indicators, such as the vertical fork/cm, horizontal fork/cm, and squat/kg, are first obtained using the analytic hierarchy process (AHP) proposed by Al-Harbi (2001). The evaluation indicator system is then divided into 19 indicators according to the AHP as follows.

(1) **Construct a judgement matrix**. The importance ratio of indicators at the same level is determined by pairwise comparison, commonly using the scale of numbers 1 to 9 and their reciprocals to define the judgement matrix. Here, 1 indicates that two factors have equal importance, 3 indicates moderate importance, 5 indicates greater importance, 7 indicates high importance, and 9 indicates extremely high importance.

(2) **Consistency test.** Following the 1 to 9 scale principle mentioned earlier, scores are assigned to the relative importance of each indicator within the indicator system based on experts' experience and practical training (Table 3). The weights of each indicator and the consistency ratio are then calculated using the eigenvector method.

Table 3. Average Random Consistency Index table.

Scale	1	2	3	4	5	6	7	8	9
RI	0	0	0.52	0.89	1.12	1.26	1.36	1.41	1.46

(3) **Determination of Subjective Weights** is performed using the following equation.

$$z_i = \frac{\sum_{j=1}^{m} a_{ij}}{m\lambda_{max}} \tag{6}$$

a_{ij} is the element in the j-th column of the judgement matrix corresponding to the i-th hierarchical factor. By normalizing the relative weights of all hierarchical factors, the subjective weight vector can be obtained.

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To achieve a more thorough, accurate and reliable weight distribution, it needs to comprehensively consider both subjective and objective weights. This approach not only balances personal judgment with data-driven results but also enhances the reliability and acceptability of decisions, adapting to complex and dynamic real-world applications. Therefore, when using AHP for decision analysis, it is both necessary and beneficial to utilize both subjective and objective weights.

Determining Objective Weights Using the Entropy Weight Method

To effectively mitigate biases formed by subjective factors and make the evaluation results more objective, this paper obtains the weights of 19 evaluation indicators based on information entropy evaluation. Assuming that *n* weight groups of samples are selected and that *m* evaluation indicators are designed, *x*-ij represents the value of the *j*-th evaluation indicator for the *i*-th sample (Kumar *et al*., 2021). The following steps are performed.

(1) **Constructing a Decision Matrix**. Construct an m×n decision matrix. The original data matrix is as follows.

$$D = (d_{ij})_{n\times m} = \begin{bmatrix} d_{11} & d_{12} & \cdots & d_{1m} \\ d_{21} & d_{22} & \cdots & d_{2m} \\ \vdots & & & \\ d_{n1} & d_{n2} & \cdots & d_{nm} \end{bmatrix}, \tag{7}$$

and each element in the decision matrix is normalized to eliminate the dimensions and differences between different indicators. The normalized score for each case under this indicator is

$$\hat{x}_{ij} = \frac{x_{ij} - X_{\min,j}}{X_{\max,j} - X_{\min,j}}, \tag{8}$$

(2) Calculating Entropy Weight and Weight of each indicator using Equation (9).

$$E_j = -\sum_{i=1}^{m} \hat{x}_{ij} \ln \hat{x}_{ij}, \tag{9}$$

$$w_j = \frac{1 - E_j}{n - \sum_{j=1}^{m}(1 - E_j)}, \tag{10}$$

After normalizing the weights of each indicator, the objective weight vector can be obtained.

(3) **Calculating Decision Scores**

Based on the normalized decision matrix and the objective weight vector, calculate the score for each decision option as follows:

$$S_i = \sum_{j=1}^{m} w_j \hat{x}_{ij}. \tag{11}$$

The higher the score of the decision-making option, the more it meets the decision-making objective.

Determination of Composite Weight

By combining the analytic hierarchy process (AHP) with the entropy weight method, suppose that the evaluator determines the weight of the importance of indicators as α_i (i=1,2,..,n) based on their objectives and requirements. Combining this with the entropy weight of the indicators yields the composite weight of indicator β_i as

$$\beta_i = \frac{\alpha_i s_i}{\sum_{i=1}^{m} \alpha_i s_i}. \tag{12}$$

In cluster analysis, there are several common clustering methods and linkage methods. Here, we assume the use of Hierarchical Clustering, as it is a common method for analyzing multidimensional data. A key step in hierarchical clustering is choosing an appropriate linkage method to measure the distance between clusters. The linkage method is chosen for hierarchical clustering to ensure that the resulting clusters are compact and robust, which is crucial for accurate and reliable data analysis. Combined with appropriate missing value handling and the calculation of objective weights, this method provides a solid foundation for further analysis and modeling.

Generation of a Cluster Analysis Dendrogram

The dendrogram of cluster analysis, also known as a phenogram, is based on the clustering structure concept. This structure is derived from similarity statistics using certain classification principles and formulas, aiming to find a more rational method of categorizing various groups. The resulting diagram, known as the cluster diagram or dendrogram, is particularly suited for effective distinction analysis of features in small samples. The characteristics of each level's study subjects can be efficiently extracted (Abecasis & Wigginton, 2005), thus facilitating the identification of talents and weaknesses of athletes for targeted training purposes.

RESULTS

Construction of the evaluation indicator system

Analyzing the composite weights of the 19 tertiary indicators for the 48-52 kg lightweight category in Table 4 reveals that 'Specialized Speed' has the highest composite weight proportion in this category, accounting for 0.3316, while 'General Endurance' is the lowest, accounting for 0.0292. This indicates that the most important indicator for measuring outstanding female Sanda athletes in the lightweight category is 'Specialized Speed', while the least important indicator is 'General Endurance'.

Table 4. Composite Weights of the Indicators for the 48-52 kg Lightweight Category

Primary Indicator	Secondary Indicator	Tertiary Indicator	AHP	Entropy Weight	Composite Weight
Flexibility	Lower Limb Flexibility	Front Splits	0.0317	0.0476	0.0425
		Straddle Splits	0.0413	0.0535	0.0623
Strength	Lower Limb Strength	Squat	0.0348	0.0437	0.0428
		Standing Long Jump	0.0315	0.0252	0.0223
	Upper Limb Strength	Bench Press	0.0244	0.0427	0.0294
		Left Straight Punch Force	0.0373	0.0064	0.0068
		Right Straight Punch Force	0.0252	0.0350	0.0249
	Specialized Strength	30-Second Plank	0.0515	0.0078	0.0113
		30-Second Leg Lifts	0.0557	0.0517	0.0810
		Sandbag Hold for 30 Seconds	0.0221	0.0285	0.0178
Endurance	General Endurance	800 m Run	0.0457	0.0226	0.0292
	Specialized Endurance	30-Second Left and Right Punches	0.0305	0.0144	0.0124
		30-Second Back Kick on Sandbag	0.0328	0.0423	0.0391
Agility	General Agility	8 m x 4 Shuttle Run	0.0946	0.0562	0.1498
	Specialized Agility	15-Second Combination of Two Straight Punches and One Round house Kick	0.0237	0.0657	0.0439
Speed	General Speed	30 m Run	0.0250	0.0194	0.0137
		50 m Run	0.0195	0.0698	0.0384
	Specialized Speed	10-Second Punch Count in Place	0.0869	0.0694	0.1697
		10-Second Kick Count in Place	0.0824	0.0698	0.1619

Analyzing the composite weights of the 19 tertiary indicators for the 56-65 kg lightweight category in Table 5 reveals that this category has relatively high composite weight proportions of 'Specialized Speed' and 'Specialized Strength', with values of 0.1405 and 0.177, respectively. 'Specialized Agility' has the lowest composite weight proportion at 0.0073. These findings indicate that the most important indicators for measuring outstanding female Sanda athletes in the lightweight category are 'Specialized Speed' and 'Specialized Strength,' while the least important indicator is 'Specialized Agility.'

Table 5. Composite Weights of the Indicators for the 55-65 kg Middleweight Category

Primary Indicator	Secondary Indicator	Tertiary Indicator	AHP	Entropy Weight	Composite Weight
Flexibility	Lower Limb Flexibility	Front Splits	0.0560	0.0809	0.0813
		Straddle Splits	0.0611	0.0681	0.0747
Strength	Lower Limb Strength	Squat	0.0425	0.0569	0.0434
		Standing Long Jump	0.0575	0.0495	0.0511
	Upper Limb Strength	Bench Press	0.0522	0.0546	0.0512
		Left Straight Punch Force	0.0586	0.0110	0.0116
		Right Straight Punch Force	0.0487	0.0528	0.0461
	Specialized Strength	30-Second Plank	0.0839	0.0151	0.0227
		30-Second Leg Lifts	0.0890	0.0806	0.1288
		Sandbag Hold for 30 Seconds	0.0340	0.0418	0.0255
Endurance	General Endurance	800 m Run	0.0579	0.0368	0.0382
	Specialized Endurance	30-Second Left and Right Punches	0.0465	0.0238	0.0199
		30-Second Back Kick on Sandbag	0.0564	0.0581	0.0588
Agility	General Agility	8 m x 4 Shuttle Run	0.0870	0.0426	0.0665
	Specialized Agility	15-Second Combination of Two Straight Punches and One Roundhouse Kick	0.0080	0.0506	0.0073
Speed	General Speed	30 m Run	0.0501	0.0507	0.0456
		50 m Run	0.0462	0.1033	0.0857
	Specialized Speed	10-Second Punch Count in Place	0.0795	0.0551	0.0786
		10-Second Kick Count in Place	0.0705	0.0489	0.0619

Analyzing the composite weights of the 19 tertiary indicators for the 70-75 kg heavyweight category in Table 6 shows that 'Specialized Speed' has a high composite weight proportion for this category, reaching 0.3297, while 'General Speed' has the lowest at 0.0099. These findings suggest that the most important indicator for measuring outstanding female Sanda athletes in the heavyweight category is 'Specialized Speed,' while the least important indicator is 'General Speed.'

Table 6. Composite Weights of the Indicators for the 70-75 kg Heavyweight Category

Primary Indicator	Secondary Indicator	Tertiary Indicator	AHP	Entropy Weight	Composite Weight
Flexibility	Lower Limb Flexibility	Front Splits	0.0150	0.0274	0.0128
		Straddle Splits	0.0195	0.0308	0.0188
Strength	Lower Limb Strength	Squat	0.0572	0.0683	0.1217
		Standing Long Jump	0.0537	0.0485	0.0811
	Upper Limb Strength	Bench Press	0.0464	0.0672	0.0971
		Left Straight Punch Force	0.0598	0.0283	0.0528
		Right Straight Punch Force	0.0473	0.0590	0.0868
	Specialized Strength	30-Second Plank	0.0747	0.0298	0.0694
		30-Second Leg Lifts	0.0790	0.0768	0.1890
		Sandbag Hold for 30 Seconds	0.0440	0.0520	0.0713
Endurance	General Endurance	800 m Run	0.0216	0.0130	0.0088
	Specialized Endurance	30-Second Left and Right Punches	0.0144	0.0083	0.0037
		30-Second Back Kick on Sandbag	0.0155	0.0244	0.0118
Agility	General Agility	8 m x 4 Shuttle Run	0.0448	0.0324	0.0452
	Specialized Agility	15-Second Combination of Two Straight Punches and One Roundhouse Kick	0.0112	0.0578	0.0202
Speed	General Speed	30 m Run	0.0118	0.0112	0.0041
		50 m Run	0.0092	0.0202	0.0058
	Specialized Speed	10-Second Punch Count in Place	0.0411	0.0400	0.0512
		10-Second Kick Count in Place	0.0390	0.0402	0.0488

For the 48-52 kg category, Radar Charts in Figure 4-5 show that the 'General Agility' and 'Specialized Speed' indicators have the highest priorities, with weights of 0.1498 and 0.1697, respectively. For the 56-65 kg category, Radar Charts 4-5 show that 'Specialized Speed' and '30s Leg Raises per Minute' have the highest priorities, with weights of 0.1288 and 0.0786, respectively. For the 70-75 kg category, Radar Charts 4-5 indicate that '30s Leg Raises per Minute' and 'Lower Limb Strength' indicators have the highest priorities, with weights of 0.1890 and 0.1217, respectively.

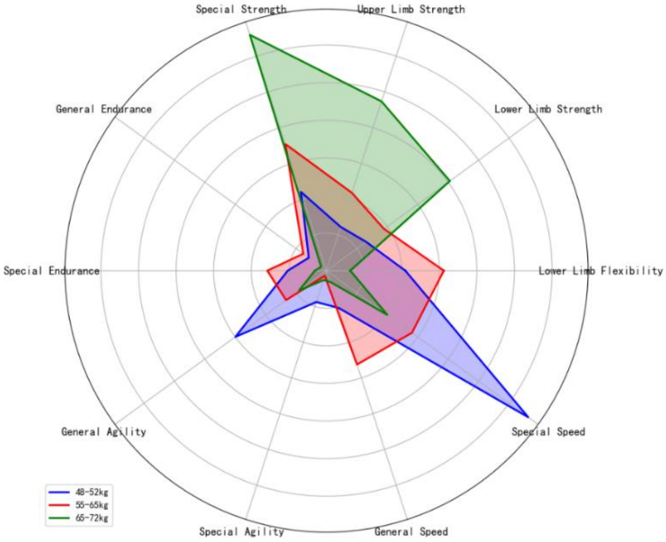

Figure 4. Comparison of secondary indicator weights across different weight categories

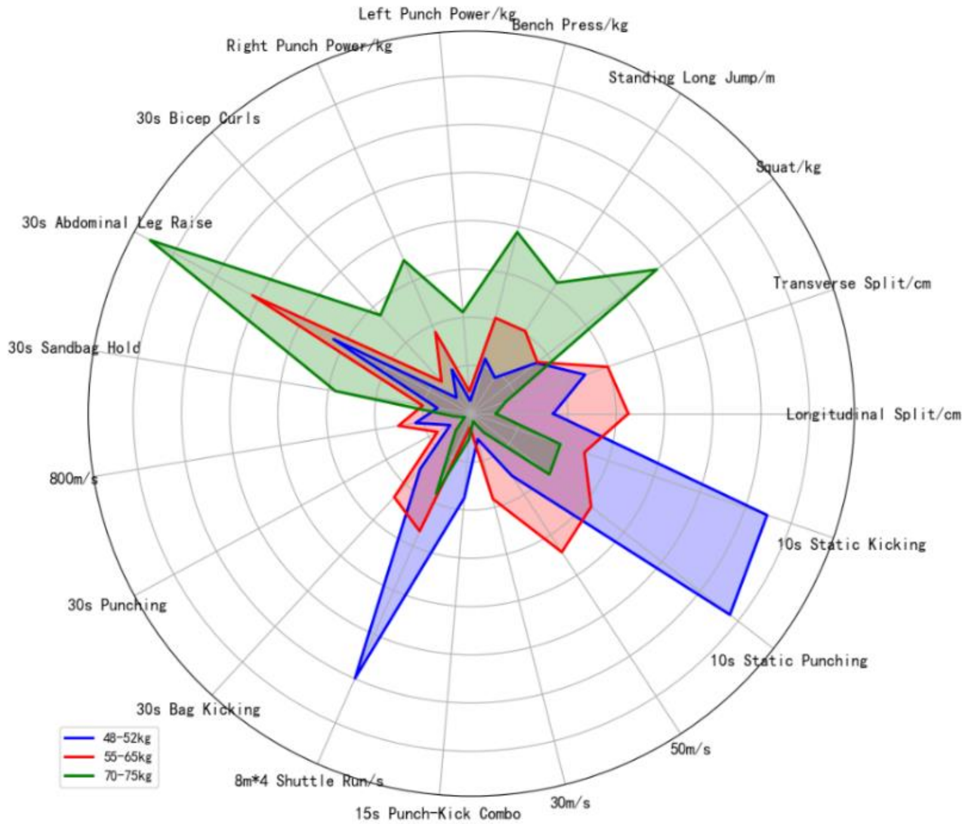

Figure 5. Comparison of tertiary indicator weights across different weights

Results of Hierarchical Clustering

In this study, the complete linkage method was chosen for hierarchical clustering to ensure that the resulting clusters are compact and robust, which is crucial for accurate and reliable data analysis. Combined with appropriate missing value handling and the calculation of objective weights, this method provides a solid foundation for further analysis and modeling. The following is the characteristics outcome of the hierarchical clustering for each category.

Lightweight category (48-52 kg)

Figure 6 shows the dendrogram of the hierarchical relationship between indicators and individual athletes for Lightweight categories. Three subgroups could be formed with distinct characteristics as discussed in the following.

Subgroup 1 (Athlete number 25, 3, 12, 2, 19, 13, 4, 7)

Characteristics: These athletes performed best in 'Vertical Fork/cm' and 'Horizontal Fork/cm', but they were weaker in '50 m/s.' These findings suggest that the athletes in Group 1 have significant flexibility and specific striking technique advantages.

Subgroup 2 (Athlete number 8, 16, 6, 14, 18, 10, 9, 21)

Characteristics: These athletes performed best in 'Squat kg' and 'Bench Press kg', but they were weaker in '800 m/s.' These findings suggest that these athletes excel in overall strength, particularly in lower limb strength, upper limb strength, and punching power.

Subgroup 3 (Athlete number 5, 22, 20, 0, 23, 1, 24, 17, 11, 15)

Characteristics: These athletes performed best in '30 s Sit-Ups' and '800 m/s', but they were weaker in '30 s Left-Right Punches/s.' These findings indicate that these athletes excel in endurance and speed.

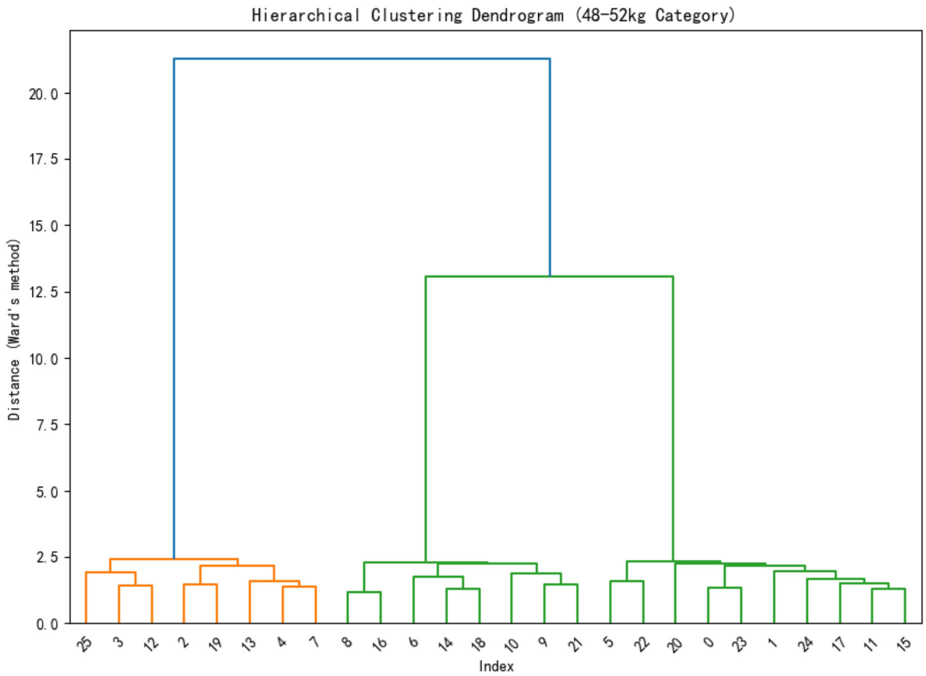

Figure 6. 48-52 kg Hierarchical Clustering

Middleweight category (56 - 65 kg)

A similar analysis was carried out for the Middleweight category where the dendrogram of the hierarchical relationship is shown in Figures 7. As in the previous, three characteristics of subgroup could be form as an outcome.

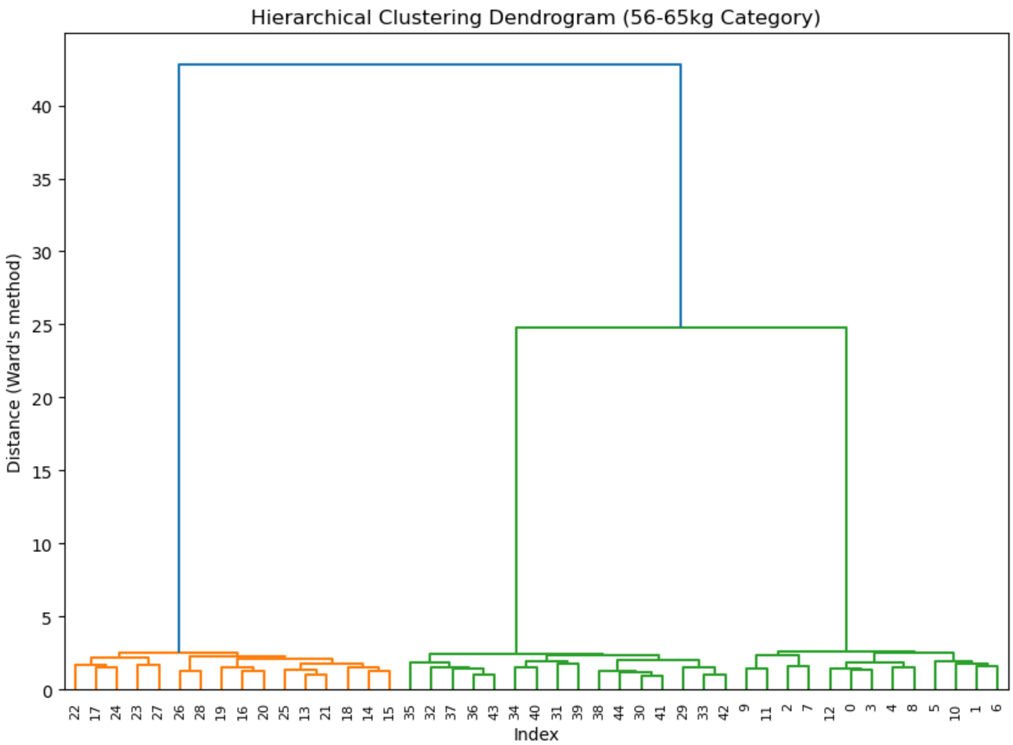

Figure 7. 56-65 kg Hierarchical clustering

Subgroup 1 (Athlete number 22, 17, 24, 23, 27, 26, 28, 19, 16, 20, 25, 13, 21, 18, 14, 15)
Characteristics: These athletes performed best in 'Vertical Fork/cm' and '30s Leg Raises per Minute' but were weaker in '10 On-the-Spot Kicking Counts,' indicating they possess outstanding flexibility and core strength.

Subgroup 2 (Athlete number 35, 32, 37, 36, 43, 34, 40, 31, 39, 38, 44, 30, 41, 29, 33, 42)
Characteristics: These athletes performed best in outstanding in '800m/s' and 'Bench Press/kg,' but were weaker in '30m/s,' indicating they possess good endurance and upper limb strength.

Subgroup 3 (Athlete number 9, 11, 2, 7, 12, 0, 3, 4, 8, 5, 10, 1, 6)
Characteristics: These athletes performed best in '8 m*4 Shuttle Run/s' and '50 m/s,' but weaker in 'Standing Long Jump/m,' indicating they possess remarkable reaction speed and short-distance speed.

Heavyweight category (70 - 75 kg)

Finally, the dendrogram of the hierarchical relationship between indicators and individual athletes for Heavyweight categories is shown in Figure 8 with the following as the outcome of the three distinct characteristics that could be formed.

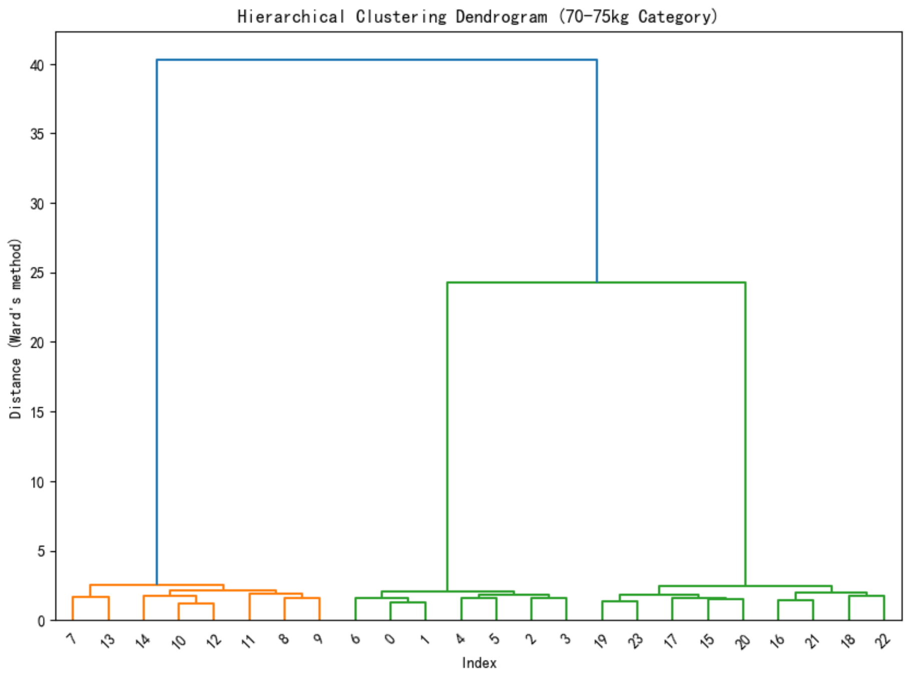

Figure 8. 70-75 kg Hierarchical Clustering

Subgroup 1 (Athlete number 7, 13, 14, 10, 12, 11, 8, 9)

Feature and Advantage Analysis: These athletes performed best in 'Squat/kg' and '30s Leg Raises per Minute' but were weaker in '8 m*4 Shuttle Run,' indicating they have excellent leg strength and core stability.

Subgroup 2 (Athlete number 6, 0, 1, 4, 5, 2, 3)

Feature and Advantage Analysis: These athletes performed best in 'Bench Press/kg' and 'Right Straight Punch Strength/kg' but were weaker in '30s Back Kick Bag Hitting,' indicating they have good upper limb strength and striking ability.

Subgroup 3 (Athlete number 19, 23, 17, 15, 20, 16, 21, 18, 22)

Feature and Advantage Analysis: These athletes performed best in the '8 m*4 Shuttle Run/s' and '10s On-the-Spot Kicking Counts' but were weaker in the '30s Sandbag Holding,' indicating they have good agility and rapid response capabilities.

The complete outcome of the Hierarchical Clustering analysis is given in Figure 7 for clarity.

Table 7. Characteristics of excellent female Sanda athletes of Light, Middle and Heavyweight

Characteristics / Weight	Subgroup	High-Level	Low-Level
Lightweight (48-52 kg)	Subgroup 1	Squat/kg' and '30s Leg Raises per Minute	50 m/s
	Subgroup 2	Squat kg' and 'Bench Press kg	800 m/s
	Subgroup 3	30 s Sit-Ups' and '800 m/s	30 s Left-Right Punches/s
Middleweight (56-65 kg)	Subgroup 1	Vertical Fork/cm' and '30s Leg Raises per Minute	10 On-the-Spot Kicking Counts
	Subgroup 2	800m/s' and 'Bench Press/kg	30m/s
	Subgroup 3	8 m*4 Shuttle Run/s' and '50 m/s	Standing Long Jump/m
Heavyweight (70-75 kg)	Subgroup 1	Squat/kg' and '30s Leg Raises per Minute	8 m*4 Shuttle Run
	Subgroup 2	Bench Press/kg' and 'Right Straight Punch Strength/kg	30s Back Kick Bag Hitting
	Subgroup 3	8 m*4 Shuttle Run/s' and '10s On-the-Spot Kicking Counts	30s Sandbag Holding

DISCUSSION

Analysis of Indicators at Different Levels

Table 4 shows that at the lower level, the comprehensive weight of “specialized speed” is the highest, indicating that speed is particularly important in small-scale competitions. This may indicate that in lighter weight competitions, athletes' quick movement and responsiveness are crucial for competitive performance. In contrast, the importance of "general endurance" is relatively low, possibly because at this level of competition, short-term high-intensity explosive power is more crucial than long-term endurance.

Table 5 shows that at the middle level, the comprehensive weights of "specialized speed" and "specialized strength" are relatively high, indicating that a combination of speed and strength is crucial for the performance of athletes at this level of competition. This may be because mid-level competitions require athletes to maintain speed while also having sufficient strength to perform technical movements. The importance of "specialized sensitivity" is relatively low, possibly because at this level, the combination of speed and strength is more important than pure sensitivity.

Table 6 shows that among the major categories, "specialized speed" has the highest comprehensive weight, indicating that even in heavier weight categories, speed is still a key competitive element. This may indicate that even at higher levels of strength and weight, fast action execution and response are still key to winning. Moreover, the importance of “general speed” is the lowest, possibly because at this level, specialized speed is more important than general speed.

Overall, combining the AHP and entropy weighting methods yields a more comprehensive and balanced evaluation. The AHP method emphasizes the judgement and experience of experts, while the entropy weight rule extracts information from the distribution of and differences in the data. By combining these two methods, we can consider expert opinions and ensure the objectivity and data-driven scientific of the evaluation. For example, at the 48-52 kg level, the high weights of the "general sensitivity" and "specialized speed" indicators reflect the experts’ emphasis on these abilities, and data analysis also supports this. In contrast, relying on a single method may cause certain important indicators to be overlooked or other indicators to be overly emphasized. Therefore, this comprehensive approach provides a more comprehensive and balanced assessment of physical fitness, which helps with developing more effective training plans and strategies. (Zhao & Wang, 2019)

Figures 4-5 show that sensitivity and speed are highly important in lower-level competitions. In contrast, indicators such as "Left Straight Boxing Strength/kg" have lower weights (0.0068), indicating their relatively low importance at this level.

Figures 4-5 show that in mid-level competitions, specialized speed and strength are relatively important. In contrast, other indicators, such as "General Speed" and "15 seconds two fists and one leg combination/time," have relatively low weights, with values of 0.0456 and 0.0073, respectively.

Figures 4-5 show that strength and specialized strength are highly important for athletes in higher-level competitions. In contrast, the "general speed" and "general endurance" indicators have relatively low weights at 0.0041 and 0.0088, respectively, indicating that at this level, these qualities may not be the primary factors in success.

Overall, these analyses reveal the different physical fitness needs and priorities of female Sanda athletes at different levels. By comprehensively considering the weights of multiple indicators, coaches and athletes can more effectively develop training plans and improve the most important physical fitness measures at specific levels of competition. Moreover, these findings indicate that athletes must consider and optimize different physical fitness indicators at different levels of competition.

Detail Analysis of Women's Traits at Various Levels

Lightweight (48-52 kg)

From Table 4, we noticed that in the 48-52kg category, the combination weights for "general agility" (0.1498) and "specialized speed" (0.1697) are the highest, while the upper limb strength, "left straight punch force/kg" (0.0068), has a low combination weight. Therefore, it is evident that agility and speed qualities are emphasized in this category, whereas strength qualities are relatively less important.

The results from the lineage clustering shown in pedigree cluster Figure 5 reveal that the first group excels in flexibility (such as longitudinal and transverse splits) and specific hitting skills (such as back whip leg strikes on sandbags), which is consistent with the high combination weight of "lower limb flexibility" (longitudinal splits/cm 0.0425 and transverse splits/cm 0.0623) in the combination weight Table 4. This indicates that athletes with these specific skills are indeed common in this group. For the second group, their performance advantage in strength-related indicators aligns with the high combination weights of "lower limb strength" and "upper limb strength" in the combination weight Table 4. This further confirms the importance of strength qualities in the 48-52kg category, especially in the lower and upper limbs. The third group exhibits outstanding performance in endurance and speed, consistent with the high weights of "general endurance" and "specialized speed" in the combination weight Table 4. This suggests that athletes in this category have potential in endurance and rapid response.

In summary, these analyses reveal the potential strengths and weaknesses of athletes in the 48-52kg category in terms of different physical qualities. Coaches can use this information to develop more targeted training plans to improve athletes' performance in competitions. Additionally, during competitions, athletes can be more effectively positioned against specific opponents to leverage their strengths. Therefore, this study puts forward targeted training suggestions for three different groups. Training for the first group: Based on these characteristics, specialized training can be arranged to further improve the flexibility and specific skills, such as the hitting accuracy, of these athletes. Training for the second group: To maximize the utilization of their advantages, the training plan for these athletes should focus on improving their strength and explosive power while also emphasizing the accuracy and speed of their techniques. Training for the third group: The training plan for these athletes should focus on improving endurance and speed training, as well as improving technical retention ability under high-intensity conditions.

Middleweight (56-65 kg)

According to the combination weight Table 5, we noticed that in the 56-65kg category, the combination weight of "lower limb flexibility" and "special strength" (30-second leg lifts/time) is higher, while special sensitivity (15-second combination of two straight punches and one roundhouse kick/times) has a lower weight. Therefore, flexibility and strength are emphasized in this category, while agility is relatively less important.

From the results of the pedigree clustering shown in pedigree cluster Figure 6, we found that Group 1 excels in flexibility and core strength (front splits/cm and 30-second leg lifts/time). This aligns with the high values in the combination weight Table 5, suggesting that athletes with these specific skills are common in this group. Group 2 shows performance advantages in strength and endurance indicators, consistent with the high combination weights of “upper limb strength” and “general endurance” in the combination weight Table 5. This further confirms the importance of strength and endurance qualities, especially in upper body strength and short- to middle-distance endurance. Group 3 demonstrates significant performance in agility and speed, consistent with the high values in the combination weight Table 5. This indicates that athletes in this group have significant advantages in reaction speed and short-distance speed.

In summary, through these analyses, coaches and trainers can develop more targeted training plans for athletes to improve their performance in the 56-65kg competition. This also provides important references for competition strategies to fully leverage athletes’ potential advantages. Therefore, this study puts forward targeted training suggestions for three different groups. Training for the first group: Training should focus on improving the flexibility and specialized strength of these athletes, for example, by increasing flexibility training and core strength exercises, to improve their competitive performances. Training for the second group: Training should focus on improving endurance and upper limb strength, such as through long-distance running and targeted upper limb strength training, to enhance the endurance and hitting power of these athletes in competitions. Training for the third group: Training should focus on improving the sensitivity and speed of these athletes, such as through explosive training. Practice and speed training can enhance their reaction and quick movement abilities.

Heavyweight (70-75 kg)

According to the combination weight Table 6, we noticed that in the 70-75kg category, the combination weight of “lower limb strength” and “special strength” (30-second leg lifts/time) is the highest, while the special endurance “about 30-second left and right punches/time” (0.0037) has a low combination weight. Therefore, strength quality is emphasized in this category, while special endurance quality is relatively less important.

The results from the pedigree clustering shown in pedigree cluster Figure 7 indicate that Group 1 excels in lower limb strength and core strength (squats/kg and 30-second leg lifts/times). Similarly, this aligns with the high values in the combination weight Table 6 of the combination weights, suggesting that athletes with these specific skills are common in this group. Group 2 shows performance advantages in upper limb strength indicators (bench press/kg and right straight punch force/kg), consistent with the high combination weights of “upper limb strength” and “strike power” in the combination weight Table 6. This further confirms the importance of strength qualities in this group, especially in upper body strength. Group 3 demonstrates significant performance in agility and speed (8m x 4 shuttle run/s and 10-second kick count in place/time), which aligns with the high values in the combination weight Table 6. This indicates that athletes in this group have significant advantages in agility and quick reaction capabilities.

In summary, this analysis method provides deep insights into the characteristics and potential strengths of athletes at different levels, helping to develop more precise training programs and competition strategies to improve the overall performance of athletes. Therefore, this study puts forward targeted training suggestions for three different groups. Training for the first group: Training should focus on improving the lower limb strength and core stability of these athletes, as well as improving their competitive performance through regular leg strength training and core stability exercises. Training for the second group: Training should focus on improving upper limb strength and hitting techniques, such as through targeted upper limb strength training and boxing techniques, to enhance the hitting power and technical accuracy of these athletes. Training suggestions for the third group: Training should focus on improving the agility and speed of these athletes. Sensitivity training and speed training should be used to increase their reaction speeds and motor agility.

From the above analysis, the characteristics of the outstanding female Sanda athletes could be summarized as shown in Table 8.

Table 8. Characteristics of Outstanding Female Sanda Athletes at Three Different Levels

Group Characteristics	Lightweight（48-52kg）	Middleweight（56-65kg）	Heavyweight（70-75kg）
Subgroup 1	Lower Body Flexibility	Specialized Strength	Lower Body Strength
Subgroup 2	Upper，Lower Body Strength	Upper Body Strength General Endurance	Upper Body Strength and Specialized Strength
Subgroup 3	General Endurance, Specialized Speed	Specialized Agility and Specialized Speed	Specialized Agility and General Speed

CONCLUSIONS

In this study, the original data were first preprocessed using box plots and standard deviation methods, reducing data errors and enhancing data accuracy. Subsequently, a combination of the analytic hierarchy process (AHP) and entropy weight method was used to assign weights to the indicators, establishing evaluation criteria for outstanding female Sanda athletes at three different levels and ensuring the scientific validity of each indicator's weight. The physical fitness qualities that athletes need to prioritize significantly differ at different weight levels. Lightweight (48-52 kg) athletes emphasize sensitivity and speed; medium weight (56-65 kg) athletes have outstanding flexibility and specialized strength; and heavyweight (70-75 kg) athletes place more emphasis on lower limb strength and core stability. These analyses yield precise training recommendations for athletes at each level, helping coaches and trainers develop targeted training plans and competition strategies to maximize their potential advantages and improve their performances at their respective levels of competition. In future stages of this study, more effective samples may also be collected from different periods to analyze the changes in the physical fitness of outstanding female Sanda athletes, facilitating a more scientific adjustment of training strategies.

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REFERENCES

[1] Abecasis, G. R. & Wigginton, J. E. 2005. Handling marker-marker linkage disequilibrium: pedigree analysis with clustered markers. *The American Journal of Human Genetics*, 77(5), 754-767.

[2] Al-Harbi, K. M. A. S. 2001. Application of the AHP in project management. *International journal of project management*, 19(1), 19-27.

[3] Cao, T. T., Lu, P. & Leng, B. 2018. Construction of special physical fitness evaluation index system for badminton players. *Sports and Sports Products and Technology*, (19), 153-154.

[4] Daniel, W. R., Warren, B. Y., David, G. B. & Warren, R. P. 2009. Effects of agonist–antagonist complex resistance training on upper body strength and power development. *Journal of Sports Sciences*, 27(14), 1617-1625.

[5] Huo, P. X. & Wang, H. M. 2017. Construction of the physical fitness evaluation index system for my country's outstanding female boxers. *Hubei Sports Science and Technology,* 36(11), 974-978.

[6] Jeon, Y. & Eom, K. 2021. Role of physique and physical fitness in the balance of Korean national snowboard athletes. *Journal of Exercise Science & Fitness*, 19(1), 1-7.

[7] Kumar, R., Singh. S., Bilga, P. S., Jatin, K., Singh, J., Singh. S., Scutaru, M. & Pruncu, C. I. 2021. Revealing the benefits of entropy weights method for multi-objective optimization in machining operations: A critical review. *Journal of Materials Research and Technology*, 10, 1471-1492.

[8] Leys, C., Ley, C., Klein, O., Bernard, P. & Licata, L. 2013. Detecting outliers: Do not use standard deviation around the mean, use absolute deviation around the median. *Journal of Experimental Social Psychology*, 49(4), 764-766.

[9] Li, J. X., Qiu, L. J., Ren, Y., Li, M. J., Li, W. J., Du, X. L., Wang, W. R., Yang, K. & Zhang, J. 2023. Preliminary construction of an evaluation index system for traditional Chinese medicine food and medicinal diet based on Delphi method and analytic hierarchy process. *Journal of Traditional Chinese Medicine*, 64(23), 2412-2418.

[10] Li, Z. E. 2004. Research on measurement indicators and evaluation standards of special physical fitness of Sanda athletes. *Hubei Sports Science and Technology*, 23(02), 165-166.

[11] Long, Y. L. 2021. *Research on Technical Analysis and Winning Factors of Outstanding Female Sanda Athletes*. MSc Thesis, Chengdu Institute of Physical Education, China.

[12] Lu, G. & Jin, Y. Z. 2009. Research on the special physical fitness evaluation standards of my country's outstanding large-level men's Sanda athletes. *Journal of Shandong Institute of Physical Education*, 25(02), 70-73.

[13] Luo, C. X. 2006. Research on the development status of physical fitness of outstanding male Sanda athletes in my country. *Journal of Shandong Institute of Physical Education*, 22 (04), 82-84.

[14] Pollesch, N. L. & Dale, V. H. 2016. Normalization in sustainability assessment: Methods and implications. *Ecological Economics*, 130, 195-208.

[15] Schwartz, J., Takito, M. Y., Del Vecchio, F. B., Antonietti, L. S. & Franchini. E. 2015. Health-related physical fitness in martial arts and combat sports practitioners. *Sport Sciences for Health*, 11(2), 171-180.

[16] Song, Y. Q. 2018. Effect of functional physical training on the physical fitness of Sanda athletes. *Journal of Gannan Normal University*, 39(06), 125-128.

[17] Wang, J. J. 2013. *Research on the Physical Training Load Structure Characteristics of Adolescent Sanda Athletes at Beijing Shichahai Sports School*. MSc Thesis, Beijing Sport University, China.

[18] Williamson, D. F., Parker, R. A. & Kendrick, J. S. 1989. The box plot: a simple visual method to

interpret data. *Annals of Internal Medicine*, 110(11), 916-921.

[19] Ye, W. 2014. Research on comprehensive evaluation of physical skills of outstanding male Sanda athletes in my country. *Chinese Martial Arts (Research)*, 3(11), 28-35.

[20] You, S. H., Wang, L. J., Qin, L. L., Wang, J. B., Zhou, Y. H., Sun, J. Y. & Wang, Y. 2019. Research on the construction of physical fitness evaluation standards for men's U15 elite echelon athletes of Shanghai Campus Football League. *Journal of Beijing Sport University*, 42(06), 41-47.

[21] Yu, H. 2005. Research on the special sports quality structure of my country's 48~56kg high-level male Sanda athletes. *Journal of Shenyang Institute of Physical Education*, 24(05), 127-130.

[22] Yu, Y.J. 2019. Research on the impact of core strength on improving the physical fitness of adolescent Sanda athletes. *Contemporary Sports Science and Technology*, 9(01), 54-55.

[23] Zhao, G. & Wang, D. 2019. Comprehensive evaluation of AC/DC hybrid microgrid planning based on analytic hierarchy process and entropy weight method. *Applied Sciences*, 9(18), 3843.

[24] Zhou, X. Q., Zhou, R. F., Han, Z. G., Wang, Y. P. & Zhang, D. Q. 2018. Construction of the evaluation index system for the core competitiveness of martial arts and traditional national sports disciplines in sports colleges. *Chinese Martial Arts (Research)*, 7(08), 6-11.

[25] Zhou, Y. & Han, Y. Y. 2015. Construction of special physical fitness evaluation indicators for college taekwondo athletes. *Journal of Heilongjiang Institute of Education*, 34(05), 179-181.