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Multi-indicator Evaluation System for Broadsword, Rod, Sword and Spear Athletes Based on Analytic Hierarchy Process

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Abstract: In the practical selection of Wushu athletes, the objective evaluation of the level of athletes lacks sufficient technical indicators and often relies on the coach's subjective judgments. It is difficult to accurately and objectively reflect the overall quality of the athletes without a fully quantified indicator system, thus affecting the level improvement of Wushu competition. The analytic hierarchy process (AHP) is a systemic analysis method combining quantitative and qualitative analysis. This paper realizes structured, hierarchized and quantified decision-making process of evaluating broadsword, rod, sword and spear athletes in the AHP. Combining characteristics of the athletes, analysis is carried out from three aspects, i.e., the athlete's body shape, physical function and sports quality and 18 specific evaluation indicators established, and then combining expert advice and practical experience, pairwise comparison matrix is determined, and then the weight of the indicators and comprehensive evaluation coefficient are obtained to establish the evaluation model for the athletes, thus providing a scientific theoretical basis for the selection of Wushu athletes. The evaluation model proposed in this paper has realized the evaluation system of broadsword, rod, sword and spear athletes, which has effectively improved the scientific level of Wushu athletes selection in practical application.

1. Introduction

Wushu is traditional Chinese sport. In the long process of development, broadsword, rod, sword and spear have become some of the main instruments of Wushu events. On the whole, the instrument is used based on the technology of long boxing, and should be used in a standard and accurate way to realize coordination between movement and method as well as between body and instrument. However, different instruments have their own characteristics and technical requirements, so the broadsword, rod, sword and spear athletes are significantly different from those of other events in the body shape, body function and physical quality requirements.

The scientific selection of Wushu talents is an important issue in the study of competitive Wushu routines, and is an important problem that needs to be solved urgently in practice. At present, many high-level coaches are still using old natural selection and empirical selection methods with no indicator system or means for scientific selection established, resulting in a higher rate of elimination, hindering improvement of the overall level of competitive Wushu technology, causing great waste of human and material resources, which greatly affected talent reserve of the competitive Wushu routine and is not conducive to the further development of competitive Wushu events. Therefore, we introduced the analytic hierarchy process combining qualitative analysis and quantitative analysis to



determine the indicator system for the selection and evaluation of broadsword, rod, sword and spear athletes, as well as the weights of all indicators to provide a new way of thinking and method for the establishment and improvement of scientific selection of talents for Wushu broadsword, rod, sword and spear events. Based on the evaluation model for broadsword, rod, sword and spear athletes analyzed and established herein, this paper designs and implements the evaluation system of Wushu broadsword, rod, sword and spear athletes selection, which is widely used in the selection of high-level competitive Wushu athletes, thus providing more effective data protection and support for scientific selection of the athletes.

2. Relevant Studies

The analytic hierarchy process (AHP) was proposed by Saaty, an American operational researcher in mid 1970s, which is a comprehensive decision-making method for multiple aims, with the combination of qualitative analysis and quantitative analysis [4]. At present, Shen Jianying et al. [9] have applied AHP in the selection of Wushu athletes, but mainly for the whole of Wushu movement, and there is still a lack of specific analysis of the characteristics of the event.

The selection and evaluation of Wushu athletes are mainly based on the method out of the coaches' experience, or on statistical analysis. For the standards for the selection of Wushu athletes, Zhao Dongsheng et al proposed a process based on the development of sports science and expert knowledge [1][5][6] and divided the selection standards, which is less quantitative and objective relatively. Ma Lingjuan et al. started from the athletes' physical characteristics, put forward the statistical method of characteristics [7][8], to analyze the selection criteria of athletes through large amount data statistics of the athletes' physical characteristics, similar is the selection of athletes based on experience-based designed characteristics[2][3], such methods are lack of sufficient expert knowledge and explanation. This paper puts forward the model of AHP, which not only takes into account the characteristics of Wushu event, but also combines practical experience and statistical data to establish a scientific and quantitative evaluation system of broadsword, rod, sword and spear athletes.

3. Hierarchical Structure Model

The athletes' physique comprises body shape, physiological function, sports quality and other aspects. According to the expert survey and related analysis combined with the characteristics of Wushu event, the analysis indicators in this paper are determined as three categories, i.e., the body shape, physiological function and special sports quality. The body shape indicator comprises seven indicators including height, limb length, width, circumference and others; the physiological function indicator comprises two, i.e., vital capacity and heart function index; the sports quality indicator comprise 18 indicators in nine items including flexibility, strength, sensitivity and balance. The indicator system is shown in Figure 1. All factors will be introduced in details below.

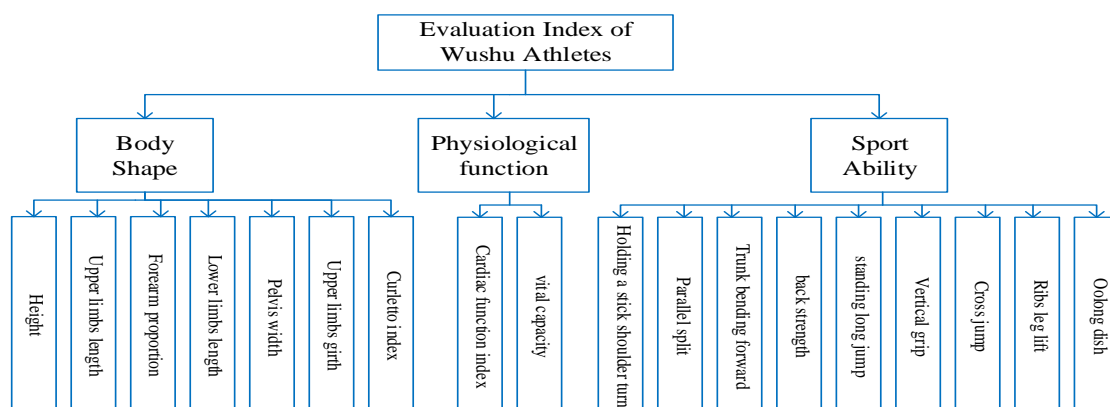


Figure 1. The evaluation indicator system for broadsword, rod, sword and spear athletes

(1) Body shape The body shape is significant for the athlete selection, including body length, sitting height, length of lower limb, pelvic width, limb dimension and other factors. ①The height and some length indicators are the indicators reflecting the skeletal development and the longitudinal body development, so the height is one of the important indicators. ②According to the principle of sports biomechanics, the total center of gravity of the upper limb is close to the rotation axis, which is beneficial to the athlete to complete the technical action. Broadsword, rod, sword and spear are extended limbs of the athletes so that the total center of their upper limb moves forward. So the length of the upper limb and forearm ratio are very important for the evaluation of Wushu athletes. ③The length of lower limbs is also an important indicator of the body shape. The length is greatly influenced by acquired factors; considering the influence of movements to the body shape, it is significant to measure the lower limbs. ④Narrow pelvis is not only good for a gymnast to exert her speed, strength and other skills in the upper limbs, but also good for her development in running & jumping capabilities. Smaller hips and light lower body mean flexible movement, agile movement, less strength use and beautiful shape. Therefore, the pelvis width is an important indicator for measuring the body shape of a gymnast. ⑤The dimensions of the limbs reflect the development of muscles & fat of a person, and the muscle elasticity & strength to some extent; the dimensions of the limbs depend on the size of the cross section of muscles, and are important indicators to measure the physical quality of a gymnast. ⑥The Quetelet Index was proposed by Quetelet reputed as “Father of Human Body Measurement”, and the index is named with his name later. In paleoanthropology and human body development evaluation, it is widely used as an ancient and famous index. The index represents the weight per cm of height, which is obtained by the proportion between the weight and the height, and serves as relative weight or the weight of specific length for reflecting the dimensions, width, thickness and mass tissue density of a human body; the index is an important indicator reflecting the uniformness of the development of a gymnast.

(2) Physiological function. When the physiological indicator is selected, we selected the exercise load function and the vital capacity test. ①The cardiac function index is a simple method to determine the athlete's heart function which is evaluated according to the calculated index. The cardiac function index indicates whether the cardiovascular system function is good or bad, the smaller the index is, the better. And the cardiovascular system function directly affects athletes' ability to bear the training and competition load and the body's recovery ability. The broadsword, rod, sword and spear events require strong power and fast speed and, therefore, require heavy load and high strength. The athletes should have a high cardiovascular system performance level. ②The vital capacity is the amount of gas exhaled at the greatest strength within unlimited time after a maximum inspiration. It represents a person's maximum ventilation ability by breathing and is one of the important functional indicators to reflect the level of athletes' growth and development.

(3) Sports quality. We evaluate athletes' sports quality from their flexibility, strength, sensitivity, endurance and skill movements. ①By improving the quality of flexibility, a better play can be given to the athletes' strength, speed, sensitivity and other sports quality and a positive effect can be generated on improving sports skills and technology, preventing sports trauma, etc. According to the characteristics of Wushu event, flexibility of the shoulder joint, hip joint and lumbar vertebrae and extension of the muscle and ligament in the leg are important to Wushu movements. Therefore, the indicator of turning the shoulder while holding a rod is selected to evaluate the flexibility of the shoulder joint and the indicator of split is selected to evaluate the flexibility of hip extension, the greater the value is, the worse the flexibility is. The stand-trunk-bending is adopted to evaluate the flexibility of the hip and lumbar spine and the extensibility of the muscles and ligaments.

②The strength quality of the athletes has a decisive role in their competitive ability and different events have different requirements on the strength quality. In Wushu event, the strength quality is also crucial. Strength can be divided into static and dynamic ones by nature. Wushu movements are a combination of both static and dynamic movements, so the indicator of back muscle strength is adopted to test the static force. ③Explosive force is a dynamic force that requires the greatest strength in the shortest possible time, it depends not only on strength but also on the combination of strength

and speed. The greater a person's instantaneous muscle contraction force is, the greater its ability of fast movement is. Standing long jump is to determine the explosive force of athletes' legs and the coordination ability of their bodies, we select standing long jump as the indicator to test the explosive force of the lower limbs and coordination ability of the waist strength. ④Burpee is to reflect the athletes' ability of quickly, accurately and coordinately changing the body posture. It is closely related to the strength, flexibility and coordination and is the comprehensive performance of coordination of the relevant parts, physical quality and sports skills during movements of the human body. ⑤Cross jump is to reflect the ability of human body in changing direction and flexibly controlling the body. Sensitivity is not only related to the excitability of the brain, to the sense of time and space and the rate of response, but also highly related to strength and contraction speed of muscles. ⑥Raising leg on wall bars is the indicator to evaluate the waist strength. Trunk is the hub that connects the upper and lower limbs and the play of their strength depends on the size of the trunk strength. The human body must form a coordinated whole in order to complete a technical movement and it relies on sufficient waist strength to complete the high quality difficult Wushu movements. ⑦Oolong dish (a movement of Wushu) is one of the basic movements of Wushu and can reflect the athlete's shoulder range of activities and arm strength, as well as agility of the upper limb movement, etc. and therefore, is a necessary special quality to master all kinds of technical movements of Wushu.

4. Hierarchical Computation Model

Through analysis of the context, we can build the corresponding three-tier hierarchical model. In the model, the target layer is the evaluation indicator system; the criterion layer is composed of three aspects: body shape, physiological function and sports quality; and the specific division of the program layer can be obtained from the context analysis. The hierarchical model is derived from the analysis of the actual problem and then layering of the relevant factors from top to bottom, the upper layer will be affected by the lower layer and the various factors in a layer are basically independent from each other.

Based on the constructed hierarchical model, we need to construct the corresponding pairwise comparison matrix to finally determine the corresponding factor weight. Through the summary of the hierarchical structure and the corresponding indicators and in the expert scoring method, questionnaire was issued to 15 experts in the field of Wushu broadsword, rod, sword and spear and 1 ~ 7 scale was used to measure the relative weight between the factors. We conducted statistics of the evaluation results of the experts, selected the weight voted for the most as the final weight, and then constructed pairwise comparison matrix of the four layers corresponding with the above layer.

After obtaining the pairwise comparison matrix, we need to calculate the maximum eigenvalue and its corresponding eigenvector for each pairwise comparison matrix, and carry out the consistency test with the consistency indicator, the random consistency indicator and the coincidence ratio. If the test is passed, the normalized eigenvector can be used as the weight vector for each program factor. The calculation formula of consistency indicator (CI) is:

$$CI = \left(\frac{\lambda_{max} - n}{n - 1} \right)$$

λ_{max} is the largest characteristic root of the matrix, n is the matrix order.

The value of the random consistency indicator (RI) is related to the order of the matrix, as follows:

Table 1. Random consistency indicators.

N	1	2	3	4	5	6	7	8	9	10	11
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51

The calculation formula of consistency ratio (CR) is:

$$CR = \frac{CI}{RI}$$

When $CR < 0.1$, the inconsistency degree of A is within the allowable range.

The pairwise comparison matrix of the criterion layer to the target layer obtained according to the expert score is as shown in Table 2. Through the analysis, it is found that the score of sports quality is the most important for athletes' evaluation, followed by the body shape and the physiological function. As per calculation, the consistency ratio is 0.056, less than 0.10, the degree of inconsistency is within the allowable range and the eigenvector can be used as the weight vector.

Table 2. Pairwise comparison matrix between Layer B and Layer A.

Evaluation Indicator System	Body shape	Physiological function	Sports quality	W	CI	CR
Body shape	1.000	3.000	0.200	0.188		
Physiological function	0.333	1.000	0.143	0.081	0.032	0.056
Sports quality	5.000	7.000	1.000	0.731		<0.10

Next is the calculation of the pairwise comparison matrix of the indicator hierarchy to the criterion hierarchy, i.e. analyzing the influence weights of the specific indicators of the body shape, physiological function and sports quality to the three types of factors. First, the body shape indicators, including seven characteristics, i.e., height, upper limb length, forearm ratio, lower limb length, pelvic width, upper limb circumference and Quetelet Index. By sorting out the experts' ratings, the pairwise comparison matrix obtained is shown in Table 3. According to analysis, we know that the pelvic width, upper limb circumference and Quetelet Index are relatively important measuring indicators for a Wushu athlete. As per calculation, the consistency ratio is 0.074, the degree of inconsistency is within the allowable range and the eigenvector can be used as the weight vector.

Table 3. Pairwise comparison matrix between Layer C and Layer B1.

Body shape	Height	Length of upper limbs	Forearm ratio	Length of lower limbs	Pelvis width	Upper limb circumference	Quetelet Index	W	CI	Consistency check
Height	1.000	0.333	0.250	0.500	0.200	0.167	0.143	0.0306		
Length of upper limbs	3.000	1.000	0.500	2.000	0.333	0.250	0.200	0.0701		
Forearm ratio	4.000	2.000	1.000	0.333	0.500	0.333	0.250	0.0809		
Length of lower limbs	2.000	0.500	3.000	1.000	0.250	0.200	0.167	0.0735	0.098	0.074
Pelvis width	5.000	3.000	2.000	4.000	1.000	0.500	0.333	0.16		<0.1
Upper limb circumference	6.000	4.000	3.000	5.000	2.000	1.000	0.500	0.238		
Quetelet Index	7.000	5.000	4.000	6.000	3.000	2.000	1.000	0.3469		

Layer B2 is the physiological function layer, measured by the cardiac function index and the vital capacity index. According to the experts' ratings, the pairwise comparison matrix between Layer C and Layer B2 obtained is shown in Table 4. It can be seen that relative to the vital capacity, the cardiac function index is a more important indicator, which may be because energy supply for Wushu mainly is the anaerobic energy supply.

CR is 0, the degree of inconsistency is within the allowable range and the eigenvector can be used as the weight vector.

Table 4. Pairwise comparison matrix between Layer C and Layer B2.

Physiological function	Cardiac function index	Vital capacity	W	CI	Consistency check
Cardiac function index	1.000	9.000	0.9	0	CR=0
Vital capacity	0.111	1.000	0.1		CR<0.10

Layer B3 is the sports quality layer, according to the weights in Table 2, we know that the layer is the most important one. According to the experts' ratings, the pairwise comparison matrix between Layer C and Layer B3 obtained is shown in Table 5. By analyzing the weight of each indicator, we can see that the basic qualities of Wushu training such as raising leg on wall bars and Oolong dish have very high weights, and burpee and cross jump which measure the athletes' agility and flexibility are also very important. As per calculation, the consistency ratio is 0.035, the degree of inconsistency is within the allowable range and the eigenvector can be used as the weight vector.

Table 5 Pairwise comparison matrix between Layer C and Layer B3.

Sports quality	Turning the shoulder while holding a rod	Split	Stand-trunk-bending	Back strength	Standing long jump	Burpee	Cross jump	Raising leg on wall bars	Oolong dish	W	CI	Consistency check
Turning the shoulder while holding a rod	1.000	3.000	4.000	2.000	0.500	0.333	0.250	0.200	0.167	0.0507		
Split	0.333	1.000	2.000	0.500	0.250	0.200	0.167	0.143	0.125	0.0247		
Stand-trunk-bending	0.250	0.500	1.000	0.333	0.200	0.167	0.143	0.125	0.111	0.0183		
Back strength	0.500	2.000	3.000	1.000	0.333	0.250	0.200	0.167	0.143	0.035	0.05	0.035
Standing long jump	2.000	4.000	5.000	3.000	1.000	0.500	0.333	0.250	0.200	0.074		<0.1
Burpee	3.000	5.000	6.000	4.000	2.000	1.000	0.500	0.333	0.250	0.1075		
Cross jump	4.000	6.000	7.000	5.000	3.000	2.000	1.000	0.500	0.333	0.1555		
Raising leg on wall bars	5.000	7.000	8.000	6.000	4.000	3.000	2.000	1.000	0.500	0.2223		
Oolong dish	6.000	8.000	9.000	7.000	5.000	4.000	3.000	2.000	1.000	0.3121		

After we get the pairwise comparison matrix of the four layers, we can combine 18 indicators to make the final evaluation of the hierarchical index system we have established according to the total order sorting. The AHP carries out decision-making and analysis according to the results represented by the weighted vector of the total order sorting.

As can be seen from the overall ranking levels, the sports quality, especially that of special Wushu, plays an important role in the evaluation system of broadsword, rod, sword and spear athletes, which also shows the importance of sports quality in the evaluation of these athletes. In addition, other important indicators include burpee and cross jump which measures the athletes' agility and cardiac function index which reflects the physique. According the order of the indicators and their corresponding weights, we can establish the quality indicator system of broadsword, rod, sword and spear athletes in the AHP. The formula is

$$S = \sum_{i=1}^{18} c_i * W_i$$

Where S is the total score for the athlete, c_i is the score for the i-th item, and W_i is the weight of the i-th item.

Table 6. Calculation result of overall order of layers.

Target layer program	Weight of indicator	Order of weights
Height C11	0.0057	17
Length of upper limbs C12	0.0132	16
Forearm ratio C13	0.0152	13
Length of lower limbs C14	0.0138	14
Pelvic width C15	0.0301	10
Upper limb circumference C16	0.0447	8
Quetelet Index C17	0.0652	6
Cardiac function index C21	0.0729	5
Vital capacity C22	0.0081	18
Turning the shoulder while holding a rod C31	0.0371	9

Split C32	0.018	12
Stand-trunk-bending C33	0.0133	15
Back strength C34	0.0256	11
Standing long jump C35	0.054	7
Burpee C36	0.0786	4
Cross jump C37	0.1137	3
Raising leg on wall bars C38	0.1625	2
Oolong dish C39	0.2281	1

5. Realization of Evaluation System for Broadsword, Rod, Sword and Spear Athletes

With the evaluation model for broadsword, rod, sword and spear athletes analyzed and established above, we have realized an evaluation system for Wushu athletes which can record the athletes' body test data and detailed scores and analysis so that the coaches and faculty members can obtain the relevant test data analysis and master the athletes' physical conditions, thus providing the basis for the selection of Wushu athletes. The system establishes a data model based on AHP with the relevant test data of the gymnasts, and calculates the indicators in the test with software, for providing physical test reports and capability analysis for individuals.

The evaluation system for broadsword, rod, sword and spear athletes can realize the function of managing the indicator test data of the athletes and automatically generate the corresponding evaluation report to provide guidance for the selection process. The system is mainly applied in the evaluation stage. After obtaining the 18 indicators of Wushu athletes test, with Wushu athletes evaluation model established above, we can comprehensively calculate an athlete's comprehensive score, and generate the test report of the relevant indicators so as to conduct a scientific and detailed assessment on the athlete. The overall flow chart of the system is shown in Figure 2:

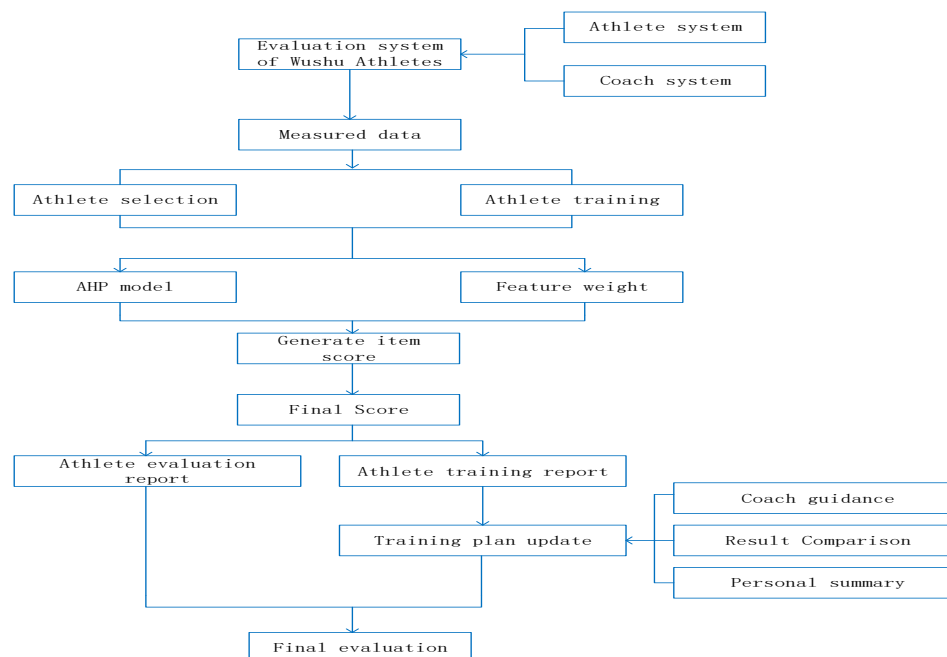


Figure 2. Flow chart of the evaluation system for Wushu athletes

We take a “martial hero” level athlete as an example to show and explain the evaluation system for broadsword, rod, sword and spear athletes. After logging in the system, a gymnast can enter the user interface with the functions of basic gymnast information maintenance, physical quality status, Wushu test requirements, Wushu test rating indicators, personal test report export, etc. The corresponding interface implementation effect is shown in Figure 3 below.

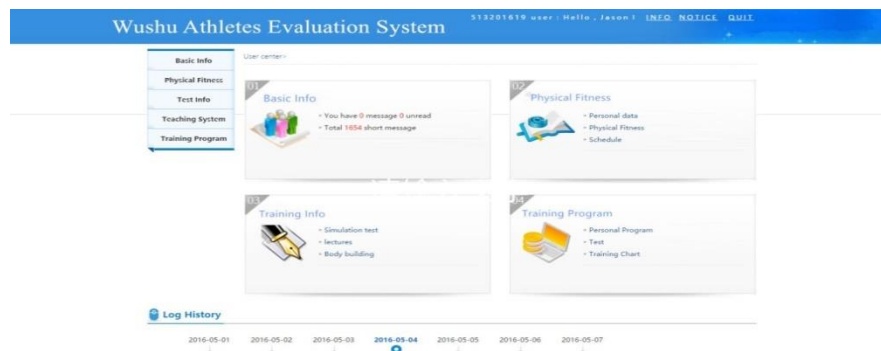


Figure 3. Main interface for Wushu athlete user

The quality indicator evaluation system of Wushu athletes analyzes mainly the scores of an athlete's 18 indicators, for establishing the evaluation model. The data analysis results can be shown in the corresponding data statistics visualization method. From a gymnast's physical quality, test requirements and test status, the test data for all of the indicators of the gymnast, as well as the details & historical development curves of the indicators; the user interface implementation effect is shown in Figure 4.



Figure 4. Interface of indicator status development curve

A coach can also view the corresponding data of athletes, and select good ones according to their conditions and test results. After completing the data of physical quality tests, a coach can visually see the distribution of the scores of the physical quality evaluations of the athletes, and the user interface implementation effect is shown in Figure 5.

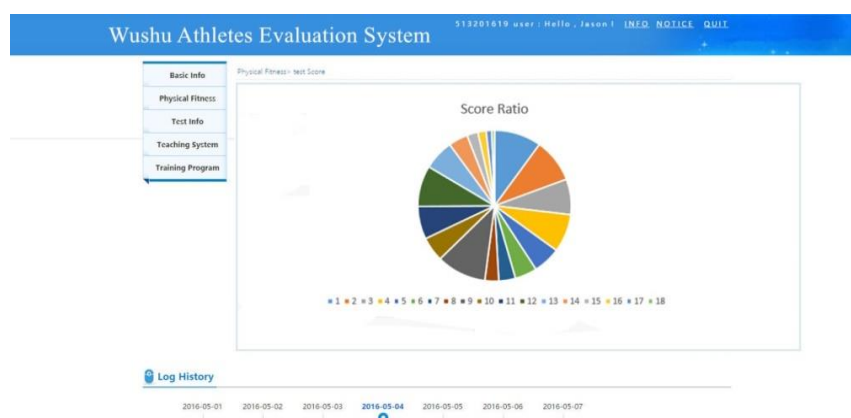


Figure 5. Interface for coach viewing physical quality status of athletes

The evaluation system for broadsword, rod, sword and spear athletes mainly analyzes scoring data of the athlete's 18 indicators. The analysis results are expressed in various forms, including curve

graphs and distribution diagrams, and so on. The complex data are intuitively expressed and can further reflect the athletes' physical quality and professional skills, thus providing the basis for scientific selection.

6. Conclusion

In the process of evaluation and selection of broadsword, rod, sword and spear athletes, the AHP can take into account the knowledge and experience of the experts concerned, avoid the shortcomings of individual subjective consciousness and one-sidedness. Therefore, the evaluation results can reflect the athlete's actual level and development potential. The AHP is simple in thinking and clear in hierarchy, and it make the complex problem of evaluating Wushu broadsword, rod, sword and spear athletes structured, hierarchized and quantified, which is very practical. Therefore, the evaluation indicator system of broadsword, rod, sword and spear athletes established in AHP is an exploration into the scientific selection of Wushu talents and also provides a new idea for the scientific selection of athletes in other sports events.

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