A Tennis Player's Momentum Assessment Based on Game Theory and Projection Pursuit Evaluation Model

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Abstract. This paper comprehensively evaluates the athletic motivation of tennis players through the game theory combination weighting model and the simulated annealing optimization projection pursuit evaluation model, aiming to uncover the key factors affecting athletes' performance. The research results indicate that the main factors influencing athletes' motivation are "Type of return" (weight 24.12%). A specific analysis reveals that Carlos Alcaraz outperformed Novak Djokovic in the 30-34 games, especially showcasing his best form in the 3rd game. The study shows that the smaller the momentum difference of the serving side, the higher the likelihood of winning the match. Although an athlete may dominate the match, the adaptability and endurance of the opponent are equally crucial, emphasizing the importance of match strategy. These findings provide theoretical support and practical guidance for the optimization of training and match strategies for tennis players.

Keywords: Tennis Player, Momentum, Portfolio Assessment Model, Game Theory, Projection Pursuit Evaluation Model.

1 Introduction

With the development of competitive sports, tennis, as a highly skilled, physically demanding, and mentally challenging sport, is receiving increasing attention. Athletes need to continuously adjust their physical, technical, and psychological states during competitions to achieve optimal performance, making the scientific evaluation of tennis players' motivational levels of great importance [1]. Traditional evaluation methods often focus on physical indicators or technical performance, neglecting the dynamic balance and mutual influence of physical, psychological, and technical factors. This issue has prompted researchers to seek more systematic and scientific methods to comprehensively evaluate the motivational levels of tennis players.

In the field of tennis players' motivational evaluation, numerous studies have focused on the impact of athletes' physical fitness, technical skills, and psychological qualities on match performance [2-4]. Traditional evaluation methods typically emphasize quantitative indicators such as ball striking speed, mobility, and win rates, lacking a comprehensive consideration of multidimensional factors. In recent years, scholars

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have begun to explore more systematic evaluation models, such as using fuzzy comprehensive evaluation, Analytic Hierarchy Process, and other methods to analyze athletes' performance [5, 6]. However, these methods often fail to fully reflect the interactions between various factors and their impact on overall performance when dealing with complex dynamic systems.

This study introduces the game theory combination weighting model and the simulated annealing optimization projection pursuit evaluation model, providing a new perspective for the assessment of tennis players' motivation. This approach not only enhances the scientificity and systematicness of the evaluation but also offers theoretical support for optimizing athletes' training, tactical decision-making, and long-term development. It contributes to the promotion of scientific management in competitive sports and the innovation of training models.

2 Methodology

2.1 Data Source

In this study, to ensure the reliability and accuracy of the research findings, we selected data from the men's singles event of the 2023 Wimbledon Championships as the core research resource (http://www.wimbledon.com, https://www.comap.com/contests/mcm-icm) [7]. The dataset involved encompasses all matches following the second round of the men's singles, documenting 31 encounters between Carlos Alcaraz and Nicolas Jarry. This dataset consists of a total of 7,284 records, detailing key moments, scores, movement patterns, serve-and-return directions, break points, and unforced errors of both players during the matches.

2.2 Identification of Key Indicators

We rated the athletes' offensive ability, defensive ability, and physical condition as Tier 1 indicators, which are the core indicators that have the most direct impact on the athletes' momentum. Then we subdivided the first-level indicators into second-level indicators after identifying the first-level indicators. Athletes' offensive ability is directly affected by the net win rate (the number of net wins/net wins, which measures an athlete's offensive ability) and the first serve win rate. An athlete's defensive ability can be broken down into first serve return, type of re-turn, and number of shots hit in a round. Physical condition can be broken down into distance traveled (which can be averaged over each round of a player's match as a measure of his or her physical strength), serve speed, and type of serve (see Fig. 1).

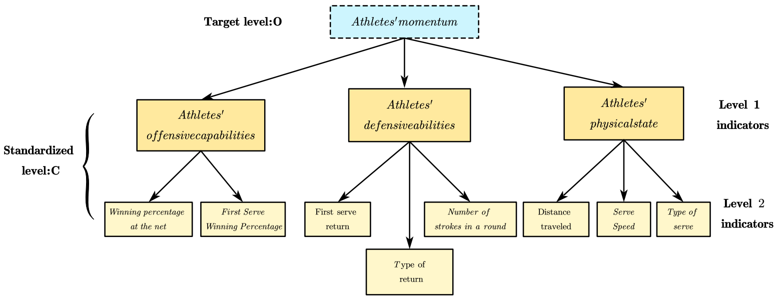

Fig. 1. Identification of key indicators.

2.3 Game Theory Combination Weighting Model

Analytic Hierarchy Process. The Analytic Hierarchy Process (AHP) is an analytical method widely used in multi-attribute decision-making [8]. By breaking down complex issues into multiple levels, it enables decision-makers to systematically evaluate the importance of various factors. AHP typically includes three levels: the objective level, the criteria level, and the alternative level. During implementation, decision-makers use a pairwise comparison approach to judge the importance of different factors, quantify these subjective judgments into weights, and thus provide a basis for decision-making. AHP also includes a consistency check to ensure the consistency of judgments, thereby enhancing the reliability of decision-making.

Entropy Weighting Method. The Entropy Weight (EW) method is a weight determination method used for multi-index evaluation and decision-making, which assesses the importance of each index based on the principle of information entropy [9]. In the EW method, each index is first standardized to eliminate the influence of dimensions. Then, by calculating the information entropy of each index, its information content and uncertainty are reflected. The smaller the information entropy, the less information the index provides in the decision-making process, and thus its weight should be higher. Ultimately, the weights of each index are calculated based on the entropy values to form a comprehensive evaluation model.

Game Theory Combination Weighting Model. The Game Theory Combination Weighting (GTCW) model is a multi-index weight allocation approach based on the principles of game theory, aimed at determining the importance of each index by analyzing the interactions and conflicts among participants [10]. In this method, decision-makers are considered as players in the game, with each player assigning weights to the various indices based on their own interests and objectives. By constructing a game model and utilizing theories such as the Nash Equilibrium, the GTCW model can reveal the mutual influence among the indices and their true value in the decision-making process. The advantage of this method lies in its comprehensive consideration of the perspectives and interests of different participants, reducing the subjective bias that may arise from a single decision-maker, thus improving the objectivity and rationality of weight distribution. The GTCW model is widely applied in fields such as social sciences, economics, and management decision-making, providing new insights and tools for complex decision-making and helping decision-makers to achieve better choices in multi-party interest games.

2.4 Simulated Annealing Optimization Projection Pursuit Evaluation Model

The Simulated Annealing Optimization Projection Pursuit Evaluation (SAO-PPE) model is a multi-index decision analysis tool that combines simulated annealing algorithms with projection pursuit methods [11]. The projection pursuit method helps decision-makers identify and analyze the key structures and patterns in data by projecting high-dimensional data onto a lower-dimensional space. In this model, the SA algorithm is used to optimize the parameter configuration in projection pursuit, enhancing the accuracy and stability of the evaluation model. Specifically, SA sets an initial temperature and a cooling strategy, randomly selects solutions and evaluates their quality, accepting better solutions while also allowing for a certain probability of accepting worse solutions to balance exploration and exploitation. The advantage of this method lies in its strong global optimization capability, and it is widely applied in complex system evaluation, engineering decision-making, and resource management, providing scientific basis and effective support for decision-makers. The objective function of the SAO-PPE model is as follows:

$$\max Q(A) = S_Z \cdot D_Z \quad s.t.\begin{cases} A > 0 \\ \sum_{j=1}^{m} a_j^2 = 1, -1 < a_j < 1 \end{cases} \tag{1}$$

$$\begin{cases} S_Z = \sqrt{\dfrac{1}{n-1}\sum_{i=1}^{n}(z_i - \overline{z})^2} \\ D_Z = \sum_{i=1}^{n}\sum_{j=1}^{m}(R - r_{ij}) \cdot I(R - r_{ij}) \end{cases} \tag{2}$$

Where S_Z is the sample standard deviation. D_Z is the local density.

3 Results

3.1 Athlete Momentum Evaluation Results

During a tennis match, a player does not win and lose all the time. Since a match consists of a number of sets, we use the set as the unit of study, with fluctuating changes in the athlete's momentum as the number of sets increases. The innings study the performance of different athletes in the game and select the athlete who performs better (see Fig. 2).

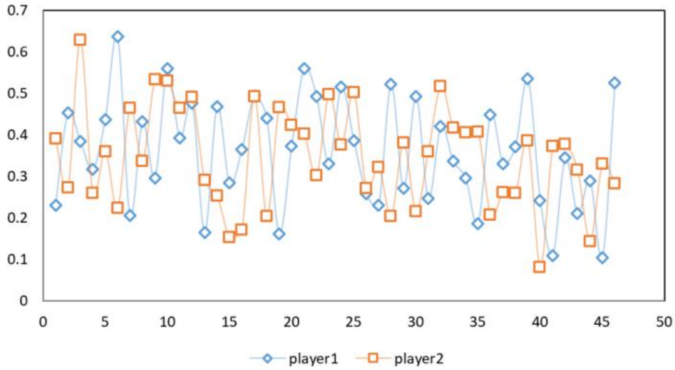

Fig. 2. Athlete momentum evaluation results.

From Fig. 2, we can clearly see the evaluation results of the two athletes' momentum in different games. The momentum of the two athletes fluctuates during a match, and the momentum is closely related to the winning or losing of the athletes. In a game, the athlete whose momentum pre-vails has a higher chance of winning the game. Therefore, in the 46 matches, Player1 has more momentum than Player2, and Carlos Alcaraz wins the game.

3.2 Sensitivity Analysis

For the rigor of the model, we vary the subjective and objective weight coefficients from -30% to +30% to study their impact on the final comprehensive weight results (see Fig. 3).

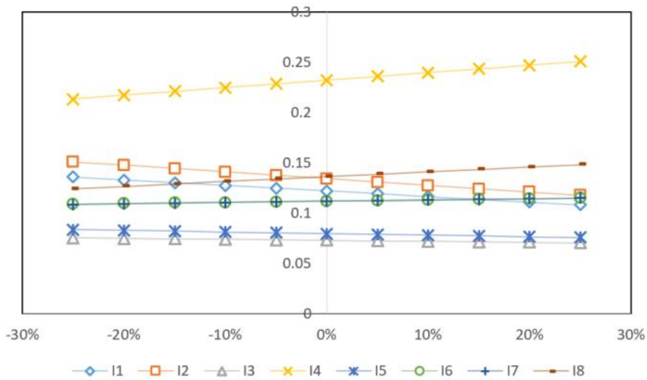

Fig. 3. Sensitivity analysis results.

From Fig. 3, we find that the change of the weights of the 8 indicators is relatively smooth, indicating that they are not sensitive to the change of the subjective and objective weight coefficients. Therefore, the changes in the proportion of subjective and objective weights have little effect on the model.

4 Conclusion

This paper conducted a comprehensive evaluation of tennis player's momentum based on the GTCW model and the SAO-PPE model. The results show that "Type of return" is the most important factor, with a weight of 24.12%. "Type of serve," "First serve winning percentage," "Winning percentage at the net," "Distance traveled," and "Serve speed" are the next in importance, with weights of 14.19%, 12.59%, 11.51%, 11.34%, and 11.31% respectively. And Carlos Alcaraz performs better than Novak Djokovic within 30-34 games, and performs best within the 3rd game. Therefore, the smaller the difference in momentum for the server, the greater the probability of winning the match. Even if an athlete is dominant for most of the match, i.e. has good momentum, this does not necessarily guarantee a win, as the opponent will adapt and maintain his/her stamina when playing against him/her. It is then possible for the opponent to subsequently gain the upper hand, so the strategy of the match is important.

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