

Research on Tennis Score Based on Momentum Quantization Model

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Abstract. The paper goal is to investigate the significance, logic, and effects of momentum in tennis matches in order to offer logical advice to athletes and tennis coaches. the paper created a quantitative momentum model and mostly finished three tasks based on the research objectives. Firstly, the paper develop a momentum quantification model and set four essential indicators to quantify the momentum. By adding together these indicators, the paper may determine a player's momentum score at a given scoring point. And a shift curve of momentum scores is shown using the momentum scores acquired at each scoring point, providing the groundwork for determining the competition's turning point in the future. Secondly, the randomness of momentum is assessed by us. To evaluate coaches' skepticism about the impact of momentum, the paper conducted two randomized experiments to investigate this issue. The first test is a randomness test based on outcome correlation. The paper calculate the correlation between the winner and the player with the highest score on the final score. The second test is the permutation test, which involves generating a large number of random permutations by redistributing the labels of the data points. It then calculates the consistent distribution between the highest momentum scorer and the competition winner under these random permutations. The test results all indicate that the player with the highest momentum score is the winner of the game. The paper proves that momentum plays a crucial role in the matches, and predicting momentum can be utilized to anticipate pivotal moments in the game.

Keywords: Momentum Score Model, Match Result Correlation, Permutation Test, Decision Tree Classification Model.

1. Introduction

In a series of sports competitions, tennis stands out as an extremely competitive and strategic ball sport. The result of a tennis match is often affected by various external factors, such as court conditions, temperature, and so on. Within this array of influencing factors, there is a concept that is frequently considered but challenging to quantify and predict: momentum. Momentum can be understood as the psychological and subsequent competitive advantage gained by a player when they continuously score due to outstanding performance in a match^[1]. In most people's minds, momentum is considered a somewhat mysterious phenomenon. However, with the advancement of science and technology, an increasing number of scientists are endeavoring to comprehend the concept of momentum and forecast its future trends using quantitative methods. It has been discovered that analyzing various match data, such as point differentials, break points, hold percentages, and serving games^[2], can help in constructing models to quantify momentum. These models can be used to explore how momentum influences the progression and ultimate outcome of a match. Through the analysis of momentum, the paper can provide crucial reference information for coaches and players, helping them better prepare for matches and formulate in-game strategies^{[3][4]}. Therefore, this article defines four indicators to quantify momentum and assigns different values to them.

2. Establishment of the Model

2.1. Indicator definition and assignment

The paper have defined four indicators to quantify momentum^[5]. Different values are assigned to these indicators based on relevant criteria, as shown in the Table 1:

Table 1. Factors defined

Factor	Condition	Momentum score change(point)
Basic score	Win a point	+1
Break point	Win a point on your opponent's service game	+5
Guaranteed score	Win a point in your own service game	+3
Reward for consecutive points	Win more than three points in a row	+2

2.2. Constructing the equations for Momentum

Firstly, the paper establish a unified momentum score model based on four indicators with assigned values: basic score (S_{base}), break score (S_{Break}), guaranteed score (S_{hold}), and continuous score reward($S_{consecutive}$), as follows:

$$\begin{cases} S_{base} = 1 \text{ point} \\ S_{Break} = 5 \text{ point (if break point won)} \\ S_{hold} = 3 \text{ point (if hold point won)} \\ S_{consecutive} = 2 \text{ point (if consecutive points won)} \end{cases} \quad (1)$$

Then, derive the momentum score ($S_{momentum}$) formula for the player at each scoring point as follows:

$$S_{momentum} = S_{base} + (S_{Break} \text{ if break point won}) + (S_{hold} \text{ if hold point won}) + (S_{consecutive} \text{ if consecutive point won}) \quad (2)$$

Due to the cumulative momentum score, the total momentum score of a player at each scoring point is calculated by adding up the player's momentum scores (S_{total}) in the game, as follows:

$$S_{total} = \sum_{i=1}^n S_{momentum_t} \quad (3)$$

Among them, $S_{momentum}$ represents the momentum score at the i -th scoring point, and n represents the total number of scoring points in the game. At this point, the momentum scoring model has been established^[6].

2.3. Solution of the Model

The paper used Python to implement the model and captured the scoring process in a total of 31 games in the dataset^[7]. Finally, The paper obtained tabulated data showing the momentum of different players for each game.

2.4. Visualization and Results

The paper visualize the data from the table and generate images to simplify and clarify the data. The paper utilize the visualization function of the model to illustrate the matching process. At the same time, the paper will use visual images to provide a detailed description of the game process and compare and analyze the results of the match numbered 1701. This will help us to determine whether the player's performance is consistent with the momentum score, in order to test the accuracy of the model.

In the match numbered 1701, the men's singles final between Carlos Alcaraz and Novak Djokovic at the 2023 Wimbledon Tennis Championships, the paper captured a visualized image of the complex momentum score as depicted fig.1 below.

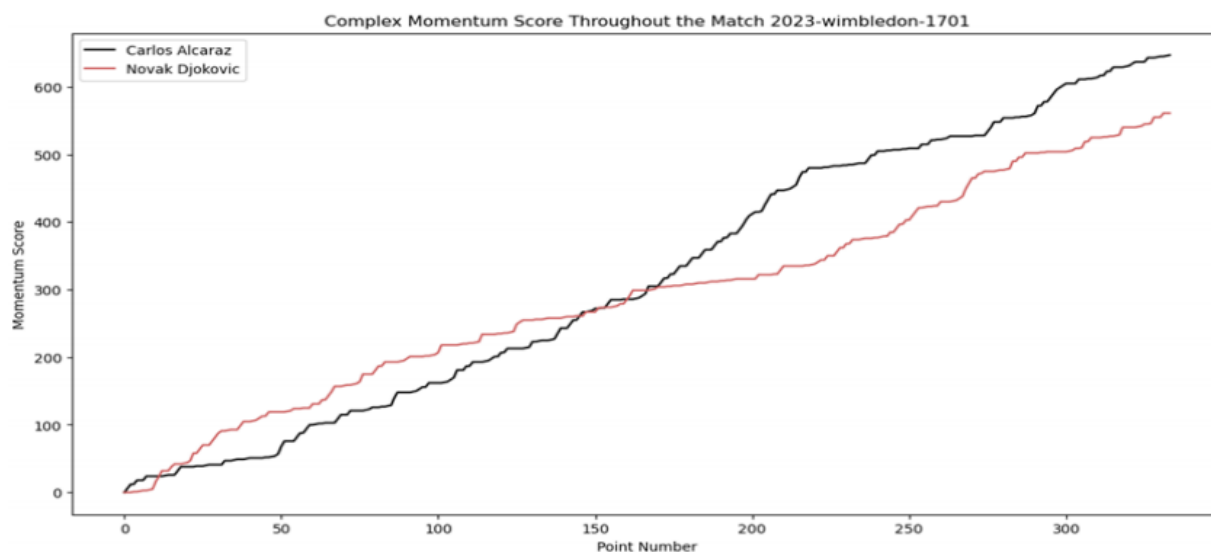


Fig. 1 Complex momentum scoring visualizations throughout the match 2023-wimbledon-1701

Through the graph, the paper can observe that in the first stage, Djokovic's momentum (red line) consistently exceeded Alcaraz's momentum (black line), which is consistent with Djokovic's 6-1 control of the game and apparent likelihood of an easy victory on the court. However, in the second stage, the momentum lines of the two players almost overlapped, and Alcaraz's momentum score was slightly higher than Djokovic's, which is consistent with the tense situation in the second set, where Alcaraz narrowly won the game. Finally, the black momentum line remained higher than the red momentum line^[8]. Although there was a decreasing trend in the momentum gap during the process, the gap quickly increased again. This is consistent with the situation where Alcaraz ultimately controlled the situation and won in each set from the third to the fifth.

The paper then conducted a similar visualization analysis of momentum scores for other matches. The following fig.2 illustrates the visualization of selected other matches.

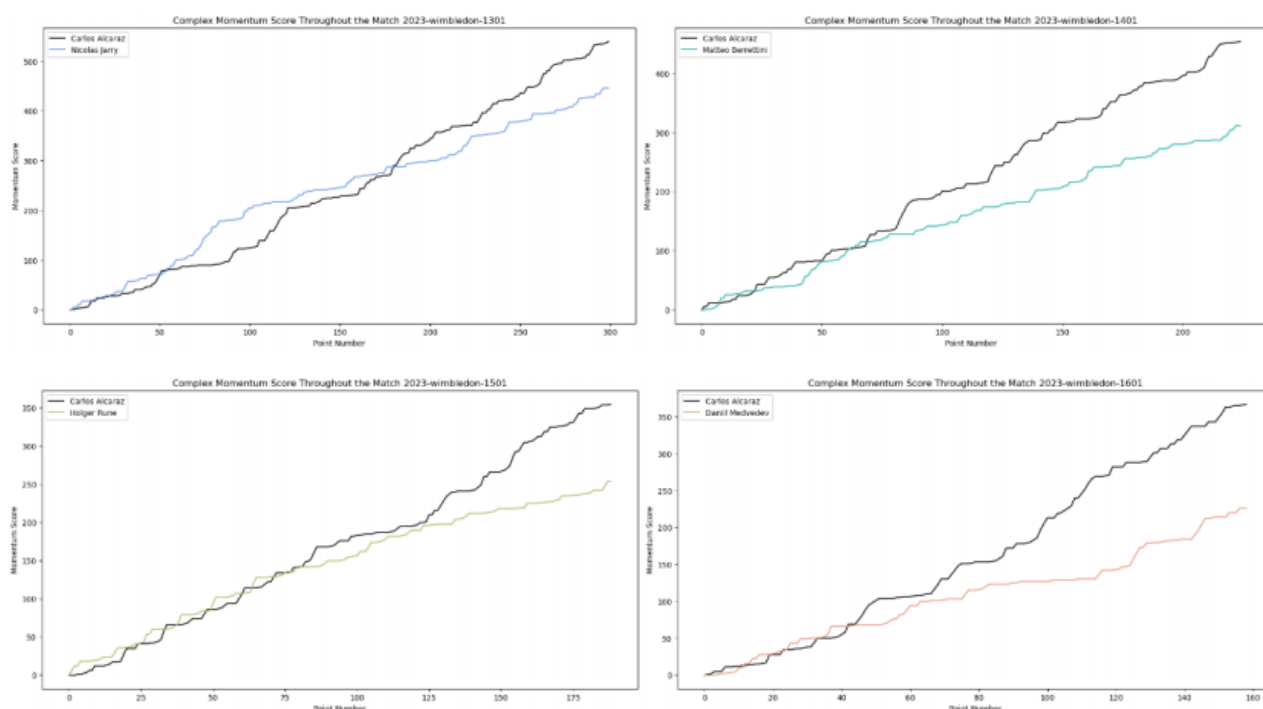


Fig. 2 Complex momentum scoring visualizations throughout the match(section)

Through the verification analysis and visual graphics display above, it was found that our momentum model results are entirely consistent with the players' performance. By utilizing momentum scores, the paper can assess the performance of any player at a specific time in the game, compare the performances of different players, and see how well they perform.

3. Random Test – Based on Match Outcome Correlation

3.1. Establishment of the Model

(1) Extract the information containing scoring details from the data file as the raw data.

(2) Determination will be made from two aspects, namely match scores and momentum scores:

Match Scores: Inference and judgment of the winner will be made by examining the last scoring point in each match.

Momentum Scores: It is assumed that the owner of the higher momentum score at the last scoring point is the winner of the match^[9].

(3) For each match, calculate the maximum momentum score achieved by each player. Assuming that Player 1 and Player 2 have momentum scores $Mp(i\ 1)$ and $Mp(i\ 2)$ at the i -th scoring point in the match, respectively, the formula for calculating the maximum momentum scores for Player 1 (Max_M1) and Player 2 (Max_M2) in the match is as follows:

$$M_{p1}^{max} = \max_i(M_{p1}^{(i)}) \quad (4)$$

$$M_{p2}^{max} = \max_i(M_{p2}^{(i)}) \quad (5)$$

The match winner can be determined by comparing the momentum scores at the last scoring point. Where $Mp1(\text{last})$ and $Mp2(\text{last})$ represent the momentum score of the last point in the game, player 1 and player 2, respectively. The formula is as follows:

$$W = \begin{cases} \text{player 1, if } M_{p1}^{(last)} > M_{p2}^{(last)} \\ \text{player 2, otherwise} \end{cases} \quad (6)$$

3.2. Solution of the Model

After determining the winner for each match and identifying the player with the maximum momentum score, the dataset containing a total of 31 matches will be grouped and analyzed to examine the association between momentum scores and match winners. The analysis results will be presented in the following Table 2:

Table 2. Relationship between maximum momentum score and match winner (section)

Match_id	The match rate between maximum momentum scorer and winner
2023-wimbledon-1301	100%
2023-wimbledon-1401	100%
2023-wimbledon-1501	100%
2023-wimbledon-1601	100%
2023-wimbledon-1701	100%

In the above table, the paper calculated the matching rate between the player with the maximum momentum score and the match winner. The results indicate that the recipient of the maximum momentum score is consistently the winner of the match. This observation suggests that momentum may play a significant role in the outcome of the matches.

3.3. Visualization and Results

Based on the above data, the paper use a scatter plot to display the maximum momentum scores of the two players in each match^[10]. The color distinguishes whether the player with the maximum momentum score is consistent with the match winner, with blue indicating consistency and red indicating inconsistency. The scatter plot for match number 1701 is shown below fig.3.

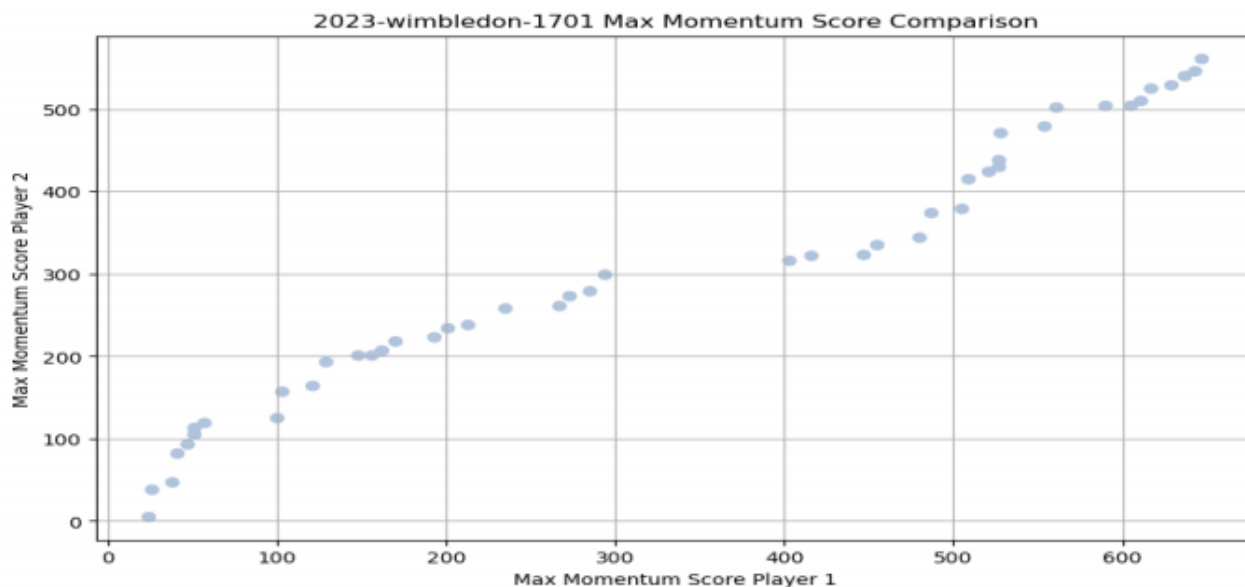


Fig. 3 2023-wimbledon-1701 Max Momentum Score Comparison

The visual representation clearly indicates that all data points are blue, meaning that the player with the maximum momentum score perfectly aligns with the match winner in every case.

4. Random Test–Based on Permutation Test

The paper requires establishing a model to clearly demonstrate the process of scoring in a game, in order to measure the performance of different players at different times.

4.1. Solution of the Model

The magnitude of the p-value indicates the probability of observing the original data in the newly generated random permutations. If the p-value is large, it suggests that there is a high probability of observing the original data even after random permutations, indicating that momentum in tennis matches is just a random occurrence^{[11][12]}. If the p-value is small, it suggests that the likelihood of observing the original data after random permutations is low, indicating that momentum in tennis matches is not a random phenomenon. After solving using Python, all Tobs values for each match are 1.0, and the p-value is 0.0. This suggests that the consistency between the player with the highest momentum score and the winner in the original data is 100%, which is a higher probability than the consistency proportion in all randomly permuted sequences. Therefore, the paper conclude that momentum shifts and player winning streaks in tennis matches are not random but are correlated.

4.2. Visualization and Results

Based on the above research analysis, the paper have plotted the histogram and the original statistic for the permutation test results of the match with the number 1701, as shown in the fig.4 below.

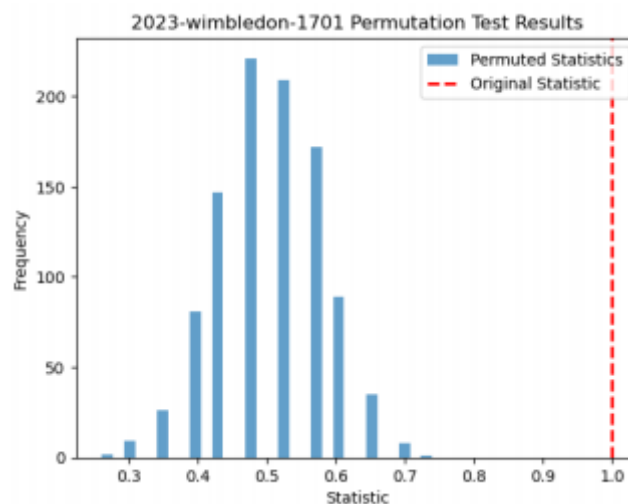


Fig. 4 2023-wimbledon-1701 Max Momentum Score Comparison

The histogram provides a clear depiction of the distribution of statistics calculated after permutation randomization. The red line representing the statistic from the original data is situated on the far right of the permutation distribution. This placement indicates that the alignment between the player with the higher momentum in the original data and the winner is statistically significant, implying a non-random occurrence.

5. Conclusions

In tennis, variations in gender, format, and venue can all impact the predictive accuracy of the model, but it still maintains a high level of accuracy. The model have developed is highly versatile, but it may require adjustments for different competitions, genders, and athlete types based on factors such as competition rules and athlete characteristics.

The results of the random tests based on match outcomes indicate a strong correlation between the maximum momentum score and the match winner. Additionally, the results of permutation-based random tests suggest that fluctuations and turning points in the matches are non-random. Therefore, the paper conclude that momentum transcends randomness, thereby dispelling the coach's skepticism. Furthermore, momentum plays a crucial role in the matches, and predicting momentum can be utilized to anticipate pivotal moments in the game.

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