ORIGINAL ARTICLE

Loss aversion under pressure: Analyzing decision-making in high-stakes tennis through Grand Slam big data

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ABSTRACT

This study examines loss aversion behaviour in professional tennis, with a focus on players' responses to high-stakes situations such as game points and break points. While prior research has provided valuable insights, it has predominantly relied on limited match samples, often confined to select tournaments or individual players. To address this limitation and enhance the generalizability of findings, the present study employs a comprehensive dataset comprising ten years (2010–2020) of five-set matches from all four Grand Slam tournaments. Anchored in Prospect Theory—which suggests that individuals are more motivated to avoid losses than to acquire equivalent gains—the analysis investigates key performance indicators including scoring success rate, serve ace rate, and double fault frequency. The results indicate that players exhibit loss-averse behaviour in specific contexts, notably by reducing double faults during break points. However, other performance metrics, such as ace rates and serve accuracy, do not consistently reflect loss-averse tendencies. A post-hoc analysis based on point differentials further elucidates the nuanced manifestations of loss aversion across varying match contexts. These findings contribute to a more robust understanding of risk-related decision-making in elite sports and offer implications for performance optimization and athlete management.

Keywords: Loss aversion, Prospect theory, Tennis, Serve performance, Risk aversion, Player behaviour, Game points, Break points.

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INTRODUCTION

The Loss Aversion Theory (LAT) is a significant concept arising at the intersection of economics and psychology, explaining that people assign different weights to equivalent amounts of gains and losses. Specifically, individuals exhibit a stronger tendency to avoid losses than to pursue gains. Despite placing greater weight on losses, people tend to be risk-seeking in the domain of losses and risk-averse in the domain of gains (Kahneman & Tversky, 1979).

Although numerous studies providing evidence for the existence of loss aversion, scepticism remains among researches about whether individuals consistently assign greater weight to losses across different contexts (Anbarci et al., 2018). For instance, previous research suggests that the tendency for loss aversion may not manifest depending on the level of prior experience and expertise (List, 2003; Levitt & List, 2008).

Therefore, previous studies have been conducted to examine whether loss aversion tendencies arise in decision-making or behaviour under controlled conditions, particularly in fields where skill and expertise are guaranteed, such as professional sports. In response to scepticism regarding loss aversion, previous research conducted field research using data from professional golfers (Pope & Schweitzer, 2011). The study verified that golfers exhibit loss aversion tendencies in actual games. Golfers were found to concentrate more in the loss domain: they were significantly less accurate in putts for "*birdie*" (one stroke under par) or "*eagle*" (two strokes under par) compared to similar putts for "*par*" or above (e.g., "*bogey*" for one stroke over par or "*double bogey*" for two strokes over par). This trend was consistent even among experienced professional golfers.

Therefore, the extant research validated loss aversion among professional golfers in the US Open tournaments (Elmore & Urbaczewski, 2021). Their analysis of data from 11 US Open tournaments revealed that top golfers exhibited substantial loss aversion behaviours. Additionally, Anbarci et al. (2018) examined loss aversion behaviours in tennis, finding that players took more risks with serve speed when trailing in points or rankings.

Greve et al. (2021) identified that soccer players were less sensitive to gains and losses in the loss frame. The study demonstrated that even in top-division matches in European soccer leagues, players showed a decrease in rational decision-making regarding fouls and an increase in loss-averse behaviour, explained by prospect theory.

However, there are lack of comprehending the mechanisms of loss aversion behaviour from a few studies due to the varying contexts of decision-making in different sports and the types of data collected in field research.

In this regard, insights gained from prospect theory can aid in identifying the conditions under which player perform optimally and those under which they encounter difficulties, highlighting the need for further research to understand player' decision-making patterns. However, many studies tend to focus on specific situations or general trends without adequately considering situational factors, thereby limiting the applicability of their findings.

In dynamic sports such as tennis, match conditions can change rapidly. Therefore, it is essential to conduct inquiries and various analyses that adequately reflect these dynamic changes and address potential issues. Conducting tailored research that considers match conditions can deepen our understanding of tennis

players' decision-making and performance, contributing to the development of training and strategies that lead to practical improvements.

Thus, this study aims to verify loss aversion behaviour in tennis games based on prospect theory. Tennis is a sport where individual skill, strategy, and psychological state play crucial roles. During matches, players continuously make decisions to maintain their service games and break the opponent's serve to gain an advantage for victory (Anbarci et al., 2018). In such decisions, both risk and reward coexist, and the Loss Aversion Theory provides critical insights into how players respond in these situations.

Against this backdrop, the objective of this study is to identify biased decision-making and behaviours in tennis players through a comprehensive understanding of prospect theory, thereby suggesting strategic directions for performance improvement. The specific aims of the research are as follows:

First, the study seeks to thoroughly understand the characteristics of tennis and define loss-averse decision-making within the context of match situations. Previous studies that identified loss-averse behaviours in tennis players often had limitations, such as viewing the player's serve as a single measurement variable without adequately considering the specific characteristics of the sport. This study aims to overcome these limitations by obtaining more comprehensive data to enhance the understanding of loss-averse situations in tennis matches.

Second, the study aims to verify the tendencies of loss aversion in tennis players. This will be accomplished through the collection and analysis of actual match data. Based on these findings, the study will propose strategic directions for players.

The structure of this study is that chapter 2 provides an understanding of prospect theory and the concept of loss aversion, reviewing prior research to identify areas that need further exploration. Chapter 3 presents the hypotheses formulated to achieve the research objectives and describes the data collection and analysis procedures. Chapter 4 details the results of the data analysis. Lastly, chapter 5 derives implications from the research findings.

Research background and hypotheses

For this study we define server' and receiver' gain and loss as Table 1. The fundamental assumption of this study is that, in loss situations, players exert greater effort to avoid losses, which subsequently leads to outcomes such as scoring points and improving serve success rates. Based on prior research, this study defines gain and loss situations for both the server and receiver. For the server, a gain situation refers to a game point, where winning one point secures the game, while a loss situation occurs when losing a point results in losing the game. In contrast, the definitions for the receiver are the opposite.

Table 1. Operational definition.

		Definition
Server	Gain	Game point situation where winning one point secures the game
	Loss	Break situation where losing one point results in losing the game
Receiver	Gain	Break situation where winning one point secures the game
	Loss	Game point situation where losing one point results in losing the game

The feeling of loss experienced by the server when losing a point in a break situation, thereby conceding the game, is likely to be greater than the value of winning a point in a game point situation to secure the game.

Similarly, for the receiver, the sense of loss in a game point situation, where losing a point result in losing the game, is expected to be greater than the value of winning a point to defend the game.

Literature review

Prospect Theory emphasizes that decision-makers do not always behave rationally due to bounded rationality in the decision-making process (Kahneman & Tversky, 2013). They point out the limitations of expected utility theory and introduce a value function that is concave in gains and convex in losses. This provides the insight that losses of the same magnitude have a greater impact than equivalent gains.

In traditional economics, the value curve T(x) reflects equal gains and losses for the decision-maker, where the perceived value by the decision-maker is the same. In other words, the happiness derived from a gain and the pain caused by a loss of the same magnitude cancel each other out, leading to T(x) = x.

As shown in Figure 1, in behavioural economics, the value curve V(x) shows that when the point lies on the positive half-axis of xxx, the decision-maker's behaviour is based on gains, while when the point lies on the negative half-axis of xxx, it reflects losses. For points A (x1, y1) and C(x3,y3), where |x1| = |x3|| and |V(x3)| > |V(x1), it holds that the pain from losses is significantly greater than the pleasure from equivalent gains.

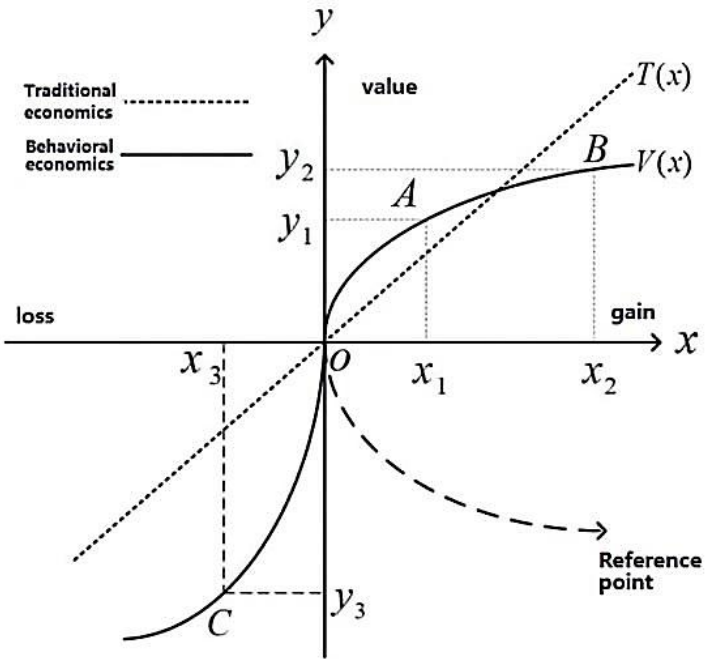

Figure 1. Value function of loss version (adopt from Liu et al., (2021)).

People do not evaluate gains or losses based on their absolute value, but rather in comparison to their personal reference point (Liu et al., 2021). The reference point can be adjusted depending on the circumstances, and the adjusted reference point serves as the basis for decision-making, potentially shifting the inflection point.

Therefore, prospect Theory can help in understanding player' decision-making processes and emotional responses in the sports field. By applying the theory to explain player' loss-averse behaviour, it can be suggested that player tend to avoid losses based on their personal reference point regarding match

outcomes. This reference point influences how player perceive and evaluate their own performance, subsequently affecting their strategic choices and psychological state during the match.

In previous research, Apesteguia & Palacios-Huerta, (2010) found that the score at the time of the shot. That is, the intermediate score as a reference point with the team taking the first kick in a penalty shootout having a 60.5% probability of winning.

Furthermore, past records, opponents and performance may serve as a reference point, influencing loss-averse behaviour. For example, Anderson & Green, (2018) found that a player's personal best score serves as a reference point in the chess game. Players exert more effort to set higher score, but after achieving a new higher score, players tend to give up at higher rates and for longer periods. This suggests that players are highly motivated when trying to surpass their past performance, but once they reach new higher score, they tend to adopt a less challenging attitude.

Pawlowski, (2021) empirically analysed the impact of opponents' performance, past performance, and expectations on player' effort and performance, treating these factors as reference points. According to Pawlowski, (2021), reference points impacting loss-averse behaviour in sports include opponent skill levels, psychological expectations, and player's past performance. For example, baseball batting averages or marathon completion times, the decimal point can act as significant reference points for player' loss-averse behaviour. Additionally, individual psychological attitudes and thought processes can also serve as reference points.

Furthermore, previous study found that bronze medallists appeared to be happier than silver medallists. This phenomenon is explained by the psychological concept of counterfactual thinking, where bronze medallists view their reference point as the fourth-place finish without a medal, while silver medallists perceive their reference point as losing the gold medal (Medvec et al., 1995).

In the realm of tennis game, Anbarci et al., (2017) provided empirical evidence that loss aversion behaviour occurs in player, particularly in tennis. When a server falls behind in points, the servers exert more effort on their serves, but as the score gap widens, this effort diminishes. This effect was more pronounced in male player than in females.

Furthermore, previous research finds that female players were significantly more likely than male players to withdraw due to concerns about COVID-19. Even after accounting for cross-country differences in preferences such as trust, patience, and risk-taking, women still exhibited higher levels of pandemic-related aversion. The model attributes about 15% of the probability of withdrawal to gender, highlighting a clear gender gap in risk aversion during the pandemic (Kowalik & Lewandowski, 2021).

Cary & Stephens, (2023) revealed that high-earning women exhibit greater risk aversion, particularly related to COVID-19. Additionally, the study highlights that women were notably more risk-averse regarding international travel during the pandemic. However, Lowrance et al., (2020) found no evidence of behaviour consistent with loss aversion predictions for either gender.

Mallard, (2016) found that both male and female players exhibited loss aversion in tennis matches, as their serve accuracy decreased when they were in the lead. Players showed a tendency to choose relatively safer serves when leading, which can be viewed as a behaviour stemming from the psychological motivation to maintain their lead. However, the analysis lacked insights into whether loss aversion tendencies were

moderated by critical moments in the match or the player's career. Moreover, the study primarily relied on internal factors (i.e., the player's mindset) to explain the reasoning behind the player' decisions, neglecting potential external factors influencing their choices.

Apart from gender differences, Krawczyk, (2019) posited out faster serve speeds were interpreted as an indication of greater effort, but he argued that faster serves might not necessarily reflect more effort. Instead, they could signify a player's intention to reduce effort. Additionally, Krawczyk highlighted the oversight of ignoring the crucial role of the receiver in tennis, which plays a significant part in the dynamics of serve-and-return interactions.

Although previous study provides many insights, the study primarily used serve speed as the main measure of player effort, but some scholars argue that serve speed may not fully reflect the effort expended by players (Anbarci et al., 2018). While serve speed plays a critical role in understanding gender differences in loss aversion, there is some disagreement over how to interpret these differences. Critics have noted that focusing on serve speed as an effort indicator is limiting, as it may not comprehensively represent overall effort.

Therefore, while various related studies have been conducted, limitations persist due to insufficient data and the lack of clear definitions of server loss and gain situations. To address these issues, this study attempts to overcome the limitation of using only serve speed as an indicator of effort by utilizing various indicators. Additionally, previous research focuses solely on gender differences without considering various individual factors. In this regard, this study draws on data from all major tournaments, which feature diverse players in different environments. Moreover, previous research is lack of understanding of psychological responses to external factors. Thus, the study controls for performance differences by using data exclusively from five-set matches. Lastly, the extant research shows utilizing insufficient data and unclear definitions of server loss and gain situations. Considering the limitation, this study employs data from all four major tournaments and defining server loss and gain situations through theoretical lens of loss aversion theory in tennis matches.

Hypotheses development

According to loss aversion theory, the emotional impact of losing a point in break point situations is significantly greater than in game point situations. The server, aware of the higher potential for loss, is likely to play more cautiously and strategically, minimizing errors to avoid losing the game. As a result, the server's winning percentage is expected to be higher in break point situations due to heightened focus and careful play. Hence, we hypothesize.

Hypotheses 1. The server's winning percentage will be higher in break point situations than in game point situations.

Loss aversion theory suggests that the potential loss in break point situations creates a heightened sense of urgency for the server. To avoid losing the game, the server may opt for faster and stronger serves, aiming to score aces directly. Since an ace is a direct and efficient way to win a point, the server is likely to attempt and succeed at more aces in break point situations to avoid the psychological burden of a potential loss. Hence, we hypothesize.

Hypotheses 2. The first serve ace rate for the server will be higher in break point situations than in game point situations.

Loss aversion theory posits that the fear of losing due to a failed serve is more pronounced in break point situations compared to game point situations. As a result, the server is expected to focus more on accuracy, aiming to land their first serve successfully. Since a successful first serve increases the likelihood of securing

the point, the server is likely to concentrate more on ensuring the first serve is accurate, resulting in a higher first serve success rate during break point situations. Hence, we hypothesize.

Hypotheses 3. The first serve success rate for the server will be higher in break point situations than in game point situations.
Loss aversion theory explains that the fear of losing due to a double fault is greater in break point situations because a double fault directly leads to conceding the game. To avoid this outcome, the server is likely to play more cautiously, ensuring that double faults are minimized. The need to prevent such costly errors should lead to a significantly lower double fault rate in break point situations compared to game point situations. Hence, we hypothesize.

Hypotheses 4. The server's double fault rate will be lower in break point situations than in game point situations.
Based on loss aversion theory, the psychological burden of losing due to a failed first return is greater in game point situations compared to break point situations. The receiver, aware of the stakes, is likely to concentrate more on successfully returning the opponent's first serve. This heightened focus on avoiding loss should result in a higher first serve return success rate in game point situations, as the receiver seeks to capitalize on the opportunity to break the server's momentum. Hence, we hypothesize.

Hypotheses 5. The receiver's first serve return success rate will be higher in game point situations than in break point situations.

METHODS AND MATERIALS

Data collection
For this study, we identify five key indicators to verify the stronger tendency for loss aversion in loss situations compared to gain situations. These indicators enable a thorough analysis of various aspects of tennis matches, enhancing the validity of the findings by leveraging a comprehensive dataset.

To test our hypotheses, data was gathered on four variables: server's scoring percentage, first-serve ace rate, first-serve success rate, and double-fault frequency. For Hypothesis 5, we employed the receiver's first serve return success rate. These five datasets were sourced from matches that went to five sets over the past two decades in the four Grand Slam tournaments (Australian Open, French Open, Wimbledon, and the US Open), as provided by tennisabstract.com. A total of 188 five-set matches and 61,473 points from the 2010s to the 2020s were included in the analysis. Table 2 presents the distribution of data collected under game point and break point situations.

Table 2. Data description.

	N(%)
Game point	11931 (71.8)
Break point	4692 (28.2)
Total	16623 (100)

Analysis procedure
To assess dynamic loss aversion in tennis match scenarios, this study employed a Z-test for independent sample proportions. The objective of this test is to compare two distinct proportions. Since the dataset is

sufficiently large, there was no need for a homogeneity of variance test, and the Z-test was chosen as an appropriate method to identify significant differences between the groups.

To test hypothesis 1, the server's scoring percentage is employed, comparing game point and break point situations to assess whether the scoring rate is significantly higher in break points. This allows us to determine if loss aversion leads to improved performance in break (loss) scenarios.

For hypothesis 2, we used the first-serve ace rate, dividing the data into game and break points, then comparing the rates. By doing so, we can identify whether the first-serve ace rate increases significantly in break points, which would indicate a loss aversion effect.

Considering hypothesis 3, the first-serve success rate is examined by categorizing the data by game and break point situations. A comparison is made to evaluate whether the first-serve success rate is significantly higher during break points, indicating a tendency to avoid losses.

For Hypothesis 4, the double-fault rate is evaluated across game and break points. The analysis helps to confirm if the double-fault rate is significantly lower in break points, reflecting a strategic reduction in errors in high-pressure situations due to loss aversion.

Lastly, for Hypothesis 5, the receiver's first-serve return success rate is used and separating the data by game and break points and comparing the success rates. This analysis determines if the return success rate is higher during game points, consistent with a loss aversion tendency in game point scenarios.

RESULTS

The analysis results of this research are presented in Table 3. Considering the results, the server's scoring success rate was compared between game point and break point situations. The success rate in game points was 0.655, whereas it was 0.617 in break points. The Z-test yielded a Z-score of -4.571 and indicating a significant difference ($p < .001$). However, the result contradicted our hypothesis, which expected a higher success rate in break point situations. Hence, H1 is rejected.

Table 3. Z-test results between game point and break point groups.

Variables		Sample proportion	SE	Z-score	Sig. (*p*)	Result
Server's scoring success rate	Game point Break point	0.655 0.617	-0.008	-4.571	2.43E-06*** (Reversed)	Rejected
First-serve ace rate	Game point Break point	0.101 0.062	0	0	-8.644	Rejected
First-serve success rate	Game point Break point	0.619 0.619	0	-0.061	.475	Rejected
Server' double-fault rate	Game point Break point	0.093 0.077	0.008	2.112	.017*	Supported
Receiver's first-serve return rate	Game point Break point	0.899 0.938	0.019	-2.041	.021* (Reversed)	Rejected

*Note. SE: Standard Error. Sig. or p-value: Statistical significance probability (the probability that the observed result is due to chance). *: p < .05 (statistically significant at the 5% level). **: p < .01 (statistically significant at the 1% level). ***: p < .001 (statistically significant at the 0.1% level, highly significant).*

The results shows that the ace rate during game points was 0.101, while it was 0.062 during break points. However, H2 was not statistically significant. We examined the first-serve success rate, which was identical at 0.619 for both game point and break point situations. The Z-score is -0.061 (p = .475), indicating no significant difference. Hence, H3 was rejected. The double-fault rate was compared to examine hypothesis 4, revealing a rate of 0.093 in game points and 0.077 in break points. The Z-test produced a Z-score of 2.112 (p < .05) and is statistically satisfied. Hence, H4 was supported.

Last, for Hypothesis 5, the receiver's first-serve return success rate was compared. In game points, the success rate was 0.899, and it was 0.938 during break points. The Z-score was -2.041, with a p-value of .021, indicating a significant difference (p < .05). However, this result also contradicted the initial hypothesis, which predicted a lower return success rate in break point situations. Hence, H5 was rejected.

Overall, the results revealed a significant result regarding the server's double-fault rate. The double-fault rate was lower in break points than in game points, demonstrating a tendency for loss aversion. However, the server's scoring rate, ace success rate, and first-serve success rate did not exhibit loss aversion, and the receiver's first-serve return success rate showed the opposite result.

Double faults, as actions that occur without interaction with the opponent, reflect a loss aversion pattern similar to that seen in golf. On the other hand, the scoring rate, ace rate, and first-serve return success rate are strongly influenced by the opponent that may explain why loss aversion is less apparent in tennis. Despite the high stakes of break point situations for servers and game point situations for receivers, their respective success rates were not higher.

Notably, even though the study focused on closely matched players in five-set matches to minimize errors, significant results were not obtained for all hypotheses. This suggests that although the psychological impact of a server or receiver losing a point in these critical situations may be greater than the satisfaction of the opponent, this emotional impact does not necessarily translate into higher scoring or success rates in actual play.

Post-hoc analysis

To better understand loss aversion in tennis, further research should establish dynamic criteria for gain and loss situations in the sport. The difference in loss aversion between tennis, with its opponent interaction, and individual sports like golf stems primarily from the dynamic and interactive nature of tennis. As players continually adjust their reference points based on the situation, future studies should consider defining reference points in a dynamic manner to assess loss aversion more accurately.

Hence, we further conducted post-hoc analysis using z-tests by dividing game point and break point situations for both servers and receivers into groups based on point differentials: larger point differential group (Group 1 and Group 3) and smaller point differential (Group 2 and Group 4). This analysis aimed to explore how loss aversion manifests in dynamic situations such as the server's scoring and ace performance under game and break points, as well as the receiver's performance in these critical moments.

Post-hoc analysis result

Table 4 illustrates that between game point and break point situations, further subdividing each into two groups based on score differences and presents the ratios for five key indicators. Examining the server's scoring success rate, it was 0.674 in Group 1, 0.634 in Group 2, and 0.655 in game point situations. In Group

3, it was 0.633, 0.609 in Group 4, and 0.617 in break point situations. The server's scoring success rate is higher in game point situations and tends to decrease slightly during break points.

Next, looking at the server's ace success rate, it was 0.12 in Group 1 and 0.079 in Group 2. In game point situations, it was 0.101, while in Group 3, it was 0.063, and both Group 4 and break point situations recorded 0.062. This indicates that the server's ace success rate is highest during game points and relatively lower during break points.

As for the server's first serve success rate, it was 0.613 in Group 1, 0.627 in Group 2, and 0.619 in game point situations. In Group 3, it was 0.629, 0.614 in Group 4, and 0.619 in break point situations, indicating that the first serve success rate remains relatively consistent.

Regarding the server's double fault rate, it was 0.103 in Group 1 and 0.08 in Group 2. In game point situations, it was 0.093, while in Group 3 it was 0.072, 0.079 in Group 4, and 0.077 during break points. The double fault rate tends to be slightly lower in break point situations compared to game points.

Table 4. Success rates of server and receiver metrics by situation.

	Group1 40-0, 40-15	**Group2 40-30, AD-40**	**Game point**	**Group3 0-40, 15-40**	**Group4 30-40, 40-AD**	**Break point**
N	6304	5627	11931	1567	3125	4692
Scoring ratio (Server's point-winning percentage)	0.674	0.634	0.655	0.633	0.609	0.617
Server's ace success rate	0.12	0.079	0.101	0.063	0.062	0.062
First serve success rate (Serve success rate)	0.613	0.627	0.619	0.629	0.614	0.619
Server's double fault ratio	0.103	0.08	0.093	0.072	0.079	0.077
First return success rate (Receiver's first return success rate)	0.880	0.921	0.899	0.937	0.938	0.938

Table 5. Differences between groups based on score differences in gain situations.

Variables		**Sample proportion**	**SE**	**Z-score**	***p*-value**
Server's point-winning percentage	Group1 Group2	0.674 0.634	0.009	4.635	1.78E-06***
Server's ace success rate	Group1 Group2	0.12 0.079	0.006	7.371	8.49E-14***
Server' first serve success rate	Group1 Group2	0.613 0.627	0.009	-1.572	.058
Receiver's first return success rate	Group3 Group4	0.937 0.938	0.001	-0.704	.241

*Note. SE: Standard Error. ***: p < .001 (statistically significant at the 0.1% level, highly significant).*

Finally, examining the receiver's first return success rate, it was 0.880 in Group 1 and 0.921 in Group 2. In game point situations, it was 0.899, while in Group 3, it was 0.937, and both Group 4 and break point situations recorded 0.938. This shows that the receiver's first return success rate is higher during break point situations.

The results of the Z-test conducted to analyse the differences in ratios between groups based on score differences in gain situations (server's game points and receiver's break points) are presented in Table 5.

In gain situations (server's game point and receiver's break point), a comparison between the group with a larger score difference (Group 1) and the group with a smaller score difference (Group 2) revealed the following: first, for the server's scoring success rate, Group 1 had a success rate of 0.674, while Group 2 had a success rate of 0.634. The Z-test yielded a Z-score of 4.635 ($p < .001$), indicating a significant difference. A similar comparison was made for the server's ace success rate between the two groups. Group 1 showed an ace success rate of 0.12, while Group 2's ace success rate was 0.079. The Z-test result was a Z-score of 7.371 ($p < .001$), demonstrating a significant difference. In terms of the server's first serve success rate, Group 1's success rate was 0.613, while Group 2's was 0.627. The Z-test showed a Z-score of -1.572 ($p = .058$), indicating no significant difference. For the receiver's first return success rate, a comparison between the group with a larger score difference (Group 3) and the group with a smaller score difference (Group 4) was conducted. Group 3's first return success rate was 0.937, while Group 4's was 0.938. The Z-test produced a Z-score of -0.704 ($p = .241$) showing no significant difference.

Next, the comparison of ratio differences between the group with a larger score difference (Group 3) and the group with a smaller score difference (Group 4) in loss situations (server's break point and receiver's game point) is presented as shown in Table 6.

Table 6. Differences between groups based on score differences in gain.

Variables		Sample proportion	SE	Z-score	*p*-value
Server's point-winning percentage	Group 3	0.633	0.015	1.587	.056
	Group 4	0.609			
Server's ace success rate	Group 3	0.063	0.010	0.104	.458
	Group 4	0.062			
Server' first serve success rate	Group 3	0.629	0.015	0.989	.161
	Group 4	0.614			
Receiver's first return success rate	Group 2	0.921	0.014	2.962	.002**
	Group 1	0.880			

*Note. SE: Standard Error. **: p < .01 (statistically significant at the 1% level).*

For the scoring success rate between the group with a larger score difference (Group 3) and the group with a smaller score difference (Group 4), Group 3's scoring success rate was 0.633, while Group 4's was 0.609. The Z-test resulted in a Z-score ($p = .056$), indicating no significant difference. A similar comparison was performed for the server's ace success rate between the two groups. Group 3's ace success rate was 0.063, and Group 4's ace success rate was 0.062. The Z-test produced a Z-score of 0.104 ($p = .456$), showing no significant difference. Regarding the server's first serve success rate, Group 3 had a success rate of 0.629, while Group 4's was 0.614. The Z-test gave a Z-score of 0.989 ($p = .161$), indicating no significant difference. Finally, a comparison of the receiver's first return success rate was made between the group with a larger score difference (Group 2) and the group with a smaller score difference (Group 1). Group 2's first return success rate was 0.921, while Group 1's was 0.880. The Z-test showed a Z-score of 2.962 ($p < .01$), indicating a significant difference.

Thus, the analysis results indicates that in game point situations, the server's scoring success rate and ace success rate are higher in the group with a larger score difference (Group 1) compared to the group with a smaller score difference (Group 2). It can also be observed that servers exhibit a stronger tendency for loss

aversion in gain situations (game points), particularly in groups with a larger score difference. Additionally, in game point situations where the server is leading significantly, the sense of loss from failing to secure the point and win the game is perceived as greater than the sense of loss experienced when leading by a smaller margin and allowing the situation to reach deuce.

DISCUSSION

The goal of this study is to apply prospect theory to tennis matches by defining gain and loss situations, analysing how players exhibit loss aversion tendencies during matches, and exploring how these tendencies affect actual match outcomes. By doing so, the study seeks to strengthen the evidence of loss aversion behaviour presented in previous research and contribute to a deeper understanding of loss aversion tendencies in tennis matches.

Unlike golf, tennis is a competitive sport between two players, where match outcomes are determined by whether a player successfully holds their serve or breaks the opponent's serve. Therefore, the sense of loss experienced by players must be dynamically designed to align with the characteristics of tennis matches. Since the score directly influences the outcome, players strive to minimize mistakes during critical points or game situations, which tends to amplify loss aversion. This study is designed under the assumption that players exert greater effort to avoid losses in loss situations, and this effort manifests in metrics such as scoring success rate and serve success rate.

Based on prior research, the study defines scoring and loss situations for both servers and receivers. For servers, a scoring situation is a game point, where winning a point results in winning the game, while a loss situation is one where losing a point results in losing the game. For receivers, the reverse applies. Servers are likely to perceive the sense of loss from conceding a break point as greater than the value of winning a point during a game point situation. Similarly, receivers will feel that the loss of a point during a game point situation, leading to losing the game, is greater than the value of winning a point and holding their serve.

The analysis results showed that the server's double fault rate was significantly lower in break point situations compared to game point situations. This suggests that players perceive the loss from a double fault to be greater in break point situations and thus actively minimize double faults in such scenarios, confirming this behavioural tendency. However, the hypotheses were rejected for the other indicators, excluding the double fault rate. To reassess these findings, the groups were reclassified based on score differences for further analysis. The results revealed that in game point situations, servers in the group with a larger score difference had higher scoring success rates and ace success rates compared to those in the group with a smaller score difference. This indicates that servers exhibit a stronger tendency to avoid losses even in gain situations (game points) when leading by a larger margin. Specifically, when the server is leading by a significant margin in game point situations, the sense of loss from failing to win the point and conceding it is perceived to be greater than the sense of loss from allowing the game to reach deuce when leading by a smaller margin.

Academic implication

This study aims to scientifically explain the impact of psychological factors on game performance by applying Prospect Theory to tennis matches and analysing players' decision-making patterns. Prospect Theory emphasizes that people have a strong tendency to avoid losses, which becomes more pronounced in dynamic sports like tennis. While previous studies have focused on general tendencies or specific situations, this study takes a more detailed and comprehensive approach by analysing various metrics using data from major tennis tournaments. By conducting customized research that considers the psychological

characteristics of tennis players and game situations, this study seeks to overcome the limitations of previous research. This approach not only offers insights into decision-making analyses that account for psychological factors in tennis but also suggests the potential for its application in other sports, making significant contributions to the fields of sports psychology and performance optimization.

Additionally, this study analyses data from five-set matches over 20 years in the four major tennis tournaments, aiming to empirically demonstrate how players experience psychological pressure during crucial moments in a match and how this pressure affects their decision-making. By achieving a more accurate understanding of players' decision-making patterns during matches, this research will serve as valuable foundational material for future studies on the impact of psychological factors on game performance.

In terms of analysis, this study analysed data from five-set matches over 20 years in the four major tennis tournaments to empirically demonstrate how players experience psychological pressure during crucial moments in a match and how this pressure affects their decision-making. Various metrics such as scoring success rate, serve success rate, return success rate, unforced errors, serve aces, and rally win rates are used to quantify players' psychological responses, and the psychological value of points in game point and break point situations is compared and analysed. This approach emphasizes the importance of empirical research, enabling a more precise and effective strategy formulation and player management.

In particular, this study contributes to understanding the psychological pressure players experience during critical moments in tennis matches and the complexity of decision-making that follows by analysing big data from all major tournaments. Analysing only a portion of the major tournaments could result in biased outcomes, so comprehensive analysis of data from all major tournaments was conducted to derive more reliable results. This helps develop strategies that stabilize players' psychological states during matches and lead to optimal performance.

Practical implication

First, this study provides contributions to optimizing player performance by providing concrete data that coaches and players can use to improve training and strategies. Through customized research that considers the characteristics of each tournament and the psychological factors specific to each player, coaches can tailor training and strategies to optimize player performance. This helps in understanding how players can perform better in certain situations and identify the circumstances where issues arise. Additionally, by analysing decision-making in high-pressure situations, coaches can gain insight into how players manage psychological pressure, which in turn can aid in developing training methods that foster greater psychological resilience.

Second, since decisions made during critical moments of a match can significantly influence the outcome, understanding players' tendencies toward loss aversion helps in comprehending how they evaluate risk and reward in decision-making. By empirically demonstrating this, the study provides valuable support for coaches and players in managing psychological pressure during key moments in matches and developing strategies that maximize performance. This not only contributes significantly to the fields of sports psychology and performance optimization but also provides specific data that can drive actual performance improvements, enabling more precise and effective approaches to game strategy and player management.

Finally, this study contributes to understanding the psychological pressure players experience during critical moments in tennis matches and the complexity of decision-making that follows. It provides insights that can help develop strategies to stabilize players' psychological states during matches and lead to optimal

performance. This data-driven approach suggests the potential for applying Prospect Theory to decision-making analysis not only in tennis but also in other sports. By enabling more precise and effective approaches to game strategy and player management, this study makes a significant contribution to the fields of sports psychology and performance optimization.

Limitation and future research

While the findings of this study provide practical guidelines that can enhance actual performance in tennis matches, there are several limitations. First, the data are limited to specific situations, making it difficult to generalize the results. Second, there may be missing variables that are necessary to fully explain loss aversion tendencies. Tennis is a sport where direct competition with an opponent and psychological battles are crucial. It demands quick actions and fast decision-making, requiring players to rapidly respond to their opponent's actions and adjust their strategies. Therefore, loss aversion in tennis can vary depending on the interaction with the opponent, significantly influencing the player's psychological state and strategy. Future research should consider more diverse match situations and additional variables for a more comprehensive analysis.

Additionally, while this study primarily focused on scoring and success rates, it is important to quantitatively analyse players' psychological states and the resulting behavioural changes. A comprehensive approach incorporating biometric signals or psychological measurements would be necessary for this. Furthermore, comparative studies with other sports could offer valuable insights into how loss aversion tendencies manifest differently depending on the type of sport.

AUTHOR CONTRIBUTIONS

WY. K. designed, reviewed, and analysed the articles and contributed to the writing of the manuscript. SK.J and JH.K reviewed the articles and contributed to the writing of the manuscript. All authors have read and agreed to the published version of the manuscript.

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Data are available upon request.

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