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Doctoral Dissertation

Velocity Dynamics: When Does the Game Get Engaging and Exciting? A Game Refinement Theory Perspective

By

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Declaration

I hereby declare that except where specific reference is made to the work of others, the contents of this dissertation are original and have not been submitted in whole or in part for consideration for any other degree or qualification in this, or any other university. This dissertation is my own work and contains nothing which is the outcome of work done in collaboration with others, except as specified in the text and Acknowledgements. This dissertation contains fewer than 65,000 words including appendices, bibliography, footnotes, tables and equations and has fewer than 150 figures.

By

MUHAMMAD NUMAN

September 2025

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Abstract

Spectator engagement and excitement are fundamental to the global appeal and sustained success of competitive sports. The interplay between game structure, scoring dynamics, and underlying psychological mechanisms significantly influences the cognitive and emotional experiences of both players and spectators. Previous research utilizing Game Refinement (GR) theory and the Motion in Mind (MiM) model has provided valuable insights into how gameplay characteristics, such as game length and scoring frequency, broadly affect spectator engagement. However, less analytical attention has been paid to the nuanced differences between high-scoring and low-scoring sports, the unique structural characteristics across sporting formats, the dynamics of uncertainty resolution, distinct phases within matches, and competitive interactions between opposing teams or players. Sports inherently vary in their scoring frequency and strategic rhythms; for instance, high-scoring sports like cricket (ODI and T20 formats) feature frequent reinforcing events that sustain continual engagement, whereas low-scoring sports such as soccer rely on rare yet intensely impactful scoring events to heighten excitement. Thus, systematically examining these inherent differences including structural variations, phase-specific engagement patterns, and competitive intensity and understanding their psychological foundations are critical for advancing theoretical insights and practical strategies aimed at optimizing spectator experience. This research integrates and expands existing frameworks to explicitly analyze these diverse aspects, providing a comprehensive and nuanced theoretical modeling of engagement and excitement dynamics across varied sporting contexts.

Despite considerable progress in understanding the general factors influencing spectator engagement and excitement, critical gaps remain in the current analytical frameworks. Existing studies predominantly focus on holistic game-level analysis, often neglecting how variations in scoring structures (high-scoring versus low-scoring), temporal segmentation (distinct phases within matches), and competitive interactions between opposing teams or players uniquely shape the spectator's cognitive and emotional experience. In particular, limited attention has been paid to systematically comparing sports with inherently different scoring frequencies and strategic dynamics, such as cricket and soccer, or exploring how psychological engagement and excitement evolve dynamically across different phases of a

match. Furthermore, existing models have not explicitly quantified the nuanced competitive interactions between teams or players that significantly influence perceived fairness, strategic intensity, and overall spectator enjoyment. These analytical oversights restrict our understanding of how specific structural and competitive elements interact to sustain and enhance spectator engagement and excitement. Addressing these gaps is essential for developing comprehensive theoretical models and practical guidelines capable of optimizing sports structures and enhancing spectator experiences across diverse sporting contexts.

This research aims to bridge these analytical gaps by systematically exploring how variations in scoring structure, game segmentation, and competitive interactions influence spectator engagement and excitement dynamics across different sporting contexts. Specifically, it comparatively analyzes the psychological mechanisms underlying spectator engagement in sports with inherently different scoring frequencies and structural characteristics, contrasting high-scoring formats (ODI and T20 cricket) with a low-scoring format (soccer). Furthermore, the research examines how distinct game phases such as opening, middle, and endgame, uniquely shape cognitive load, emotional intensity, and spectator excitement, offering a detailed phase-based understanding of engagement dynamics. Additionally, the study develops and empirically validates a novel, gravity-inspired analytical framework that explicitly quantifies competitive interactions, capturing intensity, balance, and strategic positioning between opposing teams or players. By addressing these objectives, this research advances theoretical frameworks, deepens insights into spectator psychology, and provides actionable recommendations to optimize game structures and competitive balance, ultimately enhancing spectator enjoyment across diverse sporting environments.

This research employed an integrative methodological framework combining the Game Refinement (GR) theory, Motion in Mind (MiM), and Flow in Mind (FiM) analytical models to systematically analyze engagement and excitement dynamics across cricket (ODI and T20) and soccer. Comprehensive datasets were collected from major international tournaments, the ICC ODI Cricket World Cup 2023, ICC T20 Cricket World Cup 2022, and FIFA World Cup 2022. Cricket matches were analyzed through detailed ball-by-ball data, while soccer matches were examined using minute-by-minute records, allowing fine-grained segmentation of games into distinct phases (opening, middle, and endgame). A novel, gravity-inspired analytical framework based on gravitational principles was developed to explicitly quantify competitive interactions, measuring competitive intensity, force of attraction, and potential advantage. This integrative and multi-layered analytical approach enabled robust comparative analysis across high- and low-scoring sports, distinct gameplay phases, and direct competitive interactions, providing nuanced theoretical insights and practical implications.

Keywords:

Cricket and Soccer, Engagement and Excitement Dynamics, Phase-based Analysis, Game Refinement Theory, Motion in Mind (MiM) and Flow in Mind (FiM) Models, Gravitational Analogy.

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Chapter 1

Introduction

1.1 Chapter Introduction

This chapter provides an overview of the foundational context for this dissertation, highlighting the significance and complexity of globally popular competitive sports, specifically cricket and soccer to examine the dynamics of engagement and excitement. This chapter introduces the core theoretical frameworks such as Game Refinement (GR) theory and the Motion in Mind (MiM) model, identifies gaps and challenges in existing research, and presents the problem statement, research objectives, research questions, significance, scope, and limitations of the study. Finally, it summarizes the overall structure of the dissertation, providing the reader with a coherent and logical roadmap for subsequent chapters.

1.2 Background of the Study

Competitive sports, especially globally popular ones like cricket and soccer, are more than just entertainment. They constitute significant social, cultural, and economic phenomena, captivating billions of fans worldwide and profoundly influencing global culture, media, and economies. For instance, the FIFA World Cup attracts billions of viewers, making soccer the world's most-watched sporting event [1], while cricket World Cup which is the second most popular sport in the world, particularly in South Asia, commands viewership that significantly impacts regional broadcasting markets and economies [2, 3]. The popularity and commercial success of these sports emphasize their profound societal significance beyond mere entertainment. The core attraction of competitive sports lies in their ability to deeply engage audiences through complex psychological experiences, including suspense, excitement, anxiety, and emotional investment, triggered by unpredictable and dramatic events within matches [4, 5]. Acknowledging this intricate interplay, sports analytics has emerged as a vital interdisciplinary field, integrating insights from statistics, data science, psychology, and game theory [6–13]. This growing discipline seeks not only to enhance understanding of the complex engagement and excitement dynamics but also to optimize sporting events to heighten spectator enjoyment, inform coaching tactics, and improve event management and broadcasting strategies.

Cricket and soccer provide especially compelling contexts for comparative analytical study due to their fundamentally distinct structural characteristics. Cricket, for instance, is generally a high-scoring sport characterized by frequent scoring events (runs, boundaries), which occur in a relatively small number of attempts (balls delivered). These frequent successes create rapid fluctuations in excitement and momentum. Conversely, soccer, a notably low-scoring game, features rare but highly impactful goals amidst numerous attempts, generating prolonged suspense and intense emotional peaks at critical moments. Another pivotal structural difference is the ending condition of the matches themselves. Cricket matches conclude based on variable-ending conditions such as achieving target scores or dismissing opponents, whereas soccer matches terminate strictly according to a fixed, predetermined duration, regardless of the current state of play. Despite their global prominence, these crucial structural differences in cricket and soccer have not yet been fully explored through comprehensive, comparative scientific analysis of engagement and excitement dynamics. Moreover, existing research typically examines sports independently or averages engagement across entire matches, overlooking how structural differences uniquely shape emotional intensity and psychological engagement over the course of gameplay. Therefore, cricket and soccer represent ideal candidates for comparative research, allowing for deeper insights into how game structure fundamentally influences participant and spectator engagement. By explicitly addressing these critical yet unexplored comparative dynamics, this research aims to contribute significantly to theoretical knowledge and practical applications in sports analytics, coaching strategies, game design, and event management.

1.3 Problem Statement

Over the last decade, GR theory, initially introduced by Iida Hiroyuki [14, 15], has significantly advanced the quantitative understanding of engagement by systematically analyzing how skill, chance, and uncertainty interact to make games attractive and entertaining [16, 17]. Building upon GR theory, the MiM framework further deepens insights by analogizing gameplay dynamics to physics concepts such as velocity, mass, acceleration, jerk, momentum, potential energy, and force, effectively capturing nuanced psychological and emotional states experienced during gameplay. However, despite the broad applicability, MiM framework have primarily focused on scenarios where the total number of attempts (T) significantly exceeds successful outcomes (G), thus ensuring the velocity ($v = G/T$) remains within the $[0,1]$ range. This assumption does not hold true for high-scoring sports like T20 cricket, where it is common for the total runs scored (G) to exceed the number of balls delivered (T). Consequently, velocity often surpasses 1, violating a fundamental constraint of the existing MiM framework and leading to challenges in accurate analysis. Adjustments or redefinitions to align T with these high-scoring scenarios risk misrepresenting the intrinsic nature of such sports within the GR theory. Addressing this critical gap, this dissertation explicitly differentiates between the original MiM framework, which is deeply grounded in physics-inspired analogies, and the newly proposed Flow in Mind (FiM) framework, which is derived from the foundational principles of GR theory. These frameworks are specifically refined and adapted to accurately model and analyze the complex dynamics observed in high-scoring competitive sports like T20 cricket. A detailed comparative analysis between the MiM and FiM frameworks is thoroughly presented and discussed in the methodology chapter.

Furthermore, despite numerous applications of GR and MiM to soccer, previous research [18, 19] employed an incorrect Game Refinement equation, specifically $GR = \sqrt{G}/T$, rather than the theoretically accurate form $GR = \sqrt{2G}/T$. Such inaccuracies undermine the reliability of previous findings and necessitate reanalysis using the correct formulation. Additionally, recent discussions [20, 21] within the soccer community regarding proposals to reduce match durations from 90 to 60 minutes to enhance spectator engagement has not been validated analytically, especially using GR or MiM analyses. This dissertation addresses these limitations, employing nonlinear modeling alongside correct GR formula and MiM analysis to systematically evaluate whether shorter 60-minute matches indeed offer higher engagement and exiting value.

Additionally, prior studies [16, 17] predominantly introduced comprehensive frameworks for analyzing cognitive dynamics, as well as objective and subjective engagement, focusing primarily on overall game structures rather than explicitly modeling the direct competitive interactions between individuals or teams. This dissertation significantly extends these earlier contributions by proposing a gravity-inspired analytical framework explicitly designed to quantify the competitive intensity, force of attraction, and positional advantages between opposing entities, such as players or teams, within competitive contexts. Unlike previous frameworks, our approach systematically quantifies mutual interactions, thus providing nuanced insights into the intensity, balance, and dynamics of competitive events.

Most significantly, prior GR and MiM studies have predominantly analyzed sports events as single, homogeneous entities, failing to capture the dynamics of engagement and excitement throughout distinct phases of gameplay. Sports inherently progress through discrete phases characterized by unique tactical intensity and strategic dynamics. Cricket, for instance, has explicitly defined phases such as powerplays and death overs, while soccer naturally transitions through varying periods of tactical aggression and strategic caution. Ignoring these phase-specific dynamics neglects critical insights into how excitement and engagement fluctuate. Hence, a significant gap exists in comprehensively understanding how phase structures influence engagement and excitement dynamics.

1.4 Research Objectives

By addressing these research gaps, the objective of this research is to systematically analyze the different nature sports, the in-depth structure of each sport and competitive interactions which influence the engagement and excitement dynamics, particularly in ODI cricket, T20 cricket, and soccer. Specifically, the study aims to:

1. **Examine Comparative Engagement Dynamics Across Different Sports Structures:** To quantitatively investigate and compare how inherent structural differences particularly high-scoring variable-ending (cricket) versus low-scoring fixed-time (soccer) sports affect spectator and participant engagement dynamics using the GR theory and MiM framework.

2. **Refine and Extend the GR theory and MiM Framework for High-Scoring Sports:** To address the analytical limitations of the original MiM framework when velocity ($v = G/T$) exceeds the $[0,1]$ range, specifically common in high-scoring contexts like T20 cricket. This includes clearly differentiating and rigorously comparing the physics-inspired MiM framework and the newly proposed FiM framework derived directly from GR theory ensuring accurate and theoretically consistent measurement and analysis.

3. **Correct and Validate the GR Formula for Soccer:** To rectify the previously incorrect usage of the GR equation ($GR = \sqrt{G}/T$) in soccer analyses and provide accurate recalculations using the theoretically correct formula ($GR = \sqrt{2G}/T$). This ensures a robust and reliable comparative analysis of soccer dynamics.

4. **Evaluate the Impact of Reduced Soccer Match Duration:** To scientifically assess recent proposals suggesting a reduction of soccer matches from 90 to 60 minutes, utiliz-

ing nonlinear modeling alongside correct GR and MiM analyses to determine whether a shorter duration indeed enhances spectator engagement and overall excitement.

5. **Develop a Gravity-Inspired Framework to Quantify Competitive Interactions:** To introduce and empirically validate a novel, gravity-inspired analytical framework specifically designed to quantitatively model competitive interactions between competing teams or players. This extension provides deeper insights into the competitive balance and strategic interactions that drive engagement and excitement in sports contexts.

6. **Perform Phase-Based Analysis of Engagement and Excitement Dynamics:** To systematically segment ODI cricket, T20 cricket, and soccer matches into distinct, strategically meaningful phases (e.g., opening, middle, and endgame phases) and apply phase-specific GR and MiM metrics to comprehensively capture how excitement and engagement dynamically evolve over the duration of gameplay.

These research objectives collectively address crucial theoretical and practical gaps identified in the literature, providing a deeper understanding of the interplay between game structure, competition dynamics, and psychological engagement. The outcomes from this study aim to contribute significantly to the theoretical advancement in sports analytics, inform practical decisions by coaches and sports administrators, enhance spectator enjoyment, and guide future game design and event management strategies.

1.5 Research Questions

In line with the identified research gaps, problem statement, and objectives, this dissertation addresses the following central research questions:

1. How do structural characteristics (game length and scoring frequency) influence psychological engagement and spectator excitement in team sports?

2. How can MiM accommodate high-scoring scenarios without violating the GR measures?

3. If current soccer matches fall outside the optimal GR zone, how can the game structure be redesigned to enhance fairness, spectator engagement, and excitement?

4. How can the MiM framework be extended to effectively model and quantify dynamic competitive interactions?

5. Which MiM parameters can be utilized and systematically translated into meaningful metrics to quantify competitive dynamics?
6. How do the proposed gravity-inspired metrics relate to actual competitive outcomes and reflect underlying psychological factors?
7. How can high-scoring sports (ODI and T20 cricket) and low-scoring sports (soccer) be systematically analyzed to reveal deeper cognitive and emotional engagement patterns that conventional whole-game analyses overlook?

By systematically exploring these questions, this research aims to provide comprehensive theoretical insights and practical recommendations, significantly advancing the field of sports analytics and informing strategic decision-making in game design, coaching tactics, and sports event management.

1.6 Significance of the Study

This study significantly contributes to the theoretical, methodological, and practical domains of sports analytics, particularly within the context of cricket and soccer. Its unique and comprehensive approach addresses several critical gaps identified in previous research, thereby enriching our understanding of sports engagement dynamics in several meaningful ways.

1.6.1 Theoretical Significance

This dissertation advances the theoretical foundation of GR theory and the MiM framework by explicitly addressing and overcoming inherent limitations, especially regarding their application to high-scoring sports such as T20 cricket. By clearly distinguishing between the physics-inspired MiM framework and the newly introduced FiM framework, this research provides robust, theoretically consistent methodologies for accurately modeling sports engagement dynamics under diverse scoring conditions. Furthermore, the study corrects previously misapplied formulations of GR theory, particularly in soccer analyses, thereby reinforcing the theoretical rigor and reliability of future research.

1.6.2 Methodological Significance

The introduction and validation of a novel, gravity-inspired analytical model represent a significant methodological innovation, allowing researchers and practitioners to quantitatively assess competitive interactions between teams or individuals. Additionally, the comprehensive phase-based analysis proposed in this study provides a robust methodological framework for capturing how psychological and emotional engagement evolve dynamically within different segments of gameplay. This methodological approach not only deepens analytical precision but also sets a new standard for future research in sports analytics and competitive game design.

1.6.3 Practical Significance

Practically, the insights gained from this research hold considerable value for a broad spectrum of stakeholders, including sports administrators, coaches, athletes, game designers, and fans. By quantitatively assessing the impact of match duration modifications (e.g., reducing soccer match lengths from 90 to 60 minutes), this research offers data-driven recommendations that can directly influence strategic decisions in event management and policy-making aimed at enhancing spectator engagement. Coaches and athletes can benefit from the phase-specific analyses of game dynamics, using these insights to optimize strategic decision-making, pacing tactics, and psychological preparation throughout matches.

1.6.4 Social and Cultural Significance

Given the global popularity and profound cultural importance of cricket and soccer, findings from this study extend beyond academic interest. Enhanced spectator engagement and excitement can significantly contribute to cultural enrichment, community building, and broader societal well-being. Additionally, optimized game structures and engagement strategies have the potential to attract broader audiences, boost media revenues, and positively influence regional and global sports economics.

This research offers comprehensive theoretical advancements, innovative methodologies, and practical solutions with far-reaching implications. Its outcomes not only enrich academic literature but also provide actionable insights for enhancing the experience and enjoyment of sports worldwide.

1.7 Scope and Limitations

1.7.1 Scope of the Study

The scope of this dissertation primarily encompasses the quantitative analysis of engagement and excitement dynamics within two globally popular competitive sports cricket (ODI and T20 formats) and soccer. These sports were selected due to their global popularity and their contrasting structural properties namely, high-scoring variable-ending (cricket) versus low-scoring fixed-time (soccer) formats. The study leverages the GR theory, MiM framework, and an extended FiM model, specifically examining how different sports and their structural differences such as scoring frequency, game duration, and ending conditions influence psychological and emotional experiences. Furthermore, the methodological scope includes developing and validating a novel, gravity-inspired analytical model for quantifying competitive interactions. Additionally, the research rigorously performs phase-based analysis, examining distinct segments (opening, middle, endgame) of matches. To ensure consistency and comparability, data sources are restricted to internationally recognized tournaments, specifically the 2023 ODI Cricket World Cup, the 2022 T20 Cricket World Cup, and the 2022 FIFA World Cup. This clearly defined scope ensures robust, standardized outcomes, enhancing both theoretical understanding and practical applicability.

1.7.2 Limitations of the Study

Despite its comprehensive approach, this dissertation acknowledges certain limitations that should be considered when interpreting its findings:

1. **Generalizability of Findings:** The analysis relies exclusively on data from three specific international tournaments. While these events represent peak international competitions offering high-quality datasets, the findings may not fully generalize to domestic leagues, friendly matches, or tournaments with different structural characteristics or competitive intensities. Future research could incorporate a broader range of competitions to improve generalizability and robustness of the findings.

2. **Phase Definitions in Soccer:** Unlike cricket, soccer does not feature officially defined gameplay phases (e.g., powerplays or death overs). Therefore, the segmentation into opening, middle, and endgame phases in soccer is inherently subjective and based on logical rather than established rules, potentially affecting the accuracy or interpretability of phase-specific insights.

3. **Data Collection Constraints:** The analysis relies on publicly available data, which, although comprehensive, often lack detailed contextual or situational metadata (e.g., player positioning, defensive formations, or real-time tactical adjustments). This restricts the depth of engagement modeling achievable in this study. Future research could explore the richer, multi-modal data to further justify and enhance analytical precision link to our insights.

4. **Quantification of Psychological States:** Psychological and emotional states (excitement, engagement, cognitive load) inferred through MiM metrics serve as indirect quantitative proxies rather than direct psychological measurements. Complementary qualitative research methodologies (e.g., surveys, interviews, physiological monitoring) are recommended for richer psychological validation.

Clearly articulating these limitations helps contextualize the research findings, directs future studies, and ensures transparency in interpreting the significance and applicability of the results presented herein.

1.8 Dissertation Structure

This dissertation is structured into eight chapters, systematically guiding the reader through the research process, findings, and implications as follows:

- **Chapter 1: Introduction** provides the background of the study, clearly defines the problem statement, articulates the research objectives, identifies research questions, highlights the significance of the study, and outlines its scope and limitations.

- **Chapter 2: Literature Review** offers an extensive review of existing literature relevant to GR theory, MiM framework, and previous analyses of engagement dynamics in competitive sports. The chapter identifies critical research gaps addressed in this study.

- **Chapter 3: Research Methodology** describes the research design, data collection processes, analytical frameworks, and details the specific procedures for comparative analysis, phase-based engagement analyses, and competitive interaction modeling.

- **Chapter 4: High-Scoring vs. Low-Scoring Sports** examines how different sports such as cricket (a high-scoring sport with variable end) and soccer (a low-scoring sport with fixed time) and their structural differences impact the engagement and excitement dynamics. This chapter also critically evaluate the theoretical proposal to reduce soccer match duration from 90 to 60 minutes, and correcting previously misapplied GR formula to accurately quantify potential improvements in spectator engagement and excitement.

- **Chapter 5: A Gravity-Inspired Framework for Quantifying Competitive Interactions** introduces a novel analytical approach based on gravity-inspired concepts to explicitly model competitive interactions between teams or individuals. This chapter empirically validates the effectiveness of gravity framework in sports, providing deeper insights into competitive intensity, competitive force of attraction and the positional advantages in a competitive settings.

- **Chapter 6: Phase-based Analysis of Engagement and Excitement Dynamics** conducts an in-depth exploration of how engagement and excitement evolve throughout distinct phases (opening, middle, and endgame) in ODI cricket, T20 cricket, and soccer, employing phase-specific metrics from the MiM and FiM frameworks.
- **Chapter 7: Conclusions, Limitations, and Future Work** provides a concise summary of the dissertation's primary findings and their significance, explicitly outlines methodological limitations identified throughout the research, and suggests clear directions for future studies in sports analytics, game refinement, competitive strategy, and game design.

Chapter 2

Literature Review

2.1 Chapter Introduction

This chapter systematically reviews and synthesizes existing scholarly literature related to globally recognized competitive sports, particularly cricket (ODI and T20 formats) and soccer, focusing on their structural, psychological, and engagement dynamics. Initially, the chapter presents the historical evolution and foundational structures of cricket and soccer, providing essential context to understand their distinct characteristics, gameplay rules, and inherent psychological appeals. It then assesses existing research concerning psychological and emotional dynamics experienced by players and spectators, placing specific emphasis on distinct gameplay phases such as powerplays and death overs in cricket, and strategic segments in soccer matches. Subsequently, the chapter critically examines the theoretical frameworks of GR and MiM model, which have been instrumental in quantifying and analyzing excitement and engagement across various domains. Finally, this literature review identifies significant theoretical and methodological gaps, particularly addressing previous inaccuracies in the application of GR theory to soccer and emphasizing the methodological importance of correctly incorporating velocity into the MiM analysis for high-scoring sports like T20 cricket. This comprehensive review establishes a robust theoretical and methodological foundation for the empirical analyses undertaken in subsequent chapters, ensuring clarity in how existing research informs, supports, and contextualizes this study's objectives and research questions.

2.2 Historical Development of Cricket

Cricket originated as a children's game in southeastern England by the 16th century and evolved into an established adult pastime, becoming effectively England's national sport by the 18th century [22]. Over this period, cricket's rules gradually became standardized, resulting in the first formal codification of the Laws of Cricket in 1744. These laws were further refined by 1774 with significant innovations such as the introduction of the leg-before-wicket (LBW) rule and a third stump. In 1788, the Marylebone Cricket Club (MCC) assumed custodianship of these laws, providing enduring governance to the sport [23]. Fueled by gambling and patronage, cricket spread throughout the British Empire in the 19th century, facilitating the growth of local and inter-regional competitions under a unified regulatory framework [24]. The Test format playing for 5 days, cricket's oldest and most prestigious form, emerged from this historical context, with the first Test matches played between England and Australia in 1877 [25]. Until the early 20th century, Test cricket largely remained confined to the British imperial sphere, with only three teams competing regularly until 1920 [26]. Tests are a war of attrition teams often adopt conservative tactics to avoid losing wickets, and roughly 25% of Test matches end in draws [27]. Later adaptations introduced limited-overs formats, ODI cricket, which began in 1971 featuring matches limited to 50 overs per innings, and T20 cricket, a shorter, faster-paced format that debuted in 2003.

Cricket involves two teams, each with 11 players, one designated as captain [28]. Teams alternate roles between batting and fielding. While batting, two players (one striker, one non-striker) occupy the pitch, facing deliveries from the fielding team's bowler. The fielding side consists of one bowler, one wicket-keeper, and nine strategically positioned fielders. Although players typically specialize in batting or bowling (with some capable in both roles, called all-rounders), any team member may bat or bowl during a match. Batting continues until 10 of the 11 batters are dismissed ("all out"), concluding the team's innings.

Cricket is played on a circular or oval field with a defined boundary [29]. At its center lies the pitch, a rectangular area measuring 22 yards (20.12 m) in length and 10 feet (3.05 m) in width shown in Figure 2.1. Batters score runs primarily by hitting the ball and exchanging positions at opposite ends of the pitch, each successful exchange counting as one run. If a ball reaches the field boundary by rolling or bouncing, it counts as four runs ("four"); if it crosses the boundary in the air without touching the ground, it counts as six runs ("six"). Batters may also score runs from fielding errors, known as extras. The fielding team's primary objective is to prevent runs and dismiss batters. Batters remain at play accumulating runs until dismissed ("out"). The batting team's total innings score consists of runs scored by batters and extras awarded. The team with the highest aggregate of runs typically wins the match. Matches can end in a tie if both teams score exactly the same number of runs, or as a draw in multi-innings formats if the allotted time expires before a conclusive result is reached.

2.2.1 One-Day International (ODI) Cricket

One-day cricket, introduced in the 1960s [30], emerged as a shorter alternative to traditional Test cricket, which can last up to five days [31]. Officially known as One-Day International (ODI) cricket, it formally began on January 5, 1971 [23]. Initially, ODI matches were structured as 60 overs per innings, a format used during the Prudential Cricket World Cups of 1975, 1979, and 1983 [32]. The overs were reduced to 50 overs (300 legal balls) per innings starting from the 1987 Cricket World Cup, establishing the 50-over format as the standard for ODI cricket. ODI cricket rapidly gained popularity due to its aggressive batting style, vibrant presentation, and substantially fewer drawn matches compared to traditional Test cricket. Significant early developments included fielding restrictions, which were later formalized by the International Cricket Council (ICC) as the concept of powerplay in 2005 [33]. Although informal restrictions were in place as early as the 1996 Cricket World Cup, formalizing the powerplay rules profoundly reshaped cricket's strategic framework.

In modern ODIs, the innings are divided into three distinct powerplay segments [34, 35]:

- **Powerplay 1 (Overs 1–10)**: Only two fielders are allowed outside the 30-yard circle, prompting aggressive batting from the start.
- **Powerplay 2 (Overs 11–40)**: Four fielders may be placed outside the circle, balancing offensive and defensive strategies.
- **Powerplay 3 (Overs 41–50)**: Five fielders can occupy positions outside the 30-yard circle, encouraging bowlers to adopt more defensive tactics and challenging batters to take greater risks.

An ODI match involves each team taking turns batting and bowling for 50 overs. In the first innings, the batting side (Team 1) attempts to score as many runs as possible, setting a target for the opposition (Team 2). Simultaneously, Team 2 strives to restrict Team 1 by effectively bowling and dismissing batters. In the second innings, roles are reversed, with Team 2 aiming to achieve the set target while Team 1 endeavors to prevent this by bowling efficiently and securing wickets. The ODI format demands strategic depth, technical proficiency, and physical stamina, delivering excitement and a significantly faster pace compared to the extended play typical of Test cricket [36].

Cricket is a high-scoring sport. ODI matches totals typically ranging from about 270 to 300 runs per innings in contemporary play. Historically, a typical first-innings baseline

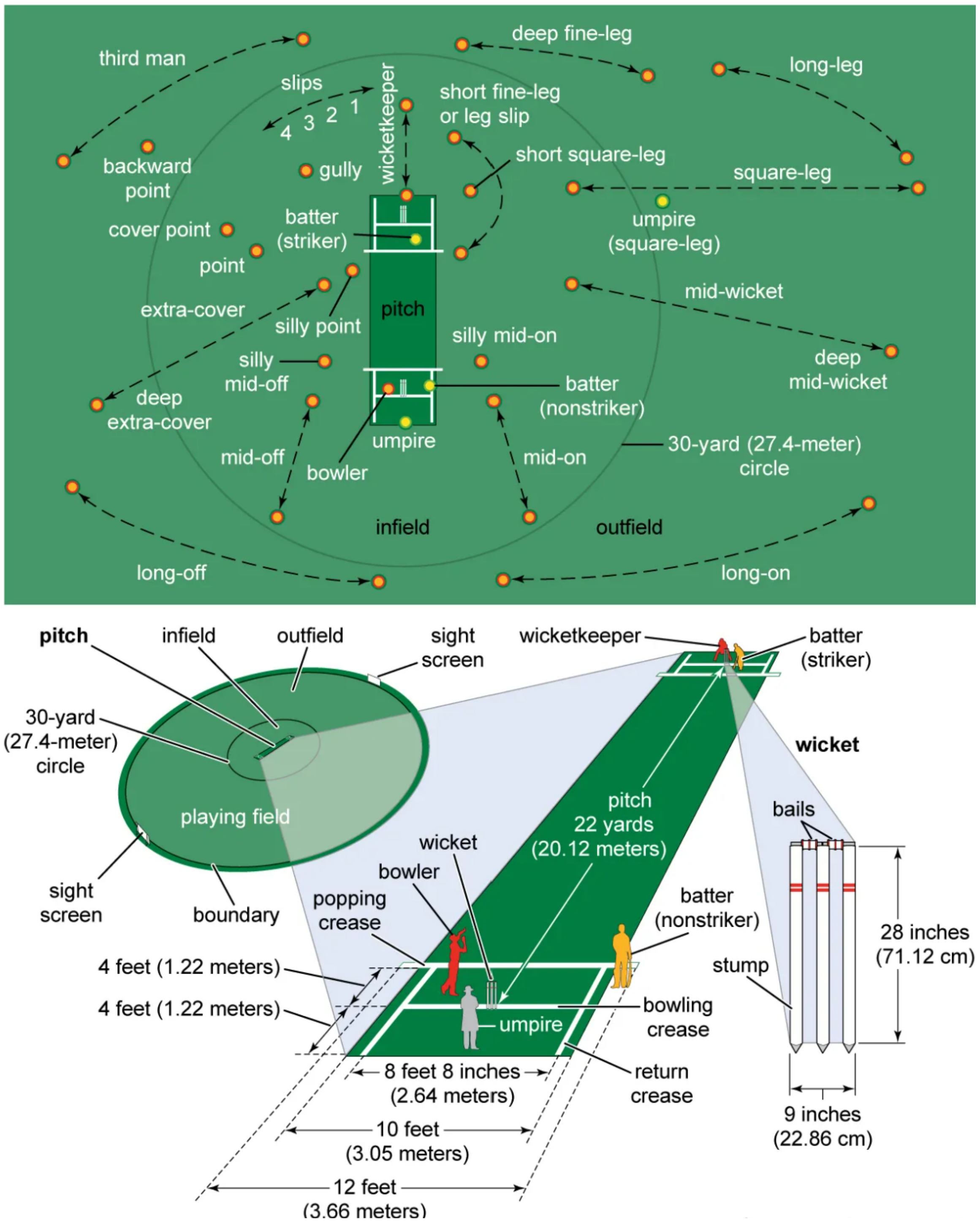

Fig. 2.1 Diagram of a cricket field, showing the 22-yard pitch at the center with wicket locations and important markings [29].

score was approximately 225 runs for the full allocation of 50 overs [37]. By the early 2000s, however, researchers observed a substantial upward trend, noting that ODI matches were achieving significantly higher totals than in previous decades. Consequently, the Duckworth–Lewis method recalibrated the average baseline to 235 runs in its 2002 revision, reflecting the improved batting standards of the 1990s and early 2000s [37]. This marked a notable shift from the 1970s–80s, when typical 60-over ODIs yielded scores around 200, increasing to approximately 250 by the 1990s for the 50-over format. Recent statistical analyses show that while the median ODI total has somewhat plateaued in the mid-200s, the incidence of extremely high scores (300+ totals) has become more frequent and often decisive in modern games [32]. For instance, a large-scale study examining 4,255 ODIs from 1987 to 2023 reported that although central scoring tendencies (mean and median) have not dramatically shifted, the right tail of the distribution has expanded, reflecting more frequent high-scoring innings [32]. Supporting this, a comprehensive performance analysis further confirmed that average team scores per match have steadily increased over recent decades [38]. These findings help teams and analysts recalibrate expectations for par scores in modern ODIs and illustrate how the format has evolved into a faster, higher-scoring contest, while still recognizing the ongoing importance of wicket preservation and tactical batting discipline in securing competitive totals.

2.2.2 Psychological and Emotional Dynamics in ODI Cricket

ODI cricket innings are structured into distinct Powerplay phases specifically designed to balance strategic depth with spectator engagement [30]. This intentional format aims to heighten excitement, drama, and the game's overall appeal. Research into spectator motivation consistently shows that drama and excitement significantly enhance viewer interest in ODIs [39]. Across the three Powerplay phases, player strategies and spectator psychological experiences dynamically evolve, influencing suspense, excitement, engagement, and motivational intensity throughout the match. Powerplay 1 (1 to 10 overs) sets an immediate tone of intensity and high energy in ODI cricket. With only two fielders permitted outside the inner circle, batting teams frequently adopt aggressive strategies to exploit these restrictions [30]. Openers are motivated to seize early initiative through attacking shots, which can quickly yield boundaries but simultaneously risk losing early wickets. Conversely, bowlers experience heightened pressure to achieve breakthroughs with the new ball before the batting side builds momentum. This tactical interplay generates early suspense, as each delivery can dramatically shift the game's momentum, sustaining intense player focus and spectator engagement. Analyses of ODI run-chases confirm considerable psychological tension among supporters even in these initial overs, driven by anxiety that the batting side may rapidly secure a decisive advantage [40]. The recognition that a swift start significantly influences match outcomes lends the opening overs unique psychological importance. For spectators, aggressive batting and potential early wickets during Powerplay 1 strongly amplify excitement; the uncertainty and anticipation at this stage effectively captivate viewers from the outset. Indeed, as noted in sports psychology literature, the start of an innings requires players to manage adrenaline and nerves meticulously, while providing fans the exhilaration associated with cricket's proverbial "opening salvo." Following the intensity of the initial overs, Powerplay 2 marks a prolonged middle phase (overs 11–40) typically characterized by strategic consolidation. With fielding restrictions relaxed (allowing up to four fielders outside the inner circle), batting strategy shifts from aggressive hitting toward steady run accumulation, emphasizing rotating strike and building a stable platform. Although this period "might not be as intriguing" and can seem predictable compared to earlier overs, it demands from batters considerable maturity, innovation, and patience to score without excessive risk [41]. Maintaining concentration and motivation during this relatively subdued phase poses significant psychological challenges for players: bowlers and fielders must remain vigilant for opportunities, while batters must avoid complacency or impatient, risky shots. Spectator engagement can decline during these quieter overs as match tempo slows. Recognizing this potential lull, cricket authorities previously introduced additional Powerplays (such as optional batting powerplays) specifically to infuse excitement into the mid-innings, addressing concerns about audience disengagement. Nevertheless, discerning fans appreciate subtle suspense during this phase recognizing that pivotal partnerships or potential collapses can quietly emerge even amid the apparent lull. Powerplay 2 thus establishes critical groundwork for the innings finale, as engaged viewers closely monitor strategic developments, understanding that team fortunes can shift subtly yet significantly in these middle overs. Consequently, although overt excitement diminishes, psychological engagement persists, with players internally focused on tactical objectives (e.g., preserving wickets for late-innings acceleration) and attentive spectators closely tracking nuanced shifts in momentum. The final 10 overs (41 to 50) Powerplay 3, represent the crescendo of an ODI innings, producing peak excitement for spectators and intense psychological pressure for players. With fielding restrictions allowing five fielders outside the inner circle, batting teams typically shift to aggressive tactics to maximize scoring opportunities in these "slog overs" [41]. Batters frequently adopt high-risk, boundary-oriented approaches, intensifying pressure on bowlers who must contain scoring and secure critical wickets. This period significantly elevates psychological stakes: batting sides with wickets in hand channel accumulated aggression into an explosive final push, generating heightened adrenaline and motivation as match-defining outcomes draw near. Conversely, bowlers confront the intense stress of "death overs," acutely aware that minor errors may result in severe punishment, rigorously testing their skill execution under immense pressure. Sports performance research highlights that such high-stakes contexts yield variable outcomes—some athletes deliver clutch performances, whereas others succumb to psychological strain. Quantitative analyses of "choking" in ODIs [42] indicate that teams occasionally squander winning positions late in matches, illustrating how elevated stress during climactic overs can impair decision-making and execution, potentially triggering batting collapses or panicked tactical errors. However, elite cricketers often demonstrate resilience and thrive despite these pressures. For instance, studies examining the "nervous nineties" phenomenon (when batsmen approach individual milestones like 100 runs) reveal increased scoring rates near milestones, reflecting adaptive strategies to manage anxiety and maintain aggression effectively under pressure [43]. From a spectator perspective, Powerplay 3 constitutes pure sporting theater, characterized by maximal suspense and emotional intensity. As the match outcome crystallizes, particularly during tight run chases or efforts to reach imposing totals fan excitement and anxiety reach a fever pitch. Recent ODI studies utilizing live spectator engagement data confirm that impactful plays in later overs provoke significantly stronger emotional responses. Boundaries or wickets in the final overs trigger substantial surges of excitement or anxiety compared to similar events earlier in the innings. In tightly contested matches, this tension manifests vividly among spectators, who experience pronounced suspense and heightened physiological responses (e.g., elevated heart rates) [40]. Sport psychologists attribute these intense spectator emotions to a sense of helpless suspense, as fans lack direct control over match outcomes. Yet, precisely this dramatic uncertainty renders ODI cricket exceptionally compelling. In climactic situations, the mutual interaction between energized crowds and players further amplifies the atmosphere: roaring fans enhance player adrenaline, while clutch performances by athletes reciprocally drive crowds into euphoria, culminating in a shared emotional climax that epitomizes the appeal of ODI cricket.

2.2.3 Twenty20 (T20) Cricket

T20 cricket, the shortest official format of professional cricket, was introduced by the England and Wales Cricket Board (ECB) in 2003 as part of a new domestic competition [27, 44, 45]. Initial ECB market research in 2000 revealed that traditional, longer cricket formats were perceived as inaccessible and incompatible with contemporary leisure habits, prompting the launch of the Twenty20 Cup, a rapid and spectator-friendly competition that quickly resonated with a broader, younger audience [46]. Designed to fit within approximately three hours, a typical T20 match is substantially shorter than an ODI match or a Test, thus encouraging a notably aggressive style of batting and frequent boundary-hitting (fours and sixes) from the onset [27]. Designed to deliver fast-paced, high-intensity gameplay, T20 cricket emphasizes explosive batting, aggressive tactics, and rapid scoring. Its global popularity features even more pronounced fluctuations in momentum, acceleration, and scoring rates throughout the game, especially during the early "powerplay" overs and final death overs, underscoring unique tactical considerations distinct from longer Test and ODI formats. Following its domestic success, T20 cricket was internationally adopted, with the first official Twenty20 International (T20I) match played in 2005. Subsequently, the International Cricket Council (ICC) established the World Twenty20 Championship (T20 World Cup), with its inaugural tournament held in 2007. By 2016, six ICC World T20 tournaments had taken place (2007, 2009, 2010, 2012, 2014, 2016).

Structurally, T20 cricket incorporates distinct gameplay phases and specialized regulations to foster an aggressive, strategically dynamic contest within its constrained format of two innings of 20 overs each (120 legal deliveries per innings), mirroring the wicket limit of traditional formats.

- **Powerplay Overs (1–6):** Similar to ODI cricket, T20 features a mandatory powerplay during the first six overs, restricting fielding teams to only two fielders outside the 30-yard circle [47]. This regulation promotes aggressive batting, incentivizing teams to deploy powerful opening batsmen aiming for high scoring rates early on. Bowlers, meanwhile, face heightened pressure due to limited defensive field options, with early wickets significantly impacting match momentum.

- **Middle Overs (7–15):** Following the powerplay, fielding restrictions are relaxed, allowing up to five fielders outside the inner circle [48]. This mid-innings period necessitates strategic batting, balancing risk-taking and wicket preservation. Batsmen typically rotate strikes regularly, seeking selective boundary opportunities. Conversely, bowlers employ diverse tactics, including spin bowling and pace variations, to regulate scoring rates effectively.

- **Death Overs (16–20):** The concluding overs, termed the death overs, are characterized by intensified batting aggression aimed at maximizing final scoring potential [49]. Bowling teams typically respond with specialized deliveries such as yorkers and slower balls to restrict run flow. Furthermore, the "one-fifth rule" limits each bowler to a maximum of four overs per innings, compelling teams to strategically allocate their bowling resources across the innings, particularly emphasizing bowler rotation during high-pressure death overs. This regulation enhances tactical complexity and strategic captaincy decisions regarding bowler deployment.

These elements ensure a T20 format of persistent excitement, appealing widely to contemporary audiences through its combination of rapid play, strategic depth, and spectator engagement.

Despite the shorter innings length (just 20 overs per side), Twenty20 (T20) cricket matches produce notably high scoring totals, typically ranging between 150 and 170 runs per team. For instance, an empirical analysis of the 2009 ICC World Twenty20 tournament reported average scores for winning teams at approximately 158 runs, compared to around 133 runs for losing sides [50]. Similarly, in franchise-based T20 competitions such as the Indian Premier League (IPL), winning teams in the inaugural 2008 season averaged about 163 runs per innings, while losing teams scored around 150 runs, emphasizing the format's consistently high-scoring nature despite its brevity relative to the 50-over ODI format. For comparison, the average winning score in the 50-over 2007 Cricket World Cup was approximately 262 runs. Even in women's T20 cricket typically characterized by slightly lower scoring averages than men's cricket a comparable scoring pattern persists. Recent analyses of elite women's T20 leagues indicated winning team totals averaging approximately 140 runs, significantly higher than the 123 runs averaged by losing teams [47]. Although these totals are somewhat lower than those observed in men's T20 matches, they nevertheless exemplify the aggressive batting style and rapid scoring rate fundamental to the T20 format. Empirical studies across various international and major league competitions (including the IPL and Big Bash League) consistently highlight that the structural limitations inherent in T20 cricket (limited to 20 overs per innings) naturally incentivize attacking play, characterized by frequent boundaries, elevated run rates, and compelling entertainment value.

2.2.4 Psychological and Emotional Dynamics in T20 Cricket

Each Powerplay in T20 cricket carries distinct psychological dynamics for both players and spectators. The shorter match duration and intense, fast-paced play make T20 inherently dramatic and appealing, significantly contributing to its popularity among fans [51]. During Powerplay 1, the opening six overs, players are highly motivated to quickly set the tone. Batting teams typically adopt aggressive tactics, capitalizing on restrictive field placements to maximize early scoring opportunities. Research into T20 tactics underscores this approach, revealing that teams prioritize rapid run-scoring over cautious wicket preservation during these initial overs [52]. Conversely, bowlers prioritize containment, strategically varying line and length to limit boundaries and counteract batsmen's aggression. This intense tactical interplay means high-strike-rate openers are often strategically deployed to exploit fielding restrictions and establish early momentum. For spectators, Powerplay 1 immediately delivers high excitement. The anticipation of boundary-hitting and early wickets generates a gripping atmosphere, engaging fans deeply as match narratives rapidly unfold. Every delivery in these initial overs carries heightened significance rapid scoring flurries electrify the audience, while early wickets add suspense by placing immediate pressure on the batting side. This swift start directly aligns with audience expectations for entertainment characterized by action and uncertainty. Indeed, empirical studies confirm that the drama and rapid scoring characteristic of T20's opening overs strongly influence spectator interest and enjoyment [51]. Consequently, Powerplay 1 is marked by intense aggression and adrenaline among players, paired with immediate engagement and excitement for spectators. During overs 7–15, the tempo in T20 cricket typically shifts toward strategic consolidation. With relaxed fielding restrictions allowing defenders on the boundary, batting teams adopt a more measured approach, prioritizing partnerships, strike rotation, and laying a platform for the final overs. This phase requires sustained concentration, patience, and tactical discipline from both batsmen and bowlers, as the immediate adrenaline rush of the opening overs subsides. Notably, statistical analyses emphasize that the middle overs significantly influence match outcomes. For instance, one study identified that outscoring opponents during the middle eight overs strongly correlates with winning T20 matches [50], highlighting the strategic importance teams place on this period. Bowlers strategically vary pace and utilize subtle deliveries to induce wickets, while batsmen focus on minimizing risks through controlled scoring. From a spectator's perspective, these middle overs might appear comparatively subdued, yet they offer distinct forms of suspense and strategic intrigue. Scoring rates usually decline during this phase, as boundary opportunities decrease and teams rely more on singles and doubles to maintain momentum [50]. While casual viewers might perceive a lull, more attentive spectators recognize the subtle escalation of tension, appreciating the tactical nuances as each run influences the match context. Fans experience a different type of excitement during this period, a growing anticipation as run rates slowly climb or wickets in hand quietly accumulate. Matches that appear stable during these overs can quickly shift following key wickets or increased scoring pressure, thereby intensifying psychological engagement. Thus, although this middle phase lacks the overt excitement of the initial and final overs, it remains psychologically characterized by sustained concentration and strategic execution among players, accompanied by vigilant anticipation and subtle suspense among engaged spectators as the stakes gradually rise toward the match's climax. The final overs represent the pinnacle of suspense and excitement in T20 cricket, characterized by intense psychological pressure on players and heightened emotional engagement among spectators. During these "death overs," players visibly exhibit high adrenaline and deliberate focus: bowlers meticulously defend targets, while batsmen strive urgently for rapid scoring, often needing substantial runs from minimal deliveries. Strategic thinking reaches its most intricate level; qualitative analyses with professional players have documented a nuanced "cat-and-mouse" dynamic, with batsmen anticipating bowlers' tactical variations such as yorkers and slower balls to carefully plan their aggressive responses [53]. For spectators, the death overs typically constitute the most thrilling segment of a T20 match, generating significant suspense and emotional intensity both in stadiums and for television audiences. Research on sports viewership confirms that suspense strongly enhances audience engagement [54], with T20 cricket's inherent uncertainty frequently preserving the match's outcome undecided until the final overs or even the final delivery. Key moments such as decisive sixes, critical wickets, or exceptional fielding efforts become memorable highlights, intensifying the entertainment value and emotional experience. Crowds often react dramatically to each significant event, with tension escalating as the required run rate tightens and remaining deliveries diminish. This phase consistently delivers compelling surprises last-ball victories, sudden batting collapses, or matches extending into a Super Over that leave lasting impressions on spectators, reinforcing their excitement and emotional connection. Ultimately, the death overs encapsulate the core appeal of T20 cricket by pushing players to high-pressure performances that rigorously test psychological resilience, while simultaneously providing spectators with intense, memorable, and emotionally charged climactic experiences.

The detailed examination of ODI and T20 cricket formats highlights their distinct psychological and emotional engagement profiles, structured explicitly by strategic powerplay phases and scoring dynamics. This study first provides a comparative analysis of the overall engagement and excitement levels in both formats by employing Game Refinement (GR) theory and the Motion in Mind (MiM) framework, quantitatively determining which format more closely aligns with optimal engagement metrics. Furthermore, to gain deeper insights into the structural nuances that shape spectator experiences, the study performs a granular, phase-based analysis of each format, explicitly examining opening, middle, and endgame segments defined by powerplay regulations. ODI cricket shows a nuanced progression, gradually intensifying psychological stakes from early aggressive play through strategic mid-game pacing to high-stakes climactic overs. In contrast, T20 cricket compresses and amplifies these psychological dynamics, offering immediate spectator excitement from aggressive opening overs, sustained strategic tension in the middle phase, and peak emotional intensity during the death overs. These complementary approaches enable rigorous assessment of how innings duration, scoring frequency, and tactical regulations uniquely influence player performance, spectator engagement, and the overall appeal of ODI and T20 cricket. Ultimately, the insights from both overall and phase-specific analyses form the critical foundation for this research's exploration of structural optimizations aimed at enhancing emotional intensity, competitive fairness, and psychological engagement across various sports contexts.

2.3 Soccer (historical evolution and modern rules)

Soccer, or association football, traces its roots to ancient and medieval ball games, with the Chinese game cuju regarded as an early precursor [55–57]. The modern sport took shape in mid-19th-century England with the codification of its first uniform rules [58]. In 1863, the English Football Association was founded and established the original "Laws of the Game" laying the foundations for contemporary soccer in subsequent decades [59, 60]. Today, association football is governed globally by a standardized set of rules, the Laws of the Game, administered by FIFA, the sport's international governing body [61]. Each match features two teams of 11 players (ten outfield players and one goalkeeper per team) competing on a rectangular pitch typically measuring between 100 and 110 m in length and 64 to 75 m in width, with a goal at each end measuring approximately 7.32 m wide by 2.44 m high [62, 63]. The detail measurement can be found in Figure 2.2 [64]. Matches consist of two halves, each lasting 45 minutes (totaling 90 minutes) [65], and teams are allowed a limited number of substitutions, historically three to replace players during play [66]. Critical gameplay rules include the offside law, which prevents attackers from gaining unfair positional advantages by requiring at least two opposing players to be between the attacker and the goal at the moment a forward pass is made [67], and regulations against fouls such as kicking, tripping, or hand-ball violations. Such infractions are penalized by the referee with free kicks or penalty kicks, and can lead to yellow-card cautions or red-card ejections for serious misconduct [68]. FIFA's stewardship of these standardized rules maintains uniform gameplay structure and competitive fairness in soccer competitions globally. Soccer's accessibility and widespread appeal have propelled it to become the world's most popular sport, now played by over 250 million people in more than 200 countries [69].

Soccer is notably a low-scoring sport, with matches typically producing around 2–3 goals on average. Historical data from the German Bundesliga (1968–2011) indicated an average of approximately 3.07 goals per match (about 1.53 per team) [70]. Similarly, analyses of ten elite European leagues between 2001 and 2009 reported consistent scoring rates, ranging from about 2.25 goals per game in France's Ligue 1 to roughly 2.85 in Germany's Bundesliga, with England's Premier League averaging approximately 2.57 [71]. Notably, scoring levels have remained consistently below three goals per game since the late 1950s [72], highlighting the game's inherent challenge in scoring. Furthermore, goals in soccer are unevenly distributed over match durations, with roughly 57% occurring in second halves compared to 43% in first halves, peaking notably in the final 15 minutes when fatigue and tactical risks often escalate [72]. Due to this difficulty in scoring, teams must generate numerous goal attempts. Classic studies, such as those by Reep, established a widely-cited benchmark that approximately one goal is scored per ten shots [73]. Supporting this, analyses of World Cup competitions

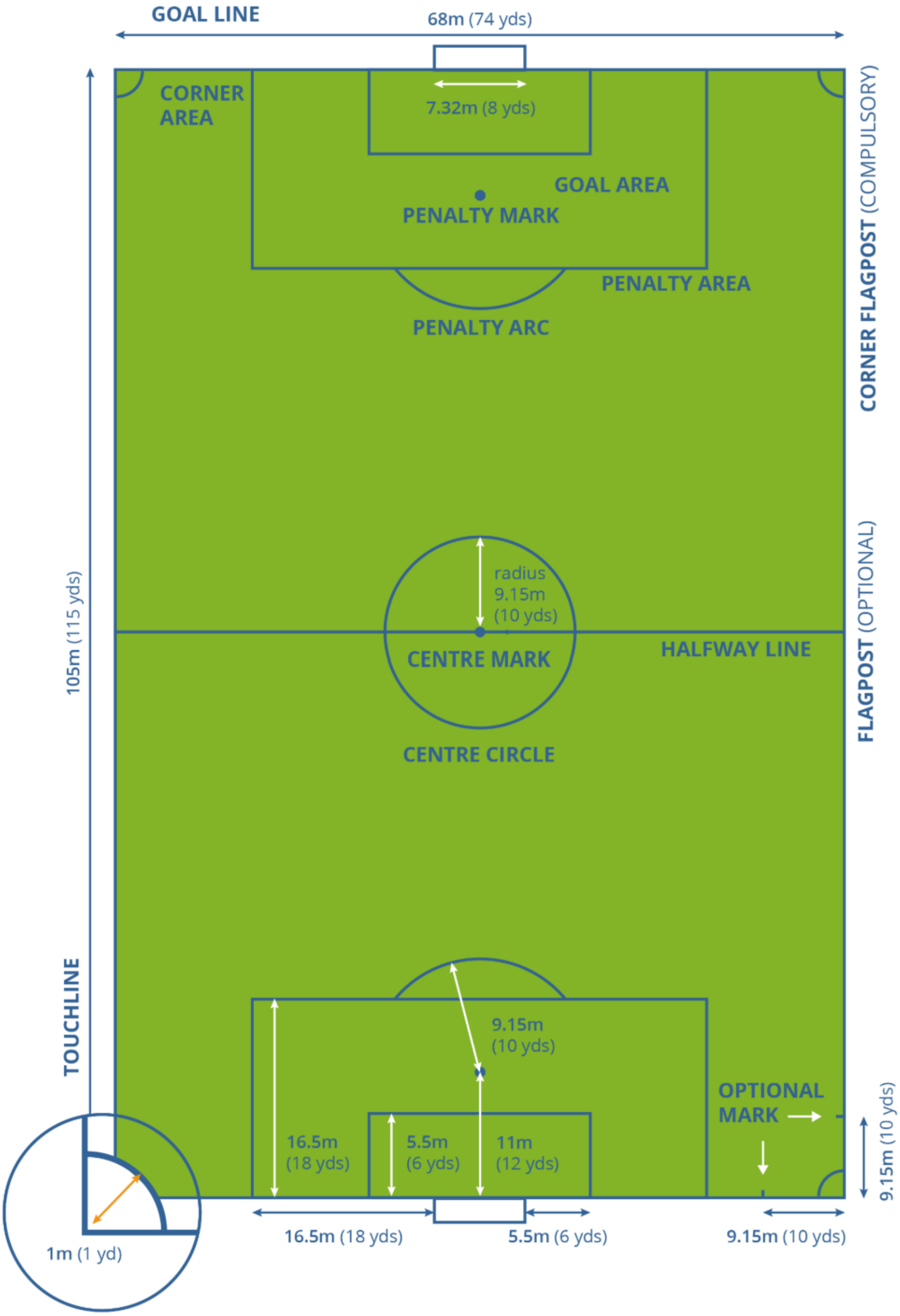

Fig. 2.2 Diagram of a soccer field [64].

consistently show finalists averaging about 18.0 shots per game compared to approximately 14.1 shots for less successful teams [74]. Similar trends appear in domestic leagues; for instance, an analysis of Spain's La Liga (2008–09) found winning teams consistently outshot their opponents and maintained higher shooting accuracy, indicating superior attacking effectiveness. Crucially, "shots on target," attempts requiring a goalkeeper's intervention, strongly correlate with positive outcomes. Research from the Greek Super League showed winning teams averaged around 5.3 shots on target per match, significantly more than their rivals [75]. Typically, professional matches might see each team generating approximately 10–15 total shots, with about 3–6 of these attempts on target. The difference in even a small number of quality attempts can decisively impact match outcomes; championship teams in Greece, for example, averaged about 2.1 goals per game versus less than one goal for lower-ranked teams [73, 74]. Thus, metrics such as average goals and shots (both on and off target) are pivotal for understanding soccer's dynamics, capturing how attacking initiatives, although frequent, translate inefficiently into goals. Higher shot counts, especially those on target, consistently correlate with winning outcomes, underscoring the critical role of attacking efficiency in soccer's low-scoring environment [74, 75].

While there is no universally accepted framework or rule of thumb for segmenting the 45-minute halves of a soccer match, analysts commonly divide them into three 15-minute intervals, effectively breaking the full match into six segments. For example, a club analysis on FC Barcelona's official website categorized match phases as 0–15 minutes (often referred to as the opening quarter-hour), 16–30 minutes (mid-half), 31–45 minutes (end of first half, excluding stoppage time), and similarly 46–60, 61–75, and 76–90 minutes in the second half [76]. The 16–30 minute period was identified as particularly productive, during which the team scored seven goals. Coaches and performance analysts often adopt flexible segmentation schemes depending on the analytical objective—for instance, they may focus on standard 15-minute intervals, full halves, or specific periods such as the final 10 minutes when late-game performance is under scrutiny [77]. Leading sports data providers like Opta frequently record events using these 15-minute blocks, and platforms such as SoccerSTATS regularly present goal statistics segmented in this way [78]. This temporal breakdown offers a practical approach for identifying timing-related trends in team performance. Although 15-minute segments are the most widely used, they are not the only option. Some analyses employ 10-minute intervals, resulting in nine total segments (e.g., 0–10, 11–20, ... 81–90), offering greater granularity. SoccerSTATS, for instance, provides both 10-minute and 15-minute breakdowns for enhanced analytical flexibility [78].

2.3.1 Psychological and Emotional Dynamics in Soccer

Research on spectator emotions during soccer matches indicates that fans typically begin viewing games with a positive, hopeful mindset, though these emotions fluctuate significantly as matches unfold [79]. For instance, supporters' happiness notably diminishes if their team is not leading by halftime, whereas dramatic late-game events, such as last-minute winning goals, can trigger significant surges in excitement and joy. This psychological dynamic underscores how uncertainty in match outcomes intensifies suspense, particularly towards the conclusion of closely contested games. An analysis of English Premier League broadcasts supports this, revealing that television audiences substantially increase during periods marked by heightened suspense and unpredictability, highlighting how such moments significantly amplify viewer engagement [80]. Supporting this phenomenon, real-time social media engagement data from World Cup matches indicate that during intensely suspenseful moments, fans tend to post fewer tweets, likely reflecting their deep immersion and focused attention on unfolding events [81]. On the field, players similarly experience distinct psychological phases during a match. At the outset, players typically exhibit high motivation and energy, diligently executing tactical plans to establish an early advantage. Performance data from UEFA Champions League matches indicate players cover the greatest distances and exert high-intensity effort predominantly during periods when the match is closely contested or when attempting to overcome deficits or break a stalemate [82]. Such behavior underscores the strong motivation to assert control during the early to middle stages of play. As matches progress, teams strategically adjust their risk-taking based on the evolving scoreline. Large-scale analyses of match segments illustrate clear strategic shifts, with trailing teams increasingly intensifying their attacking efforts in response to deficits, while leading teams often adopt more cautious, defensive strategies to maintain their advantage [83]. Interestingly, teams experiencing mid-to-late second-half draws, despite the evident urgency to score, may paradoxically adopt conservative tactics, producing fewer shots on target compared to teams holding a lead. This phenomenon highlights the intricate balance between competitive ambition and risk aversion during critical game phases, as players and coaches weigh the drive for victory against the fear of critical mistakes. In the final phase of a soccer match, psychological pressure reaches its zenith, profoundly affecting players' collective mental state. Experimental studies, such as the one conducted by Den Hartigh et al., have demonstrated that critical late-game events significantly influence players' perception of momentum. For example, a last-minute equalizer (at the 92nd minute) carries a dramatically larger psychological impact compared to a similar goal scored earlier, substantially altering players' confidence and emotional states despite identical final scorelines [84]. Such pivotal moments vividly illustrate the heightened emotional extremes euphoria or despair experienced by players, depending on whether these decisive events favor or oppose their team. Ultimately, the psychological landscape of soccer evolves dynamically across match phases: from initial optimistic intensity at kickoff, through strategic adaptation mid-game, to extreme emotional and psychological pressure as the final outcome is determined.

This study systematically examines soccer's structural components and their influence on spectator engagement and excitement. Scholars have suggested structural adjustments, such as shortening match length from the traditional 90 minutes to 60 minutes, to potentially enhance spectator engagement. Motivated by these discussions, this research employs GR theory and the MiM model to evaluate soccer's current format by explicitly incorporating game length into the analysis. Through quantitative assessments of scoring frequency, strategic tension, and emotional dynamics, the study investigates whether modifications to soccer's temporal structure could better align the sport with theoretically optimal conditions for sustained excitement and psychological engagement. Notably, prior research has not comprehensively explored soccer using phase-based analyses to identify distinct patterns of engagement and excitement. Thus, this study uniquely applies GR and MiM models across discrete gameplay phases opening, middle, and endgame to provide deeper insights into how structural elements influence spectator experience throughout the course of a match.

2.4 Game Refinement Theory and Motion in Mind Model

2.4.1 Game Refinement Theory

Uncertainty is a fundamental element in both games and sports, as it sustains engagement and competitive balance. At the start of any game, the outcome is highly unpredictable because both sides have an equal chance of success. As the game progresses, players make decisions, execute strategies, and accumulate points, gradually reducing uncertainty. However, this process must be well-regulated, if uncertainty is resolved too quickly, the game becomes predictable and unexciting [16]. Conversely, if uncertainty remains too high for too long, the game may feel frustrating or overly dependent on luck. Thus, it becomes crucial to mathematically model how uncertainty is resolved over time, ensuring that a game remains both fair and engaging. Addressing this requires a formal mathematical approach, leading to the application of the logistic model of game uncertainty which provides a mathematical framework to quantify how information about the game outcome is progressively revealed over time. It describes how uncertainty decreases as players make decisions, score points, or execute moves, following a structured progression. To mathematically represent this process, [16] consider two key observations about how uncertainty is resolved in a game. Firstly, the rate at which uncertainty is being resolved at any moment should be proportional to the amount of uncertainty that has already been resolved. This means that as more information is revealed, it becomes easier to predict the final outcome. Secondly, the rate of uncertainty resolution should also be inversely proportional to the time elapsed. This reflects the natural progression of games, where uncertainty is typically resolved more rapidly at the beginning and more gradually as the game reaches its conclusion. These principles can be expressed as the differential equation:

$$x'(t) \propto \frac{x(t)}{t} \tag{2.1}$$

where $x(t)$ is the amount of solved uncertainty (or information obtained) at time t, and $x'(t)$ is the rate at which uncertainty is being solved. Next, to remove the proportionality, the proportionality constant n is introduce, leading to:

$$x'(t) = n\frac{x(t)}{t} \tag{2.2}$$

By introducing a parameter n (where $1 \leq n \in \mathbb{N}$) depends on the structure of the game, the following differential equation is obtained:

$$x'(t) = \frac{n}{t}x(t) \tag{2.3}$$

This equation states that the rate of change of $x'(t)$ is proportional to $x(t)$ and inversely proportional to t. Here the function $x(t)$ follows the initial and final conditions given by $x(0) = 0$ and $x(T) = 1$, where $T = t$ represents the total game duration or length. Since $x(T)$ represents the normalized amount of solved uncertainty, it's assumed that uncertainty progresses within the bounds $0 \leq t \leq T$ or $\quad 0 \leq x(t) \leq 1$.

In Chess, n corresponds to the number of legal moves available at a given moment, while in sports, n represents the number of scoring opportunities or events that significantly influence the game outcome. Equation (2.3) describes how uncertainty decreases over time, being proportional to the information already gained and inversely proportional to time elapsed. For instance, in Chess, at the start of the game, the number of plausible moves is large, keeping uncertainty high. As the game progresses, optimal moves become more constrained, leading to a gradual resolution of uncertainty. Similarly, in a soccer match, the likelihood of winning fluctuates dynamically based on scoring events. If a goal is scored early, the game's uncertainty decreases significantly, whereas a tied score in the final minutes sustains a high level of unpredictability. Equation (2.3) allows for the derivation of a Game Refinement (GR) measure in the GR theory, which quantifies the rate at which uncertainty is resolved.

By solving Equation (2.3), rewrite it in a form that allows to separate $x(t)$ and t. This step is crucial because it allows us to integrate both sides separately.

$$\frac{x'(t)}{x(t)} = \frac{n}{t} \tag{2.4}$$

Now, by integrating both sides the Equation (2.5) is obtained:

$$\int \frac{dx}{x} = \int \frac{n}{t} dt \tag{2.5}$$

in Equation (2.5) the left-hand side integrates to $\ln|x|$ and right-hand side integrates to $n\ln|t| + C$, where C is an integration constant. Thus, the following is obtained:

$$\ln|x| = n\ln|t| + C \tag{2.6}$$

Now, to eliminate the natural logarithm, the both sides are exponentiate in Equation (2.7):

$$e^{\ln|x|} = e^{n\ln|t|+C} \tag{2.7}$$

Using the exponent property $e^{\ln a} = a$, the following is simplified:

$$x = e^{C} \cdot e^{n\ln|t|} \tag{2.8}$$

Since $e^{\ln|t|} = |t|$, this further simplifies to $x = e^{C}t^{n}$, where letting $e^{C} = C_1$ (a new constant) and rewrite this as:

$$x(t) = C_1 t^n \tag{2.9}$$

Now to find C_1, the boundary condition $x(T) = 1$ is used where substituting $t = T$ into Equation (2.9) the $1 = C_1 T^n$ is obtained. Now solving for C_1:

$$C_1 = \frac{1}{T^n} \tag{2.10}$$

Substituting this back into Equation (2.9) the Equation (2.11) is obtained, which is further simplified into Equation (2.12):

$$x(t) = \frac{1}{T^n} t^n \tag{2.11}$$

$$x(t) = \left(\frac{t}{T}\right)^n \tag{2.12}$$

Equation (2.12) represents the accumulation of solved uncertainty in a game as time progresses. Here, $x(t)$ denotes the proportion of total uncertainty that has been resolved by time t, where T is the total game duration or length, and n is the number of possible options or score influencing the rate of information acquisition. The exponent n plays a key role in determining the rate at which uncertainty is resolved. If n is small, uncertainty is resolved more gradually, meaning that the game retains unpredictability for a longer duration. In contrast, if n is large, the uncertainty is resolved more quickly, making outcome of the game predicable.

Computing first $x'(t)$ and second $x''(t)$ derivative

Having established the mathematical expression for how uncertainty is resolved over time in Equation (2.12), the rate of change can be examine further by computing its second derivative. The second derivative provides insights into the acceleration of information resolution during the game, helping to quantify how quickly the game outcome becomes predictable as play progresses. As we already know the function that describes the progression of solved uncertainty over time in Equation (2.12):

$$x(t) = \left(\frac{t}{T}\right)^n \tag{2.13}$$

To determine how quickly uncertainty is being resolved at any moment, the $x(t)$ with respect to t is differentiated. This gives the first derivative, $x'(t)$, which represents the rate of change of solved uncertainty in Equation (5.16):

$$x'(t) = \frac{d}{dt}\left(\frac{t}{T}\right)^n \tag{2.14}$$

Now, by applying the power rule, the following is obtained:

$$x'(t) = n\left(\frac{t}{T}\right)^{n-1} \cdot \frac{1}{T} \tag{2.15}$$

$$x'(t) = \frac{n}{T^n} t^{n-1} \tag{2.16}$$

This equation indicates that the rate at which uncertainty is being resolved is proportional to both n and t^{n-1}, which depends on the current stage of the game. Next, the $x'(t)$ is differentiated in Equation (2.16) to find the second derivative, which represents the acceleration a of solved uncertainty:

$$x''(t) = \frac{d}{dt}\left(\frac{n}{T^n} t^{n-1}\right) \tag{2.17}$$

Again using the power rule, the following is obtained:

$$x''(t) = \frac{n(n-1)}{T^n} t^{n-2} \tag{2.18}$$

This equation quantifies how fast uncertainty resolution itself is changing, which determines whether a game becomes predictable gradually or suddenly. Now, to understand how uncertainty behaves at the end of the game, the $x''(t)$ at $t = T$ is evaluated:

$$x''(T) = \frac{n(n-1)}{T^n} T^{n-2} \tag{2.19}$$

Since $T^n/T^2 = T^{n-2}$, it is simplified to:

$$x''(T) = \frac{n(n-1)}{T^2} \tag{2.20}$$

This result represents the acceleration of uncertainty resolution at the game's final stage. The second derivative helps measure how rapidly the game outcome becomes clear as the game reaches its conclusion. A higher value indicates that the game outcome transitions sharply near the end, while a lower value suggests a more gradual revelation of information.

Finally, the game refinement (GR) measure in Equation (2.21) is obtained, a key metric that quantifies how uncertainty is resolved over time. By taking the square root of the second derivative, the following is obtained:

$$GR = \frac{\sqrt{n(n-1)}}{T} \tag{2.21}$$

This measure provides a quantitative way to analyze and compare different games by assessing how well uncertainty is balanced throughout their progression. A well-balanced game ensures that players remain engaged, as uncertainty is neither resolved too quickly nor dragged on for too long.

2.4.2 Measure of GR for Board Games

In any strategic board game, a player is presented with a number of possible legal moves at each turn, known as the branching factor (B). However, rather than evaluating every move, skilled players instinctively filter their choices and focus on a smaller subset of plausible moves (b), which are strategically meaningful. This move filtering ability improves with experience, allowing stronger players to discard weak or irrelevant moves quickly, reducing cognitive load and improving efficiency. Empirical studies [16] suggest that the number of plausible moves follows the approximation $b \approx \sqrt{B}$, meaning that as the total number of legal moves increases, the subset of meaningful moves grows at a slower rate. For example, in Chess, a novice may consider almost all $B = 35$ legal moves, leading to slow and often suboptimal decisions, whereas a grandmaster intuitively filters moves down to only $b \approx 6$ strong candidates. A similar pattern occurs in Shogi, where piece drops significantly increase complexity, leading to a higher branching factor of $B \approx 80$, but skilled players refine their choices to around $b \approx 9$. In Go, due to the large board and high number of possible placements ($B \approx 250$), professionals still focus on approximately $b \approx 16$ key moves. This hierarchical decision-making process differentiates beginners from experts, as stronger players recognize and prioritize high-value moves while ignoring distractions, leading to more refined and efficient gameplay.

After skill reduces the number of considered moves from B to b, the final move selection follows a probabilistic process, influenced by factors such as time constraints, strategic complexity, and cognitive limitations. As illustrated in Figure 2.3, this transition from b to "1" represents the effect of chance in decision-making [85]. Even among strong candidate moves, players do not always select the absolute best one due to practical constraints. This introduces a level of randomness, ensuring that decision-making remains dynamic rather than deterministic. In high-pressure situations, even expert players rely on heuristic judgments, leading to variance in move selection. This aspect of human play is effectively modeled in AI algorithms such as Monte Carlo Tree Search (MCTS) [86], where moves are selected based on probability distributions rather than fixed heuristics. By incorporating stochastic decision processes, AI systems can play in a more human-like manner, adapting dynamically to game states rather than following rigid, deterministic strategies [87, 88].

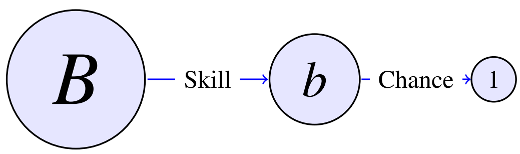

Fig. 2.3 An illustration of move selection model based on skill and chance [82]

Conjecture 1: In any game, skill can help reduce the complexity of decision-making by filtering out less important choices. This means that even a game with many possible moves can be simplified into a version where only a smaller number of meaningful options need to be considered. This transformation allows the game to be modeled as a stochastic decision process, where players choose moves based on probability rather than evaluating every possibility. This mirrors the $\alpha\beta$ algorithm, which, in the best-case scenario, reduces the number of moves considered from B^D to approximately b^D [89, 90], where $b \approx \sqrt{B}$. Such simplification allows AI to analyze games more efficiently, enabling faster and more accurate decisions.

Since the parameter n in Equation (2.21) represents the number of plausible moves (b), the direct connection is establish between the move selection model and the GR measure. This relationship indicates that as the total number of legal moves increases, the effective decision space does not grow proportionally but instead expands at a slower rate. This natural filtering mechanism ensures that games remain manageable in complexity and do not overwhelm players with excessive choices. Therefore, to quantify the level of challenge and engagement in a game, the GR measure is introduced [16]. This measure evaluates how uncertainty is resolved throughout a game by considering both the branching factor B and the average game length D. Intuitively, B represents the complexity of decision-making, while D determines how long the game sustains uncertainty before reaching a conclusion.

Since $n \approx b \approx \sqrt{B}$, thus, for a game with a branching factor of B and an average game length of D, the GR measure in board games can be approximated as:

$$GR \approx \frac{\sqrt{B}}{D} \tag{2.22}$$

Therefore, Equation (2.22) provides insight into the balance between skill and chance in a game. A well-designed game maintains an optimal level of challenge, preventing outcomes from becoming too predictable while also avoiding excessive randomness. Empirical studies by Iida et.al [16] suggest that engaging and well-balanced games tend to have GR values in the range of 0.07 to 0.08, ensuring that players remain motivated without feeling overwhelmed or frustrated. Their results in Table 2.1 highlight that well-balanced board games, such as Chess, Shogi, and Go, exhibit a GR value within the range of $[0.07, 0.08]$. This suggests that engaging and sophisticated games share a similar degree of informational acceleration, ensuring that uncertainty is resolved at a pace that maintains player engagement without making the game too predictable or overly random. The consistency of GR values across different board games indicates that this measure effectively captures the dynamic balance between skill and chance, offering a useful metric for evaluating game design.

Furthermore, to analyze the acceleration in board games, we substitute $T = D$, $x''(t) = a$, and the previously established approximation $n \approx \sqrt{B}$ into Equation (2.20). This gives:

$$a = \frac{B}{D^2} \tag{2.23}$$

Since the GR measure is defined in Equation (2.22), and the goal is to express a in terms of GR, both sides are squared:

$$GR = \frac{\sqrt{B}}{D} \tag{2.24}$$

which results in:

$$GR^2 = \left(\frac{\sqrt{B}}{D}\right)^2 \tag{2.25}$$

Expanding the square, the following is obtained:

$$GR^2 = \frac{B}{D^2} \tag{2.26}$$

Thus, the acceleration can be express in terms of the GR measure:

$$a = GR^2 = \frac{B}{D^2} \tag{2.27}$$

Conversely, solving for GR in terms of a, take the square root of both sides, obtained:

$$GR = \sqrt{a} \tag{2.28}$$

This result establishes a direct relationship between game acceleration and the GR measure, reinforcing the idea that acceleration in board games is naturally governed by the square of GR. Consequently, games that maintain a balanced level of engagement typically exhibit values of GR within a specific comfort zone ($0.07 \leq GR \leq 0.08$), ensuring an optimal rate of uncertainty resolution.

Table 2.1 Measures of game refinement for board games

	B	D	GR
Chess	35	80	0.074
Shogi	80	115	0.078
Go	250	208	0.076

Given its success in analyzing board games, the GR measure is extended to sports, which requires a more generalized approach to estimate the key parameter (n) which represents the number of plausible moves in board games raises a critical challenge. Addressing this question was crucial for extending the GR measure to a wider variety of competitive and interactive systems.

2.4.3 Measure of GR for Sports

In a game, uncertainty about the outcome is gradually resolved as the match progresses. Let $y(t)$ represent the amount of uncertainty solved by time t, and let v be the average rate at which uncertainty is resolved. A simple way to model this is using a linear relationship:

$$y(t) = vt \tag{2.29}$$

where $y(t)$ is the total solved uncertainty at time t, v is the constant rate of solving uncertainty per unit time and t represents time or game length. This assumes that uncertainty is resolved at a steady pace. However, in most real-world sports, uncertainty tends to be resolved faster near the end of the game, meaning it follows an accelerated resolution model instead of a simple linear model. To account for this, the accelerated uncertainty resolution model inspired by physics can be use:

$$y(t) = v_0 t + \frac{1}{2}at^2 \tag{2.30}$$

where v_0 is the initial rate of solving uncertainty at the start of the game and a is the acceleration of uncertainty resolution. Since there is no solved uncertainty at the start of the game ($v_0 = 0$), the equation simplifies to:

$$y(t) = \frac{1}{2}at^2 \tag{2.31}$$

This means that uncertainty is resolved slowly at first, but as the game progresses, it accelerates towards a conclusion. As we know that $t = T$, both the linear model and the accelerated model can be describe as:

$$y(T) = vT \tag{2.32}$$

$$y(T) = \frac{1}{2}aT^2 \tag{2.33}$$

Since both models lead to the same total uncertainty solved, they can be equal to each other as:

$$vT = \frac{1}{2}aT^2 \tag{2.34}$$

Solving for a

Multiply both sides by 2 to eliminate the fraction:

$$2vT = aT^2 \tag{2.35}$$

Divide both sides by T^2, thus, the following equation is obtained:

$$a = \frac{2v}{T} \tag{2.36}$$

This equation indicates that, if a game is longer (T is large), then a is smaller, meaning uncertainty is resolved more gradually. If a game is shorter (T is small), then a is larger, meaning uncertainty is resolved more quickly. But in the sports context, the game progress better captured by $v = \frac{G}{T}$ where G is the total Goals/Score, representing how often players succeed in scoring while T are the total Attempts/Shots, representing how many opportunities exist to resolve uncertainty. Thus substituting $v = \frac{G}{T}$ into Equation (2.36), the a in terms of score and attempts can be expressed as:

$$a = \frac{2G}{T^2} \tag{2.37}$$

where higher G (more goals) means the game progresses faster toward a conclusion. Higher T (more shot attempts) spreads out uncertainty resolution, making the game more skill-dependent. Thus, in sports the game balance is determined by how scoring (G) interacts with attempts (T).

Deriving the GR Measure

To quantify how well a sport balances skill and chance, we use the GR index, which measures the rate of uncertainty resolution as:

$$GR = \sqrt{a} \tag{2.38}$$

By substituting $a = \frac{2G}{T^2}$ into Equation (2.38), the following is obtained.

$$GR = \sqrt{\frac{2G}{T^2}} = \frac{\sqrt{2G}}{T} \tag{2.39}$$

GR theory has significantly contributed to the quantitative understanding of entertainment and engagement in diverse games, including classic board games such as chess, Shogi, and Go [16], as well as e-sports genres like Multiplayer Online Battle Arena (MOBA) games [91]. These board games exhibit considerable strategic depth, with GR values typically within an optimal range (e.g., chess: 0.074; Shogi: 0.078; Go: 0.076), reflecting a balanced level of uncertainty that effectively sustains player engagement. Similarly, DotA 6.80, a popular MOBA game, was reported to have a GR value of 0.078, indicating comparable refinement levels between well-designed e-sports and traditional board games. GR theory's broad applicability is evident across various domains, including board games [14, 15, 92], card games [93–95], video games [96, 91, 97], and sports [98–103]. Furthermore, GR's versatility extends beyond gaming contexts into various non-game scenarios, demonstrating its broader capability to quantify engagement and satisfaction across diverse environments [104, 105, 91, 106]. However, the application of GR theory to soccer has presented some notable inconsistencies. For example, Gao et al. [19] report a GR value 0.076 and an Addictive Density (AD) of 0.090 ($\phi = 0.84$), but closer inspection reveals formula inconsistencies. The authors employed $GR = \frac{\sqrt{B}}{D}$ instead of the widely accepted $GR = \frac{\sqrt{2G}}{T}$, and for AD, $AD = \frac{\sqrt[3]{6G}}{T}$. Applying the correct formulas yields updated values: $GR = 0.107, AD = 0.1164$, and $\phi = 0.92$. These discrepancies critically affect both numerical accuracy and theoretical interpretations. Similar methodological inconsistencies have emerged elsewhere, such as in Naying et al. [18], and Xiaohan et al. [107], where interpretations of reward frequency in soccer contexts appear misaligned with actual gameplay dynamics, casting doubt on the validity of their conclusions. Such issues reflect broader concerns regarding GR and MiM frameworks' reliability in analyzing sports dynamics. While issues have been noted in soccer, similar limitations appear in cricket research. For instance, [108] acknowledges the relevance of GR theory but does not apply its metrics to assess engagement across formats like Test, ODI, and T20. A comparative analysis using GR and MiM could offer deeper insights into how cricket's structure influences excitement and strategic depth. Moreover, their use of a hypothetical 10-over match raises questions, especially given that T20 already provides a fast-paced, engaging format. Clarifying this rationale would strengthen their contribution and improve theoretical precision in evaluating cricket's engagement dynamics.

Note on the GR measure and the sophistication of the games. An important and critical question may arise regarding the rationale for focusing primarily on the number of successful events (G), total attempts (T), and game length in evaluating game sophistication. While numerous factors such as player skill, strategic complexity, environmental conditions, and audience demographics may contribute to the perceived sophistication, quality or entertainment value of a game, the GR theory primarily focuses on two core components: the number of successful events (G), and the number of total attempts (T). These two parameters are fundamental in most of the game-play environment because they directly influence the psychological states of suspense, reward anticipation, and emotional reinforcement. Successful events (G), such as goals or scoring actions, typically create immediate excitement, while total attempts (T) sustain cognitive engagement through suspense and strategic buildup. The ratio and interplay between G and T therefore act as strong proxies for modeling the dynamic emotional rhythm of a game. Furthermore, as game length directly influences both G and T, GR theory's focus on the ratio $\sqrt{2G}/T$ provides a simplified yet powerful lens to quantify and compare games sophistication. While acknowledging that other contextual or qualitative factors also matter, the GR model deliberately isolates these two quantifiable elements to ensure the theoretical consistency and broad applicability across diverse game environments.

2.4.4 Motion in Mind Model

While GR theory provides an objective analysis of games and sports, the MiM model extends GR theory to incorporate subjective dimensions by examining players' cognitive and emotional experiences during gameplay [16, 17]. Drawing from classical mechanics, MiM analogizes agents (players) not by physical mass, but by intelligence or skill level. In this framework, a player with higher intelligence (or skill) faces lower uncertainty and is assigned a smaller cognitive mass (m), whereas a less skilled player experiences greater uncertainty and thus carries a larger m. Hence, mass in this context represents the magnitude of challenge or frequency of risk encountered by a player.

According to the MiM framework, game progress is modeled linearly, with the slope (v) representing the rate at which uncertainty is resolved. This slope is inversely related to cognitive mass, expressed as $m = 1 - v$. The calculation of v and m varies depending on the nature of the game:

- **Board games:** Let B be the average number of possible moves and D the average game length. Then:

$$v \approx \frac{1}{2} \cdot \frac{B}{D}, \quad m = 1 - v \tag{10}$$

- **Sports:** Let G be the total number of goals (or points) and T the number of shot attempts per game. Then:

$$v = \frac{G}{T}, \quad m = 1 - v \tag{11}$$

For certain sports such as table tennis or badminton, the probability of scoring in a given rally is approximately $\frac{1}{2}$, hence $v = \frac{1}{2}$. Once the velocity (v) is established, the MiM model maps additional physical quantities such as acceleration, momentum, force, and potential energy to psychological states including cognitive load, engagement, and emotional fairness and others. These mappings provide a bridge between game mechanics and human psychology, offering a comprehensive framework for understanding how uncertainty, decision-making effort, and emotional investment unfold during gameplay. The MiM model thereby deepens the interpretation of how players, teams, and spectators cognitively and emotionally experience game dynamics. Further methodological details are presented in the following section.

While no existing study explicitly addresses the methodological challenges of applying velocity to high-scoring sports such as T20 cricket. Given the velocity in MiM calculations primarily assume low-scoring frequencies as commonly seen in sports like soccer or board games, direct application of velocity ($v = \frac{G}{T}$) can potentially lead to overestimation or misinterpretation of GR refinement values in games with significantly higher scoring rates. Thus, this research contributes a novel methodological adjustment for appropriately normalizing velocity within the MiM framework, specifically tailored to accurately reflect engagement dynamics in high-scoring contexts. This ensures the robustness of GR and MiM metrics across diverse sports settings, particularly for T20 cricket, and provides a solid foundation for accurately comparing psychological and emotional engagement across games with varying scoring frequencies.

2.5 Chapter Summary

This literature review has critically evaluated existing research on cricket and soccer, emphasizing historical contexts, structural components, psychological dynamics, and theoratical frameworks such as GR and MiM. The key scientitifc, theoretical and methodological gaps identified particularly inaccuracies in applying GR theory to soccer and the challenges of velocity application in high-scoring contexts like T20 cricket necessitate methodological refinements. To address the existing gaps in this chapter comprehensively, the following chapter presents a detailed description of the research methodology, outlining the analytical data-driven approaches employed to systematically examine the engagement and excitement dynamics across cricket and soccer.

Chapter 3

Research Methodology

3.1 Chapter Introduction

This chapter provides a comprehensive overview of the methodological framework adopted to rigorously address the research objectives and questions established in Chapter 1. Specifically, it details the research design, data collection procedures, and analytical methods employed to systematically examine and compare the dynamics of engagement and excitement inherent in ODI cricket, T20 cricket, and soccer.

Building upon the outlined methodological frameworks, comprehensive and systematic data collection was conducted to facilitate rigorous comparative analyses across different sports formats. Specifically, three distinct data collection strategies were implemented: (i) data for comparative analysis across ODI cricket, T20 cricket, and soccer were meticulously gathered from officially recognized international competitions such as ICC Cricket World Cup 2023 (ODI), ICC T20 World Cup 2022 (T20), and FIFA World Cup 2022 (soccer), ensuring consistency, accuracy, and robustness across the entire dataset; (ii) data collection specifically targeted elite competitive scenarios, focusing exclusively on finalist teams in the aforementioned tournaments to examine high-level competitive dynamics and strategic interactions in depth and (iii) detailed, phase-wise data collection was performed to analyze dynamic fluctuations in engagement throughout matches by segmenting gameplay into structurally meaningful phases (e.g., powerplays and death overs in cricket, distinct time segments in soccer), utilizing official ball-by-ball and minute-by-minute records, thus enabling precise and insightful phase-specific comparisons. Collectively, these detailed and multilayered data collection processes provide a solid empirical foundation, ensuring analytical rigor, methodological transparency, and replicability of findings.

To systematically quantify and interpret the dynamics of engagement and excitement across ODI cricket, T20 cricket, and soccer, this research adopts three distinct yet complementary analytical frameworks such as GR theory, the MiM and the newly distinguished FiM framework. GR theory serves as a foundational approach, mathematically quantifying the rate at which uncertainty is resolved during gameplay to evaluate how structural variations influence overall spectator and player engagement. The MiM model extends this quantitative foundation by integrating cognitive and psychological dimensions, analogizing physical concepts such as velocity, mass, acceleration, and jerk to subjective experiences thereby capturing nuances in players' cognitive load, emotional responses, and perceived excitement. However, given identified theoretical and practical limitations in high-scoring sports contexts, this research further introduces and rigorously defines the FiM framework, carefully refining velocity normalization to ensure accurate and theoretically consistent measurements in scenarios such as T20 cricket, where scoring frequencies significantly exceed typical norms. Together, these frameworks offer a robust, multidimensional methodological toolkit, enabling deep insights into both structural and psychological aspects of sports engagement, and facilitating precise, objective, and theoretically grounded comparisons across diverse competitive contexts.

These methodological approaches outlined in this chapter lay a rigorous foundation for the empirical analyses presented in subsequent chapters. By clearly detailing the research design, comprehensive data collection procedures, advanced analytical frameworks, and novel methodological approach, this chapter ensures the clarity, methodological rigor, and theoretical consistency necessary for robust and insightful contributions to the study of engagement and excitement in competitive sports.

3.2 Research Design

This research employs a primarily quantitative, comparative analytical design to systematically examine and compare engagement and excitement dynamics across and within ODI cricket, T20 cricket, and soccer sports. The rationale for selecting this comparative and in-depth quantitative methodology stems from its capability to objectively quantify and rigorously compare structural and psychological dynamics within distinct sporting contexts. Specifically, this design is well-suited to explore how inherent variations such as the high-scoring, variable-ending structure of cricket compared to the low-scoring, fixed-duration format of soccer influence engagement levels among players and spectators.

The comparative analytical approach adopted in this study leverages three core analytical frameworks such as the GR theory, the MiM and the newly distinguished FiM framework. Each framework provides a unique lens for quantifying different dimensions of game dynamics and psychological engagement. The GR theory quantitatively measures how uncertainty is resolved throughout gameplay, enabling direct and standardized comparisons across diverse sports contexts. Complementarily, although distinct in their mathematical formulations, both the MiM and FiM frameworks integrate psychological and cognitive dimensions into the quantitative analysis. By employing analogies drawn from classical physics and GR theory, these frameworks systematically map emotional and cognitive states experienced by players and spectators such as excitement, anxiety, and perceived difficulty as gameplay unfolds.

Furthermore, this study incorporates a detailed phase-based analytical approach, systematically segmenting each match into distinct and structurally meaningful phases, such as powerplays and death overs in cricket or defined time intervals in soccer. This segmentation allows a deeper examination of the temporal fluctuations in engagement and excitement, providing insights beyond aggregate match-level analyses. By capturing how psychological dynamics evolve throughout different match phases, the study can pinpoint critical moments that significantly shape overall spectator and player experiences.

Lastly, to enrich the analytical depth, this research introduces an innovative gravity-inspired analytical framework, explicitly developed to quantify and interpret the intensity, positional advantages, and strategic interactions between competing teams or players. Drawing inspiration from gravitational physics, this novel analytical tool enhances the capacity to objectively measure and analyze competitive dynamics, offering robust insights into how different sports structures impact strategic decision-making and competitive intensity.

These integrated methodological design combining robust quantitative comparison, advanced analytical modeling, and detailed phase-wise segmentation ensures methodological rigor, theoretical precision, and insightful comparative analysis. This comprehensive and structured approach aligns directly with the research objectives outlined previously, effectively addressing theoretical gaps and providing clear, replicable, and nuanced findings on the engagement and excitement dynamics in ODI cricket, T20 cricket, and soccer.

3.3 Data Collection

The accurate measurement of GR values and scoring velocities (v) requires comprehensive data regarding average goals or runs scored ($\bar{G}$) and the average number of attempts or deliveries ($\bar{T}$). Thus, this study systematically collected datasets from major international sports competitions, specifically cricket (ODI and T20 formats) and soccer, ensuring the datasets' reliability, accuracy, and completeness.

3.3.1 Data Collection for Comparative Analysis of Different Sports

To facilitate a rigorous comparative analysis across ODI cricket, T20 cricket, and soccer, comprehensive datasets were systematically gathered from officially recognized international competitions. This ensured consistency, reliability, and robustness across all collected data.

ODI and T20 Cricket Data Collection

For ODI and T20 cricket analysis, official matches data were sourced directly from recognized cricket governing bodies. Specifically, data for ODI cricket were collected from the official website [109], covering all 46 matches played in the ICC Cricket World Cup 2023. Similarly, T20 cricket data were obtained from the official website [110], encompassing all 42 matches of the ICC T20 World Cup 2022.

To quantify scoring, the total runs scored by both teams in each match were aggregated and average as follows:

$$\bar{G}_{\text{match}} = \frac{G_1 + G_2}{2} \tag{3.1}$$

where G_1 and G_2 represent total runs scored by each team within a single match, and thus, $\bar{G}_{\text{match}}$ represents the average score of that match. The average runs across the entire dataset ($N = 46$ in ODI and $N = 42$ in T20) were calculated using:

$$\bar{G} = \frac{1}{N} \sum_{i=1}^{N} G_{\text{match},i} \tag{3.2}$$

To define the average attempts ($\bar{T}$), cricket's inherent rules were used. Each ODI match comprises 300 deliveries (50 overs), and each T20 match consists of 120 deliveries (20 overs). Thus, the initial average velocity ($\bar{v}$) was defined as the ratio of average runs of a cricket format ($\bar{G}$) to average deliveries faced ($\bar{T}$), i.e.,

$$\bar{v} = \frac{\bar{G}}{\bar{T}} \tag{3.3}$$

Given that $\frac{\bar{G}}{\bar{T}}$ can exceed 1 in high-scoring matches, particularly in T20 cricket, the scoring velocity was defined against a theoretical maximum scenario (scoring a six on every ball), which could also be normalized as scoring a four on every ball but in our analysis we consider six:

$$\bar{v} = \frac{\bar{G}}{6\bar{T}} \tag{3.4}$$

This normalization ensures that the average velocity metric consistently falls within the $[0,1]$ range, where $v = 1$ represents maximum scoring efficiency (a six every ball), and $v = 0$ indicates no scoring.

Soccer Data Collection

Soccer data were manually collected from detailed, minute-by-minute textual commentary available on the official source [111], covering all 64 matches of the FIFA World Cup 2022. Goals scored (G) and shot attempts (T) by each team were carefully documented to ensure accuracy.

Similar to cricket, average goals scored in a soccer matche were calculated by:

$$\bar{G}_{\text{match}} = \frac{G_1 + G_2}{2} \tag{3.5}$$

where G_1 and G_2 represent total goals scored by each team within a single match, and $\bar{G}_{\text{match}}$ represents the average goals within that match. The average goals across the entire dataset ($N = 64$) were calculated using:

$$\bar{G} = \frac{1}{N} \sum_{i=1}^{N} G_{\text{match},i} \tag{3.6}$$

To measure the average shot attempts ($\bar{T}$), the following formula were employed:

$$\bar{T}_{\text{match}} = \frac{T_1 + T_2}{2} \tag{3.7}$$

where T_1 and T_2 denote total shot attempts by each team and $\bar{T}_{\text{match}}$ represents the average attempts within that match. The overall average shot attempts across the entire dataset were calculated as:

$$\bar{T} = \frac{1}{N} \sum_{i=1}^{N} T_{\text{match},i} \tag{3.8}$$

The comprehensive dataset ($\mathscr{D}$) collected for analysis across cricket and soccer is formally represented as:

$$\mathscr{D} = \{D_{\text{ODI}}, D_{\text{T20}}, D_{\text{Soccer}}\} \tag{3.9}$$

Here, D_{ODI}, D_{T20}, and D_{Soccer} represent the datasets corresponding respectively to the ICC ODI World Cup (2023), ICC T20 World Cup (2022), and FIFA World Cup (2022). The observed values for the metrics G and T across the different sports are presented clearly in Table 3.1 for GR measure while 3.2 for velocity analysis.

Table 3.1 The average observed $\bar{G}$ and $\bar{T}$ for GR measure

Sport	Total Matches	$\overline{G}$	$\overline{T}$
ODI	46	258.03	300
T20	42	143.18	120
Soccer	64	2.672	22.766

Table 3.2 The average observed $\bar{G}$ and $\bar{T}$ for velocity analysis

Sport	Total Matches	$\overline{G}$	$\overline{T}$
ODI	46	258.03	300×6
T20	42	143.18	120×6
Soccer	64	2.672	22.766

3.3.2 Data Collection for Top-2 Competitive Teams in Different Sports

To perform a detailed comparative analysis specifically centered on the elite-level competitive dynamics, data collection explicitly targeted the finalists of recent international tournaments across ODI cricket, T20 cricket, and soccer. These top-performing teams were intentionally selected due to their exemplary performance and competitive stature, thus providing an optimal foundation for examining advanced competitive interactions.

Cricket (ODI and T20 Formats)

Data for ODI and T20 cricket were systematically collected from detailed ball-by-ball match records provided by the Cricsheet database [112], available in CSV format. Specifically, data from the ICC Cricket World Cup 2023 were gathered for ODI cricket finalists India and Australia, each team playing 11 matches. Similarly, data for T20 cricket were acquired from matches played in the ICC T20 World Cup 2022, with Pakistan (7 matches) and England (6 matches) as the finalists. For each match, comprehensive ball-by-ball information, including runs scored, extras, and deliveries faced by each finalist team, was extracted. This granular dataset allowed precise calculation of total runs scored (G) and total deliveries faced (T) for each team, forming the basis for subsequent analytical metrics such as scoring velocity and competitive intensity.

Soccer (FIFA World Cup)

Soccer data collection involved a manual extraction method from detailed minute-by-minute textual commentary available on ESPN's official website [111]. Specifically, match data were collected for the FIFA World Cup 2022 finalists Argentina and France, covering a total of 7 matches each. Goals scored (G) and shot attempts (T) by each team were systematically documented to ensure completeness and accuracy. The data collected were subsequently used for quantitative analyses, enabling detailed evaluation of performance efficiency, strategic dynamics, and competitive balance at the highest international soccer competition level.

The datasets specifically collected for analyzing elite competitive dynamics across cricket and soccer are formally represented as follows:

$$\mathscr{D}\text{Top-2} = D_{\text{ODI (India, Australia)}}, D_{\text{T20 (Pakistan, England)}}, D_{\text{Soccer (Argentina, France)}} \tag{3.10}$$

Here, each dataset (D_{ODI}, D_{T20}, and D_{Soccer}) precisely denotes detailed scoring and attempt records collected from their respective sources, ensuring accuracy, reliability, and replicability necessary for rigorous comparative analysis. The top-2 competitive teams $\bar{G}$ and $\bar{T}$ metrics average values across the different sports are presented in Table 3.3 for GR measure and 3.4 for velocity analysis.

Table 3.3 Team-wise $\bar{G}$ and $\bar{T}$ average values for GR measure

Sport	**Team**	**Matches Played**	$\overline{G}$	$\overline{T}$
ODI 2023	India	11	287.27	300
	Australia	11	280.64	300
T20 2022	Pakistan	7	140.86	120
	England	6	141.50	120
FIFA 2022	Argentina	7	2.143	14.286
	France	7	2.286	14.571

3.3.3 Data Collection for Phase-Wise Analysis of Different Sports

Phase-wise analysis requires detailed data collection segmented according to distinct match phases within each sport. For this purpose, the same fundamental formulations for GR and $\bar{v}$ previously introduced were applied specifically to phase-wise data.

Table 3.4 Team-wise $\overline{G}$ and $\overline{T}$ average values for velocity analysis

Sport	**Team**	**Matches Played**	$\bar{G}$	$\bar{T}$
ODI 2023	India	11	287.27	300×6
	Australia	11	280.64	300×6
T20 2022	Pakistan	7	140.86	120×6
	England	6	141.50	120×6
FIFA 2022	Argentina	7	2.143	14.286
	France	7	2.286	14.571

Cricket (ODI and T20)

Data for phase-wise cricket analysis were sourced from official ball-by-ball match records provided in CSV format from [112], covering all 46 matches of the 2023 ICC ODI World Cup and 39 matches of the 2022 ICC T20 World Cup. Matches were segmented according to cricket's inherent regulatory structure as follows:

- **ODI Cricket:** Each 50-over match was divided into three distinct phases, aligned with official powerplay regulations:
  - Phase 1 (Opening): Overs 1–10
  - Phase 2 (Middle): Overs 11–40
  - Phase 3 (Endgame): Overs 41–50
- **T20 Cricket:** Matches were segmented based on their 20-over structure:
  - Phase 1 (Opening): Overs 1–6 (Powerplay)
  - Phase 2 (Middle): Overs 7–15
  - Phase 3 (Endgame): Overs 16–20 (Death overs)

Within each phase, total runs scored (including extras) were aggregated per ball. These aggregates formed the basis for computing the phase-specific metrics G_p (total runs) and T_p (total deliveries). Averaging these values across all matches yielded the phase-wise means, enabling the calculation of:

$$\bar{v}_p = \frac{\bar{G}_p}{\bar{T}_p} \tag{3.11}$$

and the corresponding GR index GR_p using the same formulation applied to the full-match data.

Soccer

For soccer, data were manually collected from official minute-by-minute textual match commentaries available at [111], covering all 64 matches of the FIFA World Cup 2022. Goals and shot attempts were documented for each match and classified the same match data using two distinct segmentation strategies to allow comparative analysis to identify the critical phase where engagement and excitement is in peak:

- **Soccer (a)**
  - Opening Phase: 0–15 minutes
  - Middle Phase: 16–30 minutes
  - Endgame Phase: 31–45+ minutes (including stoppage time)
- **Soccer (b)**
  - Opening Phase: 0–20 minutes
  - Middle Phase: 21–35 minutes
  - Endgame Phase: 36–45+ minutes (including stoppage time)

Within each defined phase, the total number of goals (G_p) and shot attempts (T_p) were calculated and then averaged across all matches. These values were used to compute the phase-specific velocity:

$$\bar{v}_p = \frac{\bar{G}_p}{\bar{T}_p} \tag{3.12}$$

and the corresponding GR index GR_p using the same formulation applied to the full-match data. Applying consistent calculations across segmented phases ensures comparability across both Soccer (a) and Soccer (b), and reveals dynamic fluctuations in engagement and excitement throughout the course of gameplay. The phase-wise values of metrics G and T across the different sports are presented in Table 3.5 for GR measure and 3.6 for velocity analysis.

3.4 Analytical Frameworks

This section outlines the theoretical foundations and practical applications of the analytical frameworks employed to systematically quantify and analyze the dynamics of engagement and excitement in ODI cricket, T20 cricket, and soccer. Building on the methodological

Table 3.5 Phase-wise average $\bar{G_p}$ and $\bar{T_p}$ values for GR_p measure

Sports	Phase	$\overline{G}_p$	$\overline{T}_p$
ODI	Opening	54.52	60
	Middle	154.74	180
	End	47.97	60
T20	Opening	39.90	36
	Middle	64.06	54
	End	37.35	30
Soccer (a)	Opening	0.672	5.391
	Middle	0.734	5.531
	End	1.266	9.172
Soccer (b)	Opening	0.906	7.047
	Middle	0.844	5.672
	End	0.922	7.328

Table 3.6 Phase-wise average $\bar{G_p}$ and $\bar{T_p}$ values for velocity analysis

Sports	Phase	$\overline{G}_p$	$\overline{T}_p$
ODI	Opening	54.52	60×6
	Middle	154.74	180×6
	End	47.97	60×6
T20	Opening	39.90	36×6
	Middle	64.06	54×6
	End	37.35	30×6
Soccer (a)	Opening	0.672	5.391
	Middle	0.734	5.531
	End	1.266	9.172
Soccer (b)	Opening	0.906	7.047
	Middle	0.844	5.672
	End	0.922	7.328

context established previously, this research integrates three distinct yet complementary analytical frameworks such as GR theory, the MiM model, and the newly introduced FiM framework. These frameworks collectively address both the objective structural dimensions and the subjective psychological and cognitive aspects of sports engagement. Additionally, a novel gravity-inspired analytical model is presented to explicitly quantify and interpret competitive intensity, competitive interactions, and positional advantages among competing teams or players. Each framework is detailed comprehensively below, emphasizing its mathematical formulation, theoretical justification introduced in this research to ensure analytical rigor, clarity, and replicability.

3.4.1 Game Refinement (GR) Theory

Game Refinement (GR) theory, originally introduced by Iida Hiroyuki [14, 15], offers a robust mathematical framework for quantifying the dynamic interplay between skill, chance, and uncertainty in games and sports. This theory is particularly valuable to this research as it systematically captures how uncertainty and excitement evolve throughout gameplay, enabling objective comparisons of engagement across structurally diverse sports such as cricket and soccer. By measuring the rate at which uncertainty resolves during a match, the GR metric directly quantifies the inherent excitement, spectator engagement, and overall entertainment value of a sport.

This study specifically employs GR theory due to its proven effectiveness in differentiating between well-balanced, engaging games and those which are either overly predictable or excessively uncertain [16]. Such capability is crucial in comparative analyses of sports formats like ODI cricket, T20 cricket, and soccer, where structural and temporal differences significantly influence spectator and player experiences. Furthermore, the GR metric is uniquely suited to addressing the theoretical gaps highlighted previously, particularly regarding inconsistent or inaccurate applications of uncertainty resolution metrics in past studies of soccer and cricket.

In practice, GR theory provides different formulations tailored to the unique structural characteristics of games. For instance, in variable-ending board games, gameplay continues until sufficient information accumulates to determine a definitive winner, typically resulting in a GR value within the optimal excitement-engagement range (0.07–0.08). This formulation employs the branching factor (B), representing the average number of possible moves per decision, and the game length (D), representing the total number of moves, as shown in Eq. (3.13):

$$GR_{\text{Board}} \approx \frac{\sqrt{B}}{D} \tag{3.13}$$

However, sports differ fundamentally from board games due to their varying structural characteristics, such as fixed durations (e.g., soccer's 90-minute matches) or variable endings (as in cricket). In sports, uncertainty resolution and spectator excitement predominantly depend on scoring events rather than discrete moves. Thus, the GR measure for sports specifically incorporates the frequency of scoring events, represented by total goals or runs (G) and total attempts or scoring opportunities (T), as defined by Eq. (3.14):

$$GR_{\text{Sports}} \approx \frac{\sqrt{2G}}{T} \tag{3.14}$$

By applying this refined formulation of the GR metric, this research systematically evaluates how uncertainty dynamics differ across ODI cricket, T20 cricket, and soccer, thereby enabling precise identification of structural factors that optimize spectator engagement and competitive fairness. Thus, GR theory provides a foundational analytical tool that directly aligns with and rigorously addresses the comparative and theoretical objectives outlined earlier in this dissertation.

3.4.2 Motion in Mind (MiM) and Flow in Mind (FiM) Framework

In addition to the GR theory, this research incorporates two complementary cognitive-psychological frameworks the MiM and the newly introduced FiM framework. These frameworks extend the purely quantitative analysis provided by GR theory by explicitly modeling the cognitive and emotional dimensions of player and spectator engagement. The primary reason for employing MiM and FiM frameworks lies in their ability to capture nuanced psychological experiences such as excitement, anxiety, cognitive load, and perceived difficulty that significantly influence engagement dynamics but are not fully addressed by conventional quantitative metrics alone.

The MiM parameters models gameplay engagement using analogies drawn from classical physics while FiM parameters drawn from GR theory, translating objective gameplay metrics into subjective psychological experiences. A core parameter of MiM is the concept of "velocity" (v), initially defined as the ratio of successful scoring events (G) to total attempts (T):

$$v = \frac{G}{T} \tag{3.15}$$

However, the v in MiM framework effectively models cognitive and emotional states in many game contexts, it encounters a critical limitation when applied to high-scoring sports such as T20 cricket. Specifically, the original formulation may yield velocity values exceeding 1, thereby violating the fundamental conceptual boundaries ($0 \leq v \leq 1$) required for other psychological MiM parameters. For example, during the 2022 ICC T20 World Cup, the scoring velocity computed using the v formula results in:

$$v = \frac{143.18}{120} = 1.193$$

This outcome exceeds the valid range of v which undermines the interpretability of cognitive and emotional analyses. Thus, to address this one must normalize the velocity against the theoretical maximum scoring potential per attempt (in cricket, 6 runs per delivery), thus maintaining consistent and meaningful interpretations:

$$v_{\text{normalized}} = \frac{G}{6T} = \frac{143.18}{720} = 0.199 \tag{3.16}$$

This normalization ensures velocity values remain within the interpretable range [0, 1], facilitating fair and rigorous comparisons across different sports formats such as ODI and T20 cricket in this research study. It is important to note, however, this adjusted say $T' = 6T$ applies only to velocity and velocity-related measures within the FiM framework. For GR calculations, the original $T = 120$ must preserved for GR measure calculations. Because altering T' for GR measure would distort the game's true nature and produce misleading results. Therefore, the GR measure strictly uses:

- $T = 120$ for T20 cricket,
- $T = 300$ for ODI cricket,
- $T = 22.766$ for soccer.

This distinction becomes critical when analyzing acceleration a.

$$a = \frac{2v}{T} = \frac{2G}{T^2} \tag{3.17}$$

This equivalence holds true when $T = T'$, typically seen in low-scoring sports like soccer. However, in high-scoring sports like T20 cricket, where velocity normalization alters T, this relationship breaks down. For instance, consider the T20 example with $v = 0.199$ and $T = 120$ the $a = \frac{2v}{T} = 0.003$ but with $G = 143.18$ and $T = 120$ $a = \frac{2G}{T^2} = 0.0199$:

Therefore, $\frac{2v}{T} \neq \frac{2G}{T^2}$, violating the $a = \frac{2v}{T} = \frac{2G}{T^2}$ equivalency. In contrast, for soccer where no normalization is applied ($T = T'$), the relationship holds the equivalency condition true.

Thus, in such cases the $\frac{2v}{T}$ can be seen as the acceleration in the MiM framework and $\frac{2G}{T^2}$ can be seen in the FiM framework provides a methodologically sound solution for handling high-scoring sports. The acceleration in the FiM frameworks sounds reasonable for ODI and T20, while preserving the theoretical integrity of the GR measure. This distinction strengthens interpretability and analytical rigor in cognitive and emotional modeling in high scoring events.

Moreover, another important metric Addictive Density (AD), originally defined in terms of scoring events (G) and total attempts (T), the AD metric is given as:

$$AD = \begin{cases} \frac{\sqrt[3]{6G}}{T} & \text{for sports} \\ \frac{\sqrt[3]{3B}}{D} & \text{for board games} \end{cases} \tag{3.18}$$

To further clarify the distinction between the MiM and FiM parameters and facilitate interpretation through velocity (v), the AD formula can be rewritten by applying the cube root:

$$AD = \frac{6^{1/3} \cdot G^{1/3}}{T} \tag{3.19}$$

By recalling the definition of scoring velocity $v = \frac{G}{T}$, we substitute $G = v \cdot T$ into the above equation, resulting in:

$$AD = \frac{6^{1/3} \cdot (v \cdot T)^{1/3}}{T} \tag{3.20}$$

Utilizing the properties of exponents $(ab)^{1/3} = a^{1/3}b^{1/3}$, this expression can be further simplified:

$$AD = \frac{6^{1/3} \cdot v^{1/3} \cdot T^{1/3}}{T} \tag{3.21}$$

Simplifying by subtracting exponents of T ($T^{1/3} \div T = T^{-2/3}$), we arrive at the more concise form:

$$AD = 6^{1/3} \cdot v^{1/3} \cdot T^{-2/3} \tag{3.22}$$

This refined equation (3.22) clearly illustrates the direct relationship between the AD metric and the scoring velocity v, making it particularly useful within the MiM framework.

The distinctions highlighted by the different formulations for acceleration (a) and Addictive Density (AD) further reinforce the conceptual separation between MiM and FiM parameters. In simple words, metrics that explicitly depend on velocity (v) and total attempts

(T) align with MiM framework, whereas metrics directly dependent on scoring events (G) and total attempts (T) correspond to FiM framework. Comprehensive lists of MiM and FiM parameters are presented in Table 3.7 and 3.8, respectively. Thus, MiM and FiM both frameworks map key game parameters to distinct cognitive and emotional states experienced during gameplay.

Table 3.7 MiM Measures

$v = \frac{G}{T}$	$m = 1 - v$	$a = \frac{2v}{T}$	$F = ma$	$\vec{p} = mv$	$E_p = 2mv^2$	$N = \frac{1}{v}$	$MEE = \sqrt{N}$

Table 3.8 FiM Measures

$GR \approx \frac{\sqrt{2G}}{T}$	$a = \frac{2G}{T^2}$	$j = \frac{6G}{T^3}$	$AD = \frac{\sqrt[3]{6G}}{T}$	$\phi = \frac{GR}{AD}$	$PRE = \eta \cdot \frac{T}{N^2}$

After clearly distinguish the MiM and FiM parameters, this research utilizes several rigorously defined quantitative metrics from the MiM and FiM frameworks to systematically explore, measure, and interpret the dynamics of engagement and excitement across different sports formats (ODI cricket, T20 cricket, and soccer). By precisely defining each metric mathematically and conceptually, the following parameters lays the analytical foundation essential for robust comparative analysis and theoretical consistency across subsequent empirical evaluations.

Velocity v and Mass m

Within the MiM model, velocity (v) is a core concept representing the rate at which uncertainty is resolved during gameplay. This parameter is specifically selected because it directly measures the frequency and immediacy of reinforcing events (e.g., scoring), crucial for maintaining player and spectator engagement through consistent psychological reward. It measures success or progress as the ratio of successful outcomes to total attempts, reflecting a player's or team's performance efficiency. Introduced in [16], v is defined in Eq. (3.23). This metric captures scoring rate and quantifies how effectively opportunities are converted into outcomes.

$$v = \begin{cases} \frac{G}{T} & \text{for sports} \\ \frac{1}{2} \cdot \frac{B}{D} & \text{for board games} \end{cases} \tag{3.23}$$

In sports, the scoring velocity for a match m' is defined by Eq. (3.24), while the average velocity across all matches for a given sport is computed as Eq.(3.25). The average velocity

$\bar{v}$ characterizes how quickly outcomes accumulate on average. Across different sports or activities, $v \in [0,1]$, with higher values indicating greater success, progress, or winning expectancy. Velocity is central to the MiM framework and serves as a basis for deriving related cognitive measures such as difficulty ($m = 1 - v$), engagement momentum ($\vec{p}_2$), and reward frequency ($\sqrt{N}$). Analogous to physical velocity, v reflects the pace of mental engagement and decision-making relative to task success or perceived reward.

$$v_{m'} = \frac{G_{m'}}{T_{m'}}. \tag{3.24}$$

$$\bar{v} = \frac{1}{|\mathscr{M}|} \sum_{m' \in \mathscr{M}} v_{m'}. \tag{3.25}$$

Mass m, in the MiM framework, represents difficulty or cognitive load within a task, game, or decision-making context. This parameter is chosen specifically because it quantitatively captures the psychological resistance or challenge players face during gameplay, which directly influences their sense of achievement, strategic engagement, and overall cognitive experience. It quantifies the challenge or resistance a player or team must overcome to succeed. Formally, mass is defined as the complement of velocity v, given by Eq. (3.26), where $v \in [0,1]$ reflects success probability or player ability. A higher mass indicates greater difficulty, lower success expectancy, and increased psychological inertia requiring more mental effort or strategy. Thus, mass directly reflects the extent to which a game or task demands sustained cognitive resources, influencing player motivation, resilience, and emotional investment. In skill-based games, mass captures the cognitive and strategic demands relative to player ability and task complexity. In probabilistic games (e.g., lotteries or casinos), it corresponds to risk, defined as $m = 1 - r$, where r denotes the payout or return rate.

$$m = 1 - v \tag{3.26}$$

The derivation of v and m is grounded in the principle that engagement emerges from the interaction between skill and task difficulty, a core idea in engagement and flow theory [113, 114]. Flow occurs when skill (velocity) is balanced with challenge (mass), creating a dynamic equilibrium. If v is too high relative to m, the task may feel unchallenging; if m is too high, it may feel overwhelming. This formulation thus provides a mathematical model for the skill-challenge balance underlying immersive gameplay and decision-making experiences.

Acceleration a and Jerk j

Acceleration (a) quantifies the rate of change in uncertainty resolution over time, capturing the intensity or thrill experienced by the player or team. It allows us to measure how rapidly excitement builds during gameplay, which directly influences spectators' emotional engagement. In gameplay, it reflects how excitement responds to rising challenge, indicating how quickly an experience shifts from engaging to overwhelming. Within the MiM framework, a serves as a psychological analog to Newtonian acceleration and is defined by Eq. (3.27).

$$a = \begin{cases} \frac{2v}{T} = \frac{2G}{T^2} = GR^2 & \text{for sports} \\ \frac{v}{D} = \frac{B}{D^2} = GR^2 & \text{for board games} \end{cases} \tag{3.27}$$

A higher a indicates a fast-paced, thrilling experience with a strong sense of progress. Such rapid uncertainty resolution can intensify spectators' emotional responses, enhancing their overall engagement and enjoyment. However, excessive acceleration can overwhelm players, making the game feel too short or intense, potentially reducing strategic depth and inducing anxiety or fatigue. Conversely, a lower a results in a smoother, more methodical pace that supports planning and reflection, but if too low the game may feel slow, predictable, or unengaging. Thus, acceleration is a crucial parameter in balancing game pacing and optimizing emotional and cognitive engagement for both players and spectators. In board games, an optimal acceleration range ($0.005 \leq a \leq 0.006$) promotes a dynamic yet balanced flow, maintaining equilibrium between challenge and excitement.

Jerk (j), the rate of change of acceleration, quantifies sudden shifts in game momentum and affects the smoothness of engagement. It captures fluctuations in excitement and unpredictability during gameplay, reflecting how the thrill (informational acceleration) changes over time. Rapid and unexpected shifts in game momentum, indicated by high jerk values, significantly impact emotional and cognitive states by causing abrupt changes in excitement and suspense. High jerk values are associated with cognitive discomfort due to abrupt engagement shifts. Jerk is defined by Eq. 3.28.

$$j = \begin{cases} \frac{6G}{T^3} & \text{for sports} \\ \frac{3B}{D^3} & \text{for board games} \end{cases} \tag{3.28}$$

Higher j disrupts cognitive flow by inducing stress, as players struggle to adapt to sudden shifts in challenge, leading to mental overload and a breakdown in the skill-challenge balance. For spectators, high jerk can amplify emotional intensity but may also lead to fatigue or confusion if changes are excessively unpredictable or frequent. In games, this often occurs during unexpected difficulty spikes. Conversely, low j supports smooth, predictable progression, allowing gradual adaptation without excessive strain. Moderate jerk values are therefore ideal, sustaining excitement, emotional resonance, and challenge, while preserving cognitive clarity and comfort. A moderate j is ideal, sustaining excitement and challenge while avoiding cognitive fatigue. Acceleration and jerk, adapted from classical mechanics, are reinterpreted in the MiM framework to model psychological dynamics in gameplay. Aligned with engagement theory [113], which emphasizes the balance of challenge and skill, these measures reflect how gameplay intensity and responsiveness evolve over time. They directly inform game design by helping designers modulate emotional pacing and strategic flow, ensuring that the game remains thrilling yet cognitively manageable. Thus, regulating a and j in game design is essential for managing challenge progression and sustaining an engaging, yet comfortable, player experience.

Momentum $\vec{p}$ and Potential Energy E_p

Momentum, denoted as $\vec{p}$, is defined as the product of difficulty (m) and success rate (v), mirroring the classical physics concept, to quantify a player or team's cognitive drive and psychological commitment during gameplay. Formally defined in Eq. 5.16, where $m \in [0,1]$ represents normalized difficulty and $v \in [0,1]$ the success rate, the resulting $\vec{p} \in [0,1]$ captures the intensity of mental engagement. Higher momentum reflects an optimal balance between perceived challenge and skill, fostering sustained cognitive involvement and strategic focus. Conversely, low momentum indicates disengagement, arising either from boredom (tasks perceived as too easy) or frustration (tasks perceived as too difficult), causing cognitive progression to stall. Thus, momentum serves as an essential measure for evaluating and refining game design to ensure balanced psychological engagement.

$$\vec{p} = mv \tag{3.29}$$

Potential energy (E_p) represents the objective motivational potential embedded in game design, independent of the player's perception or state. It quantifies the psychological potential or latent motivational energy available within the game's structure to engage players effectively. In classical mechanics, gravitational potential energy is defined by Eq. (3.30), where m is mass, g is gravitational acceleration, and h is vertical displacement. In the MiM framework, these parameters correspond respectively to difficulty (m), acceleration or rate of informational thrill ($g = a$), and progression through gameplay ($h = x(t)$).

$$U = mgh \tag{3.30}$$

The displacement of an object under constant acceleration is given by Eq. (3.31). Substituting this into the potential energy formula in Eq. (3.30), the potential energy in gameplay, E_p, is defined by Eq. (3.32). Since $a = \frac{2v}{t}$, substituting and simplifying yields a formulation that captures the interaction between challenge (m) and performance (v). Here, m represents game difficulty, and v denotes the player's success rate or ability. This reflects the principle that a game becomes objectively engaging when challenge aligns with capability. Higher E_p values indicate greater intrinsic motivational appeal, particularly when both difficulty and ability are high. This metric supports objective evaluation of game engagement and helps guide task design to balance challenge and reward effectively.

$$h = \frac{1}{2}gt^2 \quad \text{or} \quad x(t) = \frac{1}{2}at^2 \tag{3.31}$$

$$\begin{aligned} E_p &= mah = ma\left(\frac{1}{2}at^2\right) \\ &= \frac{1}{2}ma^2t^2 = \frac{1}{2}\pi r^2 \\ &= \frac{1}{2}m\left(\frac{2v}{t}\right)^2 t^2 \\ &= \frac{1}{2}m \cdot \frac{4v^2}{t^2} \cdot t^2 \\ &= 2mv^2 \end{aligned} \tag{3.32}$$

This formulation underscores a central principle of engagement. Games become most objectively compelling when the inherent difficulty matches or slightly challenges player skill levels. Consequently, higher E_p values signify greater intrinsic motivational appeal, especially when both difficulty and ability are elevated.

Addictive Density AD and Phi Ratio (ϕ)

Addictive Density (AD) is a key metric derived from the Motion-in-Mind model, designed to quantify the unpredictability and addictive (engaging) quality of a game. Rooted in the concept of jerk (the rate of change of acceleration), AD specifically measures the emotional intensity and unpredictability players or spectators experience at critical gameplay moments. It is calculated as given by Eq. (3.33).

$$AD = \begin{cases} \frac{\sqrt[3]{6G}}{T} & \text{for sports} \\ \frac{\sqrt[3]{3B}}{D} & \text{for board games} \end{cases} \tag{3.33}$$

In board games, the ideal AD zone typically ranges from 0.045 to 0.06, where $GR > AD$, striking a balance between excitement and satisfaction. A high AD indicates that gameplay moments are emotionally charged and highly unpredictable, potentially leading to chaos. Conversely, a low AD implies overly predictable gameplay, resulting in boredom and disengagement. When combined with GR and N, AD offers a more holistic evaluation of a game's entertainment value and psychological impact. This integration enables designers and researchers to optimize emotional engagement and player retention, ensuring games maintain balanced unpredictability and consistent psychological appeal.

The phi ratio (ϕ) is a derived metric defined as the ratio of GR to AD, capturing the balance between a game's emotional unpredictability and structural sophistication. Formally defined in Eq. (3.34), it helps evaluate overall game experience in terms of unpredictability and elegance. When $\phi \approx 1$, the game achieves an optimal balance between unpredictability and structural integrity, providing an ideal mix of chaos and strategic depth for higher engagement. A value $\phi < 1$ suggests dominance of unpredictability, often linked to randomness or chance, enhancing excitement but reducing strategic depth. Conversely, $\phi > 1$ indicates a more structured, predictable experience mentally composed but potentially less thrilling. Therefore the peak engagement and psychological appeal in gameplay are typically achieved when the GR value closely aligns with AD i.e., $GR \approx AD$, yielding a phi ratio ($\phi = \frac{GR}{AD}$) approaching 1 ($\frac{GR}{AD} \approx 1$). Thus, the phi ratio (ϕ) deal with engagement and is especially useful for distinguishing games of skill and chance.

$$\phi = \frac{GR}{AD} \tag{3.34}$$

Reward Frequency N, Magnitude of Extraordinary Experience (MEE) and Potential Reinforcement Energy (PRE)

In games, players often make multiple attempts before earning a reward (e.g., scoring a run or goal), aligning with a Variable Ratio (VR) reinforcement schedule, where the unpredictability and irregularity of rewards sustain engagement and heighten motivation. Reward frequency (N), defined in Eq. (3.35), quantifies the expected number of attempts required per reward, where $v = \frac{G}{T}$ represents the success rate per attempt. Thus, N serves as a critical measure for understanding how frequently reinforcing events occur, directly influencing motivational strength and attentional dynamics. A higher N corresponds to a stronger VR schedule, requiring greater persistence and cognitive effort, enhancing player motivation through the anticipation of rare, meaningful rewards. Conversely, a lower N indicates more frequent rewards, supporting sustained attention, continuous cognitive engagement, and a smoother emotional progression. This balance between reward scarcity and frequency is crucial for maintaining both player and spectator engagement over extended periods.

$$N = \frac{1}{v} \tag{3.35}$$

The MEE quantifies the psychological intensity players experience upon achieving exceptionally rare outcomes in games. Defined by Eq. (3.36), MEE measures how emotionally significant and memorable a rare reward feels, where N denotes reward frequency, the average number of attempts required to secure such an outcome. Higher values of N indicate greater rarity, directly intensifying the emotional impact and making each success feel extraordinary. This heightened psychological intensity significantly contributes to deepening both player and spectator engagement by amplifying the perceived value and satisfaction derived from rare in-game achievements.

$$\mathrm{MEE} = \sqrt{N} \tag{3.36}$$

The PRE quantifies the psychological reinforcement or motivational strength derived from repeatedly attempting to achieve a rare outcome within a game. It is formally defined by Eq. (3.37), where η represents the number of play and N denotes the reward frequency, representing the expected number of attempts per reward.

$$PRE = \eta \cdot \frac{T}{N^2} \tag{3.37}$$

The value of T is calculated as the intersection between the acceleration (gravity-in-mind) curve $y = \frac{1}{2}at^2$ and the linear progression line $y = t$, symbolizing game progress over time. To find this intersection, we set:

$$\begin{aligned} t &= \frac{1}{2}at^2 \\ 2t &= at^2 \quad \text{(multiplying both sides by 2)} \\ 2 &= at \quad \text{(dividing by } t,\ t \neq 0\text{)} \\ T &= \frac{2}{a} = \frac{2}{GR^2} \end{aligned} \tag{3.38}$$

High PRE values indicate strong, sustained psychological reinforcement, motivating players and enhancing spectator attention through continuous anticipation of rewarding outcomes. Conversely, lower PRE values signify weaker reinforcement dynamics, which may lead to decreased motivation, diminished player effort, and potential disengagement. Analyzing intersections between PRE and MEE thus provides a robust method for categorizing games according to their reinforcement dynamics and engagement profiles.

Force F

The Force F is conceptualized as the equivalent of Newton's second law, which quantifies the motivational pressure or cognitive push that a player experiences in a game environment. It captures the relationship between perceived difficulty m and the acceleration a in engagement. F quantifies the effort required to maintain engagement within a game environment and it is defined as:

$$F = ma \tag{3.39}$$

A higher F indicates that a game requires noticeable mental effort to progress, while a lower F suggests the game experience feels smooth or self-sustaining—indicating potentially addictive or highly engaging gameplay. This measure is used in conjunction with engagement metrics to evaluate how different game settings affect player perception, motivation, and play continuity.

This methodology outlines how G and T in sports, and B and D in board games, are operationalized to evaluate gameplay, forming the foundation for GR and MiM-based metrics. We establish a consistent framework for assessing uncertainty resolution and engagement relative to game length by applying these definitions and formulas. The following section presents empirical results for these metrics, offering insights into ODI, T20, and soccer dynamics.

3.4.3 Proposed Gravity-Inspired Analytical Framework

Competitive Intensity I_c

By using the average velocities of a sport and team-wise velocity, we define the competitive intensity constant I_c, which quantifies a team's relative performance compared to the average intensity level observed in that specific sport. Formally, I_c is defined as:

$$I_c = \frac{v_i}{\bar{v}_{\text{sport}}} \tag{3.40}$$

where v_i is the scoring velocity of team i, and $\bar{v}_{\text{sport}}$ is the average velocity for the given sport.

In high-level competitive tournaments, the value of I_c typically lies close to 1:

- $I_c \approx 1$: The team performs at a level matching the average competitive intensity required to remain competitive or win.
- $I_c > 1$: Indicates above-average performance, with a higher likelihood of winning.
- $I_c < 1$: Indicates below-average performance, with reduced chances of winning.

This formulation provides a consistent and interpretable measure of how efficiently a team or player resolves uncertainty relative to the expected standard in that sport.

Competitive force of attraction F_c

The concept of competitive force of attraction F_c is inspired by the classical formulation of gravitational force. In our competitive framework, F_c captures the intensity and balance of a competitive interaction between two opposing agents (e.g., teams or players). It quantifies how strongly each agent is pulled toward the shared goal of victory, based on their momentum and the distance between their performance levels. Formally, the competitive force between two agents i and j is defined as:

$$F_{c_{ij}} = I_c \cdot \frac{\vec{p}_i \cdot \vec{p}_j}{d^2} \tag{3.41}$$

where, I_c is the competitive intensity constant, previously defined as $I_c = \frac{v_i}{\bar{v}_{\text{sport}}}$, which normalizes the team's performance relative to the average in that sport. $\vec{p}_i$ and $\vec{p}_j$ are the momenta of agents i and j, calculated as $\vec{p} = m \cdot v$, representing the combined effect of difficulty and scoring efficiency. $d = v_i - v_j$ is the competitive distance between the two agents, measuring difference in uncertainty resolution.

The value of F_c offers insights into the nature of a competitive event. A higher F_c value indicates that both teams are closely matched in terms of momentum and scoring efficiency. Such contests are typically perceived as more fair, intense, and cognitively engaging, resulting in heightened entertainment and excitement for both players and spectators. A lower F_c value suggests a disparity in skill or performance, with one team likely dominating the other. This leads to reduced uncertainty, perceived unfairness, and less engaging gameplay, diminishing the overall entertainment value. Therefore, F_c serves as a valuable metric for evaluating the competitiveness and quality of an event, offering a quantitative basis for analyzing fairness, engagement, and audience appeal in competitive scenarios.

Competitive potential V_c

Inspired by the gravitational potential concept in physics, we define the competitive potential V_c as a metric to quantify the positional advantage of a team or player in competitive scenarios.

Gravitational potential describes the work needed to move an object within a gravitational field; analogously, competitive potential reflects how close a team or player is to achieving the ultimate goal victory based on their current performance or position. Formally, we define competitive potential V_c as:

$$V_c = \frac{1}{m} = \frac{1}{1-v} \tag{3.42}$$

where, m denotes the unresolved competitive challenge or difficulty faced by a team, calculated as $m = 1 - v$. v represents the team's scoring efficiency or progress toward achieving victory.

A higher V_c indicates that a team or player has significantly reduced uncertainty and is positioned closer to the goal, implying a strong competitive advantage and increased likelihood of achieving victory. This state typically enhances motivation, excitement, and psychological momentum. A lower V_c suggests greater uncertainty or remaining challenge, meaning the team or player must exert significant effort to progress, reflecting increased competitive difficulty and psychological load. Thus, V_c effectively captures how favorably a team is positioned within a competitive environment, offering valuable insights into psychological and strategic dynamics. Teams with higher competitive potentials are generally better positioned, reflecting lower perceived difficulty and greater confidence in attaining victory, which consequently influences performance dynamics and spectator excitement.

3.5 Chapter Summary

This chapter has provided a detailed overview of the research methodology adopted to systematically investigate the dynamics of engagement and excitement across and within ODI cricket, T20 cricket, and soccer. The chapter began by clearly articulating the research design, emphasizing a comparative quantitative analytical approach capable of rigorously quantifying structural and psychological dimensions across and within different sports contexts. It detailed three comprehensive and systematic data collection strategies, emphasizing meticulous data gathering from official international tournaments, structured phase-wise segmentation to capture dynamic fluctuations, and targeted analysis of elite competitive scenarios involving finalist teams.

Subsequently, the chapter elaborated on the analytical frameworks underpinning this research. It thoroughly described GR theory as the foundational quantitative approach to measure uncertainty resolution and inherent excitement within sports. The methodological refinement introduced in the MiM framework for velocity normalization was particularly underscored to ensure accurate analysis of high-scoring contexts, specifically in T20 cricket.

Afterwards, the chapter distinguished between the MiM and FiM parameters, highlighting how these parameters extend quantitative analyses by integrating psychological and cognitive factors through analogies drawn from classical physics. Additionally, the innovative gravity-inspired analytical framework was introduced, explicitly quantifying competitive intensity, competitive force of attraction, and potential advantage, thus providing a robust toolset to deeply analyze competitive interactions.

With this rigorous methodological foundation firmly established, the research is now positioned to undertake comparative analyses across high-scoring and low-scoring sports contexts. Chapter 4 specifically leverages the methodological insights and quantitative tools presented herein, systematically exploring the structural and psychological distinctions between cricket (ODI and T20) as representative high-scoring sports and soccer as a representative low-scoring sport. This next chapter seeks to offer precise, empirically grounded insights into how scoring frequency and sport structure fundamentally shape player performance, spectator engagement, and overall sporting experiences.

Chapter 4

High-Scoring vs. Low-Scoring Sports

4.1 Chapter Introduction

This chapter presents a comprehensive comparative analysis of engagement dynamics across high-scoring sports, specifically ODI and T20 cricket, and a low-scoring sport, soccer. Building upon the theoretical and methodological foundations established in the preceding chapters, this chapter systematically applies GR theory, along with the psychologically informed MiM and FiM frameworks, to rigorously quantify and interpret how different sports and their intrinsic structure such as game length, scoring frequency, and uncertainty resolution distinctly influence player engagement, spectator excitement, and perceived fairness within these sports.

The chapter begins by exploring the theoretical background, emphasizing the crucial role of structural elements such as game length, scoring frequency, and unpredictability in shaping psychological engagement. A critical literature review is then presented, identifying existing research gaps and highlighting inconsistencies in previous applications of GR and MiM frameworks, particularly within soccer and cricket contexts. Subsequently, the methodological approach for this comparative analysis is revisited, summarizing the systematic collection of data from prominent international tournaments, including the ICC ODI Cricket World Cup 2023, ICC T20 Cricket World Cup 2022, and FIFA World Cup 2022. The chapter then provides an in-depth comparative results analysis, leveraging empirical data and metrics derived from GR theory, MiM, and FiM frameworks. This analysis highlights the distinct cognitive and emotional experiences fostered by each sport's structural characteristics. In the discussion section we explores potential structural modifications to optimize soccer's engagement dynamics. Specifically, through linear and nonlinear intensity-scaling approaches, a theoretically optimized 60-minute match format is proposed, demonstrating improved alignment with ideal GR values and enhanced spectator engagement. This chapter thus contributes significantly to understanding how targeted adjustments in game design can maximize psychological engagement and competitive fairness across different sports contexts, laying the groundwork for the advanced gravity-inspired analytical framework introduced in the subsequent chapter.

4.2 Theoretical Background

The design of sports and games relies on carefully balancing key elements such as game length, scoring frequency, and uncertainty resolution to optimize player engagement and spectator experience. Game length acts as a temporal framework that influences and often constrains other critical elements of game design, including scoring frequency, uncertainty resolution, player engagement, and spectator experience. Excessively short durations can undermine strategic depth and reduce perceived fairness, while overly extended gameplay risks viewer fatigue and waning attention [115–117]. This aligns with previous findings [16], which emphasize that the duration of play significantly affects the gaming experience and outcome anticipation. Specifically, short playtimes were perceived as unreliable, while prolonged durations diminished engagement. Well-calibrated time constraints improve spectator appeal and player immersion by reflecting traditional sports rhythms and influencing suspense, excitement, and the perceived value of each moment, shaping both cognitive and emotional responses.

Scoring frequency, closely linked to game length, shapes gameplay rhythm and emotional intensity, significantly affecting player and spectator engagement. [118] found that faster-paced formats enhance engagement by increasing scoring opportunities, with shorter matches sustaining attention and making games like tennis more unpredictable and exciting. Similarly, [119] showed increased scoring in sports like rugby strengthens engagement. These findings align with game refinement theory [107], which posits that optimizing scoring frequency and unpredictability sustains excitement by balancing challenge and enjoyment. Overall, fostering high-scoring environments can boost entertainment value and competitiveness.

Beyond game length and scoring frequency, uncertainty resolution plays a pivotal role in shaping engagement by affecting outcome predictability during gameplay. High-scoring sports like basketball and volleyball sustain suspense until the end, as frequent scoring delays resolution and maintains tension [120, 121]. In contrast, low-scoring sports such as soccer often see outcome predictability shift after a single goal [122]. From a reinforcement standpoint, high-scoring games resemble weaker Variable Ratio (VR) schedules (frequent reinforcement), while low-scoring games align with stronger VR schedules (delayed reinforcement). These structural differences shape how suspense and unpredictability unfold, impacting player motivation and spectator engagement.

Soccer, with its low scoring frequency, is among the most unpredictable sports, where a single goal can dramatically shift outcomes, sustaining high engagement for players and spectators. In contrast, cricket particularly the T20 format features frequent scoring and rapid momentum shifts, keeping outcomes uncertain until the end and heightening excitement. These regular reinforcements distribute suspense across the match, making T20 one of the most thrilling formats. Meanwhile, One Day Internationals (ODIs) offer a slower yet steady scoring pace, fostering a more strategic build-up of suspense and delivering a longer but still engaging experience.

This study examines ODI and T20 cricket, along with soccer, where game length, scoring frequency, and uncertainty resolution critically shape engagement dynamics. ODI cricket, a 50-over format, allows extended strategic play and recovery from setbacks [32]. In contrast, T20's 20-over structure promotes rapid scoring, frequent momentum shifts, and suspense until the final overs [44]. These format differences influence how uncertainty unfolds: ODIs enable gradual momentum changes, while T20s demand swift decisions where a single mistake can be decisive. Soccer, with its fixed 90-minute duration and low scoring, creates prolonged suspense, where each goal carries substantial weight and compels constant tactical adaptation [80].

Given the interplay among game length, scoring frequency, and unpredictability, a systematic approach is essential to analyze engagement dynamics. While traditional analyses rely on empirical observations, structured frameworks offer deeper insights. This study applies GR theory and the MiM framework. GR theory quantifies a game's sophistication and outcome uncertainty, both key to its entertainment value [16]. It introduces the GR metric based on the game progress model to capture the balance between skill and chance. Games with GR values between 0.07 and 0.08 fall within the "comfortable zone," where engagement peaks for players of varying skill levels [123]. Below 0.07, outcomes become overly predictable, while values above 0.08 indicate excessive randomness, where luck dominates and repeated play is needed to identify the stronger side. Thus, games within the 0.07–0.08 range strike an ideal balance, fostering fair and engaging experiences.

The Motion in Mind (MiM) model extends GR theory by analogizing game dynamics to physical motion laws. It interprets engagement and uncertainty resolution through concepts like acceleration, force, and momentum, suggesting that game progression and cognitive engagement mirror patterns of physical motion. Using the GR and MiM frameworks, we analyze how game length (T), scoring frequency as reward frequency (N) [107], and uncertainty resolution as velocity (v) [18] shape player and spectator experiences. For example, GR applied to ODI and T20 cricket reveals how length and scoring patterns affect engagement, while in soccer, it quantifies how goal frequency contributes to unpredictability

While GR theory quantifies engagement through game mechanics, it does not capture players' subjective experiences. The MiM framework addresses this gap by modeling cognitive and emotional responses using physics-inspired concepts such as velocity, acceleration, momentum and others [17]. MiM extends GR's scope by linking game dynamics to mental engagement, making it especially valuable for distinguishing between engaging and overly addictive play. It has been effectively applied in both game [18, 95, 124, 125] and non-game contexts [126, 105], offering a richer evaluation of spectator experience.

4.3 Literature Review

Sports engagement arises from game length, scoring frequency, and unpredictability, shaping player experience and spectator excitement. A key distinction across sports is their game-ending conditions, which influence strategic depth and engagement patterns. Sports can be broadly categorized into fixed-duration games (e.g., soccer, basketball), where playtime is predetermined, and variable-ending games (e.g., cricket, baseball, tennis), which continue until specific conditions are met. Comparative studies highlight differences in strategy, psychology, and suspense. In fixed-duration sports, time constraints drive adaptive tactics, such as stalling or aggressive late-game plays [127], creating intense time-induced pressure [128]. Variable-ending sports, in contrast, require sustained effort and strategic endurance [129], allowing for comebacks and prolonged suspense without a countdown. Psychologically, fixed-duration formats heighten stress through time pressure [130], while variable-ending formats demand greater resilience over uncertain durations. Although soccer has been widely studied for its balance of skill, luck, and unpredictability, cricket remains underexplored especially regarding how its varying formats affect engagement. This section reviews existing literature on soccer and cricket, framing the need for a structured analysis of unpredictability.

A key driver of engagement in soccer is its inherent unpredictability, shaped by the balance between skill and luck. [131] found that luck accounts for 60% of outcome variation in soccer, compared to 40% attributed to skill, echoing [132], which highlights luck's significant role in goal scoring. This aligns with soccer's reputation for high randomness [133], where chance events can decisively impact outcomes. Unpredictability is further quantified by Scoring Infrequency (SI), defined as $SI = max(SF) - SF$, which reflects how rarely goals are scored. Low-scoring sports like soccer ($SI = 0.91$), ice hockey ($SI = 0.79$), and field hockey ($SI = 0.89$) show greater outcome variability, as each goal carries more weight. In contrast, high-scoring sports like basketball ($SI = 0.17$) dilute randomness, reducing luck's influence.

[134] argue that sports require a balance between skill and chance to remain engaging purely skill-based competitions become predictable, while luck-driven ones lack credibility. Their findings, including a 36% upset rate in the NBA, suggest that randomness sustains suspense. However, excessive randomness can undermine engagement, as spectators value a balance between unpredictability and fairness [135].

While soccer's engagement is shaped by low scoring and high randomness, cricket offers a contrasting case, where unpredictability varies across formats. Despite its global popularity and multiple formats (Test, ODI, T20), cricket has received less attention from economists than football [136]. It is a skill-based sport, with individual performances particularly in batting and bowling essentially determining outcomes [137]. Although chance plays a role, results often follow skill-driven patterns. Unpredictability in cricket arises differently across formats, with game length being a key variable. [45] highlight T20 cricket's growing dominance, citing its fast-paced, action-packed nature as the main driver of fan, sponsor, and media appeal. A survey of 280 respondents confirms T20 as the most popular format, suggesting declining relevance for Test cricket and challenges for ODIs. Despite cricket's format-dependent variability, limited research explores how skill, luck, game length, and scoring frequency affect engagement. Comparative studies on uncertainty across formats remain sparse, leaving a gap in understanding how randomness shapes viewer experience.

Psychological suspense is a key driver of sports engagement, with research showing that outcome uncertainty and unexpected events heighten spectators' emotional responses. Studies across soccer, basketball, and American football reveal that fans are especially drawn to matches where uncertainty persists until the end [81]. In soccer, suspense is intensified by low scoring, with prolonged tension and sudden shifts creating powerful emotional experiences [80]. Analysis of English Premier League audiences shows suspense and surprise significantly boost viewer demand. Similarly, in the NBA and NFL, frequent lead changes and tight scores increase audience retention, illustrating that suspense also plays a crucial role in high-scoring sports [138]. This supports GR Theory, which suggests optimal engagement arises from a balance of suspense and skill-driven play [16]. Whether through soccer's rare but high-stakes goals or basketball's constant shifts in momentum, suspense reinforces the importance of uncertainty in sports entertainment.

GR theory has been widely applied beyond traditional sports, including board games like chess, Shogi, and Go [16], as well as e-sports genres such as Multiplayer Online Battle Arena (MOBA) games [91]. These board games exhibit high strategic depth, with GR values typically within the optimal range (e.g., chess: 0.074; Shogi: 0.078; Go: 0.076), reflecting a well-balanced level of uncertainty that sustains engagement. Similarly, a study of DotA 6.80

reported a GR value of 0.078, indicating that well-designed e-sports can achieve refinement levels comparable to classic board games.

GR theory has also been applied to soccer [19], where engagement is driven by suspense due to infrequent scoring. The study reports a GR of 0.076 and an Addictive Density (AD) of 0.090 ($\phi = 0.84$), but closer inspection reveals formula inconsistencies. The authors use $GR = \frac{\sqrt{B}}{D}$, whereas the accepted formula is $GR = \frac{\sqrt{2G}}{T}$, and for AD, $AD = \frac{\sqrt[3]{6G}}{T}$. Applying the correct formulas yields updated values: $GR = 0.107$, $AD = 0.1164$, and $\phi = 0.92$. These discrepancies affect both the reported values and their theoretical implications. Similarly, [18] presents inconsistencies in their engagement metrics for soccer, while [107] links *GR* theory with reinforcement schedules via reward frequency (N). However, their interpretation of reward frequency in soccer appears misaligned with actual game dynamics, raising concerns about the validity of their conclusions.

Such inconsistencies highlight broader concerns regarding the application of GR and MiM frameworks across sports. While issues have been noted in soccer and basketball, similar limitations appear in cricket research. For instance, [108] acknowledges the relevance of GR theory but does not apply its metrics to assess engagement across formats like Test, ODI, and T20. A comparative analysis using GR and MiM could offer deeper insights into how cricket's structure influences excitement and strategic depth. Moreover, their use of a hypothetical 10-over match raises questions, especially given that T20 already provides a fast-paced, engaging format. Clarifying this rationale would strengthen their contribution and improve theoretical precision in evaluating cricket's engagement dynamics

While prior research has illuminated the roles of game length, scoring frequency, and unpredictability in driving engagement, several gaps persist. Although soccer's randomness due to low scoring is well-documented, cricket's format-specific engagement dynamics remain underexplored. Moreover, the application of GR Theory and the MiM Framework has been inconsistent, with discrepancies in formulas and interpretations. Notably, few studies offer a comparative, quantitative framework for assessing unpredictability across sports. This study addresses these gaps by applying GR Theory and the MiM Framework to systematically analyze engagement in ODI, T20 cricket, and soccer. Through this approach, we provide mathematical and cognitive insights into how game design shapes excitement and unpredictability, offering implications for optimizing sports formats and enhancing spectator experience.

4.4 Methodological Overview for Comparative Analysis

4.4.1 Data Collection and Sources

As detailed comprehensively in Chapter 3 (Section 3.3.1), the data used in this comparative analysis were systematically collected from officially sanctioned international tournaments. Specifically, ODI cricket data were obtained from the ICC Cricket World Cup 2023 (46 matches), T20 cricket data from the ICC T20 World Cup 2022 (42 matches), and soccer data from the FIFA World Cup 2022 (64 matches). Complete descriptions of the data sources, selection criteria, and preprocessing procedures are presented in Chapter 3 and briefly summarized in Tables 3.1 and 3.2. These tournaments were specifically chosen due to their international prestige, standardized rules, extensive media coverage, and high-quality data availability, ensuring robust and reliable comparative analysis.

To ensure consistent and meaningful cross-sport comparisons, the following key metrics were adopted:

- **Scoring events** (G): Defined as the average total runs (cricket) or goals (soccer) scored per match, representing successful scoring outcomes.
- **Scoring opportunities** (T): Defined as the total available scoring chances per match, represented by total deliveries (balls bowled) in cricket and total goal attempts (shots taken) in soccer.
- **Scoring velocity** (v): Calculated as the normalized scoring rate within a standardized range of $[0,1]$, enabling direct and meaningful comparisons across diverse scoring frequencies, particularly crucial for high-scoring formats such as T20 cricket.

4.4.2 GR Measure, MiM, and FiM Parameters

This chapter employs the analytical rigor of GR theory alongside the psychologically grounded MiM and FiM frameworks to comparatively assess engagement dynamics in high-scoring (ODI and T20 cricket) and low-scoring (soccer) sports. While the theoretical foundations of these frameworks are comprehensively discussed in Chapter 3, it is beneficial here to briefly revisit their conceptual significance within the comparative context of this analysis.

GR theory provides a quantitative method to assess how effectively a sport balances skill, chance, and fairness. By quantifying the pace at which uncertainty is resolved through scoring events, GR captures the intrinsic engagement value of a sport. Sports within the optimal GR zone (typically between 0.07 and 0.08) are considered structurally refined, effectively combining competitive fairness with sustained viewer engagement. Conversely, values outside this optimal range can indicate excessive predictability (if too low) or undesirable randomness (if too high), signaling potential areas for structural refinement.

Complementing GR theory, the MiM and FiM frameworks specifically model the cognitive and emotional dimensions of engagement, illustrating how structural aspects of a sport affect players' and spectators' psychological experiences. Together, these frameworks facilitate a multidimensional comparative analysis, enabling us to clearly identify differences in how various sports balance structural clarity, fairness, and emotional intensity. This chapter systematically applies these measures to investigate how variations in game length, scoring frequency, and uncertainty resolution affect both fairness and entertainment across sports formats. Additionally, we specifically explore how structural adjustments, particularly within soccer, might optimize engagement, emotional pacing, and competitive integrity.

4.5 Comparative Results Analysis

This section provides a comparative analysis of ODI cricket, T20 cricket, and soccer, emphasizing how differences in game length and scoring structure shape psychological dynamics, particularly engagement, excitement, and perceived fairness. Using empirical data summarized in Tables 4.1 and 4.2, we systematically examine these sports through the lenses of GR theory, MiM, and FiM frameworks. The analyses explore how variations in scoring velocity, acceleration, momentum, reward frequency and others driven by distinct structural characteristics of each sport impact cognitive load, emotional pacing, and spectator enjoyment. This comparative perspective enables us to identify the role of game length and structural differences inherent in each format and lays the foundation for targeted recommendations to identify and enhance overall engagement and competitive balance if required.

Table 4.1 Velocity and MiM measures of selected sports

Sport	**G**	**T**	**v**	**m**	**F**	$\vec{p}$	$\mathbf{E_p}$	**N**	**MEE**
ODI	258.03	300×6	0.143	0.857	0.005	0.123	0.035	6.976	2.641
T20	143.18	120×6	0.199	0.801	0.015	0.159	0.063	5.029	2.242
Soccer	2.672	22.766	0.117	0.883	0.009	0.104	0.024	8.520	2.919

Figure 4.1 presents the solved-uncertainty curves for cricket (ODI and T20) and soccer, with two red dotted horizontal lines marking the GR zone (0.07–0.08), denoting the optimal engagement and fairness range for uncertainty resolution [16]. This zone reflects a comfortable thrill balance, originally established in board games. The diagonal line $y = vt$ (or $\frac{t}{2}$)

Table 4.2 GR and FiM measures of selected sports

Sport	**GR**	**a**	**j**	**AD**	ϕ	**PRE**
ODI	0.076	0.0057	0.00006	0.0386	1.964	7.168
T20	0.141	0.0199	0.00050	0.0792	1.780	3.977
Soccer	0.102	0.0103	0.00136	0.1108	0.917	2.672

serves as a baseline for comparing uncertainty resolution across different sports. To complement this, Table 4.2 lists key parameters such as G, T, GR, and a, providing a quantitative comparison of pacing and uncertainty resolution across ODI, T20, and soccer.

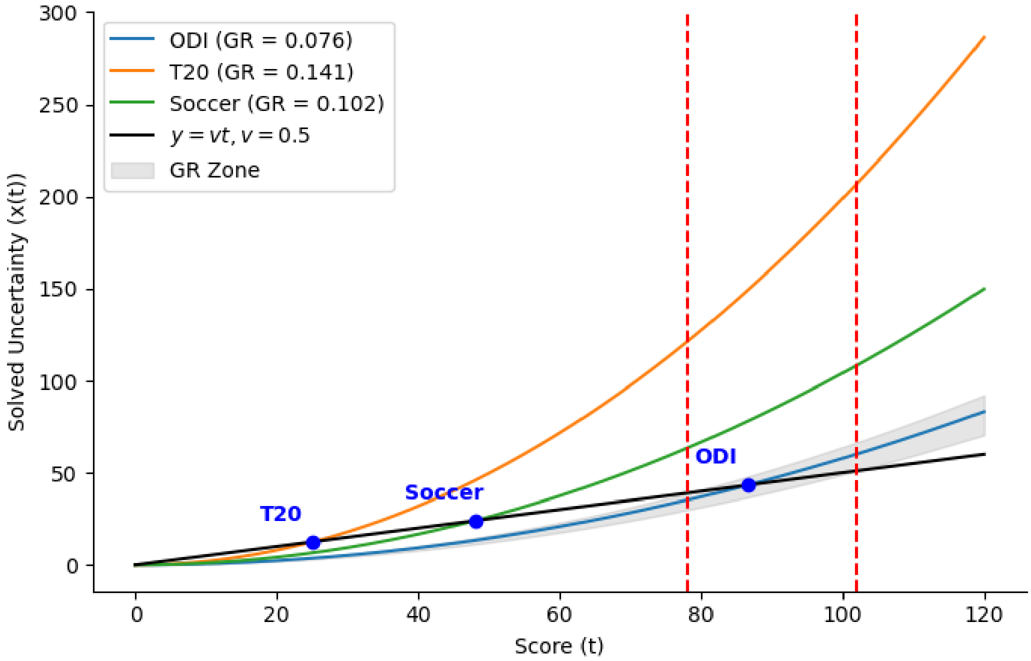

Fig. 4.1 GR measures of ODI, T20, and Soccer

ODI cricket exhibits a well-balanced structure, demonstrated by a GR value of 0.076, placing it comfortably within the GR zone. This indicates fairness, high skill orientation, and minimal influence from randomness or luck. Being within the GR zone means minimal objectivity, which implies that typically, a single match is sufficient to accurately determine the stronger team, emphasizing skill over chance. However, the low acceleration measure ($a = 0.0057$) points to a gradual build-up of excitement, comparable to the strategic progression seen in board games such as Chess or Go. While this gradual pace supports strategic depth and sustained engagement, the lengthy format of 50 overs per side may diminish excitement for casual viewers seeking quicker gratification or more dynamic pacing. T20 cricket, by contrast, demonstrates a less balanced structure, with a GR value of 0.141, significantly above the optimal GR zone. This suggests higher randomness, reduced fairness, and a greater influence of luck compared to skill. The elevated objectivity means a single match may not reliably identify the stronger team, underscoring the unpredictable nature inherent to this format. However, its higher acceleration measure ($a = 0.0199$) indicates rapid shifts in excitement, mirroring the intense emotional swings typical of fast-paced, spectator-oriented games. While this heightened acceleration delivers immediate thrills and entertainment value, the shorter format (20 overs per side) often sacrifices strategic depth and sustained narrative coherence, potentially leaving the experience feeling superficial for more analytically inclined viewers. Given this comparative analysis, it is evident that T20 cricket exceeds the optimal GR zone, suggesting potential for structural adjustments, whereas ODI cricket already resides comfortably within the GR zone, requiring no significant restructuring.

Soccer, on the other hand, exhibits a GR value of 0.101, which also exceeds the optimal GR zone, highlighting a noticeable influence of randomness and unpredictability within match outcomes. This relatively elevated GR suggests that individual matches may occasionally yield results influenced more by chance or isolated incidents rather than consistent skill dominance. However, soccer's moderate-high acceleration ($a = 0.0103$) facilitates a steady and engaging rise in excitement throughout the match, balancing strategic gameplay with moments of spontaneous thrill. Unlike T20 cricket, soccer maintains a coherent narrative arc with sufficient strategic depth, due in part to its lower scoring frequency and more extended periods of suspense. Nonetheless, the current structural characteristics of soccer might still benefit from targeted adjustments aimed at reducing randomness, thereby reinforcing fairness and enhancing the skill-oriented nature of the sport without sacrificing its inherent entertainment value.

4.5.1 Velocity v, Mass m, and Potential Energy E_p

Figure 4.2 compares cricket (ODI and T20) and soccer by plotting *mass* (m), representing challenge or cognitive difficulty, on the horizontal axis, against *velocity* (v), indicating the frequency and pace of scoring, on the vertical axis. The color intensity (hue) of each data point reflects its computed potential energy ($E_p = 2, m, v^2$), quantifying intrinsic motivational appeal based on the interaction of challenge and scoring intensity.

The analysis highlights significant differences between ODI and T20 cricket. T20 exhibits higher velocity (0.199) compared to ODI (0.143), reflecting a faster resolution of uncertainty and more frequent scoring occurrences within a shorter format. Conversely, ODI cricket demonstrates a higher mass (0.857) relative to T20 (0.801), suggesting that ODI requires greater cognitive and strategic endurance, sustained focus, and patience. Importantly,

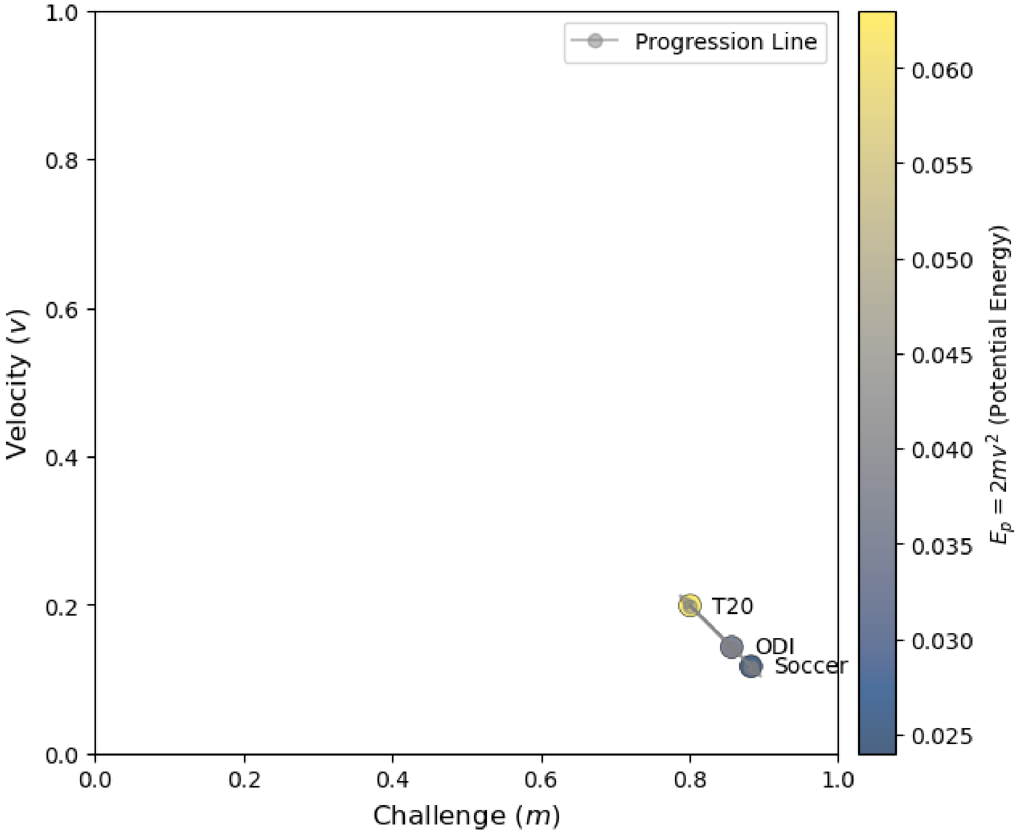

Fig. 4.2 Comparison of ODI and T20, and Soccer in terms of Velocity (v), Mass (m), and Potential Energy (E_p)

the potential energy for T20 (0.063) surpasses that of ODI (0.035), underscoring T20's intrinsic motivational strength, effectively balancing higher excitement and challenge with player capabilities. This aligns with observed trends of higher spectator engagement and entertainment in T20 matches.

Soccer, distinctively a low-scoring sport, contrasts markedly with ODI and T20 cricket in the MiM analysis. Soccer shows lower velocity (0.117), indicating infrequent scoring and a prolonged resolution of game outcomes. Additionally, it has notably higher mass (0.883), implying substantial cognitive and strategic challenges due to sustained gameplay tension, significant teamwork requirements, and intricate tactics involved in creating scoring opportunities. The relatively lower potential energy (0.024) suggests a different form of intrinsic engagement driven by extended strategic complexity rather than frequent scoring events. Consequently, soccer engages players and spectators through extended periods of strategic anticipation and tension, rather than through rapid outcome resolutions.

4.5.2 Acceleration a and Jerk j

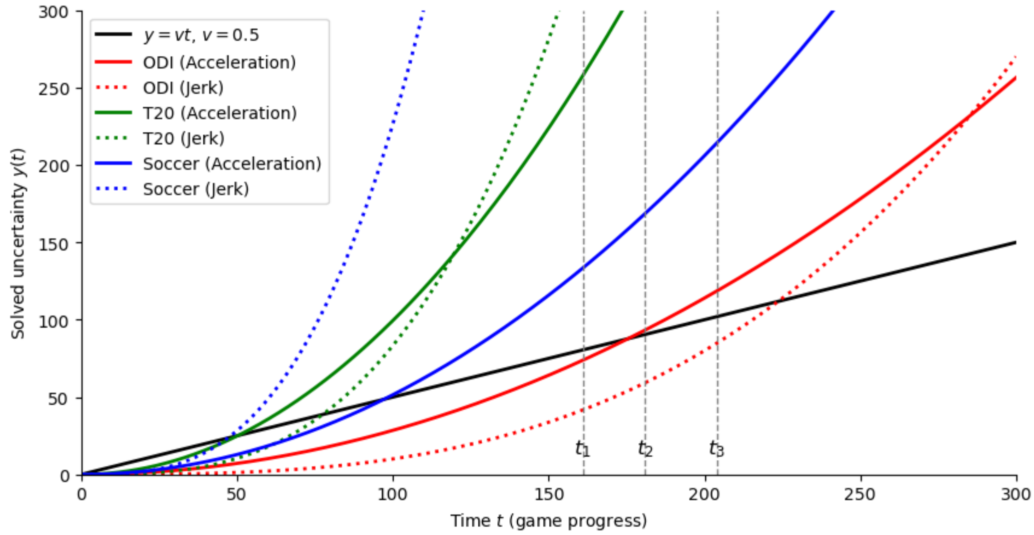

Fig. 4.3 The intersection of acceleration $a = \left(\frac{1}{2}at^2\right)$, and jerk $j = \left(\frac{1}{6}jt^3\right)$ with line $y = vt$ or $\frac{t}{2}$. The parameters t_1, t_2, and t_3 represent the thresholds for effort, achievement, and discomfort, respectively.

Table 4.2 summarizes numerical values of acceleration and jerk across selected sports, illustrating how these parameters differ based on the structure and pacing of each game. These variations are further visualized in Figure 4.3, highlighting the interplay between acceleration and jerk and their impact on the engagement and excitement dynamics. Specifically, intersection points of ODI, T20, and soccer with the reference line $y = vt$ (or $\frac{t}{2}$) illustrate their uncertainty resolution dynamics, where t_1, t_2, and t_3, corresponding to effort, achievement, and discomfort, respectively. Understanding these intersections helps to explain how varying combinations of acceleration and jerk in different sports shape distinct psychological and strategic experiences for players and spectators.

The results reveal significant insights into the gameplay dynamics of ODI and T20 cricket. In ODI, the acceleration value ($a = 0.0057$) falling within the optimal range (0.005–0.006), indicates a gradual and strategically engaging buildup of excitement, providing sufficient time for players to plan and adapt. Complementing this, the notably low jerk ($j = 0.00006$) highlights smooth momentum transitions with minimal abrupt shifts, promoting cognitive comfort and mental fluency. This stable pacing sustains a consistent psychological state, allowing players to maintain concentration and explore deeper strategic possibilities without frequent disruptions. Together, these characteristics ensure a methodical gameplay experience with balanced emotional dynamics, emphasizing sustained engagement and strategic depth. In contrast, T20 cricket exhibits a significantly higher acceleration ($a = 0.0199$), indicating rapid uncertainty resolution and intense excitement designed to captivate players and spectators within a shorter duration. This swift gameplay pace promotes thrilling, dynamic experiences but is accompanied by a moderately elevated jerk ($j = 0.00050$), substantially higher than in ODI cricket. This elevated jerk reflects frequent and unpredictable momentum shifts, creating a stimulating yet mentally demanding environment that can introduce cognitive challenges and diminish players' sense of control. Psychologically, this combination of high acceleration and elevated jerk makes T20 matches intensely engaging but also volatile and potentially stressful, characterized by rapid, sudden fluctuations in momentum.

Soccer, characterized as a low-scoring sport, shows moderate acceleration ($a = 0.0103$), suggesting a gameplay tempo conducive to strategic build-up and tactical engagement, balanced with continuous dynamic action. Despite this measured pace, soccer exhibits the highest jerk value among the sports analyzed ($j = 0.00136$), indicating frequent and abrupt momentum shifts, such as sudden goals or unexpected turnovers. These pronounced fluctuations significantly disrupt cognitive flow, generating emotional suspense and psychological tension that enhance viewer engagement and excitement. Consequently, soccer matches maintain a structured narrative through their moderate acceleration but become psychologically turbulent and dramatically compelling due to their high jerk, demanding rapid adaptability from players and adding unpredictability that heightens spectator experience.

Together, acceleration and jerk define the balance between thrill and stability in gameplay. With low values of a and j, ODI cricket prioritizes strategic depth and steady engagement, facilitating sustained concentration. T20 cricket achieves a high-energy equilibrium, combining rapid excitement with moderate instability that keeps the experience stimulating yet manageable. Soccer delivers the most emotionally intense experience, emphasizing dramatic unpredictability at the expense of structural stability, thus creating heightened suspense and continuous psychological tension.

4.5.3 Momentum $\vec{p}$ and Reward Frequency N

Momentum ($\vec{p} = mv$) and reward frequency ($N = \frac{1}{v}$) are the key metrics for understanding cognitive engagement and motivational structures in gameplay. Momentum reflects the intensity of mental engagement, determined by the interplay between perceived difficulty and success rate, while reward frequency represents the reinforcement schedule of the game, indicating the expected number of attempts needed per reward (e.g., runs, goals) and thus the predictability and motivational pull of in-game achievements. The solid green curve in Figure 4.4 shows momentum trends; red dashed lines denote reward frequency.

ODI cricket exhibits steady player engagement, as indicated by a moderate momentum ($\vec{p} = 0.123$) and a reward frequency of approximately $N = 6.976$, suggesting that reinforcing

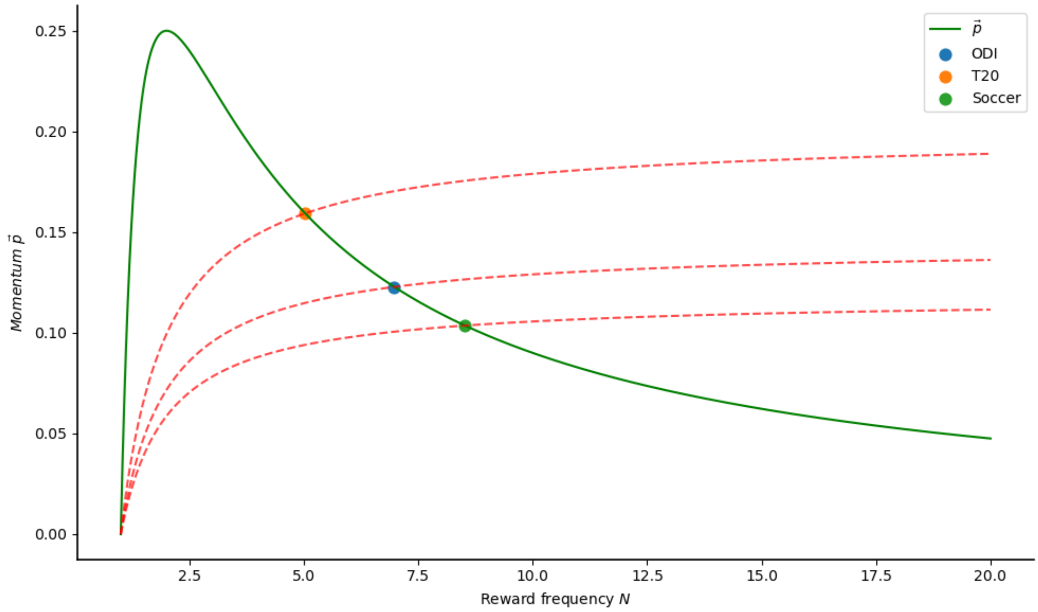

Fig. 4.4 Comparison of Momentum and Reward Frequency across ODI Cricket, T20 Cricket, and Soccer.

exciting events such as boundaries (sixes) occur roughly once every 7 deliveries. This reflects a balanced gameplay pace neither too fast nor too slow which supports sustained attention and strategic planning throughout the longer format of ODI cricket. T20 cricket, on the other hand, shows enhanced player engagement characterized by higher momentum ($\vec{p} = 0.159$) and a lower reward frequency ($N = 5.029$). Reinforcing exciting events such as boundaries (sixes) occur more frequently, approximately every 5 deliveries. This faster-paced rhythm creates immediate excitement, promotes rapid decision-making, and sustains intense player involvement throughout the shorter and more dynamic format of T20 cricket.

Soccer presents a lower momentum ($\vec{p} = 0.104$) and a notably higher reward frequency $N = 8.520$ indicating fewer reinforcing events (e.g., goals) occurring roughly once every 9 attempts. The infrequency of scoring in soccer heightens the emotional payoff associated with each goal, amplifying strategic buildup and maintaining tension throughout the match. While reinforcement occurs less frequently, soccer effectively sustains both player and spectator engagement through suspense and the amplified emotional impact of rare, decisive rewards.

4.5.4 Addictive Density *AD* and Phi Ratio ϕ

The results presented in Table 4.2 further highlight the differences in *AD* and Phi Ratio (ϕ) among the examined sports, offering deeper insights into the sports' cognitive and emotional profiles. ODI cricket, characterized by a relatively low *AD* (0.039), indicates a more predictable, less emotionally intense gameplay experience. Coupled with a high phi ratio (1.964), it is positioned toward deterministic (means less stochastic), but well structured, and strategically deep gameplay. In contrast, T20 cricket, with a substantially higher *AD* (0.079), exhibits greater unpredictability and emotional intensity, enhancing excitement and engagement. Its phi ratio (1.780), closer to the ideal midpoint ($\phi \approx 1$), suggests that T20 cricket effectively combines this unpredictability with structured strategic elements, thereby achieving an optimal balance between excitement and mental engagement. This comparison distinctly illustrates how ODI cricket emphasizes strategic determinism with lower emotional volatility, whereas T20 cricket blends predictability and unpredictability, maximizing both strategic depth and spectator appeal.

Soccer, characterized by the highest *AD* value (0.111) and a phi ratio slightly below 1 (0.917), exhibits substantial unpredictability and emotional intensity, primarily due to the continuous uncertainty of outcomes in a typically low-scoring context. The high *AD* specifically signals stronger emotional intensity, highlighting the significant emotional weight attached to rare goal events. This creates a heightened sense of suspense and deep emotional engagement among spectators. Unlike cricket formats, soccer's appeal lies not in frequent scoring but rather in the persistent potential for pivotal moments, where even subtle shifts can dramatically alter outcomes. Its phi ratio close to 1 underscores soccer's engaging balance, highly unpredictable yet strategically meaningful. This unique combination of sustained suspense, tactical depth, and rare, emotionally impactful scoring explains soccer's widespread global popularity and powerful spectator appeal.

4.6 Discussion

The empirical findings presented in the previous result analysis section demonstrate how structural elements such as game duration, scoring frequency, and scoring intensity distinctly influence engagement, excitement, and emotional dynamics in cricket (ODI and T20) and soccer. The analysis clearly illustrates that while cricket, particularly in its ODI format, closely aligns with optimal design parameters derived from GR theory and the MiM and FiM model, soccer's current structural configuration offers room for optimization. Building upon these insights, this section further explores whether targeted adjustments, specifically in match duration can effectively enhance soccer's engagement, excitement, and overall entertainment value. Given soccer's distinctive position, characterized by high unpredictability and emotional intensity yet lower scoring frequency, investigating structural modifications becomes crucial. The discussion critically examines the potential for shortening or restructuring soccer matches to align their refinement and psychological pacing more closely with ideal engagement parameters, thereby maximizing spectator appeal and cognitive engagement.

Our analysis confirms that cricket, in both ODI and T20 formats, effectively fulfills distinct structural objectives for engagement and entertainment. ODI cricket, precisely positioned within the optimal Game Refinement (GR) zone (GR = 0.076), emphasizes strategic depth, fairness, and cognitive comfort. This alignment ensures sustained player and spectator engagement over its extended duration. Conversely, T20 cricket, characterized by a significantly higher GR (0.141), intentionally sacrifices some strategic depth and fairness to deliver rapid scoring, heightened excitement, and emotional intensity. Its higher acceleration and dynamic momentum shifts optimize the spectator experience for immediate entertainment value. Consequently, both cricket formats have structurally evolved to meet their respective audience preferences, ODI catering to those seeking cognitive depth and strategic immersion, and T20 designed explicitly for entertainment and emotional thrill. Given their current alignment with engagement metrics and audience expectations, structural modifications in cricket formats appear unnecessary.

Soccer, however, presents a structural imbalance. Its GR value (0.102) lies above the optimal engagement zone, indicating an excessive influence of randomness on match outcomes, potentially compromising fairness, consistent skill demonstration, and reliable identification of the stronger team. In the standard 90-minute format, soccer averages goals $G = 2.672$ and total attempts $T = 22.766$, resulting in a scoring velocity of 0.117 and a reward frequency of approximately 8.5, signifying a goal every 8–9 attempts. Although soccer's low scoring frequency and high addictive density sustain suspense and emotional intensity through rare, high-impact goals, the elevated GR value signals an imbalance in its current structural design. Furthermore, our observations are that the existing 90-minute duration is a bit lenghty gameplay which might not be optimally aligned with spectator engagement and psychological pacing parameters. Thus, to reduce the game length, a critical question arises concerning the degree to which the match duration should be adjusted and how corresponding values of scoring frequency (G) and totoal attempts (T) should be recalibrated. To address this, we propose and apply linear and nonlinear analytical models, aiming to systematically identify an optimized match length along with proportionally adjusted parameters (G and T) to achieve ideal GR alignment, enhancing fairness, structural refinement, and overall spectator engagement in soccer.

Linear Time-Scaling Approach

The linear time-scaling model assumes that the number of goals (G) and goal attempts (T) increase proportionally with match duration. That is, if the duration of the match increases, players have more time to create scoring opportunities and convert them, leading to more goals and attempts all in direct proportion to the time added. Therefore, in this model we assume that both goals and attempts scale linearly (proportionally) with time. If match duration is increased by a factor x, then $G' = xG, \quad T' = xT$. Substituting G' and T' into the GR formula, resulted in Eq. (4.1). We want to find the value of x that reduces GR to the target value of 0.075. Thus, in soccer using the original values of $GR = \frac{\sqrt{2G}}{T} = 0.102$.

$$GR' = \frac{\sqrt{2G'}}{T'} = \frac{\sqrt{2xG}}{xT} = \frac{\sqrt{2G}}{T} \cdot \frac{1}{\sqrt{x}} \tag{4.1}$$

We get $GR' = \frac{0.102}{\sqrt{x}}$. Now setting GR' equal to the desired $GR = 0.075$, which then resulted into Eq. (4.2). Thus, the optimal new match duration becomes $90 \times 1.85 = 166.5$ minutes. The scaling factor x were used to derive the optimal values for G' and T', which gives $G' = 1.85 \cdot 2.672 \approx 4.944$ and $T' = 1.85 \cdot 22.766 \approx 42.116$. Finally the GR value is verified as in Eq. (4.4).

$$0.075 = \frac{0.102}{\sqrt{x}} \Rightarrow \sqrt{x} = \frac{0.102}{0.075} \approx 1.36 \tag{4.2}$$

$$\begin{aligned} 0.075 &= \frac{0.102}{\sqrt{x}} \Rightarrow \sqrt{x} \\ \sqrt{x} &= \frac{0.102}{0.075} \approx 1.36 \\ x &= (1.36)^2 = 1.85 \end{aligned} \tag{4.3}$$

$$GR = \frac{\sqrt{2 \cdot 4.944}}{42.116} = \frac{3.145}{42.116} \approx 0.075 \tag{4.4}$$

While mathematically sound, the linear time-scaling model may be overly idealistic, as it overlooks factors such as fatigue, strategic pacing, and diminishing returns over extended play. Empirical studies suggest that longer match durations do not yield proportional increases in performance. For example, Harper et al. [139] observed significant declines in passing and dribbling frequency during the final stages of 120-minute matches, indicating reduced player efficiency and engagement due to fatigue. These findings challenge the assumption that goals and attempts increase linearly with time, highlighting the need for alternative models that reflect real-world performance constraints.

Non-Linear Intensity-Scaling Approach

To better reflect the dynamic nature of real gameplay, we propose a nonlinear model where match intensity increases as duration decreases. Under time constraints, players tend to adopt more aggressive strategies, leading to a higher rate of goal attempts and risk–reward decisions. However, not all additional attempts convert into goals, as outcomes remain influenced by defensive responses, fatigue, and execution accuracy. Therefore, the aggression factor can be introduced as $\alpha = \frac{90}{d}$ where d is the new match duration (in minutes i.e,. 60) and the α represents how much more intense the game becomes compared to the standard 90-minute match. Next, to model how scoring dynamics scale with intensity, we define $G' = G \cdot \alpha^a, \quad T' = T \cdot \alpha^b$, where G' is the expected number of goals in the more intense match, and T' is the number of total goal attempts. a: exponent controlling how goals scale with aggression and b: exponent controlling how attempts scale with aggression.

The core idea is that goals and attempts scale differently with increased aggression. As match intensity rises (larger α), teams take more shots, so attempts increase faster, typically with $b > 1$. However, due to defensive pressure and chaotic play, scoring does not scale as quickly, hence $a < b$. A higher a implies goals scale more aggressively, while a higher b indicates a sharper rise in attempts. By tuning a and b, we can realistically model how shortening match duration increases tempo without proportionally improving scoring efficiency. We applied this to a specific case of a new match duration: $d = 60$ minutes with the aggression factor: $\alpha = \frac{90}{60} = 1.5$. Further, we assume the parameters $a = 0.512$, $b = 1.0$. Then, $G' = 2.672 \cdot 1.5^{0.512} \approx 2.672 \cdot 1.283 \approx 3.426$ and $T' = 22.766 \cdot 1.5^{1.0} = 22.766 \cdot 1.5 = 34.149$. These values reflect a realistic pattern, while the number of attempts increases sharply due to intensified gameplay, the goals increase more modestly, which is consistent with how teams behave under time pressure. The new GR value is then computed as Eq. 4.5.

$$GR = \frac{\sqrt{2 \cdot 3.426}}{34.149} = \frac{\sqrt{6.852}}{34.149} \approx \frac{2.618}{34.149} \approx \mathbf{0.0767} \tag{4.5}$$

This result is significant, as it brings soccer's GR value into the optimal refinement zone ($0.07 \leq GR \leq 0.08$), suggesting a structurally fairer and more engaging format. The 60-minute version offers a better balance between skill and chance than the standard 90-minute match. It maintains the emotional impact of rare goals while reducing randomness and enhancing structural clarity. This implies that a shorter, more intense format could improve the psychological and competitive experience for both players and spectators.

However, further reducing the duration begins to undermine refinement. At 45 minutes, the model predicts $G'' = 3.81$, $T'' = 45.532$, and a GR of 0.061, indicating overly rapid resolution and diminished strategic depth. Thus, 60 minutes appears to be a "sweet spot," optimizing engagement, fairness, and cognitive pacing. Notably, this proposal aligns with current discourse in the football community. The International Football Association Board (IFAB) has proposed reducing match time to 60 minutes of effective play to address time-wasting and improve fairness [20], while Mackay Analytics recommends a stop-clock model with a 55–65 minute duration to enhance consistency and engagement [21]. Although focused on effective playtime, these proposals reflect a shared motivation to restructure soccer for improved viewer experience.

As illustrated in Figure 4.5, the solved-uncertainty curves for the original 90-minute (blue), proposed 60-minute (green), and further compressed 45-minute (red) soccer formats clearly demonstrate the impact of match duration on GR zone with with acceleration curves. The 60-minute format's curve intersects precisely within the optimal GR zone ($0.07 \leq GR \leq 0.08$), confirming its superior alignment with ideal engagement thresholds. In contrast, the existing 90-minute format, with its GR of 0.102, sits notably above this optimal zone, underscoring the earlier discussed issue of excessive randomness and unpredictability. Conversely, the 45-minute compressed format falls below the optimal zone with a GR of 0.061, highlighting over-predictability and compromised strategic depth. The shaded area, bounded by red vertical dashed lines marking the optimal GR zone, visually emphasizes the "Goldilocks" advantage of the proposed 60-minute duration neither too brief to sacrifice strategic complexity nor too extended to reduce viewer engagement. This effectively addresses the previously identified imbalance in soccer's current 90 minutes structure. Additionally, this 60-minute format sustains soccer's intrinsic appeal as a low-scoring, strategically rich sport by slightly increasing the reward frequency ($N = 9.97$), meaning goals occur approximately once every 10 attempts, making these rare scoring events even more emotionally rewarding and exciting compared to the original 90-minute format ($N = 8.5$). Furthermore, the proposed 60-minute format promotes more frequent exciting actions such as goals (G) and attempts (T) leading to an increase intensifying gameplay. This enriched frequency of engaging events directly enhances the spectator experience, striking an optimal balance between strategic depth and emotional excitement.

An important consideration highlighted by GR theory is the nuanced relationship between acceleration and excitement, which is according to our study differs depending on the scoring dynamics inherent to each sport. Specifically, GR theory suggests that higher acceleration typically enhances excitement but it is found to be in high-scoring sports. As confirmed earlier in the case of T20 cricket, spectators' excitement is amplified by the frequent occurrence of reinforcing events such as boundaries (fours and sixes), leading to rapid momentum shifts and emotional peaks. However, this relationship is found to be reversed in inherently low-scoring sports such as soccer, where lower acceleration paradoxically intensifies excitement by making scoring events rarer and consequently more emotionally rewarding. Because, from the true nature of soccer, rarer reward increases excitement. This is thoroughly discussed in the previous sections, underscores why the proposed 60-minute soccer format with its carefully balanced GR generates heightened excitement because of the more rarer rewards. By increasing the rarity of goals (approximately one goal per 10 attempts compared to one per 9 attempts in the 90-minute format), the 60-minute structure effectively aligns with soccer's authentic nature, delivering more meaningful and thrilling scoring events within a strategically balance and more engaging framework.

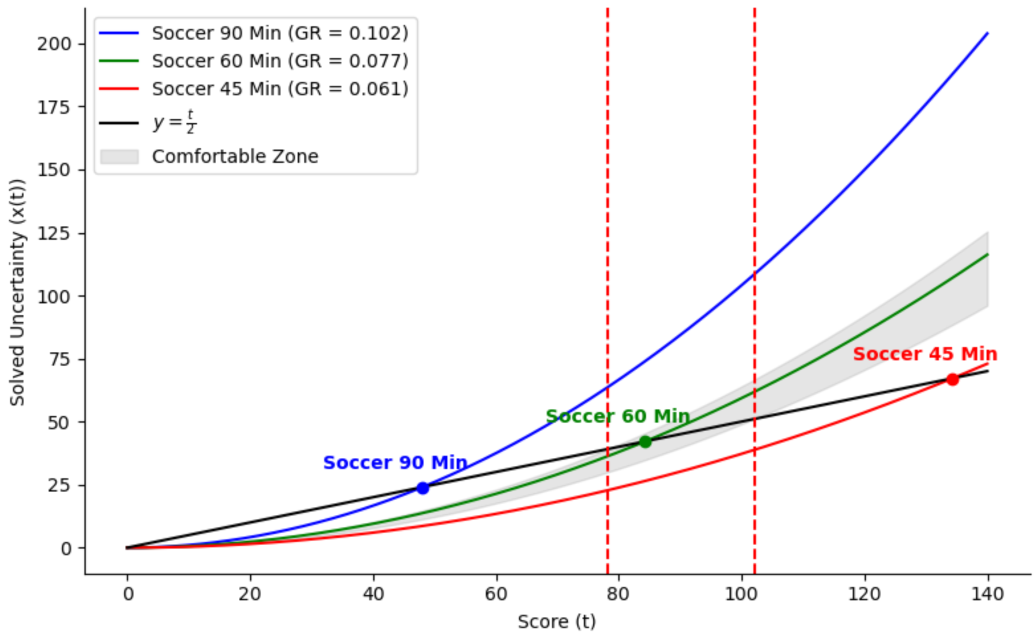

Fig. 4.5 Solved uncertainty curves for soccer under different match durations. The 60-minute format aligns closely with the comfortable GR zone (0.07–0.08), offering an optimal balance between skill and chance.

Moreover, peak engagement and psychological appeal in gameplay are typically achieved when the GR value closely aligns with AD i.e., $GR \approx AD$, yielding a phi ratio ($\phi = \frac{GR}{AD}$) approaching 1 ($\frac{GR}{AD} \approx 1$). To assess this critical balance within soccer, we compared the standard 90-minute real gameplay against the theoratical proposed 60-minute and further compressed 45-minute gameplay formats. In its current 90-minute form, soccer exhibits $GR = 0.102$, $AD = 0.1108$, and $\phi = 0.917$. While this structure successfully delivers emotional suspense and strategic depth, its elevated GR value indicates a slight imbalance favoring chance over skill, thereby exceeding the previously identified optimal GR zone ($0.07 \leq GR \leq 0.08$). Conversely, the proposed 60-minute format significantly improves this balance, achieving a GR of $GR = 0.077$ (well within the optimal engagement GR range), an AD of $AD = 0.0802$

(reflecting balanced unpredictability), and an enhanced phi ratio $\phi = 0.956$, noticeably closer to the ideal balance point of 1 than the current 90-minute format. This optimal GR and the near-equivalence to 1 variability indicate that the 60-minute format effectively boosting spectator excitement, strategic engagement, and overall competitive fairness. Although the 45-minute format achieves an even closer numerical alignment of phi ratio (0.973) to the ideal value 1, its GR value drops below the optimal threshold ($GR = 0.061$), suggesting overly rapid gameplay that potentially undermines strategic depth. Despite achieving structural-emotional symmetry, this 45-minute compressed format risks diminishing the psychological significance and strategic resonance of scoring events, ultimately compromising fairness and reducing spectator engagement.

These gameplay dynamics become even more clearer when examining acceleration (a) and jerk (j) curves across different soccer match durations. Figure 4.6 illustrates how acceleration and jerk provide insights into excitement levels and psychological comfort, reinforcing the engagement and refinement analyses presented earlier. In the current 90-minute format, the relatively higher acceleration ($a = 0.0103$) combined with an elevated jerk value ($j = 0.00136$) suggests a gameplay experience characterized by moderate excitement punctuated by abrupt, unpredictable momentum shifts. As previously discussed, such disruptions to cognitive flow increase the game's randomness, favoring chance over sustained strategic depth. The proposed theoretical 60-minute format significantly improves upon this scenario, achieving reduced acceleration ($a = 0.0059$) mean higher exitement and notably lower jerk ($j = 0.00052$). This optimal combination maintains excitement while minimizing psychological discomfort, aligning closely with ideal cognitive and strategic pacing. Lower jerk values particularly ensure smoother transitions between moments of tension and release, enhancing mental engagement and allowing for sustained strategic anticipation without cognitive fatigue. Conversely, the compressed 45-minute format further reduces acceleration ($a = 0.0037$) and jerk ($j = 0.00024$). While these minimal values indicate higher excited with reduced mental fatigue, the excessively low GR (0.061) identified previously implies an overly predictable gameplay. This resulting in strategic flatness, diminished competitive fairness, and reduced overall spectator engagement. Thus, higher excitement and lower cognitive discomfort, this compressed format fails to sustain meaningless play with strategic depth. This detailed examination of acceleration and jerk across various durations underscores why the proposed 60-minute format represents the optimal structural solution, balancing emotional intensity, cognitive comfort, strategic complexity, and competitive fairness.

The analysis of MEE and PRE across different soccer durations as shown in Figure 4.7, further clearly highlights the superior balance achieved by the proposed 60-minute format. Empirically, the standard 90-minute format ($GR = 0.102$) provides moderate emotional

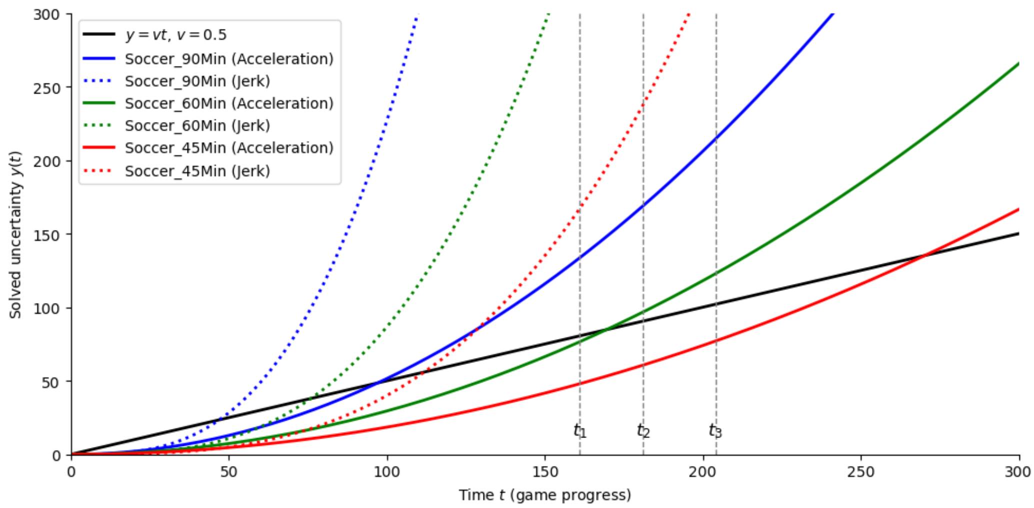

Fig. 4.6 Comparison of acceleration and jerk curves for 90-, 60-, and 45-minute soccer formats. Acceleration is shown with solid lines, while jerk is represented with dotted lines. The 60-minute format offers an ideal balance, maintaining excitement (moderate acceleration) and emotional smoothness (moderate jerk).

Table 4.3 GR, MiM and FiM measures across soccer formats with varying durations

Soccer	G	T	**GR**	v	a	j	N	**AD**	**MEE**	**PRE**
90 min	2.672	22.766	0.102	0.117	0.0103	0.0013	8.52	0.1108	2.92	2.64
60 min	3.426	34.149	0.077	0.100	0.0059	0.0005	9.97	0.0802	3.16	3.39
45 min	3.810	45.532	0.061	0.084	0.0037	0.0002	11.95	0.0623	3.46	3.76

intensity ($MEE = 2.92$), indicating a somewhat elevated psychological excitement relative to the player's typical comfort level, at a comparatively lower reward frequency ($N = 8.52$). Consequently, its PRE is relatively lower because goals are somewhat more frequent, diminishing the psychological reinforcement that arises from rarity and uncertainty. Conversely, the compressed 45-minute format ($GR = 0.061$) offers significantly heightened emotional intensity ($MEE = 3.46$), reflecting a more extraordinary psychological experience due to the increased rarity of goals ($N = 11.95$). The increased PRE here implies stronger psychological reinforcement upon goal achievement, driven by prolonged anticipation. However, this comes at the cost of strategic depth, as extreme rarity and shorting duration can disrupt game flow and spectator engagement, reducing overall competitive balance. Critically, the proposed 60-minute format ($GR = 0.077$) optimally balances these psychological dimensions, achieving ideal emotional intensity ($MEE = 3.16$) high enough to offer substantial psychological excitement without excessive discomfort and a reward frequency ($N = 9.97$) that situates its PRE curve perfectly within an optimal reinforcement zone. This ideal PRE ensures that each goal feels psychologically rewarding and sufficiently rare to maintain suspense and engagement, yet frequent enough to preserve strategic complexity and balanced gameplay. Therefore, this theoretical format effectively addresses the psychological imbalances present in the traditional 90-minute and the overly compressed 45-minute formats, optimizing both player satisfaction and spectator experience.

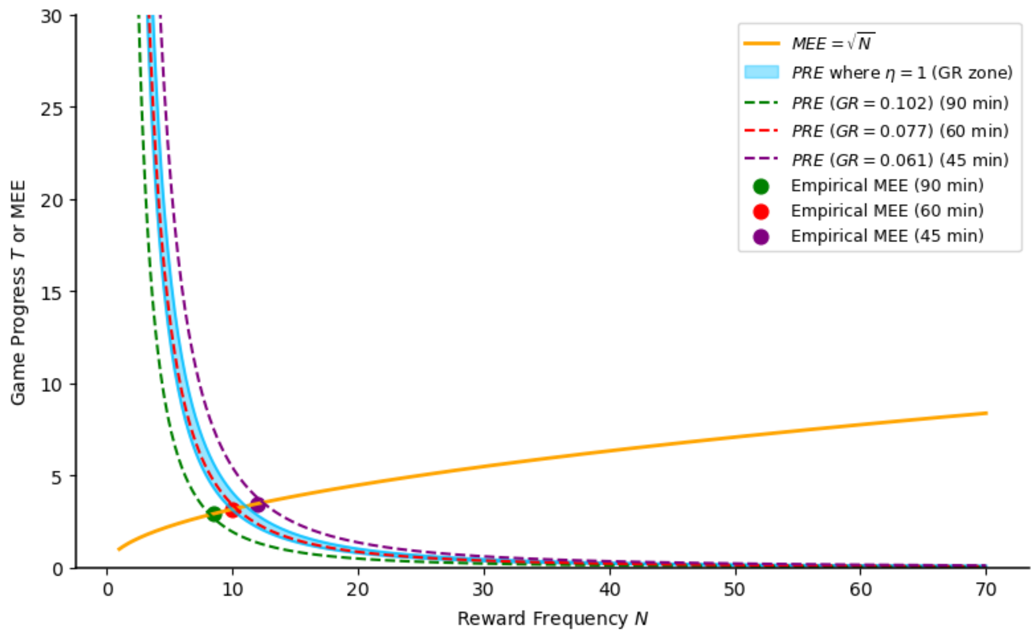

Fig. 4.7 Relationship between MEE and PRE across different soccer match durations (90, 60, and 45 minutes), and their alignment with the optimal GR zone

4.6.1 Debate Over the 90-Minute Match Length

Recent studies and surveys indicate younger fans often struggle to stay engaged for a full game. For example, 42% of 16–24 year-olds report placing less emphasis on watching an entire live 90-minute match [140]. Fans increasingly opt for highlights packages to condense the action into a shorter timeframe, rather than committing to a full match broadcast [141]. Consistent with this, Nielsen's international Fan Insights report found that the 16–24 demographic prefers short, bite-sized sports content and is less inclined to watch entire games from start to finish [142]. Their study (covering eight major markets) concluded that today's young fans "prefer shorter, 'snackable' content" and are much less inclined to sit through entire matches than older generations. Furthermore, the prominent voices such as the Real Madrid president Florentino Pérez, architect of the proposed 2021 European Super League, pointed out that "40% of young people, 16-to-24-year-olds, aren't interested in football", often because "they say the games are too long." He warned that if youths "don't watch an entire game, it's because it isn't interesting enough, or we'll have to shorten the games" [143]. Similarly, Juventus chairman Andrea Agnelli mentioned that fans might prefer to only watch a dramatic finale rather than a dull 90-minute slog [144]. Arsenal manager Mikel Arteta recently acknowledged that game durations will be reduced from 90 minutes in the future, partly to combat player fatigue amid congested fixture schedules [145]. Also, the Football's rule-makers have investigated such ideas in 2017 the International Football Association Board studied a proposal for 60-minute matches with a stop-clock (where the clock halts for ball-out-of-play, to ensure 60 minutes of effective action) [146]. Thus, the current soccer popularity alone doesn't immunize football from structural evolution. Even sport authorities and industry leaders have begun exploring rule changes (including shorter games) to keep football attractive in the future.

4.6.2 Popularity vs. Evolution

One might argue that since football is currently the most popular sport on the planet, such drastic changes are unnecessary. However, historical and cross-sport evidence shows that popularity today does not guarantee popularity tomorrow, especially if a sport fails to evolve with its audience. Global popularity often masks underlying trends; high aggregate viewership can hide the fact that key demographics (like youth) are drifting away. As noted earlier, leading football executives have sounded alarms: "Football is losing its position. The most worrying fact is that young people are less interested" [147]. Other major sports leagues have confronted similar dilemmas and responded with format innovations, even at the peak of their popularity. A pertinent example is Major League Baseball (MLB) in the United States. Baseball has long been an extremely popular sport in the U.S. (often called the "national pastime"), yet over the past decade its leadership grew concerned that younger fans were tuning out. The reason? Games had become too slow and long for modern tastes. As Encyclopedia Britannica succinctly notes, by the 2010s baseball was "losing fans because three-hour-plus games failed to keep the attention of the 21st-century viewer" [148]. In response, MLB implemented a dramatic rule change in 2023: a strict pitch clock that forces a faster pace, cutting dead time between plays. The result was immediate, the average MLB game in 2023 was about 24 minutes shorter than the year before (down to 2 hours 39 minutes, the shortest in decades). Importantly, fan reactions have been positive; attendance and TV ratings have improved, and the consensus is that the shortened game is more engaging without sacrificing the essence of the sport [149]. This shows that even a sport deeply rooted in tradition and widely beloved recognized the need to adapt structurally to retain its audience. Football finds itself at a similar inflection point: shaving off 30 minutes (while preserving actual play time) could analogously refresh the product and future-proof its appeal. Another illustrative case is cricket's transformation through the Twenty20 (T20) format. Cricket is massively popular in countries like India, Pakistan, and Bangladesh, but its traditional format (Test matches lasting up to 5 days, or even One-Day matches of 8 hours) was a barrier for many modern fans. In 2003, seeing an opportunity to engage new audiences, the England & Wales Cricket Board introduced T20, a shortened, three-hour version of cricket designed for evening entertainment and TV friendliness. This "bite-sized" cricket proved wildly successful. It attracted a new generation of fans who found the traditional game too slow [150]. T20 leagues (like the Indian Premier Leaguem, Pakistan Super League etc,.) are now among the most-watched sporting events, bringing in young viewers, families, and even global audiences that previously ignored cricket. Crucially, the rise of T20 did not kill the sport's popularity but it amplified it, while also feeding interest back into longer formats for some converts. The cricket example demonstrates that popularity can be sustained and grown by offering a format that suits contemporary lifestyles. Football's proposal for a 60-minute match has a similar spirit, a recognition that today's audiences crave faster, more intense contests, and that providing this option can secure the sport's future fanbase without undermining its core appeal.

Also, one may ask why a 60-Minute duration and why not 45 or 40 like futsal. Our theoretical proposal and analysis using the non-linear model and GR measure identified 60 minutes as an optimal compromise. Reducing the match to 60 minutes (with increased intensity) improved the balance between skill and chance, without making the game feel too rushed. In contrast, a 45-minute match is found to be overly intensified and diminished strategic depth, essentially making the game too short to develop rich tactics or comebacks.

In other words, 45 minutes would force a quick, almost frantic game that sacrifices some complexity. The 60-minute format, however, has described as a "sweet spot," neither too short to sacrifice strategic complexity nor too extended to reduce engagement. This suggests that 60 minutes allows enough time for strategic play and adjustments while still increasing the overall pace of the game. Furthermore, Futsal, the 5-a-side indoor cousin of football, uses two 20-minute halves with a stop-clock (40 minutes effective) [151]. This works for futsal because of its small pitch, fewer players, and unlimited substitutions, which create a very fast-paced, high-scoring environment. In fact, futsal games often see 5+ goals on average (e.g. 5.41 goals per game in the 2022 European Futsal Championship). A goal is scored roughly every 7 minutes in futsal, indicating a much different tempo. If we tried to apply a similar 40-minute duration to full 11-a-side football, the character of the game would change drastically. For example, tactical battles might be cut short and underdogs could simply defend for a short span to grind out results, potentially reducing the quality of play. Also, the player stamina and pacing, which are integral to 90-minute football strategy, would be far less relevant in a 40-minute game.

4.7 Conclusion

This study examined how game length and scoring frequency shape engagement in team sports by systematically applying GR theory, MiM and FiM frameworks to ODI cricket, T20 cricket, and soccer. The dual-perspective analysis quantitatively evaluated each sport's structural sophistication, scoring dynamics, and psychological pacing, revealing distinct engagement profiles. ODI cricket, with its GR value positioned firmly within the optimal refinement zone, provides a strategically rich, fair, and cognitively engaging experience. T20 cricket prioritizes rapid scoring and emotional intensity, thus maximizing spectator excitement but at the cost of fairness and skill-based outcome predictability. Soccer, despite its global popularity, exhibited a GR value above the optimal range primarily due to its low scoring frequency, resulting in structural imbalance and excessive randomness that may undermine fairness.

To address soccer's structural imbalance, we proposed an optimized 60-minute match format, derived systematically through a nonlinear intensity-scaling analysis. This format successfully achieves an optimal GR value, effectively synchronizes cognitive pacing with emotional engagement, and balances reward frequency. In contrast to the standard 90-minute and the overly compressed 45-minute formats, the 60-minute structure provides superior equilibrium between unpredictability and structural clarity, preserving soccer's strategic complexity while enhancing emotional payoff through recalibrated scoring dynamics.

Beyond these sport-specific insights, our research demonstrates that adjusting game duration and reward frequency systematically can enhance both fairness and overall engagement. The analytical frameworks employed here are widely adaptable and could be applied to other sports, e-sports, and gamified environments, particularly where balancing skill, suspense, and psychological reinforcement is essential. Nevertheless, our theoretical models require empirical validation through practical experimentation and real-world implementation, as player adaptation, spectator acceptance, and unintended consequences must be assessed.

Future studies could further explore cross-cultural variations in perceptions of engagement, long-term adaptations by players to modified formats, and broader implications for sports governance and administration. By explicitly linking cognitive dynamics to structural game design, this research contributes a novel and practically valuable paradigm for optimizing competitive experiences across diverse sporting contexts.

4.8 Chapter Summary

In this chapter, we performed a comprehensive comparative analysis of high-scoring and low-scoring sports, specifically contrasting ODI cricket, T20 cricket, and soccer, through the lenses of GR theory, and the MiM and FiM frameworks. Utilizing empirical data from international tournaments (ICC ODI World Cup 2023, ICC T20 World Cup 2022, and FIFA World Cup 2022), we quantitatively assessed how distinctly different high-scoring sports such as ODI and T20 cricket versus the infrequent yet high-impactful low-scoring sports like soccer along with structural elements such as game length and scoring frequency, influence player engagement, spectator excitement, and overall competitive fairness.

Our analysis revealed that ODI cricket, with a GR value of 0.076, resides comfortably within the optimal refinement zone, indicating a highly strategic and cognitively engaging format. In contrast, T20 cricket, despite its elevated GR of 0.141, delivers rapid excitement and emotional intensity but compromises the fairness and skill demonstration. Soccer, while globally popular, exhibited a GR value of 0.102, exceeding the optimal range and suggesting that excessive randomness sometimes influences outcomes, potentially undermining competitive integrity.

To address soccer's structural imbalance, we proposed and evaluated structural modifications, specifically examining adjustments in match duration. Through the nonlinear intensity-scaling approach, we identified a theoretically optimized 60-minute format. This proposed modification achieved an optimal GR value (0.077), aligning closely with ideal engagement parameters, thus enhancing strategic clarity, competitive fairness, and emotional intensity while preserving soccer's intrinsic suspense. The proposed 60-minute format also yielded ideal acceleration and jerk values, effectively balancing cognitive comfort and psychological excitement, and improving the reward frequency, thus heightening spectator engagement. Furthermore, aligning the GR closely with AD achieved an optimal phi ratio, signifying balanced cognitive and emotional dynamics conducive to maximum engagement and fairness. This analysis significantly extends the existing literature on sports refinement by explicitly demonstrating how targeted structural adjustments can enhance both fairness and entertainment value across different types of sports.

Having established a comprehensive understanding of how structural factors, particularly game length, scoring frequency, and uncertainty resolution, distinctly influence competitive fairness, psychological engagement, and spectator excitement across high-scoring sports (ODI and T20 cricket) and a low-scoring sport (soccer), the following chapter (Chapter 5) the competitive dynamics of top two teams in each sport. We introduce an advanced analytical framework inspired by gravitational physics, explicitly designed to quantitatively capture and analyze competitive dynamics in greater granularity. Specifically, this framework incorporates novel concepts such as competitive intensity, competitive force of attraction, and competitive potential advantage to systematically investigate interactions between competing agents. Through this gravity-inspired model, the next chapter aims to deepen our understanding of competition at both individual and team levels, providing actionable insights for strategic optimization and enhanced competitive balance within elite sports contexts.

Chapter 5

A Gravity-Inspired Framework for Quantifying Competitive Interactions

5.1 Chapter Introduction

In previous chapters, we systematically explored the structural elements that influence excitement, engagement, and fairness across distinct sporting contexts, specifically comparing high-scoring (ODI and T20 cricket) and low-scoring sports (soccer). While these analyses have offered profound insights into game refinement, psychological engagement, and emotional dynamics at a structural level, competitive interactions between opposing agents (players or teams) remain relatively underexplored. Existing frameworks, including GR theory and the MiM model, have effectively addressed the holistic cognitive and emotional experiences within games. However, they have not explicitly quantified the direct, dynamic interactions between competitors. To bridge this gap, this chapter introduces a novel analytical framework inspired by gravitational physics, explicitly extending the MiM framework to quantitatively capture competitive dynamics in elite sports scenarios. The motivation behind this innovative approach stems from intriguing structural similarities between gravitational interactions in physics and competitive interactions in sports. Just as celestial bodies are drawn into orbit by gravitational forces, competitors are pulled into intense engagement by the shared objective of victory. Recognizing these parallels provides a rich conceptual foundation to explore deeper theoretical relationships and develop meaningful quantitative metrics.

Specifically, this chapter proposes and applies three novel, physics-inspired metrics: competitive intensity (I_c), competitive force of attraction (F_c), and competitive potential (V_c). These metrics systematically quantify how strongly competitors interact (force), how closely matched they are in terms of their momentum and skill (intensity), and how strategically positioned they are to achieve victory (potential). Using data from the highest levels of international competition such as the ICC Cricket World Cups (ODI 2023 and T20 2022) and the FIFA World Cup 2022, we rigorously test and validate this gravity-inspired competitive framework.

By explicitly modeling mutual interactions between competitors, this chapter provides a granular and theoretically robust toolset beneficial for coaches, analysts, and sports organizations aiming to optimize competitive engagement, fairness, and performance efficiency. The structure of this chapter is as follows: Section 5.2 revisits the theoretical foundations underpinning gravitational analogies in competitive dynamics. Section 5.3 critically assesses the existing literature, highlighting essential research gaps addressed by this study. Section 5.4 clearly outlines the methodological framework, detailing the metrics and analytical procedures employed. Section 5.5 rigorously analyzes empirical results derived from international tournaments, providing quantitative insights into competitive interactions. Section 5.6 comprehensively discusses these findings, emphasizing practical implications and potential avenues for future research. Section 5.7 provides a concise conclusion summarizing the chapter's key contributions. Finally, Section 5.8 presents a chapter summary and seamlessly transitions to Chapter 6, setting the stage for subsequent analyses.

5.2 Theoretical Background and Inspiration

In high stakes competition, whether on the cricket pitch, the soccer field, or in digital arenas, the quest for victory profoundly shapes the behaviors and interactions of competitors. Interestingly, this competitive dynamic closely resembles gravitational attraction in physics, where invisible yet powerful forces draw celestial bodies toward one another. Just as gravity guides the motions of planets, the pursuit of victory pulls individuals and teams into intense engagement, influencing their strategies, momentum, and performance. Far from mere coincidence, these parallels reveal more profound structural similarities between the laws of physics and competitiveness in the game context. In physics, the gravitational force is the invisible pull or attraction between two masses, m_1 and m_2, separated by a distance r, is given by Eq. (5.1), where, F is the gravitational force, G is the gravitational constant, m_1 and m_2 are the masses of two different objects, and r is the distance between them [152, 153].

$$F = G\frac{m_1 m_2}{r^2} \tag{5.1}$$

Since $F \propto \frac{1}{r^2}$, as the distance increases, the gravitational force F decreases rapidly which is represented by the curved line in Figure 5.1. The gravitational field strength g varies with distance r from the center of the Earth [154]. Inside the Earth ($r < R$, where R is the Earth's radius), g increases linearly with r, following the relationship $g \propto r$. Outside the Earth ($r > R$), g decreases with the square of the distance, following the inverse square law $g \propto \frac{1}{r^2}$. The maximum value of g occurs at the Earth's surface ($r = R$), and at $r = 2R$, the field strength becomes $g = \frac{1}{4} g_0$. This behavior reflects a continuous but non-uniform transition from a linear to an inverse-square dependence in gravitational influence.

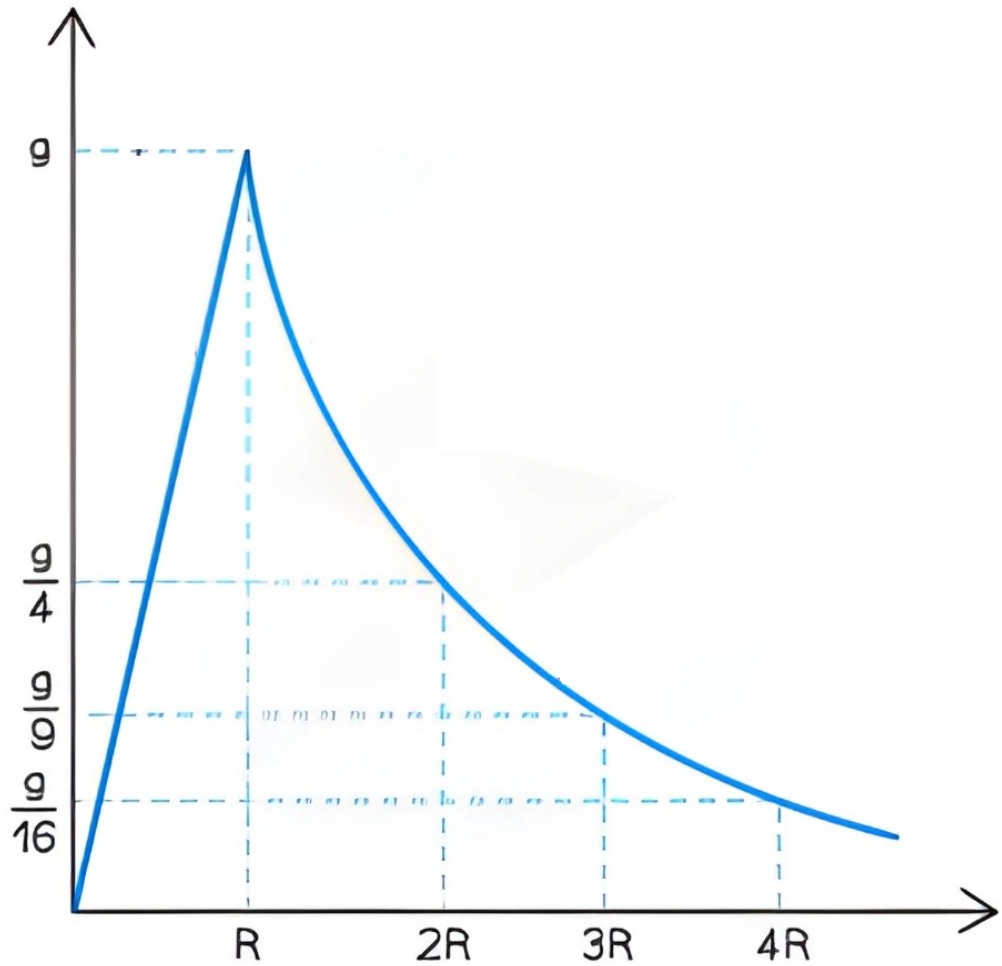

Fig. 5.1 Gravitational Force

Likewise, the gravitational potential Φ (also denoted as V) is a measure of the potential energy per unit mass at a point in a gravitational field. It tells us how much work would be needed to bring a unit mass from a reference point (typically infinity) to that point in the field [155]. Mathematically, it is defined as Eq. (5.2), where G is the gravitational constant, M is the mass generating the gravitational field, and r is the distance from the center of mass. The gravitational potential is negative, increasing as distance r decreases toward the gravitational source. This negative sign represents the attractive nature of the gravitational force.

$$\Phi = -\frac{GM}{r} \tag{5.2}$$

The Figure 5.2 illustrates this concept, depicting a satellite moving from a lower orbit (point A) to a higher orbit (point B) around Earth [156]. As the satellite moves outward, it transitions into a region of less negative gravitational potential (closer to zero), indicating an increase in gravitational potential energy. The shaded area between points A and B visually represents the work required to move the satellite outward against Earth's gravitational pull, demonstrating how gravitational potential becomes less harmful as distance increases. Having established these fundamental physical concepts, we extend these principles beyond physics, applying them to competitive scenarios such as cricket and soccer.

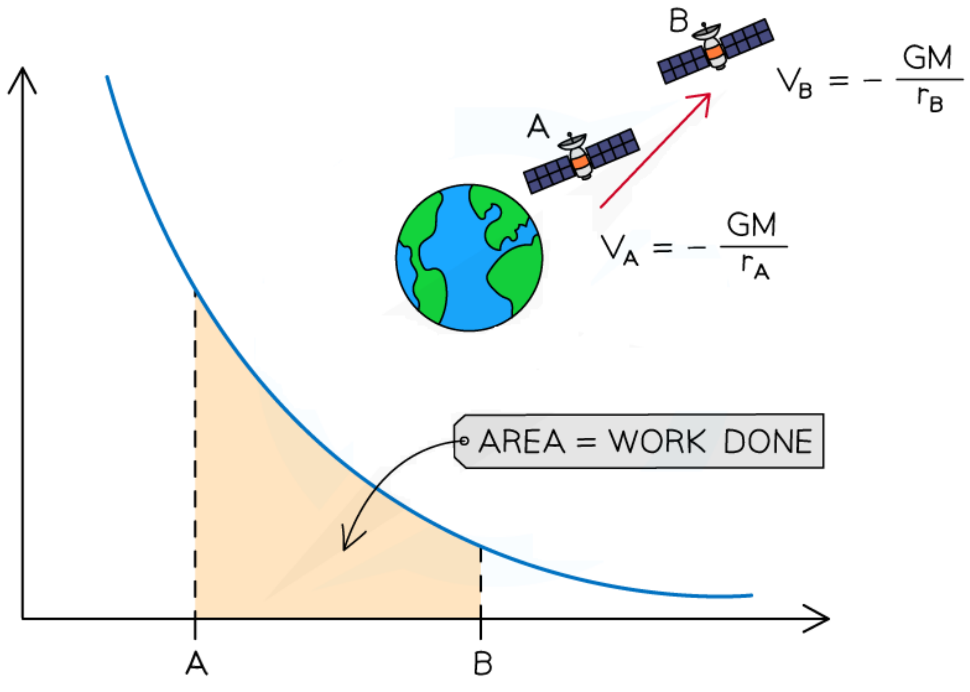

Fig. 5.2 Gravitational Potential

5.2.1 Competitive Force Analogy

In classical physics, gravitational force arises from the interaction between two masses. Newton's law of universal gravitation governs it: it is proportional to the product of the masses and inversely proportional to the square of the distance between them. This force is inherently mutual, and each mass exerts an equal and opposite influence on the other. Analogously, participants exert mutual influence on each other's performance in competitive environments, especially in high-stakes scenarios. When modeling such interactions in elite tournaments, high-pressure games, or fiercely contested arenas, the win can be conceptualized as a central mass, represented as $M = 1$, around which competitors gravitate. It exerts a gravitational pull, attracting all competitors into its field. Like Earth pulls satellites into orbit, the winning objective pulls agents with their efforts. Two agents, such as players or teams, with their skill levels, are caught in this field because of the pursuit of victory. This invisible but powerful goal of winning influences and shapes these objects in a competitive field.

However, in a competitive scenario, agents are active participants who cannot be fully represented by mass m alone, because in the game context mass reflects only the difficulty a player faces [16]. What truly defines a player's impact on the competition is their momentum $\vec{p} = mv$, a combined effect of challenge faced (mass, m) and the ability to overcome it (velocity, v), progressing through a game. Hence, a player's competitive presence or influence is better expressed as their momentum:

$$\vec{p} = m \cdot v \tag{5.3}$$

This formulation captures the combination of the challenge faced and the rate of progress, quantifying how much effort a player or team is exerting in the game towards victory. Therefore, in the context of two agents, such as players or teams, the momentum of agent i relative to agent j is defined as Eq. (5.4), where m_{ij} is the perceived resistance or competitive pressure that agent i experiences from agent j, and v_{ij} is the rate at which agent i is resolving uncertainty against agent j.

$$\vec{p}_{ij} = m_{ij} \cdot v_{ij} \tag{5.4}$$

Furthermore, in gravitational force, r, the distance between two masses representing their spatial separation, is analogous in the game context to the competitive scenario, which captures the difference in skill or ability of players or teams. Thus, we define the competitive distance between players as Eq. (5.5).

$$d = |v_i - v_j|, \quad 0 \leq d \leq 1 \tag{5.5}$$

This represents the absolute difference in progress or capability between the two agents; thus, it remains nonnegative, much like the literal distance r in Newtonian gravity. A small d indicates a competitive contest, while a large d suggests a one-sided non-competitive contest.

Thus, the competitive force exerted between two agents is Eq. (5.6), where $I_c \approx 1$ is the competitive intensity defined and evident in the methodology and result analysis sections, which replaces the gravitational constant G.

$$F_{ij} = I_c \cdot \frac{\vec{p}_i \cdot \vec{p}_j}{d^2} \tag{5.6}$$

5.2.2 Competitive Potential Analogy

Drawing inspiration from the principle of gravitational potential, in this work, we introduce the concept of competitive potential (V_c) in competitive settings. Here, we model the player's or team's position in a game as an ongoing resolution of uncertainty toward achieving victory. In this analogy, the victory or win objective is symbolized as $M = 1$, representing the total competitive challenge inherent within the game context. We define the uncertainty resolution rate as $v \in [0, 1)$, quantifying the player's or team's progress or ability toward victory. The remaining uncertainty or the unresolved portion of the challenge is then $m = 1 - v$, signifying how much effort or challenge remains. In the physics formula, the gravitational constant G is replaced by $l_c = 1$, while M, such as Earth, in the gravitational formula is replaced by $M = 1$. Thus, the V_c is expressed as Eq. (5.8).

$$\text{(Physics)} \quad V = -\frac{GM}{r} \tag{5.7}$$

$$\text{(Competition)} \quad V_c = \frac{I_c \cdot M}{1 - v} = \frac{1}{m} \tag{5.8}$$

Hence, V_c is introduced analogously to gravitational potential, representing the positional advantage in the competitive field as a competitor closer toward the goal. While V is negative and approaches zero with increasing distance, V_c increases positively as players move closer to victory, reflecting decreasing remaining challenge. Specifically, as the player or team resolves uncertainty and advances toward victory ($v \uparrow$), the unresolved challenge m decreases ($m \downarrow$), causing the competitive potential V_c to increase. This indicates that the team or player moves into a state of higher competitive potential, signifying an improved position or close to victory. In gravitational scenarios, escaping the gravitational influence becomes easier with increasing distance (less negative potential). In contrast, in our competitive analogy, the competitive potential rises as one moves closer to the victory objective (analogous to approaching the gravitational mass), meaning the remaining effort required to secure a win becomes progressively smaller. Thus, an increased competitive potential represents a more substantial positional advantage and decreases the difficulty of achieving victory.

Figure 5.3 illustrates the classical physics scenario involving gravitational interaction. A large mass M (for example, Earth) and a smaller mass m (such as a satellite) are separated by a distance r. In this scenario, mass M generates a gravitational field that naturally attracts the smaller mass m toward itself. In a parallel conceptual framework, Figure 5.4 introduces an analogy within a competitive context. Here, the large mass is labeled as Goal (Win), with a highest difficulty level in a competition $M = 1$. Two competitors, denoted as Object 1 and Object 2, are separated by a distance d, representing the gap in their skill, performance, or progress. The Goal (Win), in other words $M = 1$ generates a competitive field analogous to gravitational field, drawing each competitor toward itself. The arrows labeled $\vec{F}_c\vec{p}M$ highlight the competitive force, which depends on the momentum of each participant reflecting their ability with ongoing challenge and the central influence of the goal M. While gravitational distance indicates physical separation, in the competitive setting, d denotes the skill or performance difference between agents. A smaller d signifies a closer contest, much like stronger gravitational force at shorter distances in physics. Together, Figures 5.3 and 5.4 present a useful analogy just as mass (i.e., Earth) creates gravitational pull, the presence of a goal M creates competitive field, attracting participants into active engagement.

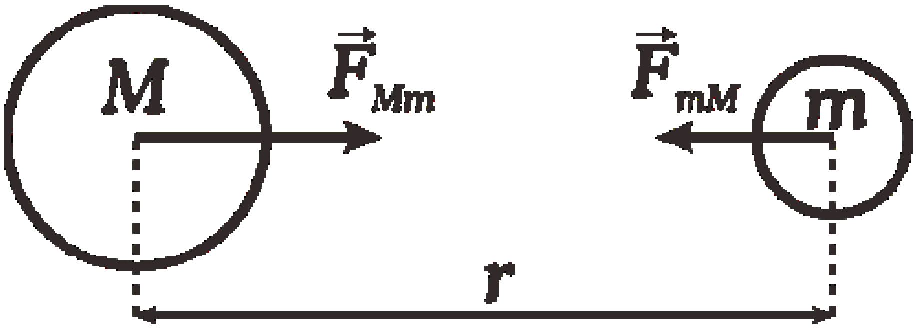

Fig. 5.3 Gravitational field

Recognizing these structural parallels between gravitational physics and competitive dynamics enables us to explore deeper conceptual relationships beyond the mere analogy. In this paper, we leverage insights from gravitational theory to propose a novel theoretical gravity model, systematically translating fundamental physical concepts such as gravitational force and gravitational potential into their competitive counterparts, as competitive force and competitive potential. In addition, we introduce the concept of I_c and momentum. This structured, analogy-driven approach provides valuable new insights into competitive interactions within sports and strategic environments. This study builds on previous work [16, 17], which proposed comprehensive frameworks to analyze cognitive and engagement dynamics, objective and subjective, within a game environment. However, these earlier models predominantly focused on the game's overall structure rather than modeling competitive

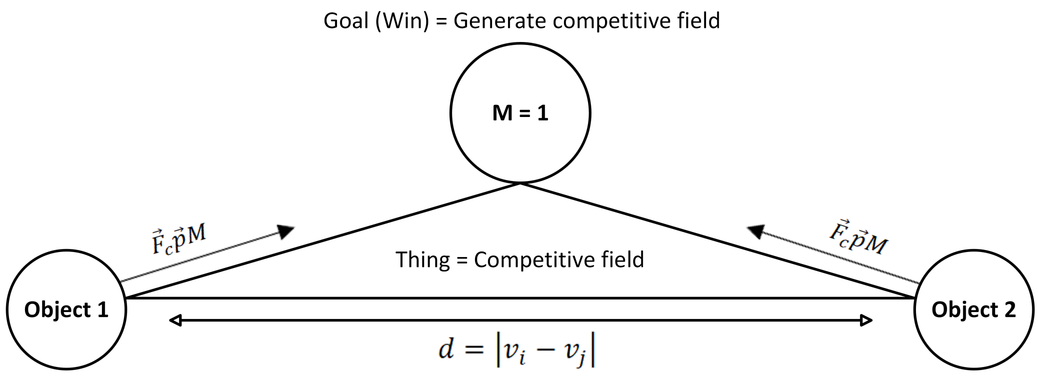

Fig. 5.4 Competitive field

interactions between individual entities or teams. In contrast, by extending the previous research, we introduce a novel physics-inspired analytical framework that explicitly quantifies key competitive parameters, such as competitive intensity, competitive force of attraction, and competitive positional advantage. By modeling mutual dynamics between opponents, our approach advances prior methodologies and enables a more granular understanding of competitive balance and engagement in adversarial contexts.

Hence, this study extends prior works [16, 17], which introduced comprehensive frameworks for analyzing cognitive dynamics, objective and subjective engagement, focusing on overall game structures rather than explicitly modeling direct competitive dynamics between individuals or teams. Our research advances these earlier works by introducing a physics-inspired analytical framework explicitly designed to quantify the competitive intensity, force of attraction, and positional advantages between opposing entities, such as players or teams, within competitive contexts. Unlike previous frameworks, our approach quantifies mutual interactions, providing nuanced insights into competition intensity and balance.

5.3 Literature Review

To establish the theoretical foundation of our physics-inspired approach to competitive dynamics, this section reviews three influential frameworks from the existing literature: the Gravity Model, Game Refinement (GR) theory, and the Motion-in-Mind (MiM) framework. Each has contributed significantly across various domains. Despite their contributions, these models do not adequately capture the nuanced interactions that arise in head-to-head competitive scenarios. This gap underscores the need for a new analytical perspective, which our study seeks to fulfill by explicitly modeling such interactions.

The gravity model, an analytical framework adapted from physics, predicts interactions such as trade, migration, and commuting between entities based on their size and distance. Mathematically, it is expressed as Eq. (5.9), where F_{ij} is the interaction magnitude between entities i and j. G is the empirical proportionality constant. M_i, M_j are the economic magnitudes (e.g., GDP, population), D_{ij} is the distance between entities, and n is the distance friction exponent. The model assumes that interactions between entities, such as trade, migration, or transportation flows, are directly proportional to their mass (economic size or capacity) and inversely proportional to their geographic or conceptual distance.

$$F_{ij} = G\frac{M_i \times M_j}{D_{ij}^n} \tag{5.9}$$

Initially proposed in [157], the model quantified international trade flows, emphasizing how economic size positively influences interactions, whereas geographic distance exerts a negative effect. The theoretical enhancements incorporated multilateral resistance and greatly enhanced the model by considering barriers to interaction relative to all entities involved, significantly increasing its explanatory power. [158, 159]. Due to its adaptability, the gravity model has found broad applications including international trade analysis, migration studies influenced by economic disparities and environmental factors [160, 161], transportation network planning [162], regional economic integration [163], and tourism demand forecasting [164]. Recently, advancements in machine learning and neural networks [165, 166] have improved the model's predictive accuracy, enabling better handling of complex, nonlinear relationships inherent in real-world interaction data.

Beyond economic and demographic applications, the gravity model has effectively extended into competitive and strategic contexts, providing insights into the spatial dynamics of interactions. This framework has analyzed dyadic competition in Olympic Games, correlating rivalry intensity with economic power and geopolitical proximity [167]. Similarly, gravity principles have examined spatial dependencies in tax competition among U.S. states [168]. In international trade contexts with imperfect competition, the gravity framework captures strategic firm behaviors such as market entry decisions and pricing strategies [169]. Moreover, gravity-based methodologies have been instrumental in competitive facility location decisions, integrating consumer attraction and spatial business rivalries [170]. Further demonstrating versatility, strategic adaptations of gravity modeling address competition among spatially distributed destinations [171]. Additionally, gravity frameworks have extended into digital realms, analyzing competitive dynamics within online interaction networks, fundamentally applicable to multiplayer gaming and e-sports environments [172]. Despite these innovative applications, explicit modeling of direct competition between two distinct agents using gravity-based principles remains underexplored.

Parallel to these developments, GR theory has emerged as a robust analytical framework for quantitatively assessing game attractiveness and player engagement. Initially developed through analyses of classical board games, GR theory evaluates the interplay between uncertainty, progression, and excitement within gameplay, identifying an optimal refinement value range (0.07-0.08) indicative of high engagement and sustained player interest [16]. MiM framework further enriched this analysis by employing analogies from classical mechanics, interpreting psychological uncertainties as mass, the pace of game progression as velocity, and excitement variations as acceleration, thus offering dynamic perspectives on player cognition and engagement. Recent advances in GR theory have broadened its analytical scope, enhancing insights into game structure and player experience. In sports analytics, GR theory quantified scoring difficulties, linking them directly to spectator excitement and global appeal through analogies with physical force and momentum [103]. Furthermore, studies demonstrate that modifications in scoring systems significantly influence game refinement metrics [99]. Complementary computational methodologies have introduced informational acceleration and jerk metrics to quantify cognitive dimensions such as thrill and unpredictability, further elucidating dynamic gaming experiences [18]. Jerk-based analyses provided critical insights into game addictiveness, pinpointing optimal alignments of refinement and unpredictability metrics for sustained player engagement [173]. Further research identified optimal equilibria in player engagement governed by player skill and risk-reward dynamics [19]. Moreover, GR theory's application in multiplayer online gaming contexts identified ideal team configurations, emphasizing balanced team metrics essential for maximizing strategic depth and player enjoyment [174].

Despite significant contributions from gravity model, GR theory, and MiM framework, limitations remain. Gravity model applications have concentrated mainly on macro-scale interactions such as economic trade flows, migration patterns, and spatial strategic decisions. However, explicit attention has not been given to nuanced two-agent competitive interactions within sports or gaming contexts. Similarly, GR and MiM analyses have predominantly focused on quantifying game attractiveness, cognitive engagement, and overall game structures rather than explicitly modeling direct competitive dynamics between individuals or teams, such as mutual interactions, competitive intensity, or positional advantages. Addressing these gaps, our research introduces a novel integration of these frameworks by explicitly modeling two-agent competitive scenarios, enriching current understandings and providing deeper insights into competitive dynamics within sports contexts.

5.4 Methodology

This section outlines the methodological framework adopted in our study. Data were collected from official repositories for three major events: the 2023 ODI World Cup (finalists: India and Australia), the 2022 T20 World Cup (finalists: Pakistan and England), and the 2022 FIFA World Cup (finalists: Argentina and France). These pairs of top teams were selected as they represent the highest levels of performance in each tournament, thereby providing a robust basis for comparative analysis. After collecting the data, we first define two primary metrics G and T which serve as the foundational pillars of our study. Once G and T are established, we introduce the concept of velocity (v) as the entry point into MiM framework, incorporating physics-inspired parameters such as mass, momentum, and others. These parameters allow us to formally establish new analogies between classical gravitational concepts and competitive dynamics, systematically translating physical principles such as gravitational force, gravitational potential, and spatial separation into competitive analogues like competitive force, competitive potential, and competitive distance, as well as competitive intensity. These analogies enable a structured analysis of competitive dynamics across the top two teams in each of the three major events.

5.4.1 Data Collection and Preprocessing

To define v, comprehensive data on G and T are essential. Accordingly, we gathered data on top-performing teams from two major international sports (ODI and T20 cricket) and soccer. The data were sourced from official repositories [109–111] to ensure both reliability and completeness.

To define G for individual teams in cricket and soccer, we consider the total number of runs (for cricket) or goals (for soccer) scored by a given team across all matches it played in the tournament. Let team T participate in N_T matches, and let $G_{T,i}$ denote the number of runs or goals scored by team T in its i^{th} match. Then, the team-specific scoring metric is defined as:

$$G_T = \frac{1}{N_T} \sum_{i=1}^{N_T} G_{T,i} \tag{5.10}$$

This formulation yields the average number of runs or goals scored per match by team T, serving as a direct indicator of that team's offensive performance during the tournament. For reference, based on the tournaments analyzed, India and Australia each played $N_T = 11$ matches in the 2023 ODI World Cup. Pakistan and England played $N_T = 7$ and $N_T = 6$

matches respectively in the 2022 T20 World Cup. Argentina and France each played $N_T = 7$ matches in the 2022 FIFA World Cup shown in Table 5.2.

To define T in cricket, we consider that 50 overs correspond to 300 balls in ODIs, while 20 overs correspond to 120 balls in T20s. Using the formula $v = \frac{G}{T}$, where G is the total runs scored and T is the total balls faced, the scoring velocity per ball is calculated for ODIs and T20s. However, simply dividing runs by balls (i.e.,$\frac{G}{T}$) can result in values greater than 1, especially in high-scoring formats like T20. Since we want velocity to represent a normalized rate between 0 and 1, we scale it against the maximum possible scoring rate which occurs when a team hits a six on every ball. A six is the highest score possible from a single delivery. Therefore, the theoretical maximum number of runs in a match is $6 \times T$. Based on this, we define normalized velocity as $v = \frac{G}{6T}$. This formulation ensures that $v = 1$ means the team scored the maximum possible runs (a six every ball), $v = 0$ means no runs were scored at all, $0 < v < 1$ reflects how efficiently a team converts actions (balls) into rewards (runs). This velocity metric provides a consistent, intuitive way to compare scoring intensity across formats like ODI and T20 cricket.

To define T for individual teams in soccer, we consider the total number of shot attempts made by a given team across all matches it played during the tournament. Let team T participate in N_T matches, and let $T_{T,i}$ denote the number of shot attempts made by team T in its i^{th} match. Then, the team-specific shots attempt metric is defined as:

$$T_T = \frac{1}{N_T} \sum_{i=1}^{N_T} T_{T,i} \tag{5.11}$$

This yields the average number of shot attempts per match for team T, serving as an indicator of the team's shots attempts performance. Therefore, the observed values for G and T for top performing teams across different sports are summarized in Table 5.2.

5.4.2 Motion in Mind Framework

The MiM model [17] facilitates the subjective analysis of events by providing a structured approach to examine cognitive experiences during gameplay. By mapping gaming parameters such as velocity, mass, acceleration, momentum, force, and others, the MiM framework qualitatively assesses cognitive dynamics like cognitive load (challenge), engagement, and emotional fairness. It captures how the mind perceives uncertainty resolution, decision-making effort, and thrill throughout gameplay. This approach effectively bridges game mechanics with human psychology, offering insights into cognitive experiences among players, teams, or spectators.

Velocity v

Within the MiM framework, velocity v represents a fundamental metric for modeling the rate at which uncertainty resolves during gameplay referred as a thing. It quantifies success or progress rate, reflecting a player's or team's performance efficiency, the proportion of successful outcomes relative to total attempts. In competitive scenarios, opposing players or teams are modeled as interacting objects within the same thing, representing the dynamic and reciprocal nature of competition. Originally introduced by [16], velocity is formally defined as:

$$v = \begin{cases} \frac{G}{T} & \text{for sports} \\ \frac{1}{2} \cdot \frac{B}{D} & \text{for board games} \end{cases} \tag{5.12}$$

This ratio quantifies the effectiveness with which opportunities are converted into outcomes, serving as an indicator of uncertainty resolution. The average velocity $\bar{v}$ of ODI, T20 and Soccer are calcualted in Table 5.1 which is useful to use in the later section of methodology to define competitive intensity I_c.

Table 5.1 Average G, T, and v values across ODI, T20, and Soccer

Sport	**Total Matches**	**G**	**T**	$v = \frac{G}{T}$
ODI	46	258.03	300×6	0.143
T20	42	143.18	120×6	0.199
Soccer	64	2.672	22.766	0.117

Given the focus on top-performing teams, scoring velocity v_T is specifically defined as:

$$v_T = \frac{G_T}{T_T} \tag{5.13}$$

where G_T denotes the total runs or goals scored by team T, and T_T represents the total attempts (e.g., balls bowled or shots taken) across all matches played by that team. Velocity v_T is normalized within the range $[0,1]$, with higher values indicating greater scoring efficiency, quicker uncertainty resolution, and thus a stronger competitive advantage. Thus, the mean scoring velocity for top-performing teams is computed as:

$$\bar{v} = \frac{1}{|\mathscr{T}|} \sum_{T \in \mathscr{T}} v_T \tag{5.14}$$

Here, $\mathscr{T}$ represents the set of elite teams, such as tournament finalists. The average velocity $\bar{v}$ encapsulates how swiftly outcomes accumulate for leading teams across various sports, providing a comparative metric for performance efficiency and uncertainty management.

Table 5.2 Team-wise G and T values across ODI, T20, and Soccer

Sport	**Team**	**Matches Played**	G	T
ODI 2023	India	11	287.27	300×6
	Australia	11	280.64	300×6
T20 2022	Pakistan	7	140.86	120×6
	England	6	141.50	120×6
FIFA 2022	Argentina	7	2.143	14.286
	France	7	2.286	14.571

Mass m

Mass m, conversely, is conceptualized as the difficulty or cognitive load inherent in a competitive task, game, or decision-making scenario. It represents the challenge or resistance that must be overcome to achieve success or victory. Formally, mass is defined as the complement of velocity v:

$$m = 1 - v \tag{5.15}$$

Since velocity $v \in [0, 1]$ denotes the likelihood of success or player ability level (ease of achieving favorable outcomes), a higher mass indicates increased difficulty, lower success expectations, and heightened psychological resistance. Thus, more mental effort or strategic engagement is required to achieve progress. In skill-based scenarios, mass reflects the cognitive and strategic demands adjusted by player capability and task complexity. In probabilistic contexts, such as lotteries or gambling scenarios, mass directly corresponds to risk, calculated as $m = 1 - r$, where r is the payout or return rate.

This conceptualization aligns closely with engagement theory and flow states [113, 114], which assert that optimal engagement occurs when player skill (velocity) matches the challenge (mass). If velocity significantly exceeds mass, the task risks becoming monotonous or unengaging; conversely, excessive mass relative to velocity can lead to frustration or overwhelm. Thus, the MiM framework mathematically encapsulates the skill-challenge balance central to immersive and rewarding gameplay experiences.

Momentum $\vec{p}$

Momentum, denoted as $\vec{p}$, is defined as the product of perceived difficulty and success rate (or player ability) within a game or activity, drawing directly from the classical physics formulation of momentum. It quantifies how strongly a player or team is cognitively driven through challenges during gameplay. Formally,

$$\vec{p} = mv \tag{5.16}$$

where $m \in [0,1]$ represents the normalized difficulty or perceived risk of the game, and $v \in [0,1]$ denotes the player's success rate or perceived ability. The resulting value $\vec{p} \in [0,1]$ captures the momentum of the mind how intensely the player engages with ongoing tasks. A higher momentum implies that the challenge level and player skill are well-matched, sustaining a compelling forward drive in engagement. Conversely, low momentum may indicate disengagement: either boredom (when tasks are too easy) or frustration (when tasks are too difficult), where cognitive movement stalls.

Competitive Intensity I_c

Using the average velocities calculated in Table 5.1 and Team-wise velocity calucated in Table 5.3, we define the competitive intensity constant I_c, which quantifies a team's relative performance compared to the average intensity level observed in that specific sport. Formally, I_c is defined as:

$$I_c = \frac{v_i}{\bar{v}_{\text{sport}}} \tag{5.17}$$

where v_i is the scoring velocity of team i, and $\bar{v}_{\text{sport}}$ is the average velocity for the given sport, as shown in Table 5.1.

In high-level competitive tournaments, the value of I_c typically lies close to 1:

- $I_c \approx 1$: The team performs at a level matching the average competitive intensity required to remain competitive or win.
- $I_c > 1$: Indicates above-average performance, with a higher likelihood of winning.
- $I_c < 1$: Indicates below-average performance, with reduced chances of winning.

This formulation provides a consistent and interpretable measure of how efficiently a team or player resolves uncertainty relative to the expected standard in that sport.

Competitive force of attraction F_c

The concept of competitive force of attraction F_c is inspired by the classical formulation of gravitational force. In our competitive framework, F_c captures the intensity and balance of a competitive interaction between two opposing agents (e.g., teams or players). It quantifies how strongly each agent is pulled toward the shared goal of victory, based on their momentum and the distance between their performance levels. Formally, the competitive force between two agents i and j is defined as:

$$F_{c_{ij}} = I_c \cdot \frac{\vec{p}_i \cdot \vec{p}_j}{d^2} \tag{5.18}$$

where, I_c is the competitive intensity constant, previously defined as $I_c = \frac{v_i}{\bar{v}_{\text{sport}}}$, which normalizes the team's performance relative to the average in that sport. $\vec{p}_i$ and $\vec{p}_j$ are the momenta of agents i and j, calculated as $\vec{p} = m \cdot v$, representing the combined effect of difficulty and scoring efficiency. $d = v_i - v_j$ is the competitive distance between the two agents, measuring difference in uncertainty resolution.

The value of F_c offers insights into the nature of a competitive event. A higher F_c value indicates that both teams are closely matched in terms of momentum and scoring efficiency. Such contests are typically perceived as more fair, intense, and cognitively engaging, resulting in heightened entertainment and excitement for both players and spectators. A lower F_c value suggests a disparity in skill or performance, with one team likely dominating the other. This leads to reduced uncertainty, perceived unfairness, and less engaging gameplay, diminishing the overall entertainment value. Therefore, F_c serves as a valuable metric for evaluating the competitiveness and quality of an event, offering a quantitative basis for analyzing fairness, engagement, and audience appeal in competitive scenarios.

Competitive potential V_c

Inspired by the gravitational potential concept in physics, we define the competitive potential V_c as a metric to quantify the positional advantage of a team or player in competitive scenarios. Gravitational potential describes the work needed to move an object within a gravitational field; analogously, competitive potential reflects how close a team or player is to achieving the ultimate goal victory based on their current performance or position. Formally, we define competitive potential V_c as:

$$V_c = \frac{1}{m} = \frac{1}{1-v} \tag{5.19}$$

where, m denotes the unresolved competitive challenge or difficulty faced by a team, calculated as $m = 1 - v$. v represents the team's scoring efficiency or progress toward achieving victory.

A higher V_c indicates that a team or player has significantly reduced uncertainty and is positioned closer to the goal, implying a strong competitive advantage and increased likelihood of achieving victory. This state typically enhances motivation, excitement, and psychological momentum. A lower V_c suggests greater uncertainty or remaining challenge, meaning the team or player must exert significant effort to progress, reflecting increased competitive difficulty and psychological load. Thus, V_c effectively captures how favorably a team is positioned within a competitive environment, offering valuable insights into psychological and strategic dynamics. Teams with higher competitive potentials are generally better positioned, reflecting lower perceived difficulty and greater confidence in attaining victory, which consequently influences performance dynamics and spectator excitement.

This methodology systematically integrates concepts from classical physics into competitive contexts, leveraging metrics such as velocity, mass, momentum, competitive intensity, competitive force, and competitive potential. By clearly defining and quantifying these metrics based on robust data from high-level cricket and soccer tournaments, our framework provides a rigorous analytical toolset for evaluating competitive dynamics. The structured, physics-inspired approach outlined here facilitates deeper insights into team interactions, performance efficiency, and positional advantages, serving as a foundation for detailed analyses presented in the subsequent result analysis section.

5.5 Results Analysis

Table 5.3 Top performing team-wise MiM metrics across ODI, T20, and Soccer

Sport	**Team**	**G**	**T**	**v**	**m**	$\vec{p}$	I_c	V_c	F_c
ODI	India	287.27	300×6	0.160	0.840	0.134	1.1160	1.190	1301.038
	Australia	280.64	300×6	0.156	0.844	0.132	1.0903	1.185	
T20	Pakistan	140.86	120×6	0.196	0.804	0.157	0.9831	1.243	31448.947
	England	141.50	120×6	0.197	0.803	0.158	0.9876	1.245	
soccer	Argentina	2.143	14.286	0.150	0.850	0.127	0.847	1.176	357.722
	France	2.286	14.571	0.157	0.843	0.132	0.8862	1.186	

This section presents the analytical outcomes derived from applying the new physics-inspired MiM framework to competitive dynamics in the selected cricket (ODI and T20 formats) and soccer tournaments. The results, summarized in Table 5.3, comprehensively quantify each team's competitive performance through key metrics such as v, m, $\vec{p}$, I_c, V_c, and F_c. The following analysis explores these metrics in detail, highlighting significant findings related to competitive intensity, competitive force of attraction and positional advantages observed among the top-performing teams.

The I_c values, summarized in Table 5.3, provide crucial insights into each team's relative performance efficiency compared to the average intensity within their respective sports. In the skill-intensive ODI competition, India's superior I_c value of approximately 1.116, indicating a scoring velocity about 11.6% above the tournament average, logically aligns with their eventual victory, underscoring the deterministic relationship between skill efficiency and competitive outcomes in longer-format competitions. Australia's slightly lower yet still above-average I_c of 1.090 highlights their strong competitiveness but suggests India's consistently superior efficiency provided a decisive competitive edge. In contrast, the T20 format inherently integrates greater uncertainty and unpredictability due to its shorter duration and higher variance in individual performances. Here, both finalists, Pakistan $I_c = 0.983$ and England $I_c = 0.988$ exhibited scoring efficiencies very close to the tournament average. Despite England's marginally superior competitive intensity, Pakistan secured victory, illustrating that in shorter formats like T20, competitive outcomes depend not solely on average efficiency but also heavily on situational dynamics, moment-to-moment decisions, and probabilistic events. Such closely matched I_c values underscore the essential unpredictability and excitement inherent in the T20 format, demonstrating that even slight variations in critical moments can decisively influence competitive results. Similarly, in soccer, France's slightly below-average competitive intensity ($I_c = 0.886$) compared to Argentina's lower value ($I_c = 0.847$) indicates a modest but noticeable performance disparity. Nonetheless, Argentina's ultimate victory further emphasizes soccer's intrinsic unpredictability, highlighting the complex interplay of skill, tactical strategy, and chance factors, thus reinforcing that in sports where chance significantly influences outcomes, I_c values alone cannot fully predict competitive success. These analyses indicate that maintaining competitive intensity at or above the sport-specific average $I_c \geq 1.0$ is crucial, particularly in skill-dominant sports such as ODI cricket, for maximizing the probability of victory. In contrast, formats characterized by shorter duration and higher unpredictability, such as T20 cricket and soccer, require recognizing the interplay between average efficiency, situational dynamics, and inherent chance factors. Hence, to achieve analytical clarity and consistency within our competitive analogy framework, we define the reference competitive equilibrium intensity as unity $I_c = G = 1$, symbolizing an ideal balance between skill, efficiency, and probabilistic outcomes.

The F_c values presented in Table 5.3 provide quantitative insights into the intensity and balance of competition among the top-performing teams across different sporting events (ODI, T20, and Soccer). These values are visually illustrated in Figure 5.5, where F_c is plotted against skill difference (d), emphasizing how closely matched the finalists were in each tournament. From the data, it is evident that the highest competitive attraction F_c was observed in the T20 cricket competition between Pakistan and England, reaching approximately 31,449. This significantly elevated value suggests an exceptionally balanced and intense competitive interaction, reflecting minimal differences in skill levels ($d \approx 0.001$), indicative of closely matched performances. Similarly, in ODI cricket, the competitive force between India and Australia recorded a substantial value of approximately 1,301, highlighting a strong yet moderately less intense competitive environment compared to T20 cricket. The skill difference remained very low ($d \approx 0.004$), demonstrating that both teams were highly competitive and closely matched. Conversely, the competitive attraction observed in soccer between Argentina and France was comparatively low, approximately 357.7, coupled with a higher skill difference ($d \approx 0.007$). This clearly indicates a more noticeable disparity in performance and uncertainty resolution rates between the two soccer teams compared to cricket competitions, suggesting that the contest was comparatively less balanced and intense. Thus, the competitive force of attraction F_c effectively quantifies and visualizes the dynamics of competitive intensity across different sporting contexts, offering valuable insights into the cognitive engagement and fairness perceived during these high-stakes competitive events. It is found that the most intense and balanced competitions arise when $\vec{p}_i \approx \vec{p}_j$ and d is minimal.

The V_c values provide insights into the positional advantages of teams across ODI Cricket, T20 Cricket, and Soccer, visually illustrated in Figures 5.6, 5.7, and 5.8, respectively. V_c reflects how close teams are to achieving victory based on their performance efficiency. In ODI Cricket (Figure 5.6), both India and Australia displayed similar V_c values (approximately 1.190 and 1.185, respectively), indicating closely matched competitive positions with minimal unresolved challenges ($m \approx 0.84$). The small shaded area represents the minimal difference in competitive potential, highlighting an almost equal likelihood of success for both teams.

For T20 Cricket (Figure 5.7), Pakistan and England exhibited the highest competitive potentials among all examined sports, with values approximately 1.243 and 1.245, respectively. The negligible difference in their unresolved challenges and absence of visible separation in their potential values underscore an extremely competitive and evenly balanced scenario.

In contrast, the soccer competition (Figure 5.8) between Argentina and France revealed distinct positional differences, with competitive potentials of approximately 1.176 and 1.186, respectively. The shaded region between the teams (with higher m values around 0.850 for

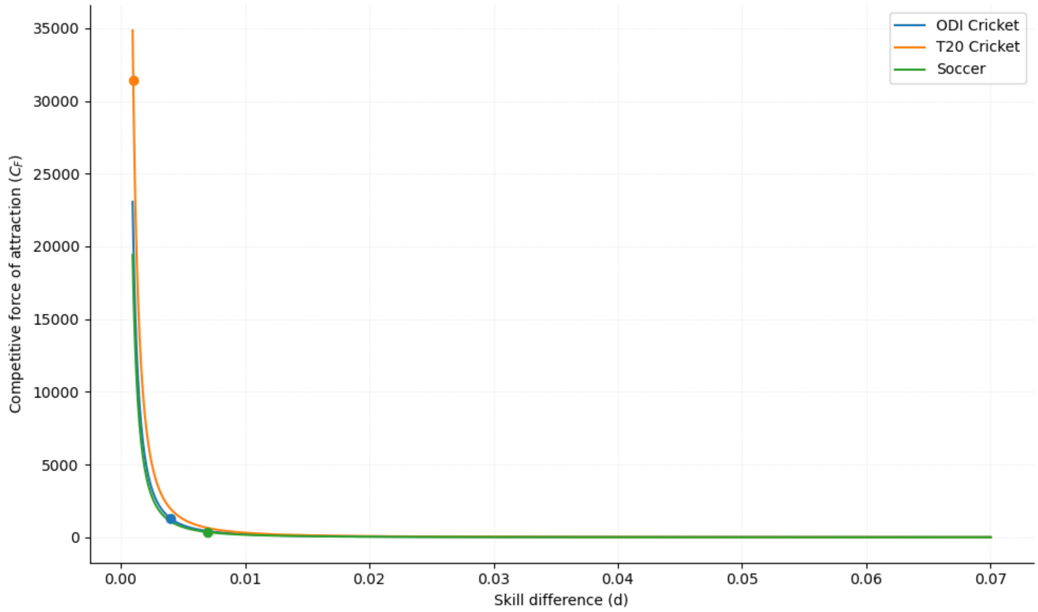

Fig. 5.5 Competitive force of attraction

Argentina and 0.843 for France) reflects a significant gap in their competitive standings, indicating a more pronounced challenge for Argentina compared to France.

As a result, competitive potential V_c effectively captures and visualizes the strategic and psychological positioning of teams in relation to their victory objectives, highlighting differences in competitive intensity and fairness across diverse sporting contexts.

5.6 Discussion

By explicitly modeling competitive interactions, our approach provides insights useful for coaches, game designers, and analysts seeking to understand or manipulate competitive dynamics, specifically by knowing about the competitive intensity measures. This explicit two-agent focus could significantly enhance decision-making, strategy formation, and performance optimization in competitive environments.

This study introduced a novel physics-inspired analytical framework designed to quantitatively evaluate competitive dynamics across major sporting events, specifically cricket (ODI and T20 formats) and soccer. By drawing structural parallels between gravitational physics and competitive interactions, we derived insightful metrics such as I_c, F_c, and V_c, providing rigorous quantitative foundations for analyzing team interactions and strategic positions.

The I_c revealed essential nuances in team performance across the analyzed tournaments. Consistent with theoretical predictions, teams exhibiting an intensity at or above the sport-

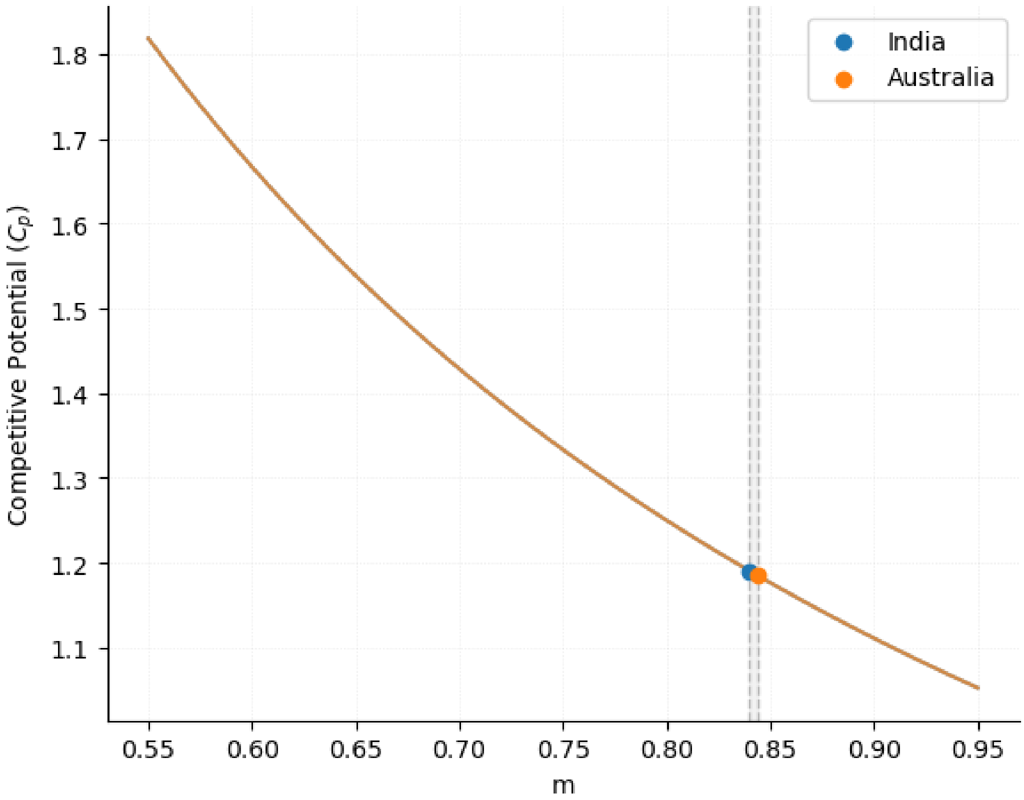

Fig. 5.6 Competitive potential in ODI

specific average ($I_c \geq 1.0$) were generally better positioned to achieve victory. Particularly, the ODI cricket finalists (India and Australia) displayed intensities significantly above average, confirming their competitive superiority and strategic effectiveness throughout the tournament. In contrast, the T20 cricket finalists, Pakistan and England, performed remarkably close to the tournament average, reflecting an exceptionally balanced competition characterized by minimal skill disparities. Interestingly, despite significant performance disparity in soccer, with France outperforming Argentina in terms of competitive intensity, the ultimate victory by Argentina highlights the complex interplay of skill, situational dynamics, and probabilistic elements intrinsic to soccer. This underscores the importance of considering chance and unpredictability alongside quantitative performance metrics when analyzing soccer competitions. It is important to note that our observed $I_c \geq 1.0$ reflects conditions typical of highly structured, elite competitive scenarios. In contrast, I_c could significantly deviate in less competitive or informal contexts, where performance disparities and motivational factors are more varied and less systematically aligned. Future research could beneficially explore these variations, examining how the competitive intensity metric

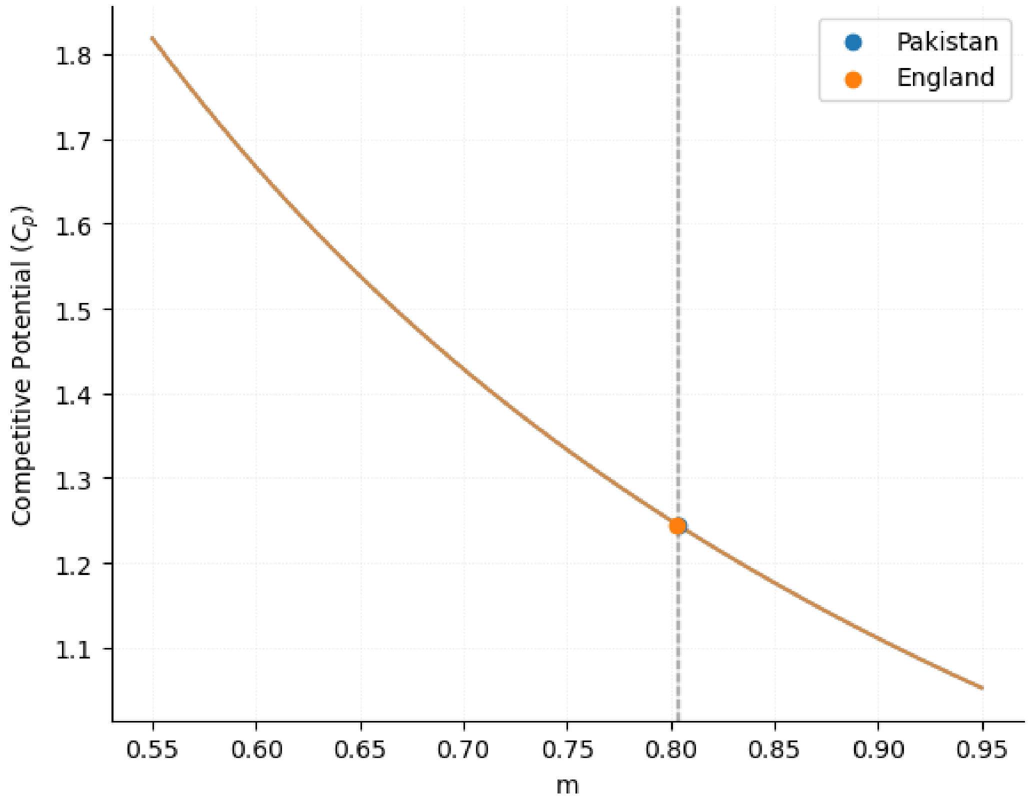

Fig. 5.7 Competitive Potential in T20

behaves under diverse conditions, including amateur competitions, or collaborative rather than competitive settings and in different domains such as board games.

The F_c, inspired by Newton's gravitational force, quantitatively characterized how closely matched and cognitively engaging the competitions were. The extremely high competitive force values observed in the T20 cricket finals underscore an exceptional balance and intensity, resonating with spectators and enhancing overall event attractiveness. Moderate competitive forces in ODI cricket similarly indicated a strong but slightly less balanced engagement. Conversely, the lower competitive force values in soccer suggested a relatively less balanced and more skill-divergent scenario. These findings align with practical observations, emphasizing cricket's inherent consistency and soccer's greater variability in outcomes, driven partially by externalities beyond measurable skills alone.

Furthermore, V_c effectively captured strategic and psychological positional advantages, demonstrating teams' proximity to victory objectives. The minor competitive potential differences in ODI and T20 cricket suggest that closely matched teams maintain comparable positional advantages throughout competition, enhancing cognitive engagement, spectator excitement, and perceived fairness. Contrastingly, soccer demonstrated clearer positional

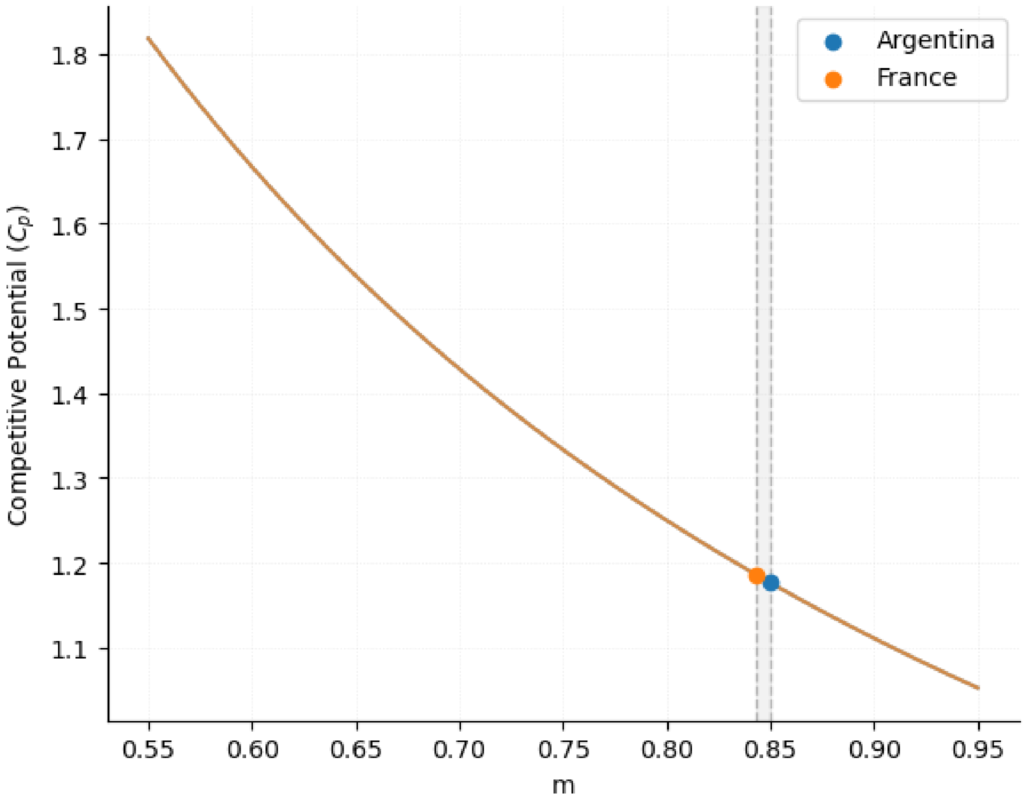

Fig. 5.8 Competitive potential in Soccer

disparities, indicating more pronounced differences in psychological momentum and strategic positioning. Thus, competitive potential serves as a valuable tool not only for quantifying competitive positions but also for strategically guiding coaching decisions, psychological preparations, and tactical adaptations during gameplay.

Compared with previous analytical frameworks such as the Gravity Model, GR theory, and the MiM framework, our model significantly advances current understanding by explicitly quantifying direct competitive interactions between two agents. Previous frameworks primarily addressed broader interactions, cognitive engagement, and overall game structures without detailed quantification of head-to-head dynamics. By explicitly modeling mutual interactions through clearly defined metrics, our approach provides deeper and more actionable insights that can directly inform decision-making in competitive settings. Furthermore, the practical implications of our findings are extensive. Coaches and analysts can leverage I_c measures for strategic benchmarking, using them to identify performance standards necessary for victory. Similarly, F_c can guide tournament organizers in structuring matchups to maximize spectator engagement, balancing fairness and intensity. Additionally, V_c offers insights into psychological and strategic preparedness, assisting coaches in decision-making regarding player selection, psychological conditioning, and tactical shifts to optimize competitive advantage.

Nevertheless, certain limitations should be recognized. Our model assumes consistent conditions and linear interpretations of competitive dynamics, which might oversimplify real-world variability and nonlinearity inherent in human sports competitions. Furthermore, data limitations from single-tournament analyses suggest future research opportunities involving longitudinal studies across multiple events, additional sports contexts, or digital competitive environments such as esports. Incorporating additional cognitive and psychological factors, as well as situational variables, into our model could enhance its predictive accuracy and practical utility. Therefore, by systematically integrating classical gravitational concepts into competitive scenarios, our physics-inspired framework provides robust quantitative tools for analyzing competitive dynamics. It offers substantial theoretical contributions and practical insights that can significantly influence strategic decision-making, enhance game fairness, and improve engagement dynamics in diverse competitive domains. Future research extending this model's applicability to broader contexts could further enhance its analytical power and practical relevance.

5.7 Conclusion

This study proposed a novel physics-inspired framework for analyzing competitive dynamics in sports, drawing analogies from gravitational physics to define key metrics such as I_c), F_c, and V_c. Applied to elite teams in cricket and soccer, the model effectively quantified performance efficiency, balance, and positional advantage. Findings showed that $I_c \geq 1.0$ is critical for success in high-stakes competitions, while high F_c values reflected balanced and engaging contests. V_c offered strategic insight into proximity to victory. Unlike prior models, our framework directly captures mutual interactions between opponents, providing actionable insights for coaching and analysis in competitive settings.

Future research can extend this model to diverse competitive and collaborative contexts, further exploring its psychological and strategic implications.

5.8 Chapter Summary

This chapter introduced and empirically validated a novel physics-inspired analytical framework designed to quantitatively evaluate competitive interactions within elite sports scenarios, specifically cricket (ODI and T20 formats) and soccer. By extending the MiM framework and drawing structural analogies with gravitational physics, three innovative metrics were systematically developed and applied: **competitive intensity** (I_c), **competitive force of attraction** (F_c), and **competitive potential** (V_c).

Key contributions and findings from this chapter include:

- **Theoretical Integration:** The chapter established robust conceptual analogies between gravitational physics and competitive dynamics, enabling deeper exploration and systematic quantification of previously intangible competitive interactions.

- **Quantitative Metrics Development:** Defined and operationalized three novel competitive metrics:

  - **Competitive Intensity (I_c):** Quantifies how efficiently teams resolve competitive uncertainty compared to sport-specific averages. The study finds that maintaining an intensity level of $I_c \geq 1.0$ significantly enhances win probability in skill-dominant sports.

  - **Competitive Force of Attraction (F_c):** Effectively captures the intensity and balance of competition, highlighting that contests with closely matched momenta and minimal skill disparities exhibit higher cognitive engagement and perceived fairness.

  - **Competitive Potential (V_c):** Measures strategic and psychological positional advantages, clearly visualizing how closely teams are positioned toward achieving victory, thus providing actionable insights for coaches and analysts.

- **Empirical Validation:** Data-driven analyses from the ICC Cricket World Cups (ODI 2023, T20 2022) and FIFA World Cup 2022 rigorously tested the proposed gravity-inspired metrics, revealing nuanced dynamics of competition specific to each sporting context. Notably, cricket competitions (ODI and T20) demonstrated closely matched interactions and higher competitive fairness, whereas soccer showcased comparatively greater variability influenced significantly by chance and situational dynamics.

- **Practical Implications:** The proposed framework offers meaningful implications for strategic decision-making, tactical planning, psychological preparation, and enhancing spectator engagement by quantifying direct competitive interactions and providing interpretable performance benchmarks.

- **Limitations and Future Directions:** Recognizing the study's assumptions of consistent conditions and linearity, the chapter identified opportunities for future research, recommending investigations across broader competitive contexts, longitudinal studies, and integrating additional psychological and situational factors to enhance predictive accuracy.

Thus, his chapter significantly advances the theoretical and methodological understanding of competitive interactions by explicitly modeling two-agent dynamics, thereby addressing critical research gaps in the existing literature. This structured, analogy-driven approach provides actionable analytical tools for enhancing performance efficiency, strategic decision-making, and cognitive engagement in elite competitive environments.

Having comprehensively explored competitive interactions at a granular level, the next chapter (Chapter 6) shifts focus back to Chapter 4's central theme examining how distinct scoring structures (high-scoring vs. low-scoring sports) influence cognitive and emotional engagement dynamics across the different phases of gameplay using the MiM framework parameters.

Chapter 6

Phase-based Analysis of Engagement and Excitement Dynamics

6.1 Chapter Introduction

Analyzing how engagement and excitement unfold across distinct phases within sporting events offers critical insights into both game design and psychological dynamics. While Chapter 4 established how structural characteristics such as game length and scoring frequency broadly shape spectator experiences, a significant analytical gap remains concerning how engagement evolves within different temporal segments of a match. This chapter specifically addresses this gap by conducting a rigorous, phase-based analysis of engagement and excitement dynamics across both high-scoring sports (ODI and T20 cricket) and a low-scoring sport (soccer). Employing the sophisticated GR theory and the psychologically informed analytical MiM and FiM frameworks, we examine major international competitions: the ICC ODI Cricket World Cup 2023, ICC T20 Cricket World Cup 2022, and FIFA World Cup 2022. This comprehensive, phase-based examination aims to reveal precisely how gameplay structure and temporal segmentation distinctly influence cognitive load, emotional pacing, strategic intensity, and overall spectator excitement throughout each segment of the match. By dissecting matches into explicit phases (opening, middle, and endgame), this analysis provides deeper insights into the psychological and strategic nuances that previous game-wide analyses may have overlooked. Ultimately, this chapter advances theoretical understandings of engagement dynamics and offers practical recommendations for optimizing the psychological and strategic effectiveness of sports at both individual and structural levels.

The remainder of this chapter is organized as follows: Section 6.2 provides a detailed theoretical background establishing foundational concepts essential for phase-based sports analysis, while Section 6.3 presents a comprehensive literature review that contextualizes prior research and identifies existing analytical gaps. Section 6.4 clearly outlines the methodology, emphasizing data collection processes and explicit game segmentation tailored specifically to cricket and soccer contexts. In Section 6.5, empirical findings are systematically presented, with detailed analysis of phase-specific GR, MiM, and FiM parameters. Section 6.6 offers a comprehensive discussion of these findings, exploring their theoretical contributions as well as practical implications for sports management, coaching strategies, and game design. Finally, Section 6.8 provides a concise chapter summary, seamlessly transitioning toward the subsequent comprehensive discussion chapter (Chapter 7), where insights from the entire dissertation are synthesized, critically evaluated, and integrated into broader theoretical advancements and practical recommendations.

6.2 Theoretical Background

Understanding the engagement and excitement dynamics remains a key objective within sports science and game analytics research. Various sports, such as cricket and soccer, are designed not only to test physical skill and strategic prowess but also to maximize emotional and cognitive engagement throughout the game. Consequently, measuring and analyzing how excitement, uncertainty, and psychological intensity evolve over the course of a sporting event has gained increasing attention from researchers aiming to optimize gameplay dynamics and audience experience [79, 175, 176]. Existing analytical approaches, particularly Game Refinement theory and the Motion in Mind (MiM) framework [16, 17], primarily treat sporting events as uniform wholes, often overlooking how distinct segments or phases within a game uniquely contribute to overall engagement. This limitation restricts deeper insights into how gameplay structure dynamically influences audience and player experiences across different temporal segments of a match.

However, sporting events typically progress through distinct phases such as the opening, middle, and endgame, each characterized by varying dynamics of performance, opportunity, and emotional intensity [177, 178]. These phases differ markedly in scoring patterns, gameplay intensity, and strategic behavior, impacting cognitive and emotional responses from both players and spectators. For example, the intensity and strategic complexity found in cricket's initial powerplay overs differ substantially from the calculated aggression observed in the final overs [30], similarly contrasting with the pacing shifts observed throughout soccer matches [179]. Ignoring these phase-specific dynamics means neglecting critical structural influences that shape the emotional and cognitive landscape of sports. To bridge this analytical gap, this study employs the physics-inspired analytical framework known as the MiM model, initially proposed by Iida and Khalid et al. [16, 17]. The MiM framework uniquely integrates classical mechanics concepts such as velocity, mass, acceleration, jerk, momentum, potential energy, and force to quantitatively capture cognitive and emotional aspects of gameplay. Unlike previous works that average metrics across entire games, this study partitions games explicitly into defined phases (O, M, and E), applying MiM parameters separately within each phase. Such a granular application of the MiM framework enables a deeper, phase-specific understanding of how distinct game segments uniquely influence engagement and excitement.

Specifically, this study explores three major international sporting events such as the 2023 ODI Cricket World Cup, the 2022 T20 Cricket World Cup, and the 2022 FIFA World Cup, feature fundamentally different temporal structures and scoring dynamics. These events were chosen explicitly due to their global prominence and distinctly contrasting strategic pacing, rules, and scoring opportunities. Through meticulous data collection from official repositories, including detailed ball-by-ball cricket data and minute-by-minute soccer records, we quantitatively examine internal gameplay phases using well-defined performance metrics (goals/runs) and opportunity indicators (shots/deliveries). This comparative analysis across distinct sports provides robust insights into the structural effectiveness and psychological dynamic inherent within each phase. Ultimately, this paper aims to reveal how phase-specific metrics derived from the MiM framework can illuminate the psychological pacing, excitement trajectories, and strategic effectiveness within each phase across different sports contexts. The findings not only contribute to a richer theoretical understanding of phase-dependent engagement dynamics but also provide actionable insights. Sport administrators, coaches, and game designers can practically leverage these insights to enhance rules, pacing strategies, and structural elements within game phases, thereby optimizing player engagement and spectator satisfaction.

The remainder of this chapter is structured as follows: Section 6.2 presents a literature review, highlighting the evolution and essential aspects of gameplay dynamics in cricket and soccer, alongside an overview of GR theory and the MiM framework. Section 6.3 outlines the methodology, briefly revisiting the game segmentation approach, data collection methods, and analytical procedures, emphasizing specific adaptations for phase-based analysis. In Section 6.4, empirical results are presented and thoroughly analyzed, revealing unique phase-specific engagement and excitement dynamics across ODI cricket, T20 cricket, and soccer. Section 6.5 provides a detailed discussion, exploring the broader implications of these findings for sports science, coaching strategies, and game design, and highlighting how distinct phases influence cognitive and emotional engagement. Section 6.6 concludes the chapter by summarizing key findings, and Section 6.7 provides a brief overview and transition to Chapter 7.

6.3 Literature Review

One-day cricket was introduced in the 1960s [30], as a shorter alternative to traditional Test cricket, which can last up to five days [31]. It rapidly gained popularity due to its aggressive batting, vibrant presentation, and significantly fewer draws compared to test longer formats. Early developments included fielding restrictions, later formalized as the powerplay by the International Cricket Council (ICC) in 2005 [33]. During powerplay overs, stricter fielding limitations reduce the number of fielders permitted in the outfield, prompting batters to employ more aggressive strokes, thus facilitating higher scoring rates. Although fielding restrictions had been informally employed since the 1996 Cricket World Cup, the formal adoption of the "powerplay" concept significantly reshaped cricket's strategic framework. On the other hand, Twenty20 (T20) cricket, introduced in 2003 by the England and Wales Cricket Board (ECB), further shortened the format to just 20 overs per innings [180, 44, 45]. Designed to deliver fast-paced, high-intensity gameplay, T20 cricket emphasizes explosive batting, aggressive tactics, and rapid scoring. Its global popularity feature even more pronounced fluctuations in momentum, acceleration, and scoring rates throughout the game, especially during the early "powerplay" overs and final "death" overs, underscoring unique tactical considerations distinct from longer test and ODI formats. Soccer, contrasting with cricket, has evolved considerably since its formal codification in 1863 by the Football Association in England [60]. As the world's most popular sport, soccer's global appeal lies in its strategic depth, continuous gameplay, and universal accessibility. A standard soccer match consists of two continuous 45-minute halves, where strategies and pacing vary markedly throughout the match [179, 122]. Unlike cricket's discrete overs, soccer gameplay progresses uninterrupted, structured primarily by strategic momentum shifts and goal-scoring opportunities rather than explicitly defined periods such as cricket's powerplays. Unlike cricket's discrete overs and explicitly defined powerplay periods, soccer does not inherently possess structured phases. However, existing studies suggest soccer gameplay generally progresses through distinguishable stages: initially, players engage in a warming-up period with cautious aggression; subsequently, teams undergo tactical adjustments during the mid-game; and finally, matches conclude with intensified offensive pressure driven by evolving tactical objectives and increased urgency as the final whistle approaches [122, 80]. Given these observations, there is a clear analytical need to explicitly divide each 45-minute half into defined phases to facilitate a structured phase-based analysis, comparable to methodologies used in cricket formats.

GR theory has significantly contributed to the quantitative understanding of entertainment and engagement in games, primarily by analyzing the balance between skill and chance. Initially developed by Iida et al. [14–16], GR theory quantitatively assesses gameplay attractiveness by measuring uncertainty and entertainment through a simple yet effective ratio involving successful outcomes and total attempts. Building upon this foundational concept, the Motion in Mind (MiM) framework [16, 17] retains the core principles of GR quantifying engagement through performance (successful outcomes) and opportunities but enriches this analysis by integrating metaphors from classical mechanics such as velocity, mass, acceleration, jerk, momentum, potential energy, force and others. These theories has been effectively applied across various types of games, including board games [14, 15, 92], card games [93–95], video games [96, 91, 97], and sports [98–103], consistently demonstrating its ability to evaluate the entertainment quality inherent in different game structures. Moreover, GR theory's versatility extends beyond game contexts; it has also been applied to various non-game scenarios, demonstrating its broader applicability in quantifying engagement and satisfaction in diverse environments [104–106, 91].

To the best of our knowledge, there is currently no existing literature explicitly analyzing the scoring and engagement dynamic nature of ODI cricket, T20 cricket, and soccer in a unified, phase-based comparative framework. Therefore, this study employs the Motion in Mind (MiM) framework, a derivative and closely connected model to Game Refinement (GR) theory, to fill this analytical gap. GR theory and the MiM framework successfully capture the overall engagement and sophistication of both game and non-game contexts, these frameworks generally treat games as uniform wholes, potentially overlooking critical nuances within distinct segments or phases of gameplay. Consequently, despite their demonstrated robustness, GR and MiM have not thoroughly explored how engagement dynamics may significantly vary across different phases such as opening, middle, and endgame within sporting events. Each phase typically exhibits unique patterns in scoring opportunities, strategic intensity, and psychological pressures that traditional GR-based analyses have largely neglected. This study addresses this critical gap by explicitly partitioning gameplay into clearly defined phases and applying MiM parameters individually within each segment. By employing such refined, phase-specific MiM analysis, we aim to provide deeper insights into how each phase uniquely shapes engagement and excitement trajectories. This nuanced approach not only advances theoretical understanding but also offers practical implications for enhancing sports management, coaching strategies, and game design.

6.4 Methodology

The methodology employed in this chapter follows the general approach and analytical framework detailed in Chapter 3. Here, a brief overview is presented, highlighting specific adaptations or unique implementations applied to the phase-based analysis of engagement dynamics for ODI cricket, T20 cricket, and soccer.

6.4.1 Game Segmentation

As outlined previously in Chapter 3 (Section 3.3.2), the analysis divides gameplay explicitly into three defined phases: the opening, middle, and endgame. These phases were determined based on official regulations and widely accepted gameplay conventions. Specifically, in the context of cricket, the segmentation aligns closely with established rules regarding powerplays and game length, while in soccer, the segmentation addresses continuous gameplay through equal and strategically informed temporal partitions. For comprehensive details on the segmentation rationale, readers are directed to Section 3.3.2.

6.4.2 Data Collection

The data utilized in this chapter includes match records from three major international sporting events: the 2023 ODI Cricket World Cup, the 2022 T20 Cricket World Cup, and the 2022 FIFA World Cup. As described in detail in Chapter 3 (Section 3.3.2), data collection involved accessing official repositories (e.g., CricSheet and ESPN databases), extracting ball-by-ball cricket data, and minute-by-minute soccer records. The datasets were systematically pre-processed to obtain phase-specific metrics required by the MiM framework. Readers can refer to Section 3.3.2 for detailed procedural information, data sources, and preprocessing techniques.

6.4.3 Analytical Framework (MiM)

The analytical approach adopted in this chapter is based on the GR theory. MiM and FiM framework developed by Iida and colleagues, comprehensively detailed in Chapter 3 (Section 3.4). While the general methodology remains consistent with Chapter 3, here, MiM and FiM parameters are specifically computed for each defined game phase separately, enabling a fine-grained, comparative analysis across the different temporal segments within each sport. Any specific adjustments or parameter considerations unique to this phase-based analysis are explicitly noted within the results section. Readers interested in a complete mathematical exposition and detailed interpretation of the MiM and FiM parameters should revisit Section 3.4.

6.5 Results Analysis

Table 6.1 Phase-wise Velocity and MiM measures

Sports	Phase	G_p	T_p	v_p	m_p	$\vec{p}_p$	N_p	MEE_p
	Opening	54.52	60×6	0.151	0.849	0.129	6.623	2.574
ODI	Middle	154.74	180×6	0.143	0.857	0.123	6.993	2.644
	End	47.97	60×6	0.133	0.867	0.115	7.519	2.742
	Opening	39.90	36×6	0.185	0.815	0.151	5.405	2.324
T20	Middle	64.06	54×6	0.198	0.802	0.159	5.050	2.247
	End	37.35	30×6	0.208	0.793	0.164	4.808	2.192
	Opening	0.672	5.391	0.125	0.875	0.109	8.000	2.828
Soccer (a)	Middle	0.734	5.531	0.133	0.867	0.115	7.519	2.742
	End	1.266	9.172	0.138	0.862	0.119	7.246	2.692
	Opening	0.906	7.047	0.129	0.871	0.112	7.752	2.784
Soccer (b)	Middle	0.844	5.672	0.149	0.851	0.127	6.711	2.591
	End	0.922	7.328	0.126	0.874	0.110	7.937	2.816

The MiM numerical results are presented in the Table 6.1 and 6.2 highlighting how these parameters vary across each phase of each sport. These trends are further visualized in the figures to clearly see the phase-based dynamics of each sport.

6.5.1 Velocity v, Acceleration a, Jerk j, Addictive Density AD and the Phi ratio ϕ

The observed variations in v, a, j, and AD across different phases provide comprehensive insights into the engagement dynamic of the understudy sports. As illustrated in Figure 6.2, in ODI cricket, the velocity (v) exhibits a consistent declining from the opening phase ($v = 0.151$), through the middle phase ($v = 0.143$), to the end phase ($v = 0.133$). This progressive decrease signifies a reduction in scoring intensity and reflects a transition from stochastic to more deterministic gameplay as the match advances, where skill increasingly dominates over chance-based events. Additionally, the opening and end phases display

Table 6.2 Phase-wise GR and FiM measures

Sports	**Phase**	G_p	T_p	GR_p	a_p	j_p	AD_p	ϕ_p	PRE_p
	Opening	54.52	60	0.174	0.0303	0.00151	0.115	1.516	1.514
ODI	Middle	154.74	180	0.098	0.0096	0.00016	0.054	1.803	4.298
	End	47.97	60	0.163	0.0267	0.00133	0.110	1.484	1.333
	Opening	39.90	36	0.248	0.0616	0.00513	0.172	1.439	1.108
T20	Middle	64.06	54	0.210	0.0439	0.00244	0.135	1.557	1.779
	End	37.35	30	0.288	0.0830	0.00830	0.202	1.423	1.038
	Opening	0.672	5.391	0.215	0.0462	0.02573	0.295	0.728	0.672
Soccer (a)	Middle	0.734	5.531	0.219	0.0480	0.02604	0.296	0.739	0.734
	End	0.0301	9.172	0.173	0.0301	0.00984	0.214	0.809	1.266
	Opening	0.906	7.047	0.191	0.0365	0.01554	0.250	0.766	0.906
Soccer (b)	Middle	0.844	5.672	0.229	0.0525	0.02775	0.303	0.757	0.844
	End	0.922	7.328	0.185	0.0343	0.01406	0.241	0.768	0.922

notably higher acceleration values ($a = 0.0303$ and $a = 0.0267$, respectively) compared to the middle phase ($a = 0.0096$), highlighting the presence of more dynamic and exciting shifts at the beginning and conclusion of the match. The a found to be higher in high-scoring sports increasing excitement. Further analysis is supported by the Addictive Density (AD) values, with the opening($AD = 0.115$) and end($AD = 0.110$) phases reflecting greater unpredictability in scoring events, which contributes to heightened spectator engagement. This observation aligns with the engagement index (ϕ), where values in the opening($\phi = 1.516$) and end($\phi = 1.484$) phases lie close to the optimal engaging zone ($\phi \approx 1$), suggesting that both phases maintain moderate-to-high engagement levels. The jerk value, which quantifies the rate of change in acceleration and associated discomfort, reaches its peak in the opening phase ($j = 0.00151$). This indicates potential psychological pressure on opponents as scoring momentum builds early in the game. However, the relatively low and stable jerk values across later phases highlight the strategic and skill-based nature of ODI cricket, where gameplay evolves with calculated pacing and tactical precision. The distinct trends observed in acceleration and jerk across the different phases can also be seen in Figure 6.1, clearly aligning with the MiM model plotting design principles [17], which emphasize capturing the dynamic shifts in excitement and stress or discomfort experienced by spectators and players.

In T20 cricket as further illustrated in Figure 6.2, the velocity (v) progressively increases from the opening phase ($v = 0.185$), through the middle phase ($v = 0.198$), to the end phase ($v = 0.208$). This steady rise indicates an escalation in scoring intensity as the match approaches its conclusion, transitioning from relatively controlled tactics towards highly dynamic and risk-oriented play. Notably, the opening($a = 0.0616$) and end phases ($a = 0.0830$) exhibit significantly higher acceleration compared to the middle phase ($a = 0.0439$), emphasizing that these phases are particularly exciting and dynamically engaging. The highest acceleration observed during the end phase underscores the climax of gameplay intensity, characterized by rapid scoring fluctuations and increased spectator thrill. Further analysis of the AD values reinforces these findings, revealing the highest unpredictability of scoring events in the end phase ($AD = 0.202$), closely followed by the opening phase ($AD = 0.172$). This elevated unpredictability significantly contributes to enhanced emotional engagement for spectators, making these phases particularly compelling. Correspondingly, the engagement index (ϕ) indicates that both the opening($\phi = 1.439$) and end phases ($\phi = 1.423$) are relatively close to the optimal engaging zone ($\phi \approx 1$), reflecting high and sustained engagement. While both phases display considerable spectator excitement, the end phase distinctly features peak acceleration and unpredictability, underscoring its role as the most thrilling segment of the match. Additionally, the jerk value, quantifying sudden shifts in acceleration and associated cognitive stress, peaks notably in the end phase ($j = 0.00830$). This high jerk value highlights the considerable psychological pressure players face as the gameplay dynamics abruptly shift, demanding rapid tactical adaptation and decision-making under intense competitive stress. The distinct trends observed in acceleration and jerk across the different phases can also be seen in Figure 6.1.

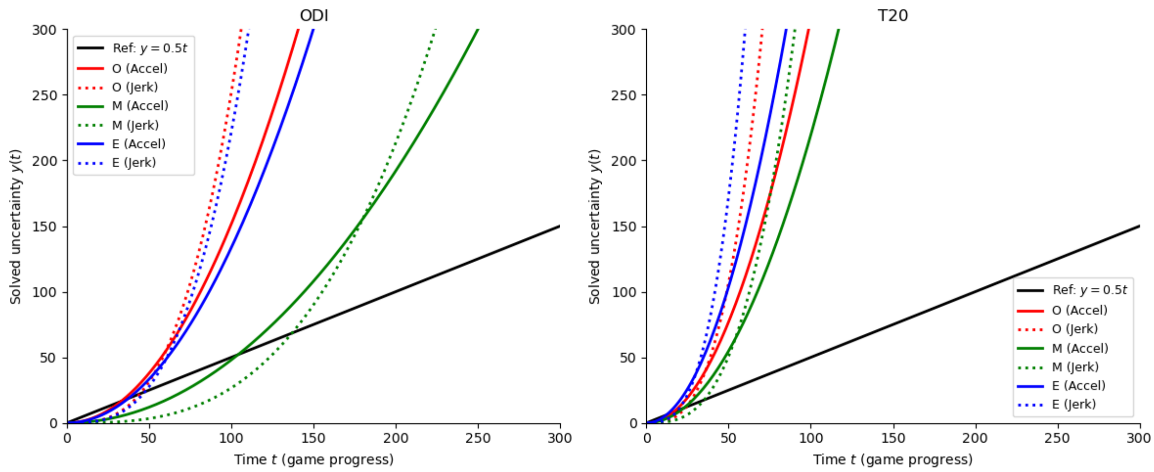

Fig. 6.1 Phase-wise comparison of Acceleration (a) and Jerk (j) in ODI and T20 cricket, across the opening, middle, and end phases.

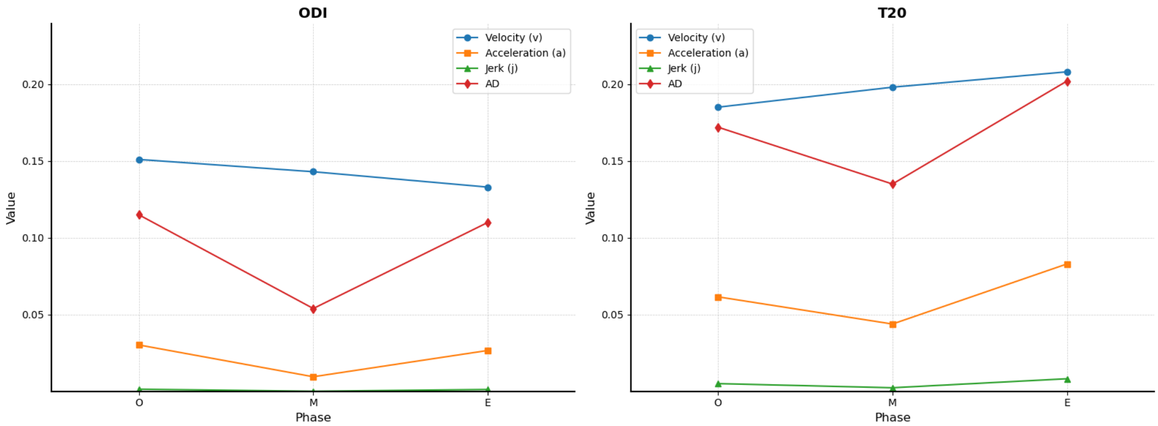

Fig. 6.2 Phase-wise analysis of Velocity (v), Acceleration (a), Jerk (j), and Addictive Density (AD) in ODI and T20 cricket, across the opening, middle, and end phases.

As illustrated in Figure 6.4, in the Soccer (a) scenario, the observed velocity in the end phase, although highest among the phases, was not significantly greater ($v = 0.138$) compared to the middle phase ($v = 0.133$), despite the inclusion of additional stoppage time extending this phase. More notably, the acceleration ($a = 0.0301$) recorded in the end phase was considerably lower than initially anticipated when compared with both the opening ($a = 0.0462$) and middle phases ($a = 0.0480$). Given soccer's inherently low-scoring nature, lower acceleration values signify greater excitement due to the heightened rarity of goals. However, the reward frequency (N) was unexpectedly lower in the end phase ($N = 7.246$) than in the middle phase ($N = 7.519$), prompting further investigation into this anomaly. To address these nuances and better reflect soccer's strategic dynamics, we introduced a revised segmentation approach (Soccer (b)), allocating a cautious opening (0–20 minutes), a balanced middle phase (21–35 minutes), and a compressed endgame (36–45+ minutes). Even under this refined segmentation, the middle phase again exhibited the highest velocity ($v = 0.149$), lowest reward frequency (N), and higher acceleration ($a = 0.0525$), confirming our expectations that the mid-game typically sees greater goal-scoring efficiency. Conversely, the endgame phase showed significantly reduced goal-scoring efficiency but higher excitement and engagement, attributed to the rarity and increased emotional value of goals despite numerous attempts. This end-phase was supported by the high psychological engagement values ($\phi = 0.809$ in Soccer (a) and $\phi = 0.768$ in Soccer (b)), indicating intense spectator emotional investment during the end phases. Further supporting evidence from the MiM framework emerged through the unpredictability metric (AD), with notably higher values recorded in the middle phases across both segmentations. These higher AD values indicated strategic volatility and unpredictability, emphasizing the mid-game's crucial role in shaping final outcomes. The end phase exhibited lower AD, suggesting greater predictability, where the observed decrease in goal-scoring efficiency implies that matches become more deterministic particularly when one team holds a lead, making it increasingly difficult for the opposing side to equalize or overturn the score during the final moments. Additionally, jerk ($j = 0.01752$) peaked during the middle phase, highlighting periods of significant tension building for the endgame. These insights, further visualized clearly in Figure 6.3, underscore soccer's distinct strategic phases, each uniquely contributing to the sport's overall excitement and spectator engagement.

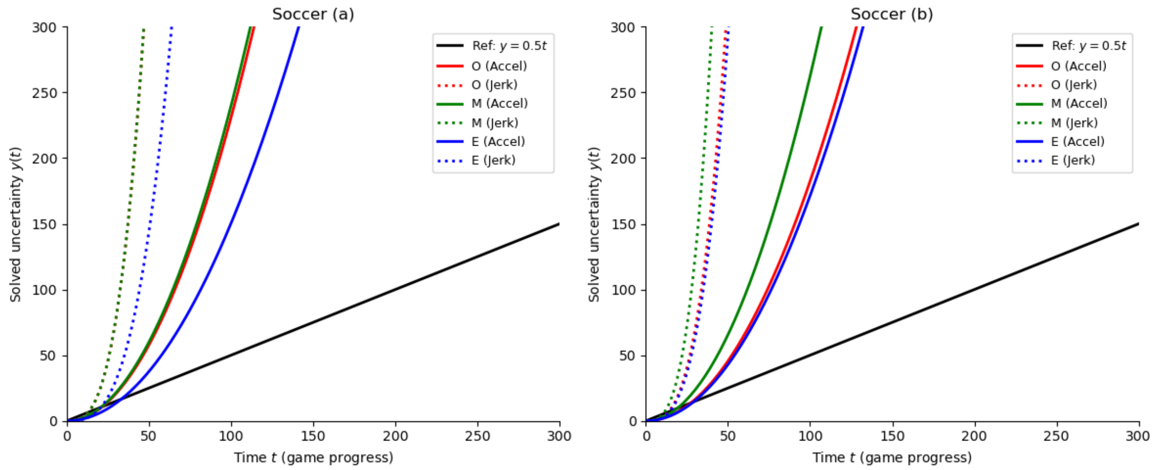

Fig. 6.3 Phase-wise comparison of Acceleration (a) and Jerk (j) between Soccer (a) and Soccer (b), across the opening, middle, and end phases.

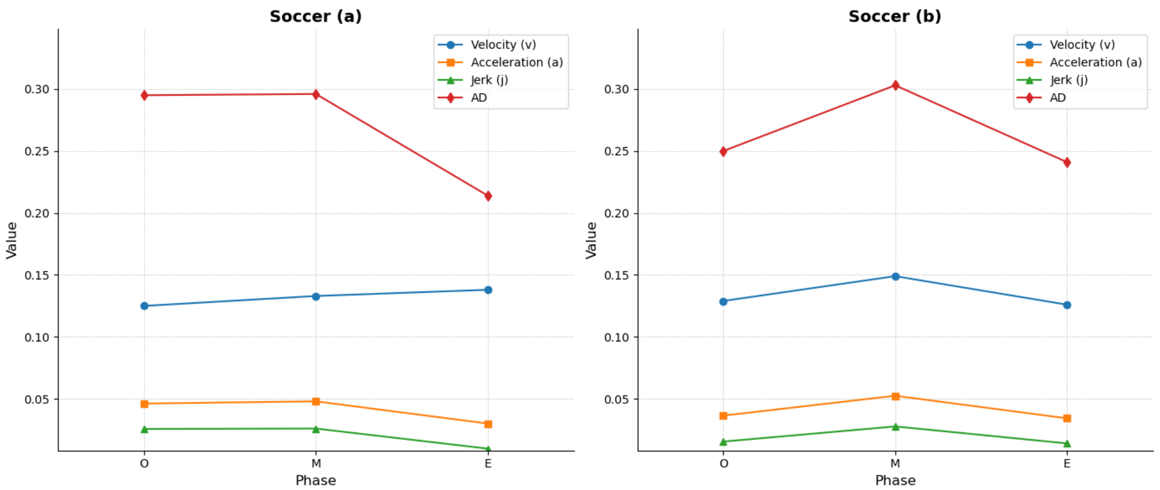

Fig. 6.4 Phase-wise analysis of Velocity (v), Acceleration (a), Jerk (j), and Addictive Density (AD) for Soccer (a) and Soccer (b), across opening, middle, and end phases.

6.5.2 Reward Frequency N and Momentum $\vec{p}$

As illustrated by the momentum ($\vec{p}$) and reward frequency (N) in Figure 6.5, In ODI the momentum progressively declines across the phases of play, corresponding to increasing difficulty or mass. Specifically, the mass values, indicative of substantial game complexity and challenge, rise consistently from the opening phase ($m = 0.849$), through the middle phase ($m = 0.857$), reaching their highest value in the end phase ($m = 0.867$). This systematic elevation in mass (m), paired with the observed reduction in velocity (the rate of successful progress), indicates a progressive decrease in momentum. Such declining momentum signals that players are encountering escalating difficulty in resolving uncertainty as the game progresses, leading to a gradual shift towards frustration or a sense of overwhelming complexity. Moreover, the progressively increasing rarity of rewarding events (N), from the opening($N = 6.603$), through the middle ($N = 6.979$), to the end phase ($N = 7.505$), further substantiates the decreasing momentum. Initially aggressive and frequent scoring transitions into increasingly strategic and cautious batting, making boundary events significantly rarer and, therefore, emotionally more impactful and extraordinary in the game's concluding phases.

In contrast, the T20 format exhibits an opposite trend. The momentum progressively increases across the phases, corresponding to decreasing difficulty or mass. The mass values decline from the opening phase ($m = 0.815$), through the middle phase ($m = 0.802$), reaching the lowest in the end phase ($m = 0.793$). This systematic reduction in mass, combined with the observed increase in scoring velocity, indicates a progressive rise in momentum. The increasing momentum implies that players face less resistance in resolving uncertainty as the match progresses, allowing for greater scoring fluency and a heightened sense of offensive rhythm. Consequently, the decreasing values of N from the opening($N = 5.414$), through the middle ($N = 5.058$), to the end phase ($N = 4.819$) highlight the increasing frequency of rewarding events such as boundaries. This reflects a gameplay evolution from initially measured aggression to highly dynamic and aggressive play, resulting in greater engagement and emotional impact in the concluding moments of the innings.

In the case of soccer, as demonstrated by Soccer (a), momentum ($\vec{p}$) progressively increases across the phases, corresponding to a gradual reduction in difficulty or mass (m). Specifically, mass decreases from the opening phase ($m = 0.875$), through the middle phase ($m = 0.867$), to the end phase ($m = 0.862$). However, the momentum observed in the middle phase closely aligns with that of the end phase, necessitating a more detailed investigation just like the close values of reward frequency (N) values between these two phases. This phenomenon is further clarified in Soccer (b), where a distinct peak in momentum occurs in the middle phase. This elevated momentum is attributed to a significantly higher velocity

($v = 0.149$) and a lower mass ($m = 0.851$), compared to the opening ($m = 0.871$) and end phases ($m = 0.874$). The middle phase, therefore, underscores psychological persistence, motivational strength, and strategic intensity, with a greater emphasis on goal-scoring accuracy rather than merely aggressive attempts. Correspondingly, Soccer (b)'s middle phase exhibits a pronounced reduction in reward frequency ($N = 6.722$) relative to both the opening ($N = 7.776$) and end phases ($N = 7.949$), further highlight the enhanced engagement and strategic effectiveness in successful shots, evidenced by improved scoring efficiency despite fewer overall attempts.

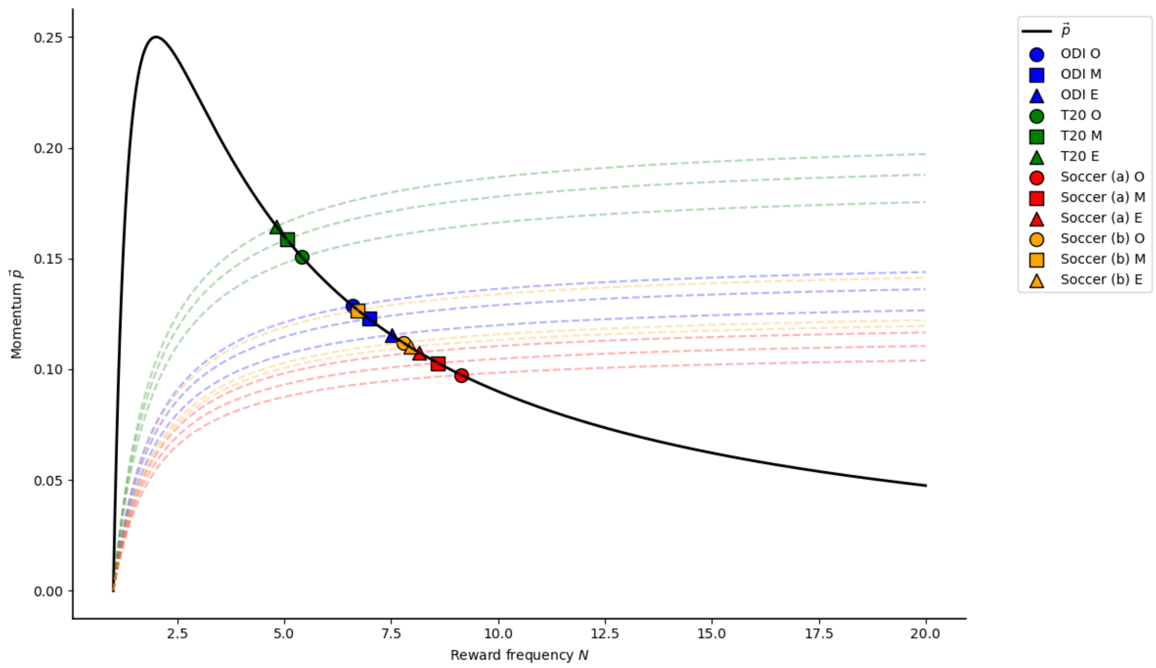

Fig. 6.5 Phase-wise comparison of Reward Frequency (N_p) and Momentum ($\vec{p}_p$) across ODI, T20, Soccer (a), and Soccer (b) formats, highlighting the evolving dynamics of reward occurrences and engagement intensity throughout gameplay phases.

6.5.3 Magnitude of Extraordinary Experience MEE, and Potential Reinforcement Energy PRE

The analysis of MEE and PRE across ODI and T20 cricket formats reveals distinctive motivational and emotional dynamics inherent to each game format. The observed (MEE) and (PRE) trends for ODI are depicted in Figure 6.6, the MEE values progressively increased from the opening(2.570) through the middle (2.642) to the endgame phase (2.739), indicating reduced frequency of rewarding events and heightened emotional intensity per boundary as the match advanced. Notably, PRE showed a distinct peak in the middle phase (4.298), compared to the opening(1.514) and endgame (1.333), highlighting that moderate MEE values corresponded to the optimal reinforcement balance for sustained engagement. Similarly, the observed (MEE) and (PRE) trends for T20 illustrated in Figure 6.7, MEE values decreased progressively from the opening(2.327) to the middle (2.249) and endgame (2.195), reflecting increasingly frequent rewarding events and sustained excitement throughout the game. Again, PRE peaked distinctly in the middle phase (1.779) relative to the opening(1.108) and endgame (1.038). This middle-phase peak in PRE for both formats may be attributed to a higher game length (T), combined with a balanced and strategically complex gameplay, which effectively reinforces player and spectator engagement. Collectively, these findings suggest that moderate reward frequencies, signified by intermediate MEE values, are consistently associated with higher PRE, optimizing emotional intensity, motivational reinforcement, and overall game enjoyment.

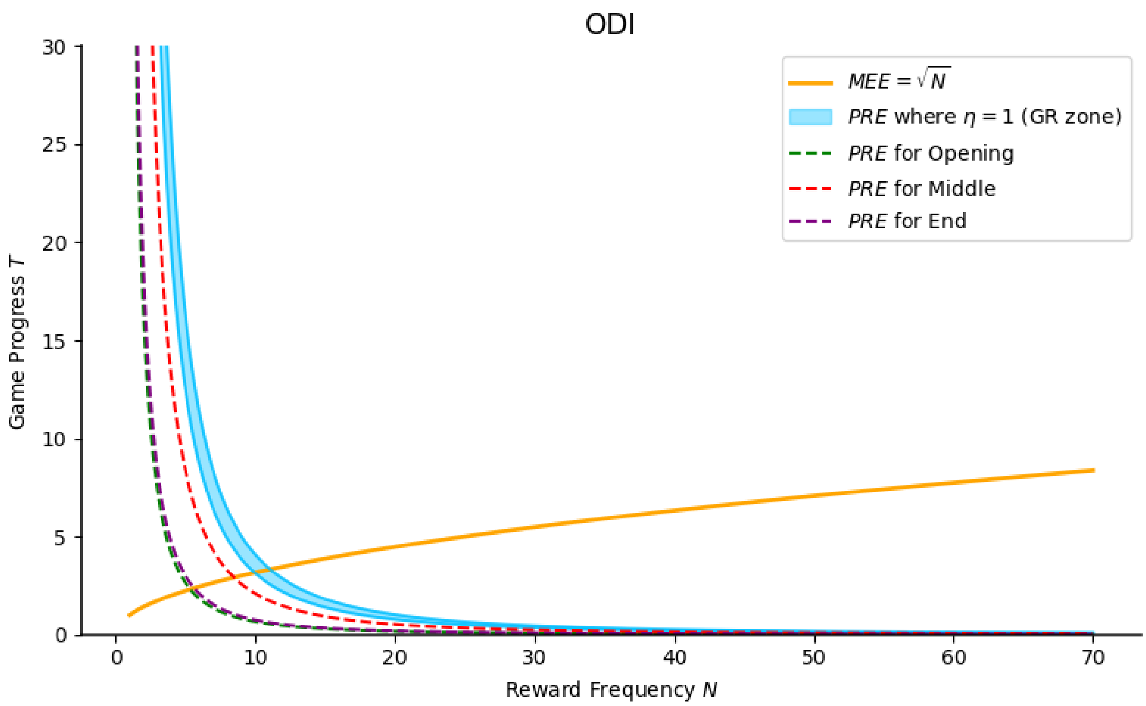

Fig. 6.6 Phase-wise comparison of the Magnitude of Extraordinary Experience (MEE_p) and Potential Reinforcement Energy (PRE_p) in ODI cricket, illustrating how emotional intensity and motivational reinforcement vary across different gameplay phases.

By further analyzing soccer using the MEE and PRE metrics revealed important psychological and motivational insights, illustrated in Figures 6.8 and 6.9. The Soccer (a) segmentation shows anomaly in the (MEE = 2.692) results during the end phase similar to

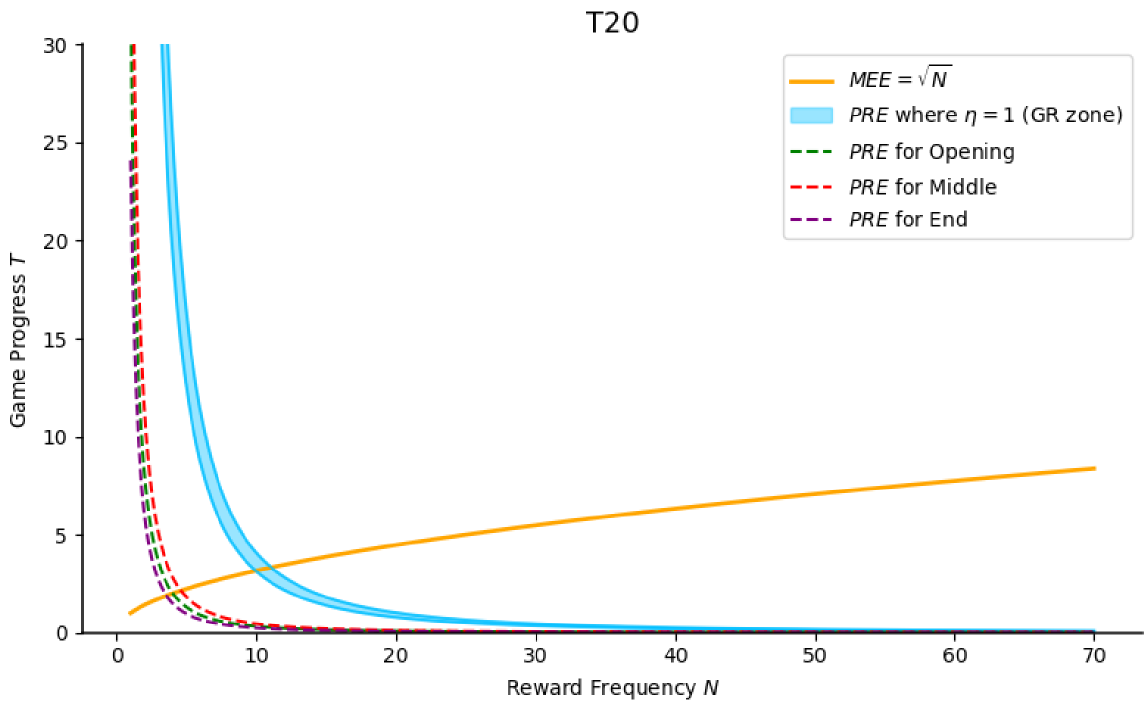

Fig. 6.7 Phase-wise comparison of Magnitude of Extraordinary Experience (MEE_p) and Potential Reinforcement Energy (PRE_p) in T20 cricket, demonstrating the dynamic shifts in emotional intensity and reinforcement across distinct gameplay phases.

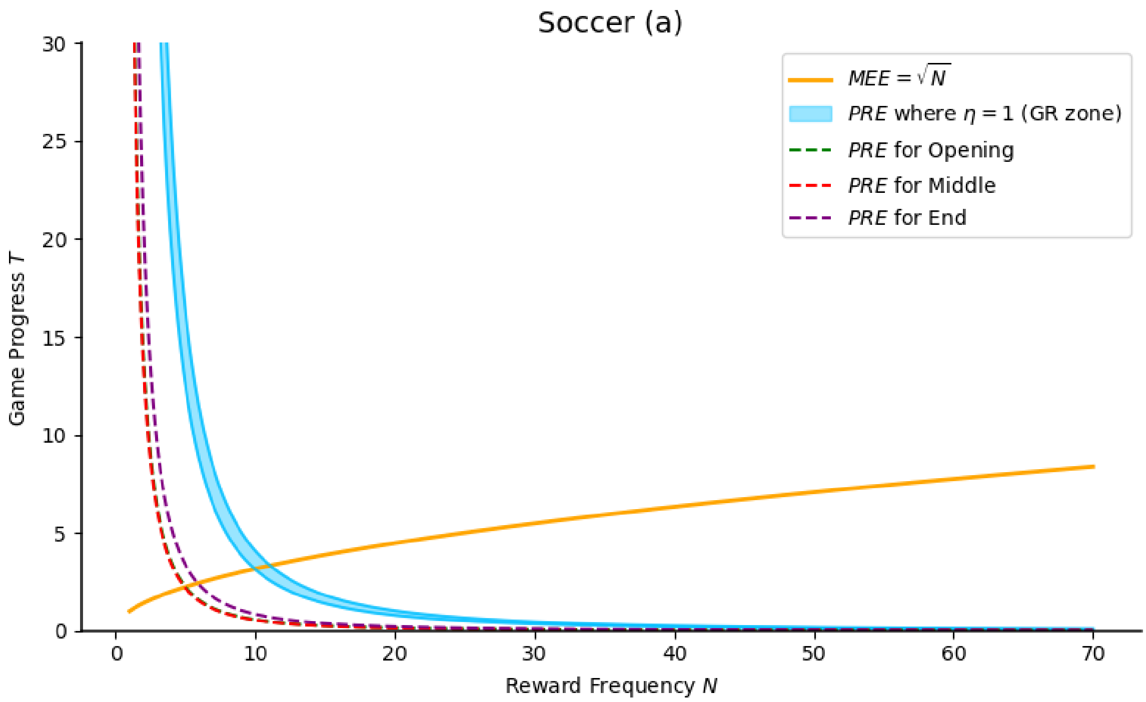

Fig. 6.8 Phase-wise analysis of Magnitude of Extraordinary Experience (MEE_p) and Potential Reinforcement Energy (PRE_p) in Soccer (a), highlighting the evolving emotional intensity and motivational reinforcement throughout each gameplay phase.

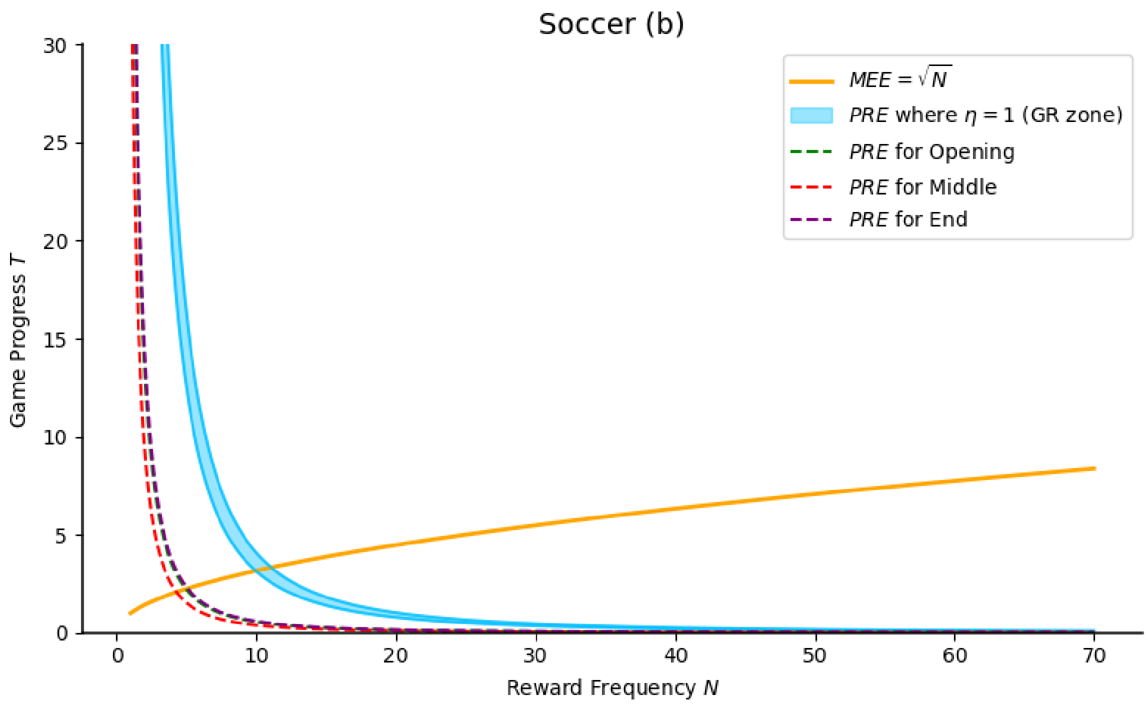

Fig. 6.9 Phase-wise comparison of Magnitude of Extraordinary Experience (MEE_p) and Potential Reinforcement Energy (PRE_p) in Soccer (b), illustrating how emotional intensity and motivational reinforcement dynamics vary distinctly across gameplay phases.

that of N values in Soccer (a) segmentation. This displaying unexpectedly milder emotional reactions (lower MEE), due to seemingly frequent extraordinary rewards (goals), contradicting soccer's inherently low-scoring, highly emotionally charged late-game nature. Such findings warranted further exploration, as intuitively, soccer's concluding phase typically involves heightened tension and emotionally intense reactions to goals due to their rarity and significant match impact. Recognizing the anomaly, (Soccer (b)) segmentation was subsequently applied. Under (Soccer (b)), the highest (MEE = 2.816) value clearly emerged in the end phase, accurately signifying stronger emotional reactions due to the rarity of successful outcomes (goals). Thus, the late-game of soccer evoke particularly intense emotional responses precisely because goals occur less frequently.

Conversely, under the (Soccer (a)) segmentation, the PRE metric robustly aligned with authentic soccer dynamics, illustrating a clear upward trajectory from the opening phase (PRE=0.672) through the middle phase (PRE=0.734), and peaking substantially during the end phase (PRE=1.266). The notably elevated PRE values in late-game scenarios confirm a robust motivational reinforcement structure, highlighting the psychological intensity and strategic urgency experienced by both players and spectators as each scoring attempt becomes decisively influential on the final outcome. Even within the refined segmentation (Soccer (b)), the end phase's motivational reinforcement energy (PRE = 0.922) remained distinctly elevated relative to the opening and middle phases, confirming again soccer's natural intensification of motivational reinforcement as matches approach critical conclusions. This reinforces the consistent observation that late-game scoring opportunities are psychologically charged, pivotal, and deeply motivational for all participants involved.

6.6 Discussion

This study systematically examined phase-based velocity and engagement dynamics using the MiM framework, identifying distinct cognitive and emotional patterns across ODI cricket, T20 cricket, and soccer. Notably, significant variations were found across and within the sports, highlighting critical structural elements influencing psychological engagement.

In ODI cricket, the observed declining velocity and increasing mass across game phases suggest a progressive intensification of cognitive load, reflecting a strategic transition toward defensive play in later overs. Significantly higher *PRE* in the middle phase emphasizes optimal reinforcement and strategic complexity, potentially enhancing player effort by balancing game dynamics toward the end. Conversely, T20 cricket demonstrated escalating velocity and declining mass throughout each phase, mirroring increased scoring intensity but risk-taking play. High jerk values, particularly notable in the end phase, underline rapid shifts in excitement and cognitive load, thereby reinforcing spectator engagement through heightened unpredictability. Cross-format cricket comparisons thus reveal crucial structural influences on engagement dynamics, with discrete overs and explicit powerplays facilitating episodic excitement. Specifically, ODI and T20 formats differ markedly in their phase-based momentum shifts, reflecting fundamental distinctions in their respective rule structures and strategic pacing.

Soccer on the other hand, exhibited the highest velocity and acceleration during the middle phase in both segmentation scenarios, suggesting an inherent mid-game scoring urgency peak. The consistently observed mid-phase peaks in soccer's velocity and acceleration, although initially counterintuitive, align closely with strategic theories emphasizing tactical adaptability and balanced player workload distribution throughout matches [179]. Elevated j and AD observed in the middle phase further highlight the phase of creating significant tension for the end-game while unpredictability increased. Such findings challenge traditional assumptions regarding a linear escalation of excitement, suggesting instead that soccer's continuous gameplay structurally promotes intensified dynamics throughout the game. These insights not only advance theoretical understanding of cognitive load and strategic volatility but also provide valuable implications for coaching strategies, emphasizing the critical role of managing player stamina and tactical flexibility during each phase of the game.

Moreover, this study reveals crucial insights. The MiM parameters, including velocity (v), acceleration (a), reward frequency (N), mass (m), and momentum ($\vec{p}$) and others, distinctly vary between high-scoring and low-scoring sports. As explicitly demonstrated in Tables 6.1 and 6.2, engagement and excitement dynamics not only differ significantly across sports but also within their respective game phases. These differences are primarily driven by each sport's unique temporal structure and strategic pacing, characterized fundamentally by total score (G) and attempts (T). This finding highlights the critical importance of analyzing the interplay between phase-specific velocity dynamics and game length (T) to comprehensively understand cognitive and emotional engagement in competitive sports contexts.

This research advances GR theory and the MiM framework by demonstrating the necessity of considering phase-specific dynamics rather than averaging gameplay metrics across entire matches. Practically, these findings suggest that sports administrators and coaches could strategically leverage phase-specific analyses provided by MiM metrics. Specifically, by applying the MiM framework to different engagement trends, administrators can refine and redesign match structures or adjust durations of critical phases (such as powerplays) to optimize both spectator engagement and player experiences. However, this study acknowledges certain limitations. Foremost is its reliance on single tournaments (i.e., World Cups for cricket and soccer). Future research could investigate multiple tournaments or leagues to determine if observed trends persist, especially in soccer, where our findings suggest phase dynamics might remain consistent despite structural variations. Additionally, future studies could explore alternative soccer segmentations such as phases of 10, 15, and 20 minutes to examine whether acceleration dynamics and goal-scoring rates consistently follow the patterns identified here. We hypothesize, based on current insights, that even in altered segmentations, acceleration may decline in longer endgame segments as the total attempts (T) increase without proportionate increases in goals (G). Further research could also extend this framework beyond traditional sports contexts. For example, the clear demarcations of opening, middle, and endgame phases in chess boardgame provide another promising avenue for validating and extending these findings. Broadening the scope to other competitive domains would further confirm the robustness of the MiM framework's applicability and potentially uncover additional nuances in cognitive and emotional engagement dynamics across diverse competitive environments.

6.7 Conclusion

This study quantitatively assessed the velocity and engagement dynamics across distinct phases of ODI cricket, T20 cricket, and soccer by employing the Motion in Mind (MiM) analytical framework. The findings notably emphasize the importance of phase-specific analysis, offering new insights that enrich both theoretical and practical understanding of different gameplay dynamics. Unlike previous works that focused on game-wide averages, this study highlights the critical influence of game segmentation on strategic pacing and emotional engagement. The comparative analysis across the three sports revealed unique phase-specific velocity patterns, demonstrating how structural differences in game design distinctly shape cognitive and emotional experiences.

Future work should extend this analysis to broader and diverse competitive contexts, including different tournaments, domestic leagues, and alternative phase segmentation approaches. Exploring such variations will further validate the generalizability of the MiM framework and refine the understanding of optimal phase structuring for enhancing player and spectator experiences.

Ultimately, the outcomes of this research underline the significance of considering structural game segmentation as a fundamental component for optimizing engagement dynamics in competitive sports, providing a solid basis for future theoretical explorations and practical innovations in sports analytics and game design.

6.8 Chapter Summary

This chapter provided a comprehensive phase-based analysis of engagement and excitement dynamics within ODI cricket, T20 cricket, and soccer by applying GR theory, MiM and FiM frameworks. By segmenting matches into opening, middle, and endgame phases, the research offered new perspectives on the psychological engagement and strategic intensity specific to each temporal segment. Through detailed analysis, the chapter highlighted how game structures and strategic elements distinctly influence spectator engagement and player intensity across different match phases. This phase-specific perspective enhances the theoretical understanding of cognitive and emotional dynamics in sports and provides valuable insights for optimizing gameplay experiences.

The comprehensive, phase-based insights into engagement and excitement dynamics presented in this chapter build upon and deepen the analyses conducted throughout Chapters 4. Collectively, these findings with chapter 5 provide a robust foundation for Chapter 7, which synthesizes the dissertation's key theoretical and empirical contributions, acknowledges methodological limitations, and identifies promising pathways for future research in sports analytics and game design.

Chapter 7

Conclusion, Limitations, and Future Work

This concluding chapter synthesizes the key insights derived from an extensive comparative analysis of high-scoring (ODI and T20 cricket) and low-scoring (soccer) team sports, focusing specifically on psychological engagement, emotional dynamics, and cognitive load. By leveraging GR theory alongside MiM and FiM frameworks, this research identifies crucial structural characteristics that significantly influence spectator experience, competitive balance, and psychological satisfaction. This section summarized the major findings, highlight theoretical contributions, acknowledge limitations, and propose directions for future research.

7.1 Conclusion

The psychological mechanisms distinguishing high-scoring cricket from low-scoring soccer hinge primarily upon the frequency and rarity of reinforcing events (scoring). Cricket achieves psychological engagement primarily through repeated and frequent rewards (runs, boundaries), sustaining spectators' excitement through constant cognitive stimulation. Soccer, by contrast, leverages infrequent scoring to generate intense emotional and cognitive payoffs from rare, highly impactful events. In cricket, the spectator preference for high-scoring dynamics strongly explains the popularity and demand for the T20 format. With its higher scoring velocity (v) and lower reward frequency (N) meaning scoring events occur frequently. Thus, T20 cricket explicitly fulfills spectators' psychological desire for rapid and continuous emotional reinforcement. This frequent-reward structure sustains immediate emotional gratification and continuous excitement, making the format highly engaging despite its greater randomness and reduced strategic depth. Conversely, ODI cricket's comparatively lower scoring velocity and higher reward frequency reflect a psychologically distinct approach, fostering deeper cognitive engagement through sustained strategic anticipation and a balanced excitement rhythm. While this structured and strategically paced reward approach offers ideal cognitive immersion and fairness, the widespread spectator demand clearly favors T20's rapid reinforcement due to its continuous psychological stimulation. On the other hand, soccer's intrinsic appeal lies precisely in the psychological intensity generated by rare, impactful scoring events. While the current 90-minute format provides prolonged suspense and strategic depth, its relatively higher scoring velocity and moderate frequency of rewarding events somewhat dilute the psychological reinforcement from scoring events, introducing excessive randomness. The theoretically optimized 60-minute format, by lowering scoring velocity and increasing reward frequency, thereby making goals even rarer, effectively amplifies each scoring event's emotional and psychological significance. Although slightly reducing strategic complexity due to increased tempo, this optimized structure significantly enhances spectator excitement through intensified anticipation and more impactful emotional rewards, better aligning with soccer's fundamental low-scoring appeal. Thus, carefully adjusting scoring dynamics to emphasize the rarity and psychological reinforcement of each event, as demonstrated by the 60-minute soccer format, would meet spectator demands more effectively, maximizing both engagement and competitive fairness.

This study confirms that structural characteristics specifically game length, scoring frequency, and uncertainty resolution profoundly influence psychological engagement and spectator excitement in team sports. Longer formats, exemplified by ODI cricket, foster deeper strategic immersion, cognitive endurance, and sustained emotional involvement due to their moderate scoring frequency and gradually paced uncertainty resolution, creating a narrative that methodically engages spectators over extended periods. Conversely, shorter, faster-paced formats such as T20 cricket leverage frequent scoring opportunities and rapid uncertainty resolution to enhance emotional intensity, instant gratification, and dramatic suspense, greatly amplifying immediate spectator excitement but often at the expense of strategic depth and competitive fairness. Ultimately, these structural trade-offs underscore the critical balance between cognitive engagement, emotional pacing, and competitive predictability. Thus, sports formats must carefully calibrate these elements to align spectator experiences with distinct psychological expectations and entertainment preferences. Furthermore, by systematically applying the GR, MiM, and FiM frameworks to soccer, this research highlights that the current 90-minute format tends toward excessive randomness, potentially diminishing fairness and excitement, although it successfully maintains strategic depth. In contrast, the theoretically optimized 60-minute format achieves superior structural balance and fairness, aligning closely with ideal psychological pacing, cognitive comfort, and emotional intensity.

However, the shorter duration introduces increased aggression and tempo, slightly reducing strategic depth. Nevertheless, this refined 60-minute structure preserves soccer's intrinsic appeal, enhancing spectator engagement by appropriately adjusting the rarity and emotional impact of scoring events, and effectively sustaining suspense. More broadly, these insights emphasize the importance of carefully calibrated game dynamics for maximizing spectator satisfaction and competitive integrity, offering a scientifically grounded approach to structural optimization in sports contexts.

Furthermore, we systematically analyze the high-scoring sports (ODI and T20 cricket) and low-scoring sports (soccer) to reveal deeper cognitive and emotional engagement patterns, this research adopted a rigorous analytical approach based on GR theory, the MiM and FiM frameworks. Unlike conventional whole-game analyses which typically average metrics across entire matches and potentially obscure crucial intra-game dynamics, this study explicitly partitioned gameplay into defined segments, capturing distinct temporal structures and strategic nuances. This systematic, granular approach revealed crucial patterns overlooked by conventional analyses.

In high-scoring formats (ODI and T20 cricket), the study identified clear variations in cognitive load, strategic intensity, and emotional pacing between different match segments. ODI cricket, for instance, exhibited decreasing velocity and increasing cognitive complexity, reflecting more deterministic, skill-based gameplay as matches progressed. In contrast, T20 cricket displayed increasing velocity, lower reward frequency, and notably higher acceleration toward the endgame, clearly indicative of escalating scoring intensity, frequent emotional reinforcement, and heightened unpredictability. This reinforced the psychological demands and spectator preference for high-scoring excitement and rapid gratification, aligning precisely with T20 cricket's widespread appeal. For low-scoring sports such as soccer, the analysis revealed unique and nuanced engagement dynamics. Contrary to expectations of linear excitement escalation, the study identified mid-match peaks in scoring urgency, acceleration, and strategic volatility. However, particularly significant was the observation from the phase-based analysis that soccer's endgame exhibited lower velocity, higher reward frequency, and crucially lower acceleration. Unlike high-scoring sports, where increased acceleration indicates heightened excitement, in soccer, lower acceleration in the endgame reflects fewer scoring events, thereby intensifying spectator excitement through heightened anticipation and emotional impact of each rare goal. This phase-specific pattern emphasizes that excitement in soccer is driven precisely by the increasing rarity and psychological reinforcement of scoring events as the match approaches its conclusion, strongly supporting the proposed theoretically optimized 60-minute format. By carefully calibrating scoring dynamics, making scoring events even rarer and strategically more impactful, the refined 60-minutes structure in Chapter 4 better captures and enhances soccer's intrinsic low-scoring appeal and intense spectator excitement.

Based on the detailed phase-specific insights presented, explicit actionable recommendations for altering game structures in ODI and T20 cricket formats may not be strictly necessary. The analysis reveals that each format naturally facilitates distinct cognitive and emotional experiences across match phases. ODI cricket progressively emphasizing strategic complexity and cognitive endurance, and T20 cricket increasingly promoting dynamic excitement and risk-intensive play as the match advances. Thus, the existing structural elements effectively serve their intended purposes, delivering distinct, well-balanced engagement dynamics. However, for soccer, recognizing the identified mid-game peaks in scoring urgency, acceleration, and strategic volatility, actionable recommendations are indeed required. Soccer administrators and game designers might first consider strategically reducing the overall match duration, as proposed in Chapter 4, to uncover distinct engagement and excitement patterns. Such a reduction in match duration could significantly enhance the cognitive and emotional dynamics experienced by spectators, leading to more aggressive, intense, and exciting gameplay. Additionally, the reducing the game-length may introduce new strategic incentives or tactical variations specifically during mid-game phase may greatly influence cognitive load management and emotional investment. Implementing these structural and strategic modifications could fundamentally heighten gameplay intensity and spectator satisfaction by better aligning the game's design with soccer's intrinsic psychological dynamics.

The MiM framework was further extended in this dissertation by integrating novel physics-inspired metrics derived from gravitational analogies, thus effectively capturing competitive interactions. To operationalize this enhanced framework, foundational MiM parameters such as velocity (v), mass (m), and momentum ($\vec{p}$) were systematically translated into meaningful competitive metrics. Specifically, velocity represents a player's or team's skill level and efficiency in resolving competitive uncertainty, while mass quantifies the perceived competitive difficulty or challenge faced. Momentum encapsulates the cognitive and strategic effort exerted by competitors to address challenges using their skill. Thus, three robust quantitative metrics such as competitive intensity (I_c), competitive force of attraction (F_c), and the competitive potential advantage (V_c) were introduced. These metrics collectively enabled detailed evaluation of performance efficiency, intensity of interactions between competitors, and strategic positional advantages within competitive contexts. The empirical validation of these proposed metrics demonstrated strong correlations with actual competitive outcomes across elite sporting events, further reinforcing their analytical robustness and practical relevance. Crucially, the study also provided interpretative depth by explicitly relating these empirical findings to underlying cognitive and emotional dimensions of competitive interactions. For instance, competitive intensity (I_c) values equal to or greater than one indicated high motivation, psychological momentum, and an increased likelihood of winning, while values below one signaled diminished motivation and reduced chances of success. Similarly, a higher competitive force of attraction (F_c) was indicative of more engaging, exciting, and psychologically stimulating contests. Finally, the elevated competitive potential advantage (V_c) values suggested a reduced perceived difficulty and lower cognitive effort required to secure victory. Thus, by quantifying the intangible cognitive and emotional dimensions, this dissertation contributes significantly to a deeper and more comprehensive understanding of competitive dynamics in sports.

This study highlights the regional popularity of cricket in South Asia and soccer in Europe by exploring their structural characteristics through both data-driven and theoretical approaches. The analysis reveals that frequent scoring significantly contributes to spectator excitement and engagement in South Asia, aligning with cricket's historical evolution from Test matches to ODIs and now to T20 formats, each progressively increasing scoring frequency. This indicate that most of the South Asian people prefer high and frequent scoring sports. Supporting this trend, previous study [181] indicate field hockey's relatively limited popularity in the South Asia region, despite its official recognition as Pakistan's national sport, primarily because it features less frequent scoring compared to cricket. Conversely, soccer's dominance in Europe illustrates a cultural preference for sports where scoring occurs less often but carries considerable emotional and strategic significance [182].

While our study primarily emphasizes structural differences to explain regional popularity, we also reference environmental factors as supplementary insights drawn from existing literature. For example, Europe's diverse and cooler climate supports soccer's year-round feasibility, even during colder months, thereby enhancing its popularity [183]. In contrast, cricket is more susceptible to weather disruptions such as rain, limiting its practicality in European climates [184]. Meanwhile, South Asia's predominantly warmer climate extends cricket's playable season, reinforcing its sustained popularity. These environmental observations, although not central to our analysis, offer contextual understanding aligned with prior research.

Furthermore, the study reveal that game length directly influences scoring frequency and overall spectator excitement. For instance, the ODI format, consisting of 50 overs, is perceived as less exciting and popular compared to the shorter T20 format, which offers a higher scoring frequency. Similarly, the traditional 90-minute soccer match appears lengthy, with scoring frequency seemingly higher compared to our proposed 60-minute format. Numerically, goals per game (3.426 in 60 minutes versus 2.672 in 90 minutes) might appear higher in shorter games; however, when goals are normalized by total attempts (34.149 in 60 minutes versus 22.76 in 90 minutes), the frequency is effectively lower. This observation indicates that a shorter, lower-scoring soccer format of 60 minutes could potentially enhance spectator excitement, aligning with European low scoring sporting preferences.

7.2 Limitation

The study provides valuable insights by employing GR theory alongside the MiM and FiM frameworks; however, several important limitations remain. Firstly, the data used were drawn exclusively from specific tournaments such as the 2023 ODI World Cup, 2022 T20 World Cup, and 2022 FIFA World Cup, which restricts the applicability of the results to different competitive contexts, leagues, and cultural environments. Secondly, the proposed theoretical models for optimizing game duration, such as the suggested 60-minute soccer format, rely heavily on simplified assumptions regarding scoring intensity and player performance. These assumptions lack thorough empirical validation and may not fully reflect practical considerations like fatigue, tactical adjustments, and spectator preferences. Furthermore, while sophisticated, the analytical frameworks employed convert physical analogies directly into cognitive and emotional terms, thereby potentially oversimplifying complex psychological and behavioral dynamics within games. In a related issue, the study's primary focus on increasing scoring frequency and structural clarity leaves out essential factors like tactical creativity, player safety, and sustained fan interest, indicating a need for a more comprehensive and balanced approach in future analyses. Moreover, the phase segmentation method, although theoretically reasonable, might inadequately represent the subtle timing dynamics present in sports like soccer, where phases are less distinct compared to cricket. Lastly, the exclusive reliance on quantitative measures (e.g., GR, MiM and FiM parameters) neglects critical qualitative aspects, such as player psychology, strategic adaptations, environmental conditions, and audience demographics factors that significantly influence engagement but are difficult to quantify with the current analytical methods. Although metrics such as (I_c), (F_c), and (V_c) introduced in this study could readily be extended to the psychological perspective of players, this dissertation predominantly addresses psychological engagement, cognitive load, and emotional dynamics from the spectators' viewpoint. The employed GR, (MiM), and (FiM) analytical frameworks are robust in capturing the spectator experience but have not been explicitly empirically validated concerning the distinct psychological experiences of players. Players' direct involvement in gameplay inherently entails higher levels of cognitive stress, emotional intensity, and strategic pressure, significantly differing from spectators' experiences. Consequently, the findings derived primarily from spectator-oriented data provide valuable but only partial insights into the full spectrum of psychological dynamics occurring during competitive play.

7.3 Future work

Future studies should first consider acquiring broader datasets from additional tournaments, leagues, and competitive contexts to enhance the generalizability and robustness of the findings. Expanding the data scope could help validate whether the observed engagement dynamics consistently hold across various settings. Subsequently, empirical validation of the proposed theoretical models, such as practically implementing and evaluating structural modifications (e.g., the optimized 60-minute soccer match format), would allow assessment of real-world player adaptation, spectator acceptance, and possible unintended consequences. Further research could also investigate cross-cultural variations, examining how structural adjustments resonate among diverse global audiences. Additionally, examining the long-term implications of such modifications on player health, spectator engagement, sports governance, and competitive balance could significantly enrich the understanding of these structural adjustments. Extending the current analytical framework to other sports, e-sports, and gamified environments contexts similarly concerned with balancing skill, suspense, and psychological rewards would further enhance the applicability and depth of these findings. Moreover, future research could explore alternative segmentation methods, especially in soccer, by experimenting with shorter or varying gameplay phases (e.g., 10, 15, or 20-minute segments) to assess whether engagement dynamics remain stable or shift significantly with different temporal structures. Incorporating qualitative research methods, such as detailed player and spectator interviews or psychological assessments, could complement and deepen the quantitative analyses, providing richer insights into cognitive, emotional, and behavioral engagement. While the current phase-based analysis has been applied to physical sports such as cricket and soccer, future research could explore whether similar trends or meaningful differences emerge when these frameworks are applied to other domains, such as mind sports (e.g., chess) or video games. Such investigations could further validate the theoretical robustness and practical versatility of the GR, MiM, and FiM frameworks across diverse competitive environments. For example, in chess where the opening, middlegame, and endgame phases are well-established within the community [185], a phase-based analysis might reveal comparable patterns as soccer in terms of piece capture rates during the middlegame. Moreover, this segmentation can also be used to analyze the frequency and strategic value of captures or other forms of intensity across phases. In domains where gameplay phases are not explicitly defined, researchers may introduce logical segmentation schemes based on structural or temporal cues to uncover phase-specific engagement or performance dynamics. This line of inquiry holds promise for broadening the applicability of the phase-based framework beyond traditional sports settings.

Last but not least, the studies could explore the proposed gravity-inspired framework across diverse competitive contexts, including amateur sports, collaborative scenarios, and digital gaming environments such as esports, to validate its broader applicability and robustness.

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List of Publications

- Degree Requirement

1. **Numan, M.**, Iida, H., & Khalid, M. N. A. (2024). Analyzing Soccer Dynamics Using the Motion in Mind Model. *Asia-Pacific Journal of Information Technology & Multimedia*, *13*(2).
2. **Numan, M.**, Iida, H., & Khalid, M. N. A. (2025). Modeling Sports Engagement: A Game Refinement Theory Perspective on Game Length and Scoring Frequency. IEEE Access. *IEEE Access Volume: 13*, Article 2169-3536. https://doi.org/10.1109/ACCESS.2025.3580196

- Under Review

1. **Numan, M.**, Iida, H., & Khalid, M. N. A. From opening to endgame: When does the game get engaging and exciting? Exploring phase-based velocity dynamics using the MiM framework. Submitted to *IEEE Access*.

- With JAIST Affiliation

1. **Numan, M.**, Subhan, F., Khalid, M. N. A., Khan, W. Z., & Iida, H. (2024). Clone node detection in static wireless sensor networks: A hybrid approach. *Journal of Network and Computer Applications*, *232*, Article 104018. https://doi.org/10.1016/j.jnca.2024.104018
2. Ullah, A., Yu, X., & **Numan, M.** (2023). Automated Video Generation of Moving Digits from Text Using Deep Deconvolutional Generative Adversarial Network. *Computers, Materials & Continua*, *Volume 77, Issue 2*. https://doi.org/10.32604/cmc.2023.041219
3. Ullah, A., **Numan, M.**, Khalid, M. N. A., & Majid, A. (2025). Words shaping worlds: A comprehensive exploration of text-driven image and video generation with generative adversarial networks. *Neurocomputing*, *Volume 632*, 129767. https://doi.org/10.1016/j.neucom.2025.129767

- Ready for Submission

1. **Numan, M.**, Iida, H., & Khalid, M. N. A. (manuscript ready for submission). A novel gravity model inspired by gravity: Extending the MiM framework for competitive dynamics in elite sports.