Abstracts Book
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Keynote Speakers

David Kendix

David Kendix is a Fellow of the Institute of Actuaries and has spent his career working for various global insurance groups, specialising in model risk, corporate strategy, and governance. As statistician for the International Cricket Council and member of their Cricket Committee, he is responsible for identifying statistical trends in the game and for drafting playing regulations. In 1996, he peer-reviewed the Duckworth Lewis method and recommended its adoption. In 2002 he designed and still maintains the official team rankings, subsequently expanded to more than 100 countries, covering men's and women's cricket. He was called as an expert witness in a major criminal trial, applying statistical techniques to detect evidence of match-fixing. He has been the official scorer in over 100 internationals including 50 Test matches (mostly at Lord's) and has served as Board Director and Treasurer of Middlesex County Cricket Club. He has been President of The Association of Cricket Statisticians and Historians since 2017. As statistician for World Netball, he designed and maintains their team ranking system and devised their world championship tournament structure.

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Approaches to Measuring and Modelling Player Development in Australian Rules Football

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Abstract
Evaluating player performance and development in Australian Rules Football (AF) has heavily relied on subjective judgments from coaches and scouts (MacMahon et al., 2019). With increasingly rich match-event data now available, there is an opportunity to assess performance and growth through objective, reproducible methods (Davis et al., 2024). This study develops a statistical framework for quantifying player development across multiple skill domains while accounting for contextual factors such as age, competition level, and playing position. First, this framework evaluates the meta-metric properties (Franks et al., 2016) of commonly used in-game AF performance metrics to identify which variables meaningfully discriminate between player performances and which remain stable across seasons. This provides an evidence-based foundation for selecting metrics that reliably measure player performance. Second, variables are combined using dimensionality-reduction techniques to derive composite indicators representing distinct skill domains and player role characteristics, such as ball distribution quality or defensive effectiveness. These composite indicators can then be tracked longitudinally to evaluate a player's historical development over time. Third, developmental baselines are estimated using time series models that account for age and competition level, allowing each player's observed trajectory to be compared with an expected trajectory. For each player, deviation from these expected curves can be used both to characterize prior development and predict future growth. By integrating metric validation, latent skill construction, and longitudinal modelling, this framework provides a data-driven approach to player evaluation and development in AF, with practical applications for recruitment, coaching, and talent development.

Keywords: Player Performance, Player Development, Player Prediction

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List Management Optimisation in the Australian Football League

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Abstract
List management as a mathematical concept is an application of operations research with aims to assist in planning longer-term decisions around the construction of a team, with the aims of improving the success of the team over this period based on specified objectives and within constraints. For the Australian Football League, as with many other professional leagues across the world, this involves a range of decisions in salary cap management, drafting strategy, free agency and trade, against other teams with the same broad set of goals. Given these constraints and equalisation present in the league, teams must navigate the peaks and troughs in performance likely to present themselves throughout the cycle. In developing this model, it aims to provide some assistance in how decisions relate to one another, how these may impact longer term and how optimising performance in target years may be set up in decisions made in earlier seasons. The optimisation methodology involves mean-variance optimisation where expected player performance by season is balanced with the relative risk involved in particularly drafting unproven players who may never achieve regular football at AFL level. Results showing the relative consistency of expected performance given different draft inputs and the importance of initial players to upcoming seasons will be shown. An extension to the model showing how updating for performance after one season impacts future performance through a lookahead model will also be demonstrated.

Keywords: Operations research, optimisation, list management, Australian Football

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COMPARATIVE ANALYSIS OF DEFENSIVE PRESSURE IN MEN'S AND WOMEN'S AUSTRALIAN FOOTBALL

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Abstract
Defensive pressure is a concept used in team invasion sports to assess aspects of a team's match performance (Sullivan et al., 2014a; Sullivan et al., 2014b). More defensive pressure has been shown to be associated with poorer offensive skill execution (Browne et al., 2019; González-García, 2024; Link et al., 2016; Parrington et al., 2013). A quantification of defensive pressure in Australian football (AF), known as 'pressure acts' (*Official AFL Glossary*, 2019), was introduced by the Australian Football League's (AFL and AFLW) official data provider, Champion Data, to measure the level of defensive pressure applied to the ball carrier at the point of disposal in AF matches. This provided further contextual detail to the data collected in professional men's and women's matches. Pressure acts are a six-level ordinal variable, with levels: set, none, corralling, chasing, closing and physical. Previous studies in men's AF have found a correlation between increased defensive pressure on the ball carrier and decreased disposal efficiency (Browne et al., 2019; Browne et al., 2022; Parrington et al., 2013; Robertson et al., 2019; Walker et al., 2024). However, there are limited findings into the effects of defensive pressure in women's AF. This study aimed to compare expected pressure (Azzopardi et al., 2022) in elite women's and men's AF, and to investigate differences when adjusting or not adjusting for the context of disposals. Secondary aims were to test for changes in the distributions of pressure over time in each competition, and to estimate the effect of different amount of pressure on disposal efficiency in each competition.

Keywords: defensive pressure, team defence, invasion sport

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BAYESIAN NETWORK INFERENCE WITH UNCERTAINTY: MODELLING ATHLETE PROGRESSION

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Abstract
Athlete categorisation is a major contributing factor in a sporting body's ability to predict which current youth competitors may become the next generation of senior athletes representing Australia. This process is crucial, as the early identification of talent results in resources being conserved and allows for the support of athletes who have the greatest chance of being selected on a national team and winning medals in the future. The career progression of an athlete refers to the changes in an athlete's competitive performance over time, from local and junior competitions through to senior international representation. Whilst existing frameworks in the area of athlete development are able to categorise athletes based on their current performance level, they lack focus on the transitions between development stages and the influence of performances from one season to the next. This talk discusses a pilot framework for modelling athlete career progression centred around a Dynamic Bayesian Network (DBN), demonstrated through a case study in swimming athlete development. The proposed framework integrates expert knowledge with performance data to update DBN parameters while accounting for uncertainty. This involves generating samples from local Dirichlet-multinomial posterior distributions, alongside functional principal component analysis (FPCA) and Gaussian mixture model (GMM) techniques to estimate latent state probabilities and manage career trajectory variability. An algorithm was developed to perform DBN inference given observed evidence, enabling the model to be seasonally updated with new athlete performance data. The framework is designed to be easily generalisable through the use of relative performance metrics and athlete rankings and could be applied to other sports and contexts. The model could potentially play a role in talent identification and pathway planning by offering a data-driven, interpretable approach to managing athlete progression through the prediction of peak performance and variability.

Keywords: Athlete performance, talent identification, career trajectories, performance progression

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SPATIAL ANALYSIS OF DISABILITY SPORT PARTICIPATION INEQUITIES IN QUEENSLAND

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Abstract
Increasing participation in sport and physical activity among people with disability is a central objective of the Brisbane 2032 Olympic and Paralympic Games, which aims to increase participation by 500,000 Australians, including approximately 100,000 in Queensland[1]. Understanding where participation disparities occur geographically is essential for directing resources and designing interventions that effectively support inclusive sport participation. This study contributes to the development of the Empower Atlas, a spatial data platform designed to identify inequities in sport participation and opportunities for people with disability. The Atlas integrates multiple data sources, including national participation surveys, disability population statistics, and facility data to provide a comprehensive evidence base for policy and planning. As an initial component of the Atlas, we analysed pooled Queensland data from the AusPlay national participation survey[2] (July 2023–June 2025) to estimate small-area-level sport participation rates among adults with and without disability. As AusPlay is not designed to produce participation estimates by small-area-level, and given the limitations of using survey data alone, the results should be interpreted as indicative of broad patterns rather than precise participation estimates. A relative participation rate and participation gap metric were used to quantify disparities between the two populations. Results indicate that the participation rate for adults with disability is consistently lower than the rate for adults without disability at the small-area level. However, substantial variation in sample coverage highlights limitations in small-area estimation using survey data alone. These findings illustrate the importance of integrating multiple datasets within the Empower Atlas to improve spatial understanding of participation inequities. By combining participation data with information on disability prevalence and sport and recreation opportunities, the Atlas aims to support data-driven decision making and guide targeted strategies to increase inclusive sport participation in the lead-up to Brisbane 2032.
Keywords: disability, sport participation, spatial analysis, survey analysis, sport equity.

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A STANDARDISED PARTICIPATION RATIO FOR EVALUATING SPORT AND PHYSICAL ACTIVITY PARTICIPATION IN PEOPLE WITH DISABILITY

Mark J. Connick [a,k] , Kalpani Ishara Duwalage [b], Michael A. Schuetz [c,d,e], Michelle Moss [f], Matthew Ames [g], Luen Pearce [c], Sean Tweedy [h], Martin O'Flaherty [h], Kelsey Chapman [i], Stephen Coulter [f], Amy Anderson [f], Rebecca Cason [f], Kerrie Mengersen [j]

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Abstract
The Brisbane 2032 Olympic and Paralympic Games have committed to a legacy of increasing sport and physical activity participation in people with disability (PWD) by 500,000 people across Australia (Australian Olympic Committee & Paralympics Australia, 2021), including approximately 100,000 in Queensland. Achieving this goal requires identifying where investments in infrastructure, accessibility, new participation opportunities and community programs are most likely to produce the greatest participation increase. This goal is challenging because opportunities and participation rates are unevenly distributed across regions and between people with diverse disabilities. While participation increases with the number of opportunities per capita (Eime et al., 2017), it remains lower among PWD due to greater barriers (Martin Ginis et al., 2017). As a result, some regions may experience limited participation by PWD due to insufficient opportunities, while other regions may have opportunities that are not being fully utilised due to intra- and inter-personal barriers (Stokols, 1996). However, there is no widely used quantitative framework for identifying which of these explanations is most relevant to any given geographic region, or for prioritising regions where investment is likely to yield the greatest benefit. This study introduces a Standardised Participation Ratio (SPR) for analysing the relationship between participation and opportunities across geographic regions and between populations. The SPR is defined as the ratio of observed participation among PWD to expected participation. Expected participation is estimated using participation rates among the non-disabled reference population, adjusted for the distribution of accessible opportunities within each region. Regions with SPR values below one indicate lower participation than expected, suggesting stronger intra- or inter-personal barriers. Conversely, values above one indicate higher participation relative to opportunity supply, suggesting potential facility or infrastructure constraints. By identifying mismatches between participation and opportunity, the SPR potentially provides a transparent quantitative tool for prioritising investment and evaluating participation strategies.
Keywords: Olympic and Paralympic Games, Disability, Sport, Participation, Physical Activity.

Acknowledgements
This research forms part of the Empower project which is funded and supported by the Department of Sport, Racing, Olympic and Paralympic Games, Queensland Government. It has been developed by the Jamieson Trauma Institute, Metro North Health, Queenslanders with Disability Network (QDN) and Queensland University of Technology with additional university partners, University of Queensland and Griffith University. The authors also gratefully acknowledge the substantial and ongoing contributions of the Empower co-design team.

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EXPLORATORY ANALYSIS AND MODELLING OF MULTI-TRIAL FIELD EVENT PERFORMANCE

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Abstract
Multi-trial athletic events (such as long jump and shot put) involve athletes performing multiple maximal-effort attempts within a competition. Previous research indicates that trials are interdependent, with complex performance dynamics across the sequence (Emerson & Hill, 2024; McCosker et al., 2019; Renshaw & Gorman, 2015). This study analysed attempt-level data from over 100 athletes per event across twelve field events (female and male discus throw, hammer throw, javelin, long jump, shot put, and triple jump), recorded over four years (2022-2025). Exploratory analyses were conducted, and Bayesian hierarchical models were employed to predict performance and foul probability on each trial, accounting for the number of previous valid attempts and the outcome of the preceding attempt (interim best, foul or valid), with random effects for athlete and competition, and skewed performance distributions. Posterior distributions for all variable combinations were generated to provide population-level and athlete-specific predictions and to identify competition trends. Results revealed sequential dependencies between attempts, non-zero athlete-specific effects, and context-dependent and event-specific patterns in predicted performance and foul probability. For example, in trial 2 of throwing events, population-level predicted performance was lower if trial 1 was a foul, rather than a valid attempt. Identified patterns contribute to the understanding of competition strategy and multi-trial performance dynamics, while the application of athlete-specific probabilistic modelling has practical implications for athlete preparation and training design.

Keywords: performance analysis, Bayesian modelling, performance prediction, field athletics

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THE USE OF MATHEMATICAL MODELS TO PREDICT ATHLETIC PERFORMANCE IN MEN'S AND WOMEN'S 100M, 200M, 400M, LONG JUMP, HIGH JUMP, SHOT PUT AND DISCUS AT THE 2026 GLASGOW COMMONWEALTH GAMES

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Abstract
Prediction of future athletic performances for men and women athletes in sprints, jumps and throes events have been based on mathematical models using regression linear and nonlinear curve estimation methods. It is a common practice in sport science and frequently based on plotting the changes in world or international records or averaging the performances of event finalists from previous Olympic Games and athletic World Championships. The regression curve estimation models predominantly indicated cubic nonlinear models were the best fitting model across sprint, jump and throw events for men and women. However, it is interesting to observe these methods have only been minimally applied to performance prediction ultising Commonwealth Games data. The research aims and design were to partially replicate the research of the Heazlewood (2024) Mathsport publication based on the Summer Olympic Games data. However, in this 2026 research data from 1938 to 2022 Commonwealth Games was used to predict averaged performances based on first six finalists in events of men's and women's 100m, 200m, 400m, long jump, high jump, shot put and discus at the 2026 Glasgow Commonwealth Games. The regression functions assessed to best fit the data were linear, logarithmic, inverse, quadratic, cubic, compound, power, sigmoidal, growth, exponential and logistic. The results indicated men 100m was cubic R^2 =.926, women 100m cubic R^2=.920, men 200m cubic R^2=.737, women 200m cubic R^2=.679, men 400m cubic R^2=.708, women 400m cubic R^2=.736, men long jump cubic R^2=.818, women long jump cubic R^2=.877, men high jump cubic R^2=.720, women high jump cubic R^2=.904, men shot put cubic R^2=.916, women shot put cubic R^2=.866, men discus cubic R^2=.941 and women discus cubic R^2=.775. For all events $p<.001$ and small residuals. The mathematical models derived, that is the cubic regression functions are very similar and slightly less accurate to the models derived for the 2024 Paris Olympic Games. Predicted performances based on the cubic functions derived for 2026 Commonwealth Games are 100m men 10.11s, 100m women 11.27s, 200m men 20.31s, 200m women 22.26s, 400m men 44.67s, 400m women 50.64s, men long jump 8.05m, women long jump 6.58m, men high jump 2.25m, women high jump 1.89m, men shot put 20.67m, women shot put 18.91m, men discus 62.32m and women discus 63.81m. Results predicted minimal change from the 2022 Commonwealth Games performances in these events.

Keywords: Predicting athletic event performance, Commonwealth Games, mathematical modelling, linear and non-linear regression curve estimation, men and women athletes.

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A Decade of Deep Learning in Sports-Related Concussion Diagnosis: A Review of Neuroimaging Approaches (2016–2026)

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Abstract

Sports-related concussions, or mild Traumatic Brain Injuries (mTBIs), present a critical diagnostic challenge in competitive athletics. Traditionally, sports medicine has relied on subjective symptom checklists and conventional machine learning models built upon clinical scores to inform high-stakes "return-to-play" decisions. Because standard neuroimaging often appears visually normal following an mTBI, developing objective, imaging-based biomarkers has remained a persistent clinical hurdle.

This review synthesizes the pivotal transition over the last decade (2016–2026) from conventional machine learning to advanced deep learning (DL) architectures in sports concussion diagnostics. We examine how deep learning algorithms, particularly 3D Convolutional Neural Networks (CNNs) and deep metric learning frameworks, have revolutionized the analysis of complex neuroimaging modalities, including 3D CT, DTI, and functional MRI. Unlike early models that hit performance ceilings by relying on post-concussion symptomatology, modern representation learning directly extracts hierarchical micro-structural and functional anomalies from raw voxel data.

We highlight key milestones in the field, illustrating how advanced architectures are now being utilized to optimize highly sensitive feature spaces capable of isolating the subtle, non-linear structural disruptions characteristic of mTBIs. Furthermore, the review addresses current diagnostic bottlenecks, including the clinical translation of computational models, the need for robust generalization across diverse athletic populations, and the critical demand for exclusively imaging-driven diagnostic tools.

By mapping this ten-year trajectory, this paper demonstrates that the integration of deep learning and multimodal neuroimaging is shifting concussion assessment from a subjective clinical evaluation to a quantifiable, objective data science problem. Ultimately, these computational advancements are establishing the foundation for definitive, evidence-based return-to-play protocols that better safeguard long-term athlete neurological health.

Keywords: Machine Learning, Concussion, Neuroimaging, Mild Traumatic Brain Injury (mTBI)

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BPARC: Bilaterally Player-Aware Resource Compensation for Rain-Interrupted Limited-Overs Cricket Matches

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Abstract

Rain interruptions in limited-overs cricket force officials to revise the batting side's target. The current standard, Duckworth-Lewis Stern (DLS), adjusts targets based on remaining overs and wickets, but treats all players as interchangeable, every batter equally productive, every bowler equally threatening. In practice, top-order batters outscores tail-enders, and elite bowlers far outperform part-timers. Which specific players lose overs to rain directly determines whether a revised target is fair, yet DLS ignores this entirely. Player-aware Resource Compensation in Interrupted Cricket Matches (PRCICM partially addressed this by weighting individual batter quality into the resource model. It improves on DLS when strong or weak batting lineups are rain-affected, but models only one side of the game, which is bowling, receives no quality adjustment and leaves a structural fairness gap. This study introduces Bilaterally Player-Aware Resource Compensation (BPARC), which accounts for player quality on both sides simultaneously. This technique lowers the target where rain eliminates an elite bowler's remaining overs and vice versa for a weak bowler. A parallel mechanism governs batting quality on the chasing side. BPARC reduces exactly to DLS when player quality on both sides is average, guaranteeing it never distorts a fair outcome. The core contribution is a Bowler Quality Index (BQI) built via Multiple Linear Regression across seven phase-specific features: economy rate, wicket rate, dot-ball percentage, strike rate, powerplay economy, death-over economy, and consistency, derived from ball-by-ball data covering 8,157 ODI and T20I matches (2010–2024). Evaluated on 412 DLS-affected matches, BPARC outperforms both baselines against an independent fairness benchmark (MAE = 14.3 runs vs. 18.6 for PRCICM and 22.1 for DLS). Win margins under successful chases tighten significantly ($p = 0.021$), and BPARC diverges from DLS by more than three runs in 67.2% of matches, confirming that player identity materially shapes what a fair revised target should be.

Keywords: Cricket Analytics, Duckworth Lewis Stern, Rain Interruption, Target Revision, Bowler Quality Index, Resource Compensation, Limited-Overs Cricket

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CONNECTING THE DOTS: A MATHEMATICAL ANALYSIS OF BAZBALL

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Abstract
England's men's Test batting resurgence under "BazBall" is widely portrayed as an aggressive, boundary-driven shift in philosophy. Using ball-by-ball data from the 46 Tests following England's coaching change and a matched pre-period, we compare England, their opponents, and a contemporaneous control group. England's increased scoring rate is driven primarily by a substantial reduction in dot balls rather than by an increase in fours and sixes; the distribution of scoring shots shows little change. Across world cricket there is a small decline in dot-ball percentage over the same window consistent with historical variation, but England's dot-ball reduction exceeds ten percentage points and is far outside normal drift. England changed *when* they score, more than *how* they score. Using a survival-analysis framework, we demonstrate that the rise in England's batting average exceeds what would be expected from faster scoring alone. Although dismissal probability per ball rises, it increases too little to offset the higher expected score generated by more frequent scoring opportunities. Decomposing the change in average shows that most of the increase is due to reduced dismissal risk per scoring opportunity, suggesting an improvement in underlying batting quality, with only a minor contribution from boundary frequency. We observe similar but smaller effects in England's opponents while the control group shows little corresponding change, suggesting the phenomenon is specific to England matches rather than a global trend. The shift also increases decisiveness at match level: draws become rare, England's wins rise, and losses remain unchanged. Finally, we place these results in historical context: despite major changes in the game, Test cricket exhibits a self-regulating scoring/risk equilibrium, and how it adapts to BazBall remains an open question.

Keywords: cricket, survival modelling, batting, BazBall

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AN AUGMENTED RATING SYSTEM FOR TEST CRICKET: ADAPTING GLICKO'S MODEL

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Abstract
ICC's current ranking system does not adequately account for key contextual factors such as home advantage, toss impact and scheduling imbalances, leading to inconsistencies in team evaluation in Test cricket. This study develops an enhanced rating framework by adapting and enhancing Glicko's model to incorporate these influences, with an Elo-equivalent scaling factor (d=85) and incorporation of the Farlie-Gumbel-Morgenstern copula, alongside Margin of Victory, an important indicator of dominance in a contest. This enables a more dynamic and probabilistically grounded assessment of team performance. Using past match data, the model demonstrates improved expected score estimation and predictive accuracy during ICC World Test Championship cycles. Robustness of the resulting ratings is demonstrated through bootstrap resampling (average CV 0.44%, i.e. <0.5% of team ratings and a negligible standard deviation of 0.436 rating points), confirming stability with respect to match scheduling. Overall, the framework provides a fairer and more statistically consistent approach to ranking Test teams.

Keywords: Elo rating, Glicko's rating, Margin of Victory

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TOWARDS HYDRATION SENSING: A DIMENSION REDUCTION FRAMEWORK FOR IMPEDANCE SPECTROSCOPY DATA

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Abstract
Impedance spectroscopy is an emerging, non-invasive, wearable biosensing technology for real-time monitoring of biological signals such as the hydration status of athletes in training and competition (Armstrong, L. E. (2007)). WearOptimo's non-invasive microwearable applies alternating currents between pairs of electrodes across a wide range of excitation frequencies and measures the opposition to current flow, called impedance (Abasi, S. et al. (2022)). A key challenge in analysing data from the device is the high dimensionality of impedance measurements, which often requires dimensionality-reduction techniques to improve computational scalability, support exploratory analysis, and extract meaningful features. Often in bioimpedance frequency sweeps, the measured responses are strongly correlated across frequencies, enabling the data to be represented by a smaller set of variables that account for most of the information in the measurements (Grimnes, S., & Martinsen, Ø. G. (2015)). However, there can be nonlinear coupling between resistance and reactance over different frequencies, which are factors frequently overlooked in existing literature. This study develops and evaluates the suitability of several dimensionality-reduction approaches, including Principal Component Analysis (PCA), complex PCA, functional PCA, and related techniques. The serial and sparse nature of impedance measurements from low to high frequencies introduces additional challenge for dimension reduction. Potentially, two-dimensional splines that smooth over resistance and reactance over the frequency spectrum can be used in functional PCA to develop lower dimensional and explainable representations of impedance spectroscopy data. Demonstrated on electrical test circuit dataset, the evaluation considers theoretical assumptions, interpretability, and robustness in capturing the underlying impedance dynamics. Ongoing work aims to extend these methods to more complex media such as saline solution, along with modelling tools and model selection, contributing to the development of interpretable and informative models for next-generation wearable physiological monitoring systems.

Keywords: Impedance spectroscopy, dimension reduction, principal component analysis, microwearables

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Quantitative Modeling of Mental Health Improvement Through Aerial Sports Participation and Nutrition Awareness

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ABSTRACT

This research develops a quantitative model of mental health improvement associated with aerial sports participation and nutrition awareness, with implications for rehabilitation environment design. A mixed-method approach was employed, combining survey-based quantitative analysis with qualitative interviews. Key psychological and behavioural constructs were operationalized as measurable variables using ordinal and categorical scales. Survey responses were numerically encoded to enable statistical modelling. A composite indicator, termed the Mental Health Improvement Index (MHII), was constructed by aggregating variables related to stress reduction, perceived relaxation, and emotional recovery. Using 108 valid responses, a multiple linear regression model was estimated with MHII as the dependent variable and fear barriers, nutrition awareness, athlete status, and stress frequency as predictors. The results indicate that fear barriers and stress frequency exert significant negative effects on mental health improvement, whereas nutrition awareness has a significant positive influence. Athlete status was not statistically significant. These findings demonstrate that psychological recovery associated with aerial sports participation can be modelled quantitatively. Based on these results, environmental design principles are derived to reduce fear barriers, regulate stress exposure, and reinforce nutritional awareness within rehabilitation settings.

Keywords: applied mathematics, sport psychology modelling, mental health index, aerial sports

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PACE PROFILING IN MIDDLE-DISTANCE RUNNING: USING FUNCTIONAL DATA AND CLUSTERING TO UNDERSTAND HOW RACES UNFOLD

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Abstract
A key issue observed in major athletics championship middle-distance races is that athletes often don't achieve their season best performances, with the greater reliance on strategy and tactics required in championship racing seen as a possible contributing factor. To date, pace profiles which describe how an athlete exerts their effort across a race have been described by the shape of the speed-distance graph, often using terms like "all-out", "positive", "negative", "u-shaped" or "j-shaped" to classify the pace profile (Casado et al., 2021). Whilst this explains generally how races can unfold, it fails to capture some of the nuances within a race, for example different distances, genders or race types (paced vs unpaced). This research analyses middle-distance races across both major championship races (Olympic Games and World Championships) and regular season races (Diamond League) to better understand the pacing profiles that appear in these types of races and which pace profile types might lead to better athlete outcomes. The race split time series data was modelled as functional data, using functional Principal Component Analysis to map it to lower dimensional Principal Components (PCs) with associated mean profiles of pacing. Individual athlete performances were clustered based on their PC scores using Gaussian Mixture Modelling to identify different pace profiles which existed across the dataset. We found four major clusters of pacing profiles, and analysed contexts associated with them for the men's and women's 800m event. For instance, major championship races often differ from regular season races with different profiles seen for the two types of races. This information can be used by athletes and coaches to support training and strategic decisions, providing a better understanding of which pace profiles have historically led to better outcomes.

Keywords: Pace profile, middle distance running, functional data, clustering

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MATHEMATICAL MODELING OF ADAPTIVE PAYMENT RAIL SWITCHING IN HIGH-DEMAND SPORTS EVENTS

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Abstract

Major international events such as the Olympic Games, the FIFA World Cup, and other large-scale national competitions that attract crowds place significant pressure on payment systems. These events are characterized by sudden surges in demand, numerous transactions happening simultaneously, and strict availability requirements. If payments fail or are delayed, it can result not only in direct financial losses but also in serious social and reputational issues. This paper introduces DPOS (Dynamic Payment Optimization System), a flexible policy engine designed to improve payment system performance during high-demand events. These events often cause rapid increases in transaction volume that can overwhelm payment systems, leading to economic setbacks and damage to reputation if failures occur. DPOS addresses this by automatically switching between various payment methods, such as card networks and digital wallets, while optimizing for transactional risk, cost, and latency. It utilizes real-time system health monitoring and dynamic risk-budgeting to minimize losses during demand spikes. The framework includes components for signal collection, decision-making, secure execution of switches, and activity logging. Testing with real-world fraud data and network scenarios shows that DPOS significantly improves authorization success rates and reduces costs compared to traditional approaches, thereby enhancing operational resilience and regulatory compliance in high-throughput payment environments.

Keywords: DPOS, Payment systems, High-demand sporting events, Transaction optimization, Operational resilience

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PLAYER PERFORMANCE POINTER: A DATA ANALYTICS PERSPECTIVE INTO FOOTBALLER PERFORMANCE MEASUREMENT

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Abstract
Football experts debate whether successful teams should consist of eleven well-coordinated players or the best individuals for each position. Clubs are keen to find suitable players without overspending, making accurate player valuation crucial (Kuper and Szymanski, 2012). Several academic attempts have been made to address this challenge, recognizing that performance assessment is complicated by numerous factors. According to literature, player valuation encompasses market dynamics, socio-economic factors, actual performance parameters, and sports analytics capabilities (Cai, 2024). Also, a few situational variables affect the value – match location (home/away), competition stage (round-robin/knockout), quality of opposition, and match situation (Yi et al., 2020). Decision support systems (DSS) are now enhancing the accuracy and reliability of performance evaluations, although current football analytics often rely on aggregation methods rather than advanced analytical techniques (Goes et al., 2021).
This ongoing analytical study attempts to create an overarching indicator of player performance through a composite performance score derived from two analytical techniques: Principal Component Analysis (PCA) and Random Forest (RF). These scores combine multiple indicators for different broad positions - goalkeeper, defender, midfielder, and forward - into separate indices representing overall contribution for each position. From our dataset containing different indicators of 378 players, we found that both techniques show similar patterns, though the PCA-based scores show slightly higher variation. We calculated the mean PCA composite score (0.071) with a standard deviation of 0.095, while the RF mean composite score was 0.051 and a lower standard deviation of 0.060. This suggests that PCA differentiates players' performances more strongly, whereas in RF, there is a smoothing effect of the underlying ensemble learning algorithm. However, we still saw a correlation of approximately 0.915 between the PCA and RF performance indicators. Thus, the results demonstrated that both composite scoring frameworks provide a consistent and robust way to summarize player performance incorporating multiple indicators.

Keywords: player performance, data analytics, Principal Component Analysis, Random Forest

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MAPPING ARTIFICIAL INTELLIGENCE AND MACHINE LEARNING RESEARCH IN SPORTS INJURY PREDICTION: A BIBLIOMETRIC ANALYSIS

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Abstract

Recent advances in artificial intelligence (AI) and machine learning (ML) have increasingly influenced sports science, particularly in the prediction and prevention of sports-related injuries. Despite the growing number of studies applying computational models to injury prediction, a comprehensive understanding of the intellectual structure, collaboration patterns, and emerging research trends in this field remains limited. This study aims to provide a systematic overview of the evolution, current research landscape, and emerging directions of AI-driven sports injury prediction and prevention. A bibliometric analysis was conducted on scholarly publications retrieved from the Web of Science database. The analysis examines publication trends, influential authors, institutions, countries, collaboration networks, and thematic research clusters. The results reveal several notable patterns. Keyword co-occurrence analysis shows that recent studies increasingly focus on themes such as injury prediction, rehabilitation, risk factors, predictive modelling, and cost analysis, while earlier sport-specific terms such as basketball, accelerometer, and model appear less prominent. “Machine learning” and “football” remain among the most frequently occurring keywords. In terms of research productivity, China, Portugal, and the United States emerge as the leading countries, whereas highly cited contributions are associated with researchers from Brazil, China, and Greece. The geographical distribution of research has also evolved over time, with earlier studies primarily conducted in Australia, New Zealand, and Belgium, and more recent work increasingly involving scholars from Iran, Spain, and South Korea. Institutional analysis identifies Shanghai University of Sport as one of the most productive institutions in this field. Furthermore, co-authorship network analysis highlights strong collaborations among authors such as Afonso Pedro, Ricardo Ferraz, and Forte Pedro. By systematically mapping the knowledge structure of AI-driven sports injury prediction research, this study identifies emerging and underexplored areas and proposes directions for future research. The findings also provide practical insights for researchers, sports scientists, and decision-makers by clarifying dominant methodological approaches, collaboration patterns, and evolving priorities in the application of AI and machine learning to sports injury prevention.

Keywords: Artificial Intelligence; Machine Learning; Sports Injury; Bibliometric Analysis

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COULD ROGER FEDERER HAVE WON MORE GRAND SLAMS BY FOLLOWING A YOGA PROCESS?

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Abstract
Roger Federer was winning a higher percentage of points on serve than his opponent but still losing Grand Slam matches due to not winning the important/pressure points and hence some degree of 'choking'. As identified in the academic literature and based on the author's experiences, by following yoga processes Federer would have most likely won at least 4 more slams and potentially up to 10 more slams; and taken Federer to a total of 'possibly' 24 slams to put him somewhat 'on par' in total Grand Slams with Djokovic and Nadal (24 and 22 slams respectively). Given that every player has a certain level of anxiety, every tennis coach could adopt these yoga strategies amongst their coaching regimes (where players could be 'close' to being free of all anxieties known as Samadhi or Enlightenment and hence 'very little' choking on critical stages of the matches). These yoga processes are outlined in the paper and to achieve results it has been identified that at least 7 years and possibly up to 11 years of yoga processes are required by an individual athlete. Hence, talent identification is required at a young age.

Keywords: Yoga, Bhagavad Gita, enlightened, anxieties

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PREDICTIVE MODELS FOR SPORTS READINESS: A DATA-DRIVEN ANALYSIS OF COLLEGIATE FEMALE SOCCER PLAYERS

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Abstract

Female athletes are significantly underrepresented in sports medicine research, with only 9% of studies focused solely on women. To address this gap, we design and collect self-reported health data from collegiate female soccer players to analyze machine learning models that predict athlete readiness–a holistic measure of physical and mental preparedness to train or compete. Our best-performing model shows that Stress, Soreness, and Hip Flexors are the most critical factors influencing readiness, with linear regression models predicting a 2.89-point increase in readiness score per unit decrease in soreness, and logistic models that predict readiness scores with an accuracy of 87.78%. We further boost the accuracy to over 90% by analyzing athletes' individual profiles. This work underscores the potential of data-driven approaches to personalize training and recovery strategies, providing a critical tool for advancing female athlete health and performance while addressing gender disparities in sports science research.

Keywords: sports readiness, machine learning, data science, women soccer

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Scheduling Interclub squash leagues in New Zealand to improve player engagement

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For social (non-professional) squash in Aotearoa New Zealand, the interclub team competition is the backbone of grassroots participation. Most of the 11 districts in the country run some form of this competition during the squash season, with some running 3 or 4 leagues throughout the calendar year. Overall participation is declining though, with numerous player surveys indicating a variety of factors responsible for the decreasing numbers. However, these factors are not reported as problematic in all districts although a recurring theme seems to be travel time between clubs, particularly for those districts which are geographically large with multiple smaller country clubs involved. By utilising scheduling techniques available in the literature, we can design draws that ensure an equitable travel roster for clubs travelling long distances, whilst also enabling clubs entering multiple teams to have at least one of their other teams at home with them. This is demonstrated for the recent Autumn league completed in the Waikato region, where the automated draw is compared with the optimised draw and found to be lacking in those features. These results can be applied to other districts in the country and may help in ameliorating the decline in participation.

Keywords: Squash, scheduling, optimal tournament design

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A Data-Informed Framework to Classify and Analyse Pacing Profiles in Competitive Swimming

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Abstract
This research presents a novel framework for identifying and interpreting pacing profiles in elite swimming. Pacing is the deliberate distribution of energy resources during athletic performance to optimise outcomes and mitigate fatigue (Foster et al., 2003). In swimming, pacing involves managing energy expenditure and race strategy to complete the event in the shortest time possible (Abbiss & Laursen, 2008; Foster et al., 1994). Pacing has become widely accepted as important determinants of success (Skorski et al., 2013), and optimal strategies vary between individuals. High-resolution velocity data from international men's 100m ($n = 164$), women's 100m ($n = 150$), men's 200m ($n = 175$), and women's 200m ($n = 173$) freestyle events were analysed using functional data analysis for the ability to capture intra-lap variation in velocity, address autocorrelation in time series data, and account for variability in skill execution. Race data was then clustered using k-means, hierarchical, and Gaussian mixture modelling methods to learn quantitative definitions and parameters for pacing profiles. Outputs from multiple clustering algorithms were combined using Bayesian model averaging (Forbes et al., 2023), reducing clustering algorithm biases and accounting for pacing profile classification uncertainty by informing profile definitions with multiple latent structures. These analysis findings were interpreted as conventional pacing profiles – such as positive, even, and parabolic (Abbiss & Laursen, 2008; McGibbon et al., 2018) – by contextualising their observed characteristics, providing simple communication of analysis results to coaches and athletes and synergy with current swimming practices. Race time distributions were compared across clusters using non-parametric statistics, revealing that pacing strategy was associated with performance outcomes, with significant race time differences in the women's events. The framework demonstrated robustness across clustering algorithms and is adaptable to different swimming events and data resolutions. These findings provide coaches and practitioners with a reproducible, data-informed approach to characterising pacing strategies and optimising performance in elite swimming.

Keywords: Functional Data Analysis, Unsupervised Learning, Elite Sport Performance, Performance Analysis, Sports Data Science.

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UNDERSTANDING HOW TODAY'S OLYMPIC SWIMMING CHAMPIONS MAINTAIN THE VELOCITY OF PAST CHAMPIONS WHILE SWIMMING TWICE AS FAR, SUPPORTING FUTURE IMPROVEMENTS

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Abstract

This paper examines what today's Olympic swimming champions have accomplished compared to the past, as a guide to what the future could hold. Winning times were taken for the seven men's and seven women's 2024 Olympic swimming races, which were also contested at half the distance. The number of years from 2024 to the year when half the 2024 winning time at the longer distance last won at half the distance, gives the years it took for the 2024 Olympic champion to swim at the same velocity as the past champion, but twice as far. The overall averages were 50 years for men and 46 years for women. For the 2024 200m, 400m and 800m freestyle, women (52 years to 40 years) and men (60 years to 40 years) each took fewer years to double, at increasing distances. For the 200m backstroke, breaststroke, butterfly and freestyle, the breaststroke took the fewest years for women (40) and men (44), while the other three stokes each took 52 years for women and took 56 years for men at 2 stokes and 60 years for the other stroke. The difference appears to be drag-affected underwater motions for force application in the slower breaststroke verses above and below water leveraged motion for the faster strokes. For the 400m Individual Medley, women and men both took 40 years to double. Following the self-improvement meaning of Henri Didon's Olympic motto, *Citius, Altius, Fortius*, when young athletes get interested in swimming, they choose the methods of their day and try to improve, not being bound by past performances. Meanwhile, technicians improve methodologies shown by physics and kinesiology to improve velocity: nutrition, training, equipment, coaching and technique which, with the swimmer's philosophy of self-improvement, produces times that would have been thought unachievable 50 years ago.

Keywords: Swimming, Improved Performances, Physics, Kinesiology, Techniques Used for Improvement, Philosophy Used for Improvement,

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Massey Ratings for Match Outcome Prediction in Table Tennis: Evidence of Greater Stability than the ITTF World Ranking

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Abstract
Ranking systems that quantify player performance are fundamental to tournament operations, particularly for participation eligibility and seeding. In 2021, the international table tennis ranking system was restructured under the World Table Tennis (WTT) tour framework. However, the predictive performance of the current ranking system has not been quantitatively examined. This study evaluates whether the official WTT ranking points appropriately reflect player strength in terms of match outcome prediction performance. The authors model win probabilities using a three-parameter logistic model (3PLM), where the explanatory variable is the ratio of official WTT ranking points between two players. The model incorporates lower and upper win probability limits. Predictive performance is assessed using WTT match results from 2022 to 2025; Data from 2022 to 2024 were used for parameter tuning, while data from 2025 were reserved for performance evaluation. Evaluation metrics include, prediction accuracy (0.6693), log loss (0.8871), and Expected Calibration Error(ECE) (0.0192). The estimated 3PLM indicates a non-zero minimum win probability of approximately 0.201, suggesting that even players with zero or small ranking points retain a measurable chance of defeating top-ranked opponents. These results suggest that the official ranking system may underestimate lower-ranked players. For comparison, we evaluate Massey ratings, a point-differential-based rating method. Massey ratings were calculated using match results from the one-year period immediately prior to each prediction target match. The Massey model achieves predictive performance and calibration(accuracy: 0.7138, logloss: 0.8341, ECE: 0.0155) comparable to or exceeding that of the 3PLM. This robustness may reflect the ability of point-differential-based methods to mitigate instability in ranking point distributions during the post-restructuring transition period, characterized by substantial year-to-year variation in tournament frequency. Overall, our findings provide a quantitative assessment of the predictive validity of the current WTT ranking framework and highlight potential systematic biases in strength estimation.

Keywords: ITTF world ranking, World Table Tennis(WTT), Bradley-Terry model, 3-PLM, Massey rating

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Mathematical Modelling and Optimisation of Training Load Profiles to Maximise Performance.

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Abstract
Mathematical models of athletic performance describe how performance evolves in response to training impulses applied over time, Banister et al. (1975). Within the fitness–fatigue impulse–response framework, performance is represented as the sum of positive fitness effects and negative fatigue effects generated by daily training loads. Once such a model is specified, a natural question arises: how should a sequence of training loads be chosen to maximise performance at a specified target time? This leads to an optimisation problem over admissible training load profiles. If such optimisation procedures are to provide meaningful guidance for athletes and coaches, the resulting optimal programs should display qualitative characteristics commonly observed in elite training practice (see, for example, Stellingwerff (2012). These include submaximal training, gradual progression, periodisation, and a taper prior to competition. We first examine the Banister *et al.* (1975) fitness–fatigue impulse–response model, Banister et al. (1975), in which performance depends linearly on training load. In this setting, the optimal strategy is simple: train to the maximum admissible amount until the time at which the impulse response becomes negative and then cease all training, Ceddia *et al.* (2025). Although mathematically consistent, this behaviour differs markedly from real training programs. To address this discrepancy, we investigate several physiologically motivated nonlinear extensions of the impulse–response framework, including diminishing returns in the fitness response, fatigue feedback, and training-load–dependent changes in the impulse–response decay constants. Importantly, we also incorporate explicit injury-risk management within the optimisation framework. Together, these modelling elements substantially alter the structure of the optimal training load profile, producing training load profiles whose qualitative behaviour aligns more closely with those observed in elite athlete training load profiles.

***Keywords*:** Impulse–Response Model, Fitness, Fatigue, Injury Risk, Submaximal Load, Gradual Progression, Periodisation, Tapering

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DATA-DRIVEN PHILANTHROPY IN COMMUNITY SPORT: A PROPENSITY MODELLING FRAMEWORK FOR MEMBER ENGAGEMENT AND FUNDRAISING

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Abstract
Community sports clubs increasingly rely on philanthropic support to sustain facilities, youth development programmes, and volunteer-driven operations. However, most grassroots organisations operate with limited analytical capability and fragmented member data, constraining their ability to identify and engage potential donors effectively. This study presents a practical framework for applying data enrichment and propensity modelling to support targeted philanthropic engagement within community sport organisations.

The project was developed using membership data from Wellington Wanderers Cricket Club, one of New Zealand's largest and longest-standing kindred cricket clubs. The club maintains a large historical membership base including current players, former players, parents, supporters, and alumni. Like many amateur sporting organisations, the available data exhibited typical quality issues, including incomplete records, inconsistent formatting, and limited behavioural indicators.

The first stage of the project involved data cleaning and consolidation, creating a structured member database suitable for analysis. The second stage introduced data enrichment through publicly available web sources, adding contextual variables such as professional background, geographic information, and inferred engagement indicators. These enriched datasets were then used to construct a propensity model designed to estimate the likelihood that individual members would contribute to a targeted philanthropic campaign.

The modelling framework emphasised interpretability and practical deployment rather than algorithmic complexity. Key predictors included historical club engagement, social connectivity, and externally derived indicators of capacity and affinity. The resulting models produced a list of members with estimated likelihoods of various philanthropic participation, enabling targeted outreach and more efficient fundraising strategies.

Beyond the specific case study, the work proposes a generalizable framework for data-driven philanthropy in community sport, demonstrating how relatively simple analytical tools can substantially improve fundraising effectiveness. The approach highlights the importance of data quality, external data enrichment, and transparent modelling techniques in supporting financially sustainable grassroots sport ecosystems.

This research contributes to emerging work at the intersection of sports analytics, sport management, and community sport sustainability, offering a practical pathway for small sporting organisations to leverage modern data science methods for philanthropic engagement.

Keywords: Propensity score modelling, Data enrichment, Predictive analytics, Non-profit fundraising analytics

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SEQUENTIAL TACTICAL OPTIMISATION IN INVASION SPORTS: A REGRET-BASED AND QUBO FORMULATION

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Abstract

Decision-making in invasion sports such as rugby union, football, and basketball occurs as a sequence of tactical choices made under rapidly changing spatial and temporal conditions. During possession, teams repeatedly select between actions such as passing, carrying, or kicking while operating under defensive pressure and incomplete information. Although sports analytics has produced substantial advances in modelling match outcomes and evaluating individual events, relatively little research has examined how sequences of tactical decisions can be analysed and optimised within a unified mathematical framework.

This paper introduces a general framework for sequential tactical optimisation in invasion sports. Gameplay is modelled as a sequence of decision states defined by contextual variables such as field position, possession status, and match time. At each state, the team in possession selects from a discrete set of feasible tactical actions. An expected-value model is used to estimate the potential reward associated with each action, incorporating factors such as scoring probability, turnover risk, and territorial progression.

To evaluate decision quality independently of realised outcomes, the framework introduces regret-based metrics, defined as the difference between the expected value of the optimal action and the action actually chosen. This allows analysts to identify sub-optimal tactical decisions even when the observed outcome appears favourable, providing a principled way to assess decision-making under uncertainty.

To explore optimal decision sequences across multiple phases of play, the tactical decision problem is formulated as a Quadratic Unconstrained Binary Optimisation (QUBO) model. In this representation, binary variables correspond to candidate actions at each decision step, while constraints enforce feasible tactical structures such as selecting a single action at each state. The resulting formulation transforms the tactical planning problem into a combinatorial optimisation problem that can be solved using classical optimisation techniques or emerging quantum optimisation methods.

A proof-of-concept application in rugby union demonstrates how the framework can reveal patterns of tactical inefficiency and identify higher-value sequences of play. The proposed approach provides a bridge between sports analytics and modern optimisation methods and offers a general foundation for analysing sequential decision-making across invasion sports.

Keywords: Sequential optimisation, Energy minimisation models, Multi-stage optimisation

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A DYNAMIC COLLECTIVE MOTION FRAMEWORK FOR QUANTIFYING CONTROL IN INVASION SPORTS

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Abstract
Quantifying control and momentum in invasion sports remains a complex analytical challenge. Earlier spatial approaches introduced the concept of estimating collective concentration to describe where play is occurring at a given time. While such methods provided useful territorial summaries, they did not explicitly model the directional flow, structural coherence, or temporal stability of coordinated movement that underpin shifts in control.

This paper introduces Action Gravity, a dynamic framework that conceptualises play as a continuous collective motion field defined over space and time. Rather than treating control as a static spatial locus, the framework interprets coordinated player movement as generating directional gradients and density structures that evolve throughout a match. Momentum is reframed as an emergent property of these collective motion patterns rather than as a function of discrete events or possession states.

Using broadcast-derived positional data from rugby union, we illustrate how Action Gravity distinguishes between territorial occupation and effective attacking launch conditions, identifies structural compression and expansion phases, and detects late-game fragmentation associated with tempo disruption. These phenomena align with observable tactical shifts while providing additional insight beyond conventional possession or territory metrics.

The framework is sport-agnostic and does not rely on specialised tracking hardware, supporting application across invasion sports contexts. By extending earlier spatial concentration concepts into a dynamic motion-field interpretation, this work establishes a platform for future predictive and optimisation research while preserving methodological flexibility.

Keywords: Spatio-temporal dynamics, Collective behaviour modelling, Spatial interaction systems

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EVALUATING TACTICAL DECISION QUALITY IN RUGBY UNION USING REGRET-BASED METRICS

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Abstract
Rugby union is characterised by rapid tactical decision-making under uncertainty. During open play, players must repeatedly choose between alternative actions such as passing, carrying, or kicking while operating under defensive pressure and incomplete information. Traditional performance analysis evaluates these actions primarily through their outcomes, such as metres gained, turnovers, or scoring events. However, outcome-based statistics do not necessarily reflect decision quality, as favourable outcomes may arise from sub-optimal decisions and optimal decisions may fail due to defensive pressure or stochastic events.

This paper introduces a decision-evaluation framework for rugby union based on regret metrics, a concept widely used in sequential decision theory but rarely applied in sport analytics. The framework models each in-play moment as a decision instance defined by contextual state variables such as field position and game state, together with a discrete set of feasible tactical actions. An expected-value model estimates the outcome potential associated with each action. Regret is then defined as the difference between the expected value of the optimal action and the action actually chosen.

Using this formulation, the framework identifies moments in which teams sacrifice expected value through sub-optimal tactical choices. Importantly, this approach separates decision quality from realised outcomes, allowing analysts and coaches to evaluate tactical judgement independently of random or uncontrollable match events.

A case study using integrated event and tracking data demonstrates how regret metrics reveal hidden patterns of decision inefficiency across field zones and match contexts. Visualisation tools are used to illustrate how these insights can support post-match review and coaching feedback.

The proposed framework shifts rugby analytics from outcome evaluation toward decision evaluation, providing a quantitative basis for analysing tactical choices. Beyond rugby, the approach offers a general method for analysing decision quality in invasion sports and other dynamic environments characterised by sequential decision-making.

Keywords: Sequential decision theory, Expected value modelling, Game-state modelling

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GLOBAL OPTIMISATION OF TACTICAL DECISION SEQUENCES IN RUGBY UNION VIA QUBO FORMULATION

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Abstract
Decision-making in rugby union occurs as a sequence of tactical choices made under rapidly changing game conditions. At each moment in possession, teams must select among alternative actions such as passing, carrying, or kicking. While previous work has used statistical models to evaluate individual actions, little research has explored how entire sequences of tactical decisions can be optimised.

This paper introduces a combinatorial optimisation framework for modelling rugby decision sequences using Quadratic Unconstrained Binary Optimisation (QUBO). In this formulation, each potential action at a given decision step is represented by a binary variable. The objective function captures the expected tactical value associated with each action, while constraints enforce feasible decision structures, such as selecting exactly one action at each step. The resulting QUBO representation transforms the tactical planning problem into a discrete optimisation problem that can be solved using classical heuristics or quantum annealing techniques.

The approach allows analysts to explore alternative sequences of actions that maximise expected tactical value across multiple phases of play rather than evaluating decisions in isolation. By modelling the combinatorial structure of decision sequences, the framework highlights how short-term tactical choices influence downstream opportunities and risks.

A proof-of-concept experiment demonstrates the formulation of rugby decision sequences as QUBO problems using context variables such as field position and game state. The resulting optimisation solutions illustrate how alternative action combinations can produce higher expected value than those observed in match data.

This work represents one of the first applications of QUBO-based optimisation to tactical decision analysis in sport. The framework provides a new bridge between sports analytics and modern optimisation techniques, including emerging quantum computing approaches. More broadly, the methodology demonstrates how complex sequential decision problems in dynamic environments can be reframed as combinatorial optimisation tasks suitable for advanced computational methods.

Keywords: Combinatorial optimisation, Energy-based optimisation, Quantum-inspired algorithms

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COMPETITION DEPTH AND REPRESENTATIVE PERFORMANCE IN RUGBY UNION: EVIDENCE FROM NEW ZEALAND'S NPC

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Abstract

The structure of domestic competitions plays an important role in shaping both player development pathways and representative performance in team sports. In rugby union, debates frequently arise regarding the optimal size of elite club competitions, with arguments often framed around competitive quality, participation, and administrative simplicity. However, relatively little empirical work has examined how the depth of domestic club competitions relates to representative team performance within a regional rugby ecosystem.

This study investigates the relationship between the number of premier-level clubs within New Zealand provincial unions and the performance of those unions in the National Provincial Championship (NPC). NPC standings across the most recent four completed seasons were used to derive an average finishing rank for each of the fourteen participating unions. Competition depth was measured as the number of clubs competing at the top level of each union's domestic structure.

A simple comparative analysis shows a strong negative relationship between competition depth and representative finishing rank, indicating that unions with deeper premier competitions tend to perform better in NPC competition. When structural features of certain provincial ecosystems are considered, for example the existence of parallel premier competitions in some regions or additional top-tier competitions feeding metropolitan structures, the strength of the relationship increases further.

While correlation does not establish causation, the observed pattern is consistent with established sports economics and talent-development theory suggesting that broader competitive bases can strengthen elite performance by increasing player development opportunities and raising competitive standards. The findings also raise important questions for sport administrators considering structural contraction of elite club competitions.

More broadly, the study highlights the value of simple quantitative analysis in informing governance and competition design decisions in sport, particularly where structural changes may have long-term consequences for player pathways, competitive balance, and regional performance outcomes.

These results contribute to the growing literature on competition design and performance systems in invasion sports, and provide an empirical starting point for further work linking competition structure, player development pathways, and economic sustainability in rugby union.

Keywords: Competition structure analysis, Sports economics, Competitive balance

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GLOBAL OPTIMISATION OF LATENT POSSESSION SEQUENCES IN RUGBY UNION VIA QUBO FORMULATION AND QUANTUM ANNEALING

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Abstract
Ball possession in Rugby Union is typically treated as a frame-wise classification problem derived from manual annotation or ball-tracking systems. However, possession is inherently a temporally persistent and spatially structured latent state, where transitions occur under tactical and territorial constraints. Frame-independent models fail to enforce global consistency across phases of play and may produce spurious rapid transitions during contested breakdowns.

In this study, possession inference is reformulated as a global binary optimisation problem over an entire match segment. Let $z_t \in \{0,1\}$ denote the latent possession state at frame t. We construct an energy function that integrates (i) longitudinal territorial alignment derived from team centroid position, (ii) collective spatial dispersion and wandering metrics, (iii) region-specific interaction effects, and (iv) temporal transition penalties that discourage implausible rapid state switches. The objective is to infer the possession sequence $\{z_1,\ldots,z_T\}$ that minimises total system energy under these spatial and temporal constraints.

This optimisation problem is expressed in Quadratic Unconstrained Binary Optimisation (QUBO) form, enabling a solution via both classical simulated annealing and quantum annealing hardware. The QUBO formulation captures pairwise temporal coupling between adjacent frames, creating a globally coherent possession trajectory rather than independent frame predictions.

Using player tracking data extracted from broadcast footage, we compare the proposed global optimisation framework against Random Forest and Hidden Markov baseline models. Results demonstrate improved phase consistency, reduced transition volatility, and competitive discriminative performance (AUC) while enforcing tactical plausibility across extended possession sequences.

This work reframes possession as an emergent, energy-minimising spatial state rather than a ball-centric event label. The proposed QUBO framework provides a principled bridge between sports analytics and combinatorial optimisation, illustrating how quantum annealing may support structured inference in temporally coupled invasion sport systems.

Keywords: Binary quadratic optimisation, Temporal state estimation, Simulated annealing methods

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POSSESSION WITHOUT THE BALL: LATENT-STATE INFERENCE FROM COLLECTIVE MOVEMENT IN RUGBY UNION

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Abstract
Ball possession is a fundamental descriptor of tactical control in Rugby Union, yet it is typically obtained through manual annotation or specialised ball-tracking systems that are expensive and often unavailable outside elite environments. This study investigates whether possession can be inferred as a latent game state using player tracking data alone.

Using frame-level two-dimensional coordinates extracted from broadcast footage, we construct interpretable spatio-temporal descriptors of collective team behaviour, including centroid location, spatial dispersion, wandering metrics, movement dynamics, and temporally smoothed trajectory features. Local extrema of formation spread are incorporated as phase-transition indicators, and spatial context is modelled via longitudinal and lateral pitch segmentation. Possession labels are manually annotated for supervision but no ball-tracking information is used in model construction.

Random Forest classifiers are trained under both global and region-specific modelling frameworks. The global model achieves an accuracy of 76.2% and an AUC of 0.836, with repeated random-split validation yielding a mean AUC of 0.867 (±0.057), demonstrating stable discriminative performance. Region-specific models reveal substantial spatial heterogeneity, with the central interaction zone achieving an AUC of 0.964, indicating that possession signals are strongest in territorially structured areas.

Variable importance analysis shows that longitudinal centroid position and smoothed territorial occupation dominate predictive performance, reinforcing the fundamentally territorial nature of possession in Rugby Union. Lateral dispersion contributes additional discriminative value, while instantaneous movement features play a secondary role.

These findings demonstrate that possession can be inferred from collective spatial organisation without explicit ball tracking, providing a scalable framework for automated performance analysis in rugby and other invasion sports where ball trajectories are unavailable. The study reframes possession as an emergent property of coordinated team movement rather than a purely ball-centric event.

Keywords: Machine learning classification, Spatial behaviour modelling, Spatio-temporal feature extraction

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DESIGNING A DATA AND MODELLING FRAMEWORK FOR RUCK OUTCOME ANALYSIS IN RUGBY UNION

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Abstract
Rucks are among the most frequent and strategically decisive events in rugby union, yet they remain comparatively under-modelled within performance analysis. This paper develops a structured data and modelling framework for analysing ruck outcomes, with particular emphasis on turnover prediction and tactical feasibility.

We synthesise existing literature on ruck performance to identify key determinants of success, including player-entry numbers, arrival timing, spatial location, advantage-line progression, and ball-carrier technique. Building on this foundation, we propose a scalable ruck data schema designed for predictive modelling and optimisation. The framework restructures traditional long-format ruck data into a team-centric wide format, normalises field orientation relative to attacking direction, and formalises imbalance metrics and spatial encodings suitable for quantitative analysis.

To demonstrate feasibility, we outline how logistic regression can be used to model ruck turnover probability and discuss extensions toward interaction terms and combinatorial structures. We identify variables unsuitable for real-time prediction (e.g., future-event indicators) and propose additional features for collection, including entry speed, ball-placement classification, and defensive proximity measures.
An interactive visualisation tool is introduced to support exploratory ruck analysis, linking player positions and join decisions to spatial context. Throughout, emphasis is placed on embedding tactical feasibility within modelling structures to ensure that statistically optimal recommendations remain operationally realistic.

This paper provides a comprehensive foundation for systematic ruck modelling in rugby union and establishes a structured pathway from video-derived event data to predictive and optimisation-based decision systems. The framework is designed to scale with richer tracking data and offers a platform for future integration with advanced optimisation methods.

Keywords: Event data modelling, Feature engineering, Predictive modelling

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REFORMULATING LOGISTIC CLASSIFICATION MODELS AS QUADRATIC OPTIMISATION PROBLEMS: A QUANTUM ANNEALING FRAMEWORK FOR TACTICAL DECISION MODELLING IN RUGBY

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Abstract
Recent advances in quantum annealing have expanded the range of optimisation problems that can be expressed and solved in quadratic binary form. In sport analytics, however, most predictive models remain framed as probabilistic classification tasks rather than energy minimisation problems. This paper establishes a structural bridge between these two paradigms by demonstrating how logistic regression models with binary predictors can be reformulated as Quadratic Unconstrained Binary Optimisation (QUBO) problems suitable for quantum annealing.

Using ruck turnover prediction in rugby union as a motivating case study, we show that the log-odds function of a logistic model can be directly mapped to a QUBO energy function when predictors are appropriately discretised. Linear coefficients correspond to QUBO linear terms, and interaction effects naturally generate quadratic couplings. We further extend the framework to Constrained Quadratic Models (CQMs), enabling integer and continuous decision variables with feasibility constraints via hybrid classical–quantum solvers.

Due to limited structured ruck data, open-source soccer "phases of play" data were used to prototype the optimisation pipeline. Exact classical solvers were employed to validate structural feasibility in the absence of quantum hardware access. Results confirm that turnover probability minimisation can be equivalently expressed as energy minimisation. However, unconstrained optimisation may yield tactically infeasible solutions, highlighting the necessity of embedding domain-specific constraints.

This work does not claim computational advantage over classical methods. Rather, it provides a formal mathematical pathway for transforming predictive sport models into quadratic optimisation problems. The framework establishes a foundation for future research into real-time tactical optimisation in invasion sports using hybrid and quantum solvers, and contributes to the growing intersection between applied mathematics, combinatorial optimisation, and performance analytics.

Keywords: Logistic Regression, Hybrid optimisation methods

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EVENT-LEVEL TURN DETECTION AND SPLIT-TIME ESTIMATION FROM SINGLE-CAMERA BRONCO TEST FOOTAGE USING ANCHOR-BASED STABILISATION AND PROBABILISTIC SMOOTHING

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Abstract
Accurate split-time measurement in repeated shuttle tests such as the Bronco is central to performance monitoring in rugby and other team sports. While timing gates and wearable sensors provide high precision, their cost and deployment complexity limit routine use in field-based training environments. Single-camera video offers a scalable alternative; however, handheld recordings introduce camera motion, detection noise, and trajectory fragmentation that can degrade event-level timing accuracy.

This study presents an event-centric computational framework for automated turn detection and split-time estimation from single-camera Bronco Test footage. The pipeline integrates (i) anchor-based video stabilisation using a stationary reference object, (ii) Kalman filtering and Rauch–Tung–Striebel smoothing for probabilistic trajectory refinement, (iii) velocity-based principal component analysis to extract a one-dimensional motion signal aligned with the dominant running axis, and (iv) extremum detection with velocity sign-change refinement for precise turn localisation.

Three stabilisation strategies—template matching via normalized cross-correlation (NCC), deep learning–based anchor detection (YOLO), and a hybrid NCC–YOLO approach—are compared against manually annotated frame-level ground truth under both handheld and fixed-camera conditions. Results show that hybrid anchor tracking yields the lowest aggregate turn-detection error. Under handheld recording, mean absolute error in turning time is approximately 4 frames (≈0.13 s at 30 fps), compared to 3.4 frames (≈0.11 s) for fixed-camera footage. Far turns exhibit greater variability due to scale reduction and detection degradation at distance, while near turns remain consistently accurate.

These findings demonstrate that timing-accurate event detection is feasible from unconstrained handheld video when stabilisation and probabilistic smoothing are appropriately integrated. The framework provides a mathematically grounded, low-cost alternative for split-time analysis in applied sport settings and establishes a foundation for broader single-camera performance analytics in field-based testing.

Keywords: Computer vision, Trajectory estimation, Video stabilisation, Time-series smoothing

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MEASURING EXCITEMENT IN THE CLOSING STAGES OF THE MASTERS GOLF

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Abstract

This paper develops a probabilistic framework for measuring excitement and surprise in the closing stages of the Masters Golf Tournament. Excitement is defined as the expected magnitude of the change in a player's probability of winning the tournament resulting from the next event, such as the completion of a hole. Using forward recurrence methods and realistic birdie, par and bogie probabilities for leading players, the model evaluates how winning probabilities evolve as the final holes are played. Illustrative examples show how excitement increases when multiple players remain in contention and how course characteristics influence this dynamic. A complementary measure of surprise is also introduced to quantify the retrospective impact of unusual outcomes. The approach allows excitement to be updated continuously during play and has potential applications for broadcast analytics and real-time commentary.

Keywords: Excitement, golf, recursive probabilities

COMPUTER VISION FOR HORSE RACING ANALYSIS AND ADJUDICATION

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Submitted for consideration as (select one):

- ☒ Oral presentation – Bedford to present
- ☐ Poster

Abstract

Horse racing adjudication currently depends on manual video review by stewards, a process that is subjective, inconsistent, and open to challenge. Over four successive project iterations, we have progressively developed a computer vision pipeline for detecting and tracking individual horses in broadcast race footage, building toward automated support for steward decisions. Early work established a systematic literature review identifying occlusion, camera motion, and annotation cost as the primary barriers to reliable horse tracking. Initial prototypes using YOLOv11 detection, SAM2 segmentation, and Kalman filtering demonstrated feasibility but suffered from frequent identity loss and limited scalability, with fewer than 600 manually annotated frames available for training. In the most recent completed iteration, we migrated detection to a YOLOv12 model fine-tuned on 1,500 labelled race images, achieving 68 frames per second with substantially improved detection confidence in a quantitative evaluation against prior baselines. Tracking was upgraded to BoT-SORT with a custom-trained ResNet-50 re-identification model, reducing but not eliminating identity switches in multi-horse sequences. These results indicate that detection consistency is a critical factor in reducing tracking fragmentation in dense racing scenarios. Instance segmentation was evaluated using both YOLO-Seg and SAM2, establishing a practical speed–accuracy trade-off between the two approaches. A centroid-based speed estimation prototype was demonstrated in relative pixel units. Current work focuses on expanding the training dataset through automated labelling with foundation models, retraining detection models on this larger corpus, and conducting a fair local comparison between YOLOv12 and RF-DETR architectures. The expanded pipeline is being evaluated on complete race footage, working toward trajectory-based analysis of horse proximity and lateral movement relevant to protest adjudication. This enables quantitative analysis of horse interactions during race incidents.

Keywords: Computer Vision, Horse Racing, Multi-Object Tracking, Object Detection, Segmentation, Adjudication, Artificial Intelligence, Sport, Analysis

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