15th International Symposium on Computer Science in Sport IACSS 2025

September 12 - 15, 2025

Tokyo Gakugei University
Tokyo, Japan

Abstract Book

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15th International Symposium on Computer Science in Sport

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Keynote & Symposium

Keynote I

Technology Meets Pedagogy: Advancing Effective Teaching and Learning in 21st-Century Physical Education and Sport

Koh Koon Teck
Nanyang Technological University

Abstract

The integration of technology with pedagogy is transforming teaching and learning in physical education and sport (PES) in the 21st century. When thoughtfully embedded within instructional frameworks, technologies such as video analysis tools, wearable trackers, systematic observation instruments, and digital learning platforms enhance not only student engagement and learning outcomes but also the effectiveness of teachers and coaches. This pedagogical-technological synergy supports data-informed instruction, facilitates personalized and differentiated learning, and promotes active, reflective, and student-centered practices.

For educators and coaches, technology enables new avenues for real-time feedback and evidence-based reflection, fostering more efficient planning, implementation, and evaluation of practices. By aligning technological tools with sound pedagogical principles, PES professionals can create more inclusive, engaging, and impactful learning environments that address the diverse needs of 21st-century learners.

This presentation highlights key features and strategies from several completed projects, illustrating the "what" and "how" of integrating technology with pedagogy to transform teaching and learning in PES. Implications for teacher and coach professional development, practice, and policy—particularly in the context of adult learning—will also be discussed.

Keynote II

A Challenge to Data-driven Physical Education: The Values of Sports Analytics as Teaching Materials and the Role of Data Science

データ駆動型体育教育への挑戦：スポーツアナリティクスの教材としての価値とデータサイエンスの役割

Hirotaka Jo
Shizuoka Sangyo University

Abstract

Physical education in schools aims not only to develop motor skills and improve physical fitness, but also to deepen students' understanding of the principles behind movement and sports, and to foster collaborative learning. To achieve these goals, educators must design instruction and provide teaching materials that enhance the quality of learning.

In recent years, teaching materials that incorporate ICT and EdTech have made significant strides, mirroring advances in hardware and software used in the broader field of sports. These innovations offer enormous potential—not only supporting active learning and STEAM education, but also contributing to social and emotional learning (SEL).

However, several challenges remain in effectively integrating ICT and EdTech into physical education. These include the risk of over-reliance on tools, potential reduction in physical activity due to device usage, and financial limitations that hinder sustainable implementation in schools.

This presentation introduces a practical case study in which teachers use objective data collected through sports analytics to enrich learning in physical education. We will highlight the pedagogical value of ICT and EdTech when treated not just as tools, but as teaching materials, and discuss the essential role that data science and computer science can play in realizing data-driven physical education.

学校における体育教育の目的は、運動技能を発達させ、体力を向上させるだけでなく、運動やスポーツの背後にある原理の理解を深め、協調的な学習を促進することである。これらの目標を達成するために、教師は学習の質を高める指導を設計し、教材を提供しなければならない。

近年、ICTやEdTechを取り入れた教材は、幅広いスポーツ分野で使用されているハードウエアやソフトウエアの進歩を追うように、大きな発展を遂げている。これらのイノベーションは、アクティブラーニングやSTEAM教育をサポートするだけでなく、社会性と情動の学習（SEL）にも貢献するなど、大きな可能性を秘めている。

しかし、ICTやEdTechを効果的に体育教育に取り入れるには、いくつかの課題が残されている。それは、ツールへの過度の依存のリスク、デバイスの使用による身体活動の低下の可能性、学校での持続可能な導入を妨げる財政的制約などである。

本発表では、スポーツアナリティクスを通じて収集された客観的データを活用し、教師が体育教育の学習を充実させる実践事例を紹介する。また、ICTとEdTechを単なる道具としてではなく、教材として扱う場合の教育的価値を確認し、データ駆動型体育教育の実現にデータサイエンスとコンピュータサイエンスが果たすことのできる本質的な役割について議論する。

Keynote III

The Role of Footwear and Playing Surface Interaction in Sports Performance: Insights from Biomechanical Data Analysis

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Universiti Teknologi MARA

Abstract

Footwear and playing surfaces are critical determinants of athletic performance, with their interaction exerting a significant influence on biomechanics, perceived comfort, and injury risk. The integration of advanced data analysis techniques within biomechanical research is essential for identifying patterns and relationships that underpin performance optimization and injury mitigation strategies. The demands of each sport necessitate a sport-specific pairing of footwear and surface to maximize performance outcomes and minimize hazards such as slips and falls. Footwear is engineered to deliver support, stability, and impact attenuation in alignment with the functional requirements of specific sporting activities. For instance, soccer footwear is designed to enhance traction during rapid directional changes, whereas shoes for court sports prioritize lateral stability and surface grip. Similarly, the type of playing surface, ranging from natural grass and artificial turf to hardwood and synthetic composites, modulates the mechanical interaction between the athlete and the ground, thereby affecting movement dynamics and force transmission. Notably, discrepancies between surface types, such as those between natural and synthetic turf, can alter shoe-surface interaction and athlete perception, with implications for both performance and safety. This keynote will present a series of studies based on mechanical and biomechanical data, elucidating the complex interactions between footwear and playing surfaces. Emphasis will be placed on empirical findings across various sports, including soccer, futsal, and court-based disciplines, to illustrate how these interactions shape athletic outcomes.

Keynote IV

Beyond Quantity: Value-Driven Data Strategy for Elite Athlete Empowerment

Ozaki Hiroki
Japan Institute of Sport Science

Abstract

At the Japan Institute of Sports Science (JISS), multidisciplinary teams of experts in biomechanics, exercise physiology, sports psychology, nutrition, and conditioning provide comprehensive scientific support across various sports.

Recent advancements in compact, high-precision devices have made it easier to collect extensive kinematic and conditioning data, not only during training but also in competition. This influx of data presents significant opportunities for athlete development.

However, elite athletes must also possess the crucial ability to self-sense and regulate their movements, physical condition, and psychological state. Simply providing raw device data risks hindering this self-regulation. Therefore, a strategic approach to data feedback is vital to nurture, rather than inhibit, their intrinsic awareness and adaptive skills. Moreover, key to implementing sport science support is clarifying which performance elements the data aims to improve and ensuring data collection doesn't disrupt coaching or training.

This keynote will highlight an example of JISS's integrated support model. It will then delve into our internal discussions on analyzing vast device data, deciding which data to present to athletes and coaches, who should explain the data and how, and when and what data should be delivered.

Symposium I

Developing a Curriculum for Remote Physical Education: International Practices and Future Directions

Ediz Kaykayoglu[1], Naoki Suzuki[2], Toshihiro Nakashima[3], Koji Murase[4] & Seiji Okuma[5]

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[4] Wakayama University

[5] Tokyo International University

Abstract

The accelerated adoption of remote education due to the COVID-19 pandemic presented significant challenges, particularly for physical education (PE), a subject traditionally reliant on physical interaction and direct instruction. In response, educators and researchers worldwide have explored innovative solutions for remote physical education, transforming these challenges into opportunities for curriculum development.

This symposium, moderated by Dr. Ediz Kaykayoglu, CEO of BEAK, will showcase successful international cases, each providing unique insights into remote PE curriculum design and delivery. By examining diverse educational levels, regions, and cultural contexts, this session aims to highlight effective strategies and propose directions for future curriculum enhancement.

1) Dr. Naoki Suzuki (Tokyo Gakugei University, Japan) will introduce his collaborative project involving high schools in Japan and the Philippines. His presentation will emphasize the integration of virtual reality (VR) and metaverse platforms into PE curricula, highlighting how cross-cultural online interaction can positively influence student engagement and identity through the "Proteus Effect."

2) Dr. Toshihiro Nakashima (Hokkaido University of Education, Japan) will discuss his remote PE practices across multiple locations in Hokkaido. He will illustrate the development of curriculum models adapted to regional characteristics, student autonomy, and teacher collaboration facilitated by digital technology.

3) Prof. Koji Murase (Wakayama University, Japan) will present remote PE practices tailored for early childhood education. His session will explore practical approaches to conducting online physical activities, emphasizing motor development, active participation by families, and creative instructional methods designed specifically for young learners.

4) Prof. Seiji Okuma (Tokyo International University, Japan) will highlight collaborative remote PE initiatives between Japan and Indonesia. His analysis will focus on curriculum co-design, mutual understanding, and intercultural sensitivity fostered through shared online physical education experiences.

Following the presentations, Dr. Kaykayoglu will facilitate a comprehensive discussion addressing the current challenges and emerging opportunities in remote PE curriculum design. The panel will explore strategies to ensure accessibility, inclusivity, cultural relevance, and technological innovation, ultimately aiming to improve the quality of remote physical education worldwide. This symposium offers valuable insights for educators, curriculum developers, and researchers seeking to leverage international and intercultural perspectives to enhance future PE curricula.

Symposium II

Sports Analytics (Teaching and Research at the Intersection of Computer Science & Sports Science) - Bridge Professorship Computer Science & Sports Analytics

Pascal Bauer[1], Martin Lames[2], Arnold Baca[3], Matthias Kempe[3] & Luis Holzhauer[1]

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[2]Technische Universität München
[3]University of Vienna

Abstract

The establishment of joint professorships at the interface of sport science and computer science marks a key step toward developing new curricula and fostering interdisciplinary research. This session would highlight best practices and future opportunities for institutionalizing sports analytics in higher education, including discussions on how to effectively teach data literacy and computer science (e.g. data-science and machine learning) skills to sport science students and/or provide application knowledge to computer/data science students.

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Theme:
Visual Analysis

Code 27

Design of Virtual Tennis Courts and Spectators

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Abstract

Constructing a highly realistic virtual tennis court and creating an immersive court atmosphere can significantly enhance tennis players' psychological adaptability and anti-interference capabilities in international competitions, as well as facilitating the full utilization of their technical and tactical skills.With the advancement of computer graphics technology, the developmental achievements of digital humans have been widely applied across diverse industries. The group animation effects of digital characters offer a more powerful means of simulating realistic competition atmospheres.

This study initially constructs a 3D model of the tennis court based on authentic environmental parameters. Using AI image generation and open-source character generators as references, a 3D model database of spectators was developed. Secondly, limb movements and facial expressions of live tennis match spectators were collected and analyzed. The three-dimensional spectator models were categorized into primary and secondary levels, followed by rigging and parameterization of their motions and expressions. This process enabled the pre-configuration of emotional characteristics for the virtual audience. Finally, all generated data were imported into the Unity3D engine to achieve interactive effects. Based on match scenarios (such as game progress and the score difference between players), varied spectator reaction mechanisms were generated, encompassing body movements, facial expressions, and sound effects, thereby creating an immersive atmosphere that closely mirrors real-world tennis matches. Training in a virtual tennis court prior to significant international competitions can effectively enhance athletes' adaptability to the atmosphere of major events.

KEYWORDS: 3D MODELS, VIRTUAL COURTS, VIRTUAL SPECTATORS, ATMOSPHERE SIMULATION

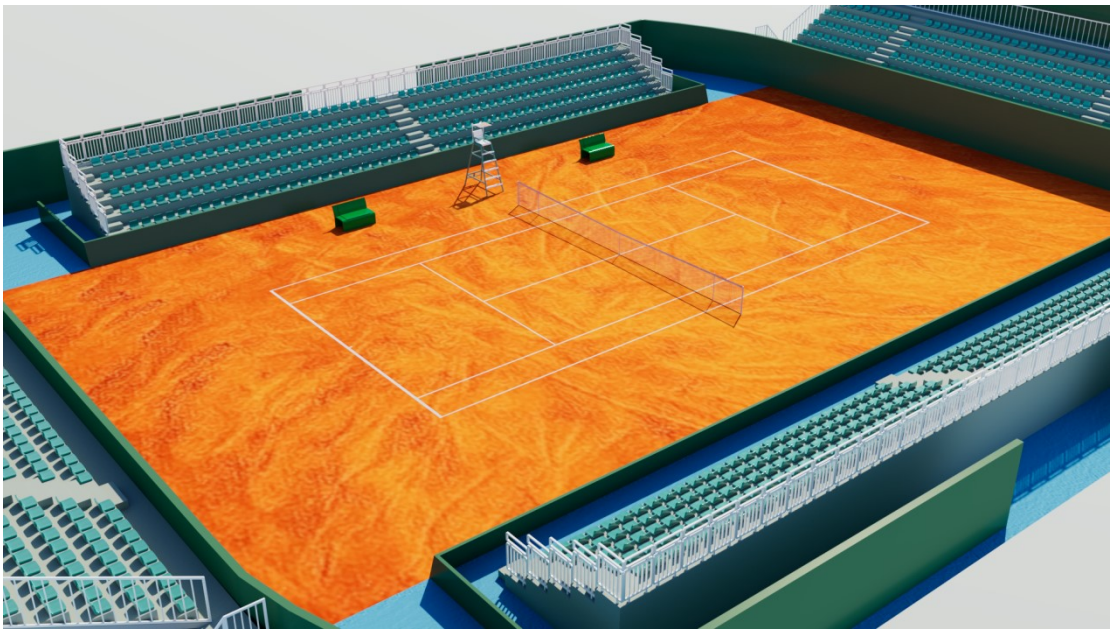

Figure 1. A simulated rendering of a tennis court scene.

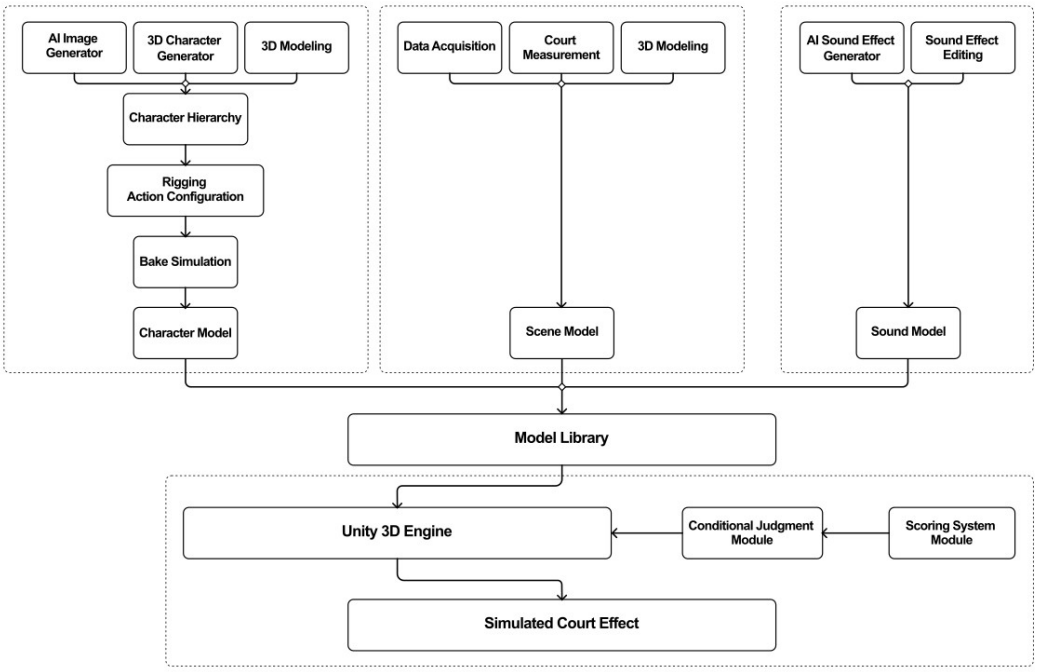

Figure 2. Schematic diagram of the design process for a virtual tennis court.

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Code 29

Sports-vmTracking: Pose-Driven Virtual Markers for Identity-Preserving Tracking in 3x3 Basketball

Li Yin[1], Calvin Yeung[1], Qingrui Hu[1], Jun Ichikawa[2], Hirotsugu Azechi[3], Susumu Takahashi[3] & *Keisuke Fujii[1]*

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[3] Doshisha University

Abstract

Multi-Object Tracking (MOT) enables continuous identification of players in team sports videos. However, frequent occlusions and visual similarity often cause identity switches (IDSW), reducing tracking accuracy. Traditional tracking-by-detection methods are limited by detector performance in team sports scenes. In contrast, human pose estimation is more robust under occlusion and thus better suited for such environments. Building on the vmTracking method by Azechi and Takahashi (2025), we introduce Sports-vmTracking, a pose-based virtual marker (VM) MOT approach designed for team sports. This method builds on the vmTracking approach developed for multi-animal tracking with active learning. First, we constructed a 3x3 basketball pose dataset for VMs and applied active learning to enhance model performance in generating VMs. Then, we overlaid the VMs on video to identify players, extract their poses with unique IDs, and convert these into bounding boxes for comparison with automated MOT methods. Using our 3x3 basketball dataset, we demonstrated that our VM configuration has been highly effective, and reduced the need for manual corrections and labeling during pose model training while maintaining high accuracy. Our approach achieved an average HOTA score of 72.3%, over 10 points higher than other state-of-the-art methods without VM, and resulted in 0 ID switches, as shown in Table 1. Beyond improving performance in handling occlusions and minimizing identity switches, as illustrated in Figure 1, our framework also significantly improves time and cost efficiency compared to traditional manual annotation.

KEYWORDS: SPORTS, MULTI-OBJECT TRACKING, POSE ESTIMATION, VIRTUAL MARKERS, ACTIVE LEARNING

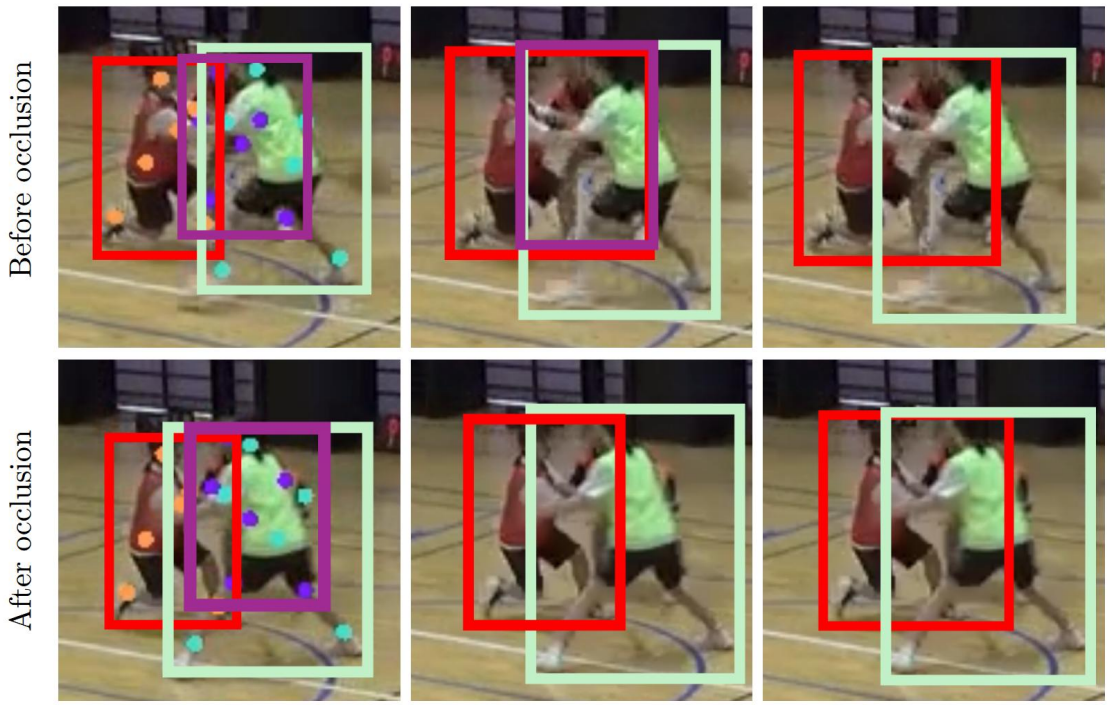

Figure 1. Result examples on our 3x3 dataset. Sports-vmTracking handles occlusion better than BOT-SORT(Aharon, Orfaig, & Bobrovsky, 2022) and Deep-EIoU(Huang et al., 2024), successfully detecting heavily occluded players (in purple) and maintaining consistent IDs.

Table 1. Tracking performance comparison across methods, including BoT-SORT (Aharon et al., 2022), Deep-EIoU (Huang et al., 2024), Basketball-SORT (Hu, Scott, Yeung, & Fujii, 2024), and maDLC (Mathis et al., 2018), along with our proposed Sports-vmTracking method. HOTA (Higher Order Tracking Accuracy): A unified metric balancing detection, association, and localization accuracy. DetA (Detection Accuracy): Measures the accuracy of correctly detecting all targets. AssA (Association Accuracy): Evaluates the correctness of identity assignment across frames. FN (False Negatives): Number of missed targets that were present but not detected. FP (False Positives): Number of incorrect detections where no target was present. IDs (Identity Switches): Counts how often the tracked identity of a target changes incorrectly over time.

Method	HOTA	DetA	AssA	FN	FP	IDs
Deep-EIoU	58.0 ± 6.0	56.3 ± 4.2	60.2 ± 9.6	63.0 ± 34.4	277.6±119.5	6.2 ± 4.7
BOT-SORT	55.7 ± 6.4	55.0 ± 3.0	56.9 ± 11.1	58.9 ± 34.1	342.8±139.6	8.1 ± 5.0
Basketball-SORT	61.5 ± 4.9	58.3 ± 2.9	65.1 ± 8.3	53.2 ± 24.2	231.4±140.9	4.3 ± 3.0
maDLC	52.4 ± 7.0	58.5 ± 4.5	47.6 ± 10.3	186.9± 70.4	3.6 ± 3.3	9.9 ± 4.9
Sports-vmTracking (ours)	**72.6 ± 2.7**	**69.9 ± 2.9**	**71.9 ± 3.2**	**3.0 ± 2.9**	**3.0 ± 2.9**	**0.0 ± 0.0**

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Code 32

Trends and Performance Visualization of Clutch Time in Japan's Professional B. League

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Abstract

Clutch time, the final five minutes of a basketball game when the score margin is five points or less, is widely recognized as a pivotal period in which decisive actions and tactical adjustments can alter the game's outcome (NBA.com, 2024). Recent high-stakes competitions in Japanese basketball, such as the 2024 Paris Olympics and key FIBA World Cup matches, have emphasized the critical importance of performance. As the competitiveness of Japanese basketball is improving, the importance of tactics and performance during clutch time is increasing accordingly. In recent years, studies on clutch-time performance in basketball have advanced, primarily focusing on performance analyses within the NBA (Sarlis et al., 2024). However, systematic investigations of clutch-time dynamics within Japan's professional leagues remain scarce.

In this study, we analyzed detailed play-by-play data and box scores from 739 games in the 2023–24 Japan's Professional B. League season, supplemented by data from B. LEAGUE CHAMPIONSHIP. We focused on three key shooting zones—In the 3-Point, Paint, and the Mid-Range Area—and utilized advanced metrics such as Effective Field Goal Percentage (eFG%)—a measure of shooting efficiency that accounts for the value of 3-point shots—and True Shooting Percentage (TS%)—a comprehensive success rate that accounts for 2-point shots, 3-point shots, and free throws to capture the effect of shot selection on scoring efficiency (Freitas, 2021; Oliver, 2004). By integrating traditional statistical measures with modern analytical techniques, we conducted a comprehensive evaluation of offensive performance under extreme pressure.

Our analysis reveals that shooting efficiency in both the paint and 3-point areas consistently exceeded 50% regardless of the moment, whereas mid-range shooting lagged significantly behind, reflecting a clear tactical preference for high-percentage shot locations (Figure 1). Although 3-point efficiency exhibited a modest decline during clutch time, likely due to intensified defensive pressure, the correlation analysis suggests a potential positive relationship between a higher 3-point efficiency at crucial moments and win percentage (r=0.28, p=0.18), although the result is not statistically significant (Upper part of Figure 2). According to the League and Championship data analysis, the championship data demonstrated a more pronounced drop in 3-point success, suggesting that defensive adjustments in high-stakes games can substantially counteract the benefits of an aggressive outside-shooting strategy (Figure 3). Furthermore, although an elevated succession of 3-point attempts generally correlates with

overall offensive success (r=0.63, p=0.006), overreliance on such attempts during clutch time appears to inhibit performance.

These findings highlight the importance of adaptive shot selection during clutch time. Coaches should prioritize strategies that preserve overall shooting efficiency by balancing aggressive 3-point attempts with safer, high-percentage shots in the paint. The data suggest that even marginal improvements in clutch shooting efficiency can yield significant winning contributions, emphasizing the value of tactical flexibility and situational adjustments.

In conclusion, the insights derived from our analyses offer actionable guidance for coaches and teams in the B. League, suggesting that strategic adjustments aimed at preserving shooting efficiency under pressure can substantially enhance competitive performance and overall win probability.

490 words

KEYWORDS: CLUTCH TIME, B.LEAGUE, SHOOTING EFFICIENCY, 3-POINT PERFORMANCE

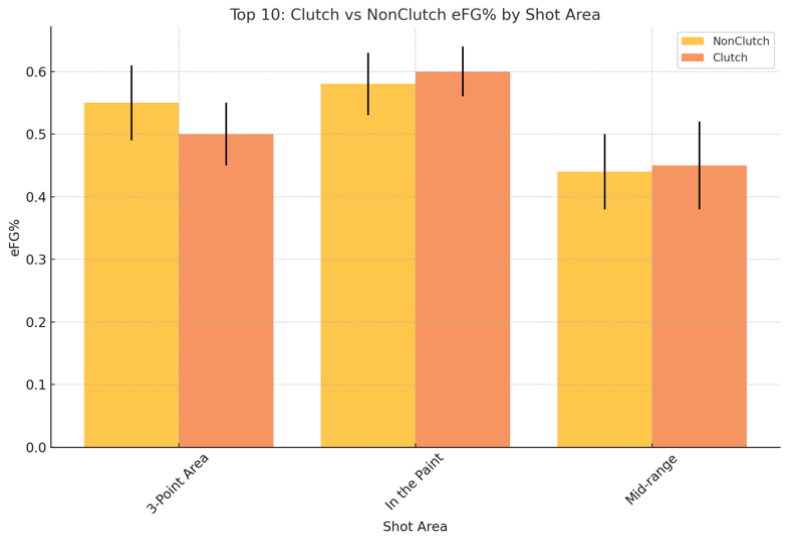
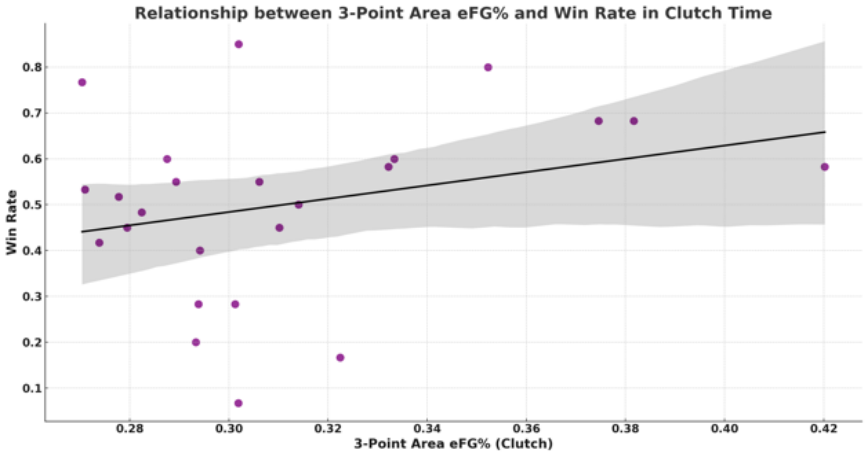


Figure 1. Effective Field Goal Percentage (eFG%) by shot area for the top 10 teams.



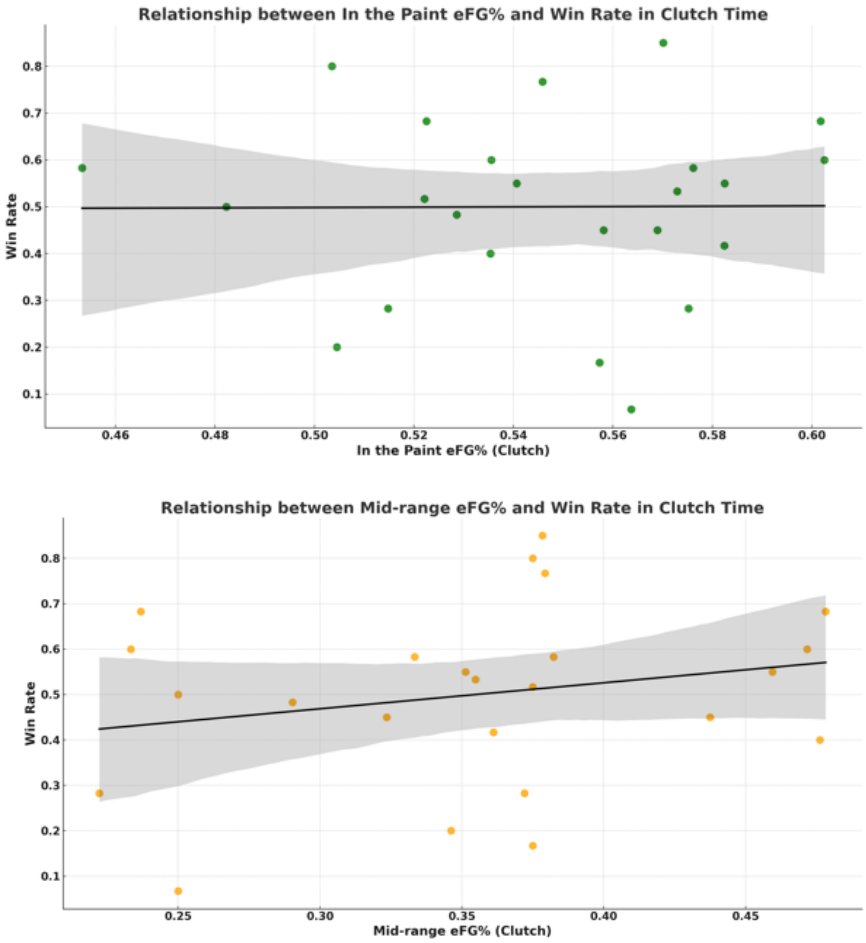
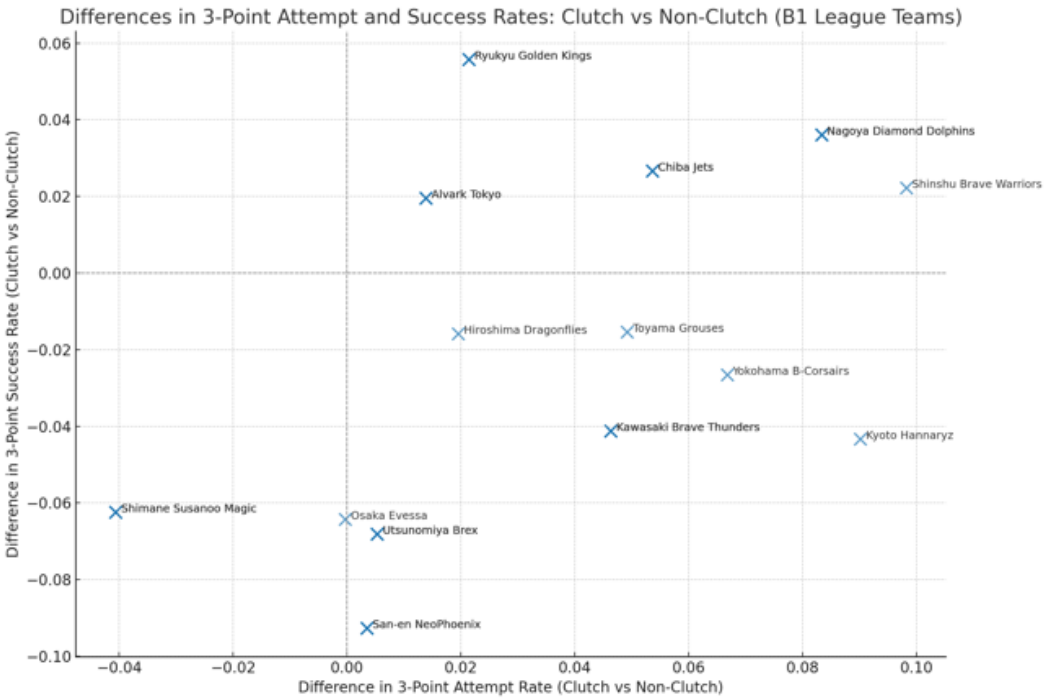


Figure 2. Correlation between eFG% by shot area and win percentage during clutch time. The upper, middle, and lower parts are the results in the 3-Point, Paint, and the Mid-Range Area, respectively.



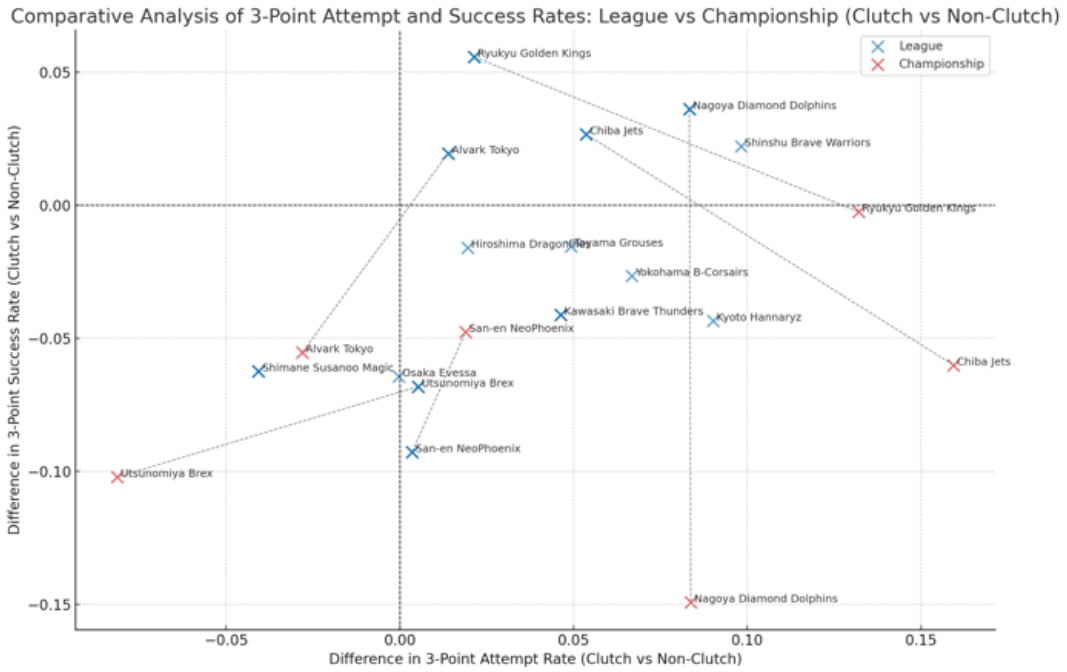


Figure 3. Changes in the number and percentage of 3-point shots for all teams and CHAMPIONSHIP teams. The upper part shows the difference in 3-point shot success and attempt rates between clutch time and non-clutch periods across all teams. The lower one shows the comparison of 3-point performance in clutch vs. non-clutch periods for teams that qualified for the CHAMPIONSHIP, based on data from both the regular season (blue) and the CHAMPIONSHIP (red). Red plots are not shown for teams that had no clutch-time minutes during the CHAMPIONSHIP.

Acknowledgement

This work was supported by the Sports Data Science Subcommittee of the Japan Statistical Society, School of Statistical Thinking at the Institute of Statistical Mathematics of the Research Organization of Information and Systems, and Data Stadium, Inc. The authors express their gratitude to the following organizations:

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Code 33

Augmented Reality Immersion as a Mediator between Physical Activity Attitude and Depression, Anxiety, Stress among Youth

Arvin A. Andacao[1], Arianne Michael Sim M. Tuano[1], Hazel Joyce M. Cariaga[1], Leonard Sydrick H. Pajo[1], Pink Floyd M. Boyles[1], Rey L. Rabuya[1] & Naoki Suzuki[2]

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[2]*Tokyo Gakugei University*

Abstract

Mental health problems continue to rise globally, especially among youth and students, prompting the need for proactive, holistic interventions. This research aimed to determine the mediating effect of Augmented Reality Immersion (ARI) on the relationship between Physical Activity Attitude (PAA) and levels of Depression, Anxiety, and Stress (DAS) among the youth. Structural Equation Modeling (SEM) was employed to analyze the mediating effects. Prior to data collection, ethical approval was obtained from relevant authorities, including the Office of the President for college students (n=41), and the Schools Division Superintendent and School Principal for basic education teachers (n=9) and students (n=10). Informed consent and parental consent were secured, with the research objectives clearly explained to all participants. Out of 155 initial participants, a total of 60 youth respondents who fully completed the survey after experiencing the Physical Education Metaverse applications were included in the final analysis. Three questionnaires were administered, namely, Youth PAA Scale (Simonton et al., 2020), ARI Questionnaire (Georgiou & Kyza, 2017), both using 5-point Likert scale, and DAS Scales – Short Form (Lovibond & Lovibond, 1995), using 4-point Likert scale. Descriptive statistics and SEM were statistical tools, with the model developed using the Analysis of Moment Structure (AMOS) software. The findings revealed that participants exhibited a strong sense of positive and negative affect of physical activities, characterized by a deep appreciation of life, viewing it as essential to their overall health, while consistently rejecting negative perspectives. The ARI demonstrated a very high level of interest engagement, along with high levels of usability, engrossment, and total immersion. Psychological indicators showed that participants experienced low levels of depression and anxiety and were able to manage daily stress effectively. Meanwhile, the initial structural model established a good overall fit to the data. Despite a slight shortfall in the Tucker Lewis Index (TLI), the combination of other fit indices, including CMIN/DF, RMSEA, NFI, CFI, RFI, and IFI results met the recommended threshold values, confirming the model's robustness. Finally, the analysis confirmed that PAA significantly influenced both ARI and DAS, while ARI also emerged as a meaningful mediator between PAA and DAS.

KEYWORDS: AUGMENTED REALITY, PHYSICAL ACTIVITY, DEPRESSION, ANXIETY, STRESS

Code 34

Supporting Gymnastics Training with Virtual Reality: The Impact of Head-Mounted Displays

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Abstract

Introduction

The use of virtual reality (VR) in technical acrobatic sports, such as apparatus gymnastics, has been scarcely researched, mainly due to the complexity of movements and kinesthetic perception. Balance beam elements, which require high balance and control, could benefit from VR-based training (Bürger et al., 2022). However, the head-mounted display (HMD) may influence execution due to its size, weight, and limited field of view (Ritter et al., 2023). This study investigates which basic gymnastics elements are most suitable for execution with an HMD in future VR training interventions.

Methods

Thirty-six active competitive gymnasts executed five elements covering various balance beam characteristics, three times each in randomized order. Elements were performed on a methodical beam (height: 10 cm) with and without an HMD (HTC VIVE Pro Eye), which displayed the real environment through its cameras (pass-through mode). All trials were filmed and evaluated by four licensed judges for recognition and execution according to international scoring rules. To assess HMD influence on recognition, success rates per element and condition were calculated. Execution scores were analyzed descriptively and compared between conditions using paired Wilcoxon signed-rank tests with effect sizes.

Results

Recognition rates were lower with the HMD for all elements except the full turn, which showed no difference. Minor decreases were observed for jumps with half turn (–5.8 percentage points (pp)) and split jumps (–12.0 pp), while larger declines occurred for handstands (–32.0 pp) and split leaps (–43.7 pp).

Execution scores revealed significantly higher deductions with the HMD across all elements ($p < .05$), with large effect sizes ($r > .78$). Smaller performance differences appeared for handstands ($\Delta_{deductions} = 0.19$ pts) and split jumps ($\Delta_{deductions} = 0.20$ pts), moderate differences for split leaps ($\Delta_{deductions} = 0.37$ pts), and largest for elements involving longitudinal axis rotations, such as the full turn ($\Delta_{deductions} = 0.53$ pts) and jump with half turn ($\Delta_{deductions} = 0.49$ pts).

Discussion

Lower recognition rates in the HMD condition, particularly for handstands and leaps, may stem from restricted field of view, latency, and reduced image resolution

in pass-through mode. These factors can disrupt spatial perception and require sensory recalibration to maintain balance. Distorted distance perception may further compromise execution. Although execution scores were significantly lower across all elements, notable trends emerged: elements involving longitudinal axis rotations showed the greatest performance drop, likely due to limited peripheral vision and delayed image updates at the HMD's edges. According to scoring rules, differences for jumps, handstands, and leaps represent small (0.1 pts) to medium (0.3 pts) deviations and may improve with longer familiarization.

Conclusions

Execution is affected by the HMD across all elements. Due to lower pass-through resolution, simulated environments may yield better recognition and execution quality. Extended familiarization could further reduce performance gaps. Jumps from a standing position and acrobatic non-flight elements are less affected and appear most suitable for future VR training. Leaps also show promise with advanced hardware, as simulated height allows gymnasts to safely practice overcoming mental barriers and adapting to the beam's height, while remaining at floor level.

KEYWORDS: HEAD-MOUNTED DISPLAY, VIRTUAL REALITY, ARTISTIC GYMNASTICS, BALANCE BEAM, MOVEMENT EXECUTION

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Code 36

Assessing the Readiness of LPU-Manila Students for Virtual Reality Integration in Physical Education Classes

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Abstract

The growing interest in immersive technology applications in education—particularly in sport and physical education—has led to increased exploration of Virtual Reality (VR) in facilitating interactive, skill-based learning environments. This study investigates the readiness of college students enrolled in Physical Education (PE) at Lyceum of the Philippines University – Manila (LPU-Manila) for the adoption of VR in PE courses. A descriptive-quantitative research design was employed using a customized survey instrument grounded in the Technology Acceptance Model (TAM), measuring students' perceptions of VR in relation to usefulness, ease of use, and behavioral intention. A total of 278 respondents completed a five-part questionnaire assessing awareness, technological competence, perceived usefulness, behavioral intention, and perceived barriers. Analysis of collected data reveals a strong perceived usefulness of VR in PE ($M = 4.05$, $SD = 0.69$) and high behavioral intention to adopt the technology ($M = 4.12$, $SD = 0.71$). Results also show that while students are generally open to the integration of VR, moderate technological competence ($M = 3.47$, $SD = 0.82$) and concerns about physical authenticity and accessibility remain significant barriers. The findings validate the implementation of strategic, student-centered VR models in PE settings, supporting ongoing innovations in immersive physical education and aligning with global trends in educational technology integration. The study contributes to a growing body of research highlighting the pedagogical and technological readiness required for immersive technology adoption in sports and physical education, as emphasized in recent systematic reviews on VR trends in education (Martín-Gutiérrez, Mora, Añorbe-Díaz, & González-Marrero, 2022).

KEYWORDS: VIRTUAL REALITY, PHYSICAL EDUCATION, STUDENT READINESS, EDUCATIONAL TECHNOLOGY, TECHNOLOGY ACCEPTANCE

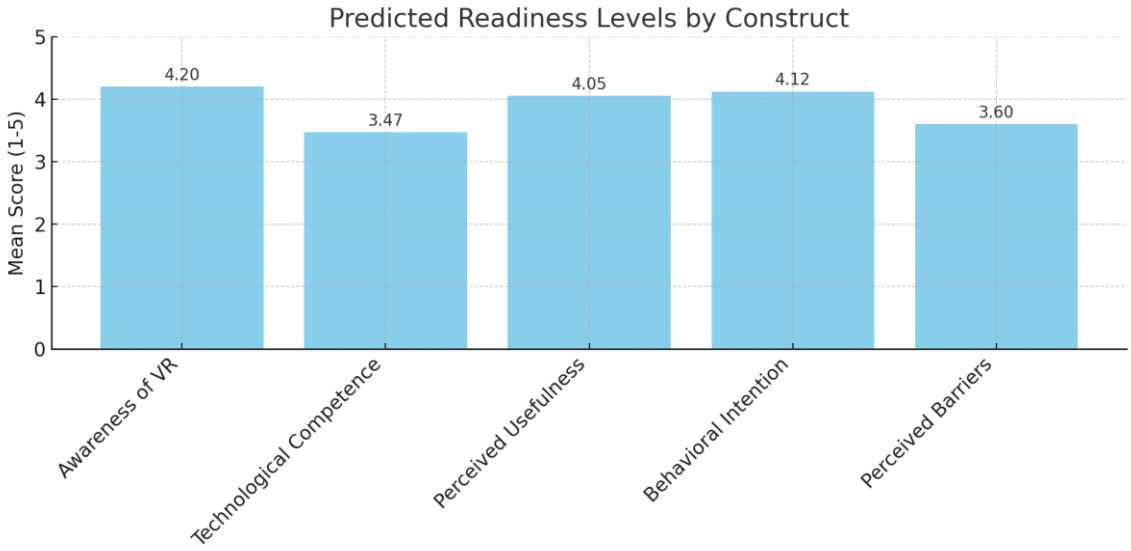

Figure 1. This figure illustrates the average Likert scale ratings for each readiness factor among surveyed PE students at LPU-Manila. Results indicate high levels of behavioral intention and perceived usefulness, while technological competence and perceived barriers remain areas of moderate concern.

Table 1. Mean scores and standard deviations for five constructs measured in the study: awareness of VR, technological competence, perceived usefulness, behavioral intention to use VR, and perceived barriers. The data reflect students' levels of readiness based on a five-point Likert scale.

Readiness Factor	Mean	Standard Deviation
Awareness of VR	4.20	0.65
Technological Competence	3.47	0.82
Perceived Usefulness	4.05	0.69
Behavioral Intention	4.12	0.71
Perceived Barriers	3.60	0.74

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Code 38

Affective Figurations in Virtual Sports Environments

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Abstract

Introduction

Digital technologies are fundamentally transforming sporting practices, creating new forms of participation that transcend spatial and situational constraints. This sociological study investigates how technological changes produce new forms of communal experiences in virtual environments. The research examines virtual cycling platforms as an example of a "digitally extended sport" (Kim et al., 2025) where technology facilitates participation and social interaction across geographical distances.

Research Design

To analyze these communal experiences, the study applies the concept of *atmosphere*, conceptualizing it as a socio-technical figuration: an arrangement of technical features, social interactions, and environmental designs that produce shared experiences. Following Gugutzer's (2012, 2020, 2023, 2024) neo-phenomenological approach, atmospheres are understood as embodied, affective qualities that are collectively produced yet individually experienced. Atmospheres extend established HCI frameworks by addressing a dimension that bridges individual experiences of social presence (Biocca et al., 2003) and virtual togetherness (Durlach & Slater, 2000). While traditional presence research distinguishes between technological immersion and psychological experience (Slater & Wilbur, 1997), the atmosphere concept examines how affective qualities emerge collectively across physically separated but virtually connected bodies.

Methodologically, the research employed ethnography within the HCI research context to investigate complex social phenomena that quantitative methods cannot adequately capture (Adams et al., 2008; Lazar et al., 2017; Hammersley & Atkinson, 2019). The ethnographic approach enabled the observation of group dynamics and visual interactions in the virtual environment while simultaneously examining participants' social and physical contexts, revealing how socio-technical figurations translate into atmospheric qualities in digitally extended sporting experiences.

A six-month immersive fieldwork combined participant observation with semi-structured interviews (n=12), allowing to explore not only on-screen interactions but also contextual situations users were simultaneously involved in—addressing the critical question of ‘what's going on behind and besides the screen’.

Results

Data analysis through grounded theory (Clarke, 2005) revealed collective experiences that align with Lazar et al.'s (2017) observation that "as soon as we start using computing technologies for communication and collaboration, we start forming groups." This study interprets these group formations through the theoretical lens of atmosphere, theorizing them as *collective atmospheres*. The findings identify four key socio-technical elements constituting these atmospheres:

(1) avatar customization systems enhancing identity formation; (2) contextually relevant communication tools fostering interpersonal awareness; (3) synchronized event mechanics facilitating temporal alignment; and (4) persistent social structures supporting community development.

Discussion

From a sociological perspective, this study contributes to understanding how digital technologies reconfigure sporting practices and communities. The research provides a conceptual framework for analyzing social dimensions in virtual environments, highlighting atmospheric qualities as emergent properties of socio-technical figurations.

KEYWORDS: ATMOSPHERE THEORY, DIGITAL SPORT, ETHNOGRAPHY, QUALITATIVE RESEARCH, VIRTUAL COMMUNITIES

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Code 42

Bridging Vision and Language for Tennis Analysis: A RAG-Based Approach

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Abstract

Elite tennis relies heavily on tactical analysis. While elite players can play every stroke in the book, game strategy planning often differentiates outcomes. Technology aiding the keen observations a coach and player make can significantly enhance the potential of an athlete. This paper presents a framework to provide data-driven solutions to questions an athlete asks, such as: "Why am I conceding points during baseline rallies?" and "Am I effectively utilising the entire court with my stroke play?". A key analytical challenge is identifying pivotal moments or shots within rallies that precede point termination, often occurring before the final ball contact. Automated identification of tactically significant moments requires integrating domain knowledge from tennis literature, expert insights, and game rules. This requires identifying complex game states, tactically disadvantageous 'out-of-position' situations where players fail to recover court positioning (e.g., regaining a central baseline position) between opponent shots. To address this, we developed a pipeline to capture and analyse these elements from monocular match video. Object detection was performed using two fine-tuned YOLO models: one for ball detection, and the other for player and racket tracking. The court is detected using a fine-tuned ResNet-50 model. Linear interpolation bridged ball tracking gaps between detections across frames. While existing methods either require manual intervention, specific action detection models (Shu & Zhang,) or wearables (Ganser, Hollaus, & Stabinger,) to confirm the presence of a shot played, our system employs a novel 3-stage automated process: 1) Detect potential shots based on changes in ball trajectory along the court's long axis; 2) Confirm shots by checking how close the player's dominant wrist (tracked with MediaPipe) is to the ball; 3) Alternatively, using the "thwack" sound to verify if a shot was played (Caprioli et al.,). Figure 1 provides an example of the shot detection results. MediaPipe also enables player posture tracking. We defined 'out-of-position' states using descriptors indicating poor recovery or balance, such as being forced into defensive stretches, or failing to regain optimal court positioning. Posture analysis further aided in detecting whether a forehand or backhand stroke was played. Shot type classification (e.g., Serve, Groundstroke, Volley, Smash) was achieved by combining multiple cues: the player's location on the court (proximity to baseline or net), the height of ball contact (e.g., for overheads), and the resulting ball trajectory characteristics. A homography matrix mapped image pixel coordinates to standardised real-world court dimensions for player position storage, shot location analysis (in/out), and determining the hitting player. These extracted parameters populated a structured dataset as shown in Table 1. This dataset was fed to a large language model (LLM) along with domain-specific context using Retrieval-Augmented Generation (RAG). The qualitative evaluation demonstrated the system's ability to generate relevant answers to tactical queries (e.g., 'What patterns lead to me losing long rallies?'), providing insights into common rally trends and tennis dynamics. This work presents a novel automated pipeline for generating rich tactical tennis datasets from monocular video, enabling both data-driven insights via a RAG-LLM interface and providing valuable resources for further research in the sport.

KEYWORDS: POSE ESTIMATION, SHOT CLASSIFICATION, SPORTS ANALYTICS, RETRIEVAL-AUGMENTED GENERATION (RAG), TENNIS

Table 1: Excerpt from the extracted dataset showing key positional and shot parameters.

Rally	Shot	Player	Shot From	Shot To	P1 Pos	P2 Pos	Hand	Shot Type	Speed	Outcome	Time
1	1	1	BL-L	Ad Box	(4.3, 0)	(10.8, 23.7)	N/A	Serve	146 km/h	During	00:02
1	2	2	MC-L	MC-L	(4.7, 1.0)	(10.8, 22.4)	BH	Groundstroke	115 km/h	During	00:03
1	3	1	BL-L	MC-L	(2.1, 0.4)	(9.5, 23.7)	FH	Groundstroke	125 km/h	During	00:04
1	4	2	BL-L	MC-C	(5.5, 0.9)	(9.7, 23.7)	BH	Groundstroke	118 km/h	During	00:05
1	5	1	BL-L	Ad Box	(2.3, 0.8)	(6.0, 23.6)	FH	Groundstroke	122 km/h	During	00:06
1	6	2	BL-L	MC-L	(5.5, 1.0)	(10.8, 23.8)	BH	Groundstroke	115 km/h	During	00:08
1	7	1	BL-L	BL-R	(2.3, 0.0)	(4.8, 23.0)	FH	Groundstroke	130 km/h	During	00:09
1	8	2	BL-R	Net	(5.4,0.2)	(2.7, 22.6)	FH	Groundstroke	110 km/h	P1 wins	00:11

Note: Abbreviations used - BL: Baseline, MC: Midcourt, Ad Box: Advantage Box, C: Center, L: Left, R: Right, FH: Forehand, BH: Backhand. Player column indicates Player 1 or Player 2.

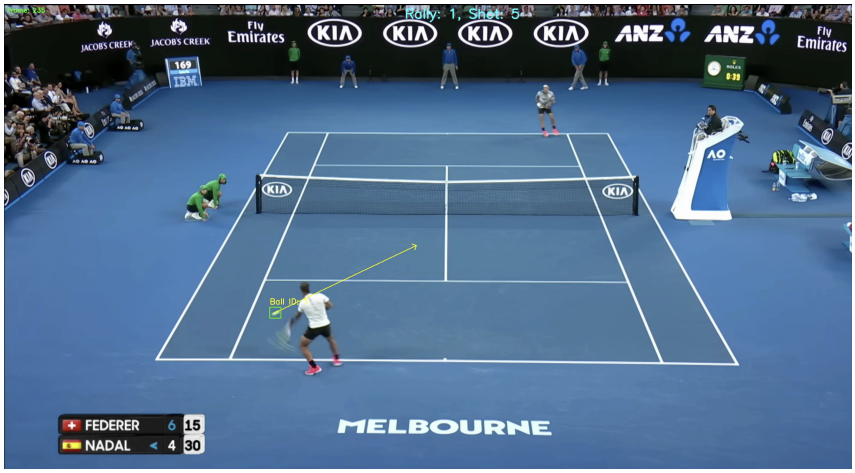

Figure 1: Example frame showing Rafael Nadal executing a forehand groundstroke vs Roger Federer during analysis.

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Code 65

Real-Time Table Tennis Ball Speed Estimation: A YOLO-Based Dual-Camera

Khanh-Duy Nguyen[1], MinTe Sun[1], Quoc-Viet Nguyen[1], Kazuya Sakai[2] & *Wei-Shinn Ku[2]*

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Abstract

In all kinds of ball sports, table tennis stands out for its exceptionally fast-moving ball, a consequence of the small ball size and short distance between players. This characteristic presents significant challenges for analyzing player performance and developing effective game strategies. We propose a deep learning system based on YOLO architecture to detect and estimate the flying speed of table tennis balls in real-time, utilizing a dual-camera setup rather than the conventional single camera approach. Our methodology employs a high-speed camera to generate ground truth data, while two low-speed cameras are used for the primary system configuration. Results demonstrate a clear performance advantage of the dual-camera approach over single-camera systems and highlight the potential for constructing low-cost solutions for accurate table tennis ball speed estimation.

KEYWORDS: TABLE TENNIS, SPEED ESTIMATION, DUAL-CAMERA SYSTEM, YOLO.

Code 74

A Visual Analytics System for Match Efficiency in Soccer

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Abstract

Match efficiency is an effective method to explain why a soccer team could win a match. In this work, we design and develop a visual analytics system for an in-depth and comprehensive analysis of soccer match efficiency. With this system, we invited a soccer domain expert to conduct a case study that involved 1,224 matches in the five major European soccer leagues for the 2017/18 season. The results show that the net efficiency can effectively explain why a certain team could win a match. Besides, our visual analytics system could support in-depth analysis of soccer match efficiency such as the identification of the factors affecting match efficiencies and the comparison with other teams. The system is publicly available online: https://ses.sportvis.cn/.

KEYWORDS: SOCCER, MATCH EFFICIENCY, VISUAL ANALYTICS

Table 1. Description of the event attributes.

Attribute	Description
Team	The team that possesses the ball.
Time	The time that the event occurred in the match
Event Type	The technique that the player interacts with the ball (i.e., *pass*, *dribble*, *shot*, *tackle*, etc.).
Result	The result of the event (i.e., *succeeded* or *failed*).

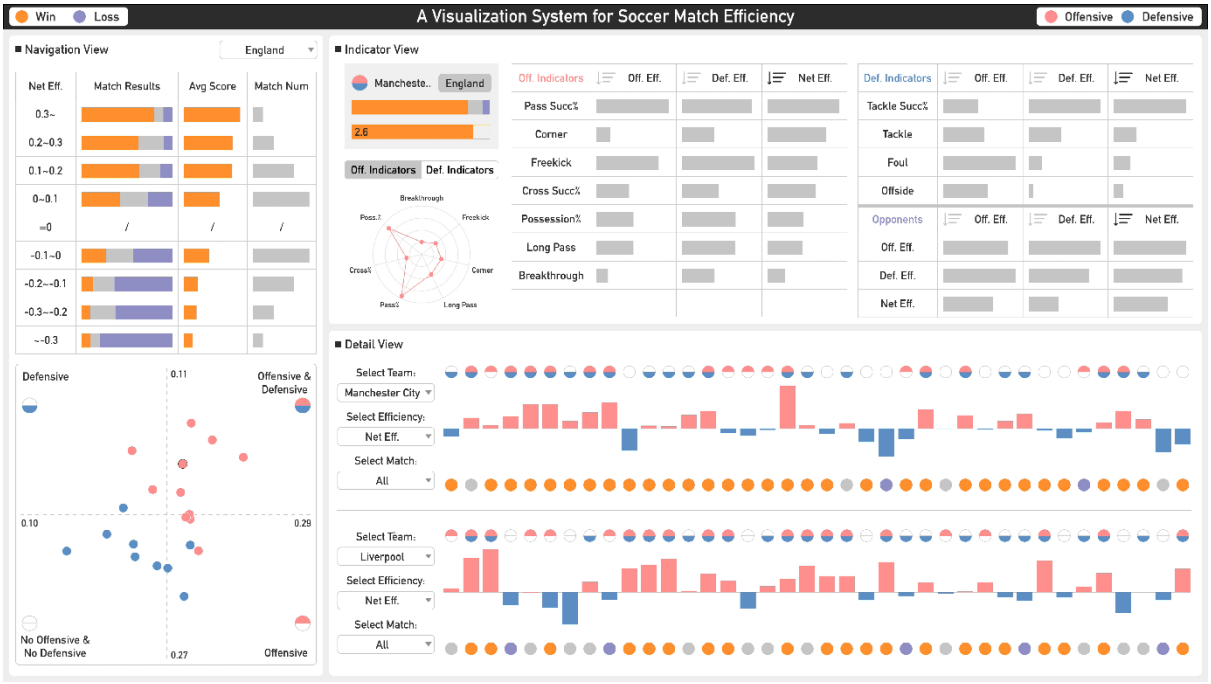

Figure 1. The user interface of the visual analytics system for match efficiency in soccer.

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Code 99

Changes in Psychological Learning Factors According to Participation in Metaverse-Based Archery Classes and Academic Major: Applying a Solomon Four-Group Design

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Chung-Ang University

Abstract

Recently, metaverse technology has garnered attention as an alternative educational environment capable of overcoming the spatial and temporal constraints of traditional physical education. In particular, archery classes—which demand precision and focused attention—may benefit significantly from simulation-based training in immersive virtual environments. This study aimed to experimentally examine the effects of participation timing in metaverse-based archery classes on learners' levels of specialization, risk perception, and intention to continue exercising.

The participants were 20 undergraduate students majoring in either physical education or nursing at a university in the Seoul metropolitan area. They were randomly assigned to four groups while maintaining a balance across academic majors. The experimental group consisted of 10 students (5 from each major) who participated in two metaverse-based archery sessions held at different times in the semester: early (Weeks 3 and 4), middle (Weeks 7 and 9), or late (Weeks 15 and 16). The control group (10 students) did not participate in any metaverse sessions and served as a comparison group. To account for testing effects, each group was further divided into those who received a pretest and those who did not, thereby forming a full Solomon four-group experimental design.

Self-report questionnaires were used to measure specialization, risk perception, and exercise adherence intention, with all items rated on a 5-point Likert scale. Specialization was measured with 6 items (Cronbach's $\alpha = .82$), risk perception with 5 items ($\alpha = .79$), and exercise adherence intention with 4 items ($\alpha = .85$). All participants completed the surveys at Week 2 (pre-test) and Week 16 (post-test). Data were analyzed using two-way ANOVA via SPSS 28.0, examining the main effects and interaction effects of metaverse participation and academic major.

The results revealed significant differences based on participation in the metaverse-based archery classes. Compared to the control group, students who participated in the metaverse training showed significantly lower levels of specialization ($F=6.37$, $p=.001$) and risk perception ($F=5.29$, $p=.003$), but significantly higher exercise adherence intention ($F=7.84$, $p<.001$). The mean specialization score of the experimental group was 2.6 (SD=0.5), compared to 3.4 (SD=0.6) in the control group; risk perception scores were 2.3 and 3.5, respectively. In contrast, the exercise adherence intention was higher in the experimental group (M=4.4) than in the control group (M=3.1).

There were also significant differences by academic major. Students majoring in physical education reported higher specialization (F=4.16, p=.006), lower risk perception (F=3.89, p=.027), and greater exercise adherence intention (F=4.54, p=.018) than nursing students. This suggests that prior athletic experience and familiarity with physical training contributed positively to their archery learning experience.

Finally, an interaction effect between metaverse participation and academic major was found for exercise adherence intention (F=5.11, p=.001). Specifically, physical education students who participated in metaverse-based classes reported the highest level of adherence intention (M=4.8, SD=0.3), while nursing students in the control group recorded the lowest levels of specialization (M=2.3), highest risk perception (M=3.8), and the lowest exercise adherence intention (M=2.9). These findings suggest that the educational effects of metaverse-based instruction may be further enhanced

KEYWORD: METAVERSE, SPORTS, ARCHERY, PHYSICAL EDUCATION CLASSES

15th International Symposium on Computer Science in Sport

IACSS 2025

September 12 - 15, 2025

Tokyo Gakugei University
Tokyo, Japan

Theme:
Computer Study

Code 07

A look at Tactical Creativity of Tennis Players using Computer Vision

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Abstract

Despite the existence of tracking data in Tennis (i.e., ball and player position) at least for international high level tournament (e.g., Hawk Eye data), their access is very limited and protected. Recent developments in computer vision however could provide similar data at a large scale and for any match that is broadcasted on television, potentially with a cost of lower accuracy. In this project, we developed a full pipeline using computer vision and data analytics to automatically collect tracking data, specifically shot trajectories, during any broadcasted or self-recorded tennis match. We applied this approach to 25 matches from 3 different professional tournaments. From the trajectory data, we first tried to replicate the results from Benguigui et al. (2024) who were looking at ball trajectories and receiver position at the time of the shot on a limited data set (i.e., Hawk Eye data from one tournament), getting similar results with our self-collected data. In addition, we looked at the statistical distribution of patterns of two successive shots (i.e., looking at where the ball is sent knowing where the ball is coming from). Using simple Markov Models, „unexpected“ return shots were identified as the different between 1) the probability of observing this actual shot direction knowing where the ball is coming from and 2) the predicted/expected shot direction from the Markov Model. The highest this difference, the more unexpected was the shot performed by the player, which provides an average „tactical creativity“ score when average for all the shots per player. This average player tactical creativity index was therefore significantly correlated with the player's ATP ranking, suggesting tactical creativity as a key factor for long term performance in tennis. In conclusion, computer vision provided a decent way of data collection *in situ* (i.e., during actual competition) with sufficient accuracy to derive useful insight on the game and potential for individual performance analysis (e.g., match preparation).

KEYWORDS: TENNIS, COMPUTER VISION, CREATIVITY, PERFORMANCE ANALYSIS

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Code 17

Expected Goals (xG), a Machine Learning-based Performance Indicator – Why does it fail to predict match outcomes?

Martin Lames

Technical University of Munich

Abstract

Introduction: The concept of expected goals (xG) was introduced in performance analysis (PA) only about a decade ago. The core information, the scoring probability of individual shots at goal, is obtained with Machine Learning (ML) methods. Each shot in a representative training sample of football matches is characterized by a model-specific set of variables, e.g., distance and angle to goal, positions of goalkeeper and defenders. In a supervised learning approach, this situational configuration is associated with its success (goal–no goal).

This learned association is applied to a new match to obtain a scoring probability for each shot at goal in that match. Subsequently, the xG of the two teams is calculated as the sum of their shots' scoring probabilities, and the match outcome is predicted based on the difference in xG. The aim of this study is to validate these predictions.

Methods: A sample of xG values from 5 seasons of German Bundesliga was scrutinized for the relation between xG and actual goals per team per match (n=3.060). The differences between two teams' xG was examined for its power to predict match outcomes.

Results: Figure 1 shows the relation between xG and number of goals scored per team and match. When 0 and 1 goal are scored, xG overestimates the number of goals scored, when more than 1 goals is scored, xG underestimates the number of goals scored.

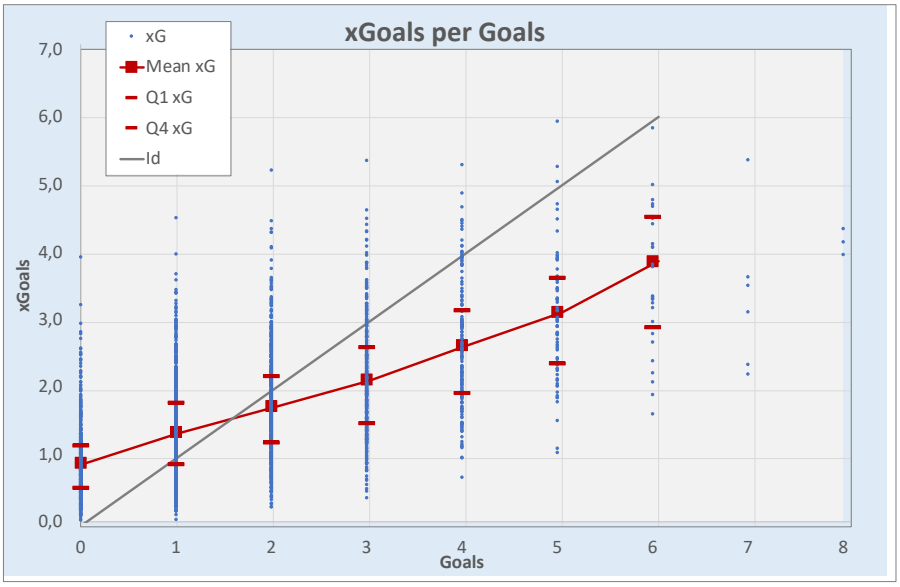

Figure 1. Actual goals and expected goals of 5 Bundesliga-Seasons (n=3.060)

The best predictions for a match outcome are obtained when not trying to predict draws. Predicting a win when xG difference is ≥ 0 and a loss when < 0 results in a percentage of 57,91% of correct predictions. This is only a few percent higher than guessing and lower than predicting the outcome with shots on goal difference (60,12%)!

Discussion: First of all, one has to acknowledge that in the beginning, xG was not meant to predict match outcomes as low frequencies of shots per match would prohibit powerful predictions. In addition, flaws in the underlying training set of matches could prevent good goal number predictions for single teams and matches. From a practical point of view, the notion that only shots at goal stand for scoring opportunities is flawful as, for example, missing a "deadly" pass in front of the goal just does not appear in xG. Statistically, the bias observed for zero goals scored is systematic as each shot at goal leads to a xG contribution thus zero goals would only be predicted correctly if there was exactly no shot at goal. The reason for the systematic underestimations of goals scored when there are more than 2 goals remains to be investigated.

Conclusion: xG may be taken as a summative indicator of the quality of chances in a match. Nevertheless, it fails to arrive at good match predictions because the limited number of shots in a match prohibit precises predictions and the nature of the goal scoring process is inherently non-linear and thus escapes from linear ML-predictions.

Code 21

Research on the Classification and Counting of Table Tennis Forehand and Backhand Movements Based on Machine Vision

Jiao Yu-ming & *Li Rong-zhi*

Shanghai University of Sport

Abstract

With the intelligentization of competitive sports, the refined analysis of table tennis players' technical movements has become critical for enhancing training efficiency. To address the limitations of traditional manual observation-based motion analysis methods, such as low efficiency and high subjectivity, this study proposes an improved YOWO-based table tennis action recognition model. The model employs Darknet-53 to enhance the spatial feature extraction capability of video frames, introduces the SKNet attention module to improve the detection of small targets, and utilizes the CBAM attention mechanism to address the insufficient feature fusion of the two branches in the YOWO model, aiming to optimize the classification of basic table tennis actions. The results show that:(1) In ablation experiments, the improved YOWO model achieves higher action classification accuracy than the original YOWO model and partially improved YOWO models;(2) In comparative experiments, the improved YOWO model outperforms I3D, C3D, and the original YOWO model in action classification accuracy. The conclusion indicates that the improvements of the 2D CNN branch and feature fusion of the YOWO model effectively enhance the accuracy of the model in the classification of basic actions in tabletennis.

Keywords:TABLE TENNIS SPORT; ACTION RECOGNITION; DEEP LEARNING; YOWO MODEL

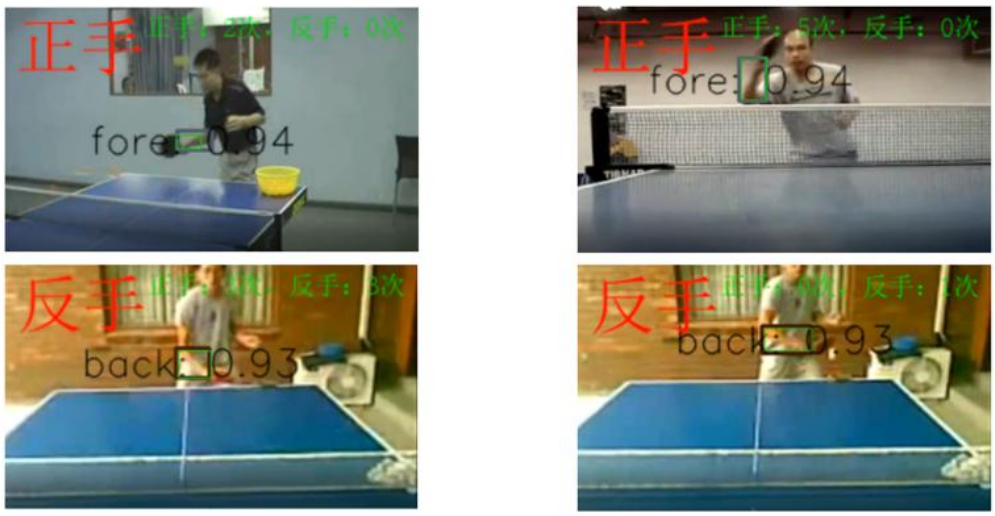

Figure 1. Detection performance on self-built dataset

Table 1. Performance of different models on the self-built dataset

Method	Frame-mAP	video-mAP		
		0.1	0.2	0.5
C3D	72.1	72.1	66.5	41.4
I3D	75.0	76.1	70.6	45.7
YOWO	87.2	82.5	75.8	47.8
YOWO+Darknet-53 + SKNet +CBAM	88.3	83.8	77.0	49.6

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Code 24

Empowering Volleyball Coaches: A Mobile Application for Match-up Optimization

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Abstract

A particularly unique and critical aspect of volleyball strategy stems from its rotation rule, which dictates the cyclical movement of players through six distinct zones on the court (Durkovic et al., 2007). This rule inherently creates a dynamic interplay of player positions and responsibilities, leading to a multitude of potential "match-ups" between opposing players in different rotations (López et al., 2023). Effective coaching necessitates a deep understanding of these match-ups to exploit opponent weaknesses and maximise team strengths in various game scenarios (Laios & Kountouris, 2010, 2011). However, the real-time analysis and optimization of player match-ups across the six rotations present a significant cognitive and logistical challenge for coaches, particularly under the pressure of live competition. The rapid pace of the game, coupled with the continuous shifts in player positioning due to rotation, can make it difficult to effectively track and leverage favorable match-ups. Moreover, while traditional notational analysis provides valuable post-game insights, a tool that empowers coaches with actionable information for in-game match-up adjustments is highly desirable. To address this need, we propose developing a mobile application designed to empower volleyball coaches with tools for real-time and pre-game match-up optimization (Laios & Kountouris, 2011). This application will leverage the fundamental principles of volleyball rotations and the impact of player positioning on team efficiency in various situational parameters, such as serve, serve reception, attack, block, defence, and counter-attack. The application aims to provide coaches with insights into potential strengths and weaknesses within specific rotations and against opposing line-ups. Coaches will be able to input their team's starting line-up and track the rotation of both their team and the opponent in real-time. This will assist coaches in making informed decisions about tactical adjustments, including strategic substitutions (e.g., setter-opposite substitutions to alter match-ups) and targeted instructions for specific player interactions (e.g., identifying favourable blocking match-ups against key attackers). The application is built as a mobile-first Progressive Web App (PWA) to meet the demanding conditions of volleyball matches, where stable internet access is not always guaranteed. The architecture focuses on offline-first performance, ensuring the coach can use the app reliably even in remote or low-connectivity environments. The application is developed using Angular, leveraging its strong modular structure and built-in support for PWA features. IndexedDB is used for local data persistence, allowing coaches to store and retrieve match information directly on the device,

without the need for a remote database. The app is also wrapped with Capacitor, enabling native deployment on Android (already released) and iOS (in progress). Choosing the PWA model provides key advantages: seamless installation via the browser, cross-platform support, low resource usage, and automatic updates. This approach ensures a consistent, lightweight, and robust experience across different devices — exactly what's needed courtside. By providing a user-friendly interface and leveraging the power of mobile computing, this application aims to significantly enhance coaches' ability to understand and strategically manage player match-ups throughout a volleyball game.

KEYWORDS: ASSISTIVE TECHNOLOGY, PROGRESSIVE WEB APP, ROTATIONS, MATCH ANALYSIS,

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Code 30

Exploring Motor Creativity in Tennis through Computer Vision

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Abstract

Currently, there are extensive amounts of game statistics being collected in the game of tennis. With majority of it being the traditional technical match statistics (e.g., rally length, speed of serve), there seems to be a lack of analysis for creativity in tennis. Creativity has become one of the highly desired traits in sport due to the fact that it allows for players to produce unconventional plays or movements that often gives them an advantage. With that in mind, this study aims to quantify creativity through kinematic movement patterns to ascertain the presence of creativity in elite tennis. Specifically, the study assesses technical tennis movements and kinematic data (e.g., shot locations, movement variability during swing return, time to contact the ball, angle of wrist during initiation of swing). We analysed 20 elite tennis games (i.e., ATP1000 or Grand Slams tournaments) in the singles men category. From the trimming and masking of video footage to the derivation of joint kinematics (i.e., joint angles and distances), it was fully automated with the use of computer vision and data analytics. Due to the nature of the algorithms, we were able to attain these data through the use of a marker-less motion capture system which would contribute to the ecological validity of this study. Upon clustering the relevant joint kinematics, we could differentiate one's motor creativity based on the statistical rareness of each movement. Furthermore, by applying other common creativity measures (i.e., fluency, flexibility), we were able to categorise each player's movement patterns which would potentially provide a numerical score to one's motor creativity (i.e., creativity index). A low cluster variation of movement patterns could suggest that the individual has lower motor creativity, as he demonstrates lesser exploratory movements during the game. With the quantification of creativity based on movement patterns, it allows for the establishment of correlation between motor creativity and performance abilities. Through this correlation between one's creativity index and ATP ranking, we can identify that experts generally display a larger variety of creative movement patterns. The implementation of computer vision significantly streamlined the workflow in the study as we were able to automate processing, reduce complexities and enhance data analysis. In future applications, this method has the potential to substantially advance player analysis by facilitating the automated and efficient quantification of performance metrics through computer vision techniques.

KEYWORDS: MOTOR CREATIVITY, TENNIS, COMPUTER VISION, PERFORMANCE ANALYSIS

Code 39

Athlete- and movement-specific clustering of halfpipe snowboard tricks using inertial measurement unit data

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[2] German Sport University

Abstract

Snowboard freestyle is a highly complex sport in which individual style is one of the judging criteria. Previous studies have demonstrated the reliability of inertial meassuremt units (IMUs) for capturing rotational parameters relevant to performance in snowboard freestyle (Gorges et al., 2025). Other researchers have shown the potential of uniform manifold approximation and projection (UMAP) for visualizing high-dimensional biomechanical data related to individual movement patterns (Duncanson et al., 2024).

The aim of this study was to explore whether snowboard tricks exhibit distinguishable patterns in IMU-based board quaternion data, and whether trick-specific or athlete-specific clusters emerge in a high-dimensional feature space. In addition, data preparation strategies were poprposed, such as correcting for initial orientation, to improve the consistency and separability of movement patterns.

Data were collected using Xsens IMUs (Movella Holdings Inc., Henderson, USA) and synchronized with video footage (N = 4 elite-level athletes, n = 199 halfpipe tricks, ranging from 180° to 1080° rotation). The analysis focused on synchronized quaternion data captured during the airtime phases (from takeoff to landing), with trick-specific metadata including riding direction, rotational direction and amount of rotation.

Data preparation involved multiple preprocessing steps to ensure consistency and comparability across trials: Initially, quaternion polarity was corrected by enforcing temporal continuity through sign alignment ($q_i \cdot q_{i-1} \geq 0$). Spurious spikes were removed using a sliding window mean filter (if $|q_i - (q_{i-1} + q_{i+1})/2| > 0.05$, then $q_i \leftarrow (q_{i-1} + q_{i+1})/2$). Each quaternion sequence was interpolated to a uniform length T using linear interpolation to standardize temporal resolution across tricks. Subsequently, all quaternions were rotated into a common reference frame by applying the inverse of the initial orientation ($q_i \leftarrow q_0^{-1} \cdot q_i$) to remove global orientation bias. Finally, cumulative rotation was computed as the sum of angular differences between consecutive quaternion frames, with $\Delta\theta_j = ||\log(q_j \cdot q_{j-1}^{-1})||$ [°] and $\theta_i = \sum_{j=1}^{i} \Delta\theta_j$ [°]. The values were scaled by 1/180 for normalization. The resulting time series had a shape of T × 5, representing [w, x, y, z, θ_i] for each time step.

UMAP (n_components = 3, n_neighbors = 150, min_dist = 0.3, metric = "cosine + euclidean") was applied for dimensionality reduction. Cluster quality was assessed using Silhouette and Davies-Bouldin scores, and 3D visualizations were used for qualitative analysis.

Overall the UMAP showed a clear separation for clusters of similar tricks (Figure 1 left) and additionally, a semantic spatial grouping based on trick rotation and rotation direction. When looking at athlete specific clustering (e.g., shown for all 540° tricks on the left side of Figure 1) even a separation for the same tricks performed by different individuals was apparent.

This baseline study provides insight into the structure of quaternion-based trick data and supports future machine learning applications towards automatic trick detection and style analysis. Especially the athlete-specific movement patterns clustering of the rotational data promises valuable opportunities for personalised coaching, performance monitoring, and the development of athlete-tailored classification models.

KEYWORDS: ELITE SPORTS, UMAP, WERABLE SENSORS, QUATERNIONS

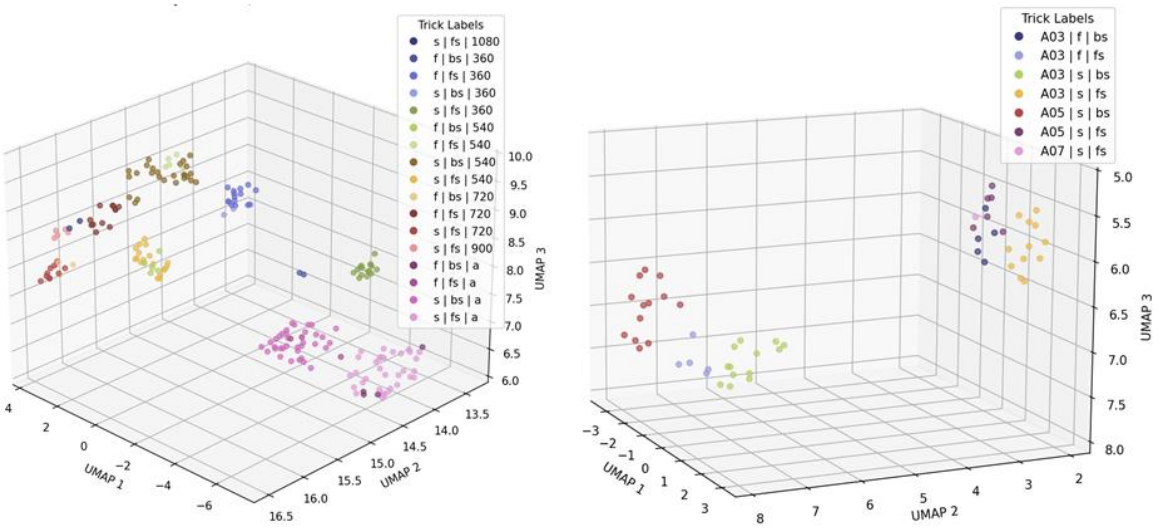

Figure 1. UMAP clustering of all tricks (left) separated by riding direction (forward – f /switch – s) and rotational direction (frontside – fs /backside – bs) as well as 540 tricks (right) separated additionally by athletes.

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Code 41

Feasibility of 3D Markerless Kinematic Analysis in Bouldering Using a Dual-Camera Computer Vision Approach

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Abstract

Precise quantification of movement is essential for understanding motor learning processes in sport climbing. While previous studies have relied primarily on 2D video analysis to assess climber kinematics, such methods are limited by perspective distortion and the inability to capture out-of-plane motion. As bouldering consists of dynamic 3D movements, this study investigates the feasibility of using a low-cost markerless 3D motion capture workflow to analyse whole-body kinematics during bouldering, with the aim of improving the accuracy and ecological validity of climbing movement analysis.

A single experienced climber was recorded performing a predefined bouldering route using two video cameras positioned to provide overlapping views of the climbing wall. The footage was processed using the markerless motion capture system to capture 3D data in bouldering. The key kinematic variables extracted were the hip displacement and trajectory path used as a measure of entropy and climbing fluidity.

The results demonstrate that a dual-camera computer vision approach can reliably reconstruct 3D body trajectories during climbing, even in the presence of partial occlusions and dynamic movements. Compared to standard 2D tracking, the 3D workflow provided enhanced spatial accuracy, particularly in the sagittal plane, and enabled more precise assessment of lateral body shifts. The system also facilitated detailed analysis of body positioning strategies and learning processes across successive climbing attempts.

This pilot study supports the feasibility of using a low-cost, markerless 3D computer vision system for kinematic analysis in complex sport environments such as bouldering. The integration of such methods offers new opportunities for tracking motor learning and movement variability over time, with potential applications in athlete monitoring, skill acquisition research, and coaching feedback systems.

KEYWORDS: MARKERLESS MOTION CAPTURE, SPORTS PERFORMANCE ANALYSIS, COMPUTER VISION, CLIMBING

Code 43

Implementation of Thin Film Pressure Sensors in Sporting Gloves: Structure Design and Analysis for Climbing

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Abstract

Climbing sports rely greatly on body posture and weight distribution, especially that of the fingers. To better measure the forces our fingers endure in climbing, pressure sensors, a staple in sports analysis, where the most common practice is the measurement of foot pressure for walking pose analysis are needed. However, rarely has the issue of hand pressure been brought up in wearable sensor technology, due to the little space our fingers allow for sensor placement, delicate motion that requires a complex analysis plan, and the varying regulations of sporting gloves in different sports. This paper explains the designs of our prototype glove analysis system that inlays thin film pressure sensors (FSR) to acquire force distribution values on each finger to assess climb motion, combined with IMU sensors to track hand position, and pose analysis of limb posture on OpenCV, with a final result of detailed feedback on finger and body posture and fatigue levels. Also, the data collected via FSR are then labeled with the analyzed motion and corresponding boulder formation type to form training data for a NN model that determines the climbing motion. This first prototype was designed for climbing sports, thus incorporating an inner layer of rubber gloves to enhance friction, a middle layer of FSR sensors positioned on each of our phalanges which are then processed by an ESP32 board located on the back of our hand, and an outer layer of thin yet heavy duty fabric used in modern climbing gloves, giving a solid foundation for future variations for implementation on other sporting glove usage and grip analysis.

KEYWORDS: CLIMBING, PRESSURE SENSORS, IMU SENSORS, POSE ANALYSIS, SPORTS PHYSIOLOGY

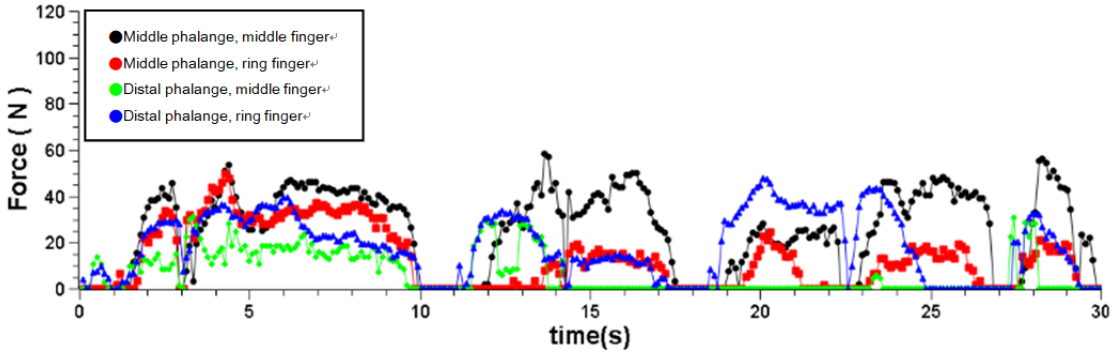

Figure 1. Pressure sensing data from a 4 pressure sensor inlay when climbing through a selected path of 5 boulders. A direct numeric scale of the force applied to each phalanx can be observed, and analysis by comparing the weight distribution and line shifting with respect to time on each phalanx can show how the athlete is gripping the boulder, and how each movement applies stress. This data can be processed directly to determine current human behavior, and is also trained with collected boulder shape for an action recognition model, also, when multiple iteration are compared side by side, movement speed and gripping posture (weight distribution) are crucial to determining fatigue.

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Code 85

Exploring Sports Video Collection with Embedded Visualizations

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Abstract

Nowadays, video is an important data source that contains rich information for sports data analysis. Despite the high value, efficiently processing and interpreting the visual content of a sports video collection is regarded as a difficult problem. Existing video visualizations apply computer vision techniques to extract data attributes from videos and design systems with facet views to help users gain insights into the video collection. However, the visual content of videos and the facet views are usually separated. Users still require considerable effort to watch the video and connect the data insight to the visual content. To close this gap, we propose a video analysis framework to help users directly interact with the video content and perform in-situ video analysis with embedded interactive visualizations. The framework includes the following steps to achieve the in-situ video analysis: 1) extracting interactive elements from videos, 2) binding extracted data to the elements, and 3) rendering visualizations into videos. We use football as our scenario and implement a proof-of-concept system to help experts explore a set of football videos. The effectiveness of the framework is evaluated with a quatitative experiment and case studies.

KEYWORDS: SPORTS VIDEO ANALYSIS, VIDEO COLLECTION, FOOTBALL ANALYSIS

15th International Symposium on Computer Science in Sport

IACSS 2025

September 12 - 15, 2025

Tokyo Gakugei University
Tokyo, Japan

Theme:
Sport Performance

Code 02

Assessment of Functional Movement Screen and Kinematic Parameters during Wrestling Techniques Using Inertial Measurement Unit Sensors

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Abstract

A functional movement screen (FMS) is an assessment system that identifies movement profiles and injury risks in athletes. This is also used to determine sport-specific performance and training effectiveness. It includes seven fundamental movement tasks; each task's completion level is scored (Cook, Burton, Hoogenboom, & Voight, 2014b; Parchmann & McBride, 2011). With advancements in sensor technology, inertial measurement unit (IMU) sensors have been widely utilized in sports science. Several studies have utilized IMU sensors to explore the relationship between functional movements and joint mobility (Whiteside et al., 2016). They suggest that IMU sensor-based systems can potentially be used to assess FMS. However, few studies have assessed functional movements and kinematic parameters in wrestling with IMU sensors. Therefore, we aimed to determine FMS and kinematic parameters in wrestlers using wearable sensors.

In this study, ten healthy controls and ten male wrestler students participated. They completed the 7 tasks of the FMS, and wrestlers performed wrestling techniques. Each FMS test was manually scored between 0 and 3 (Cook, Burton, Hoogenboom, & Voight, 2014a). After conducting FMS tests, scores were averaged and compared between the control and wrestler groups. Wrestlers were then divided into groups based on their FMS scores: group A:>15 scores; group B: ≤15 scores. Then, they performed two types of techniques, such as double leg attack and arm throwing techniques while wearing an Xsens wearable system (Xsens MVN). Kinematic parameters, such as the displacement and velocity of the CoM were calculated. These parameters were then compared between groups A and B. A previous study has shown that the velocity and displacement of the CoM are associated with the effectiveness of leg attacks in wrestlers (Yamashita et al., 2020).

Total FMS scores were 17.2±1.0 and 16.2±1.6 in control and wrestlers, respectively (Table 1). No statistical differences were found, but scores significantly differed in shoulder mobility and active leg raise tests ($p<0.05$). Generally, the control group had higher shoulder flexibility, while the wrestlers had a better ability to disassociate the lower extremities from the trunk.

During double leg attacks, group A lowered their CoM position by about 5 cm more than group B ($p<0.05$), but there was no significant difference in CoM velocity. Similarly, group A lowered their CoM position by about 4 cm more than group B during arm throwing. But, they showed higher propulsive velocity of the CoM. Maximum CoM velocities were 0.89 m/s and 0.74 m/s for groups A and B, respectively (Figure 1). Those who scored 15 or higher had an 18 % faster CoM velocity and a 9% lower CoM position during arm throwing.

We demonstrated the relation between FMS scores and kinematic parameters in wrestling. Our findings indicate that higher FMS scores are associated with greater CoM velocity and the ability to maintain a low-level CoM position during wrestling. Therefore, the FMS can effectively assess athletes' movement profiles and performance levels while identifying potential risk factors for injury or pain. This highlights the FMS as a valuable tool for evaluating athlete performance and its potential applications for training correction and injury prevention in wrestlers.

KEYWORDS: FUNCTIONAL MOVEMENT SCREEN, WRESTLING, KINEMATICS, INERTIAL SENSORS

Table 1. FMS scores in control and wrestlers

	FMS tests	**Control**	**Wrestlers**	**P value**
1	Deep squat	2.4±0.5	2.2±0.4	0.355
2	Hurdle step	2.4±0.5	2.0±0.4	0.087
3	Inlune lunge	2.5±0.5	2.3±0.4	0.388
4	Shoulder mobility	2.7±0.6	1.9±0.8	0.034
5	Active leg raise	2.3±0.4	2.9±0.3	0.004
6	Push up	2.9±0.3	2.9±0.3	1
7	Rotary stability	2.0±0.4	2.0±0.4	1
	Total score	**17.2±1.0**	**16.2±1.6**	**0.117**

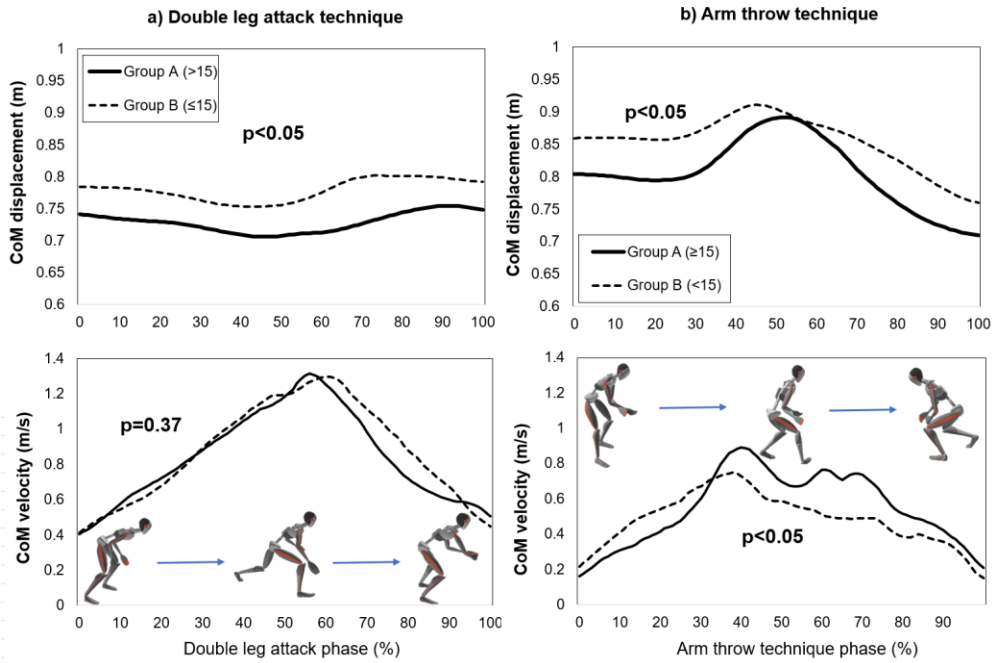

Figure 1. CoM displacement and velocity in (a) double leg attack and (b) arm throw techniques. (The lines represent the averages for each group)

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Code 04

A CASE STUDY ON MUSCLE ACTIVATION PATTERNS OF AN ELITE MALE HAMMER THROWER – PART I: LOWER BODY MUSCLES

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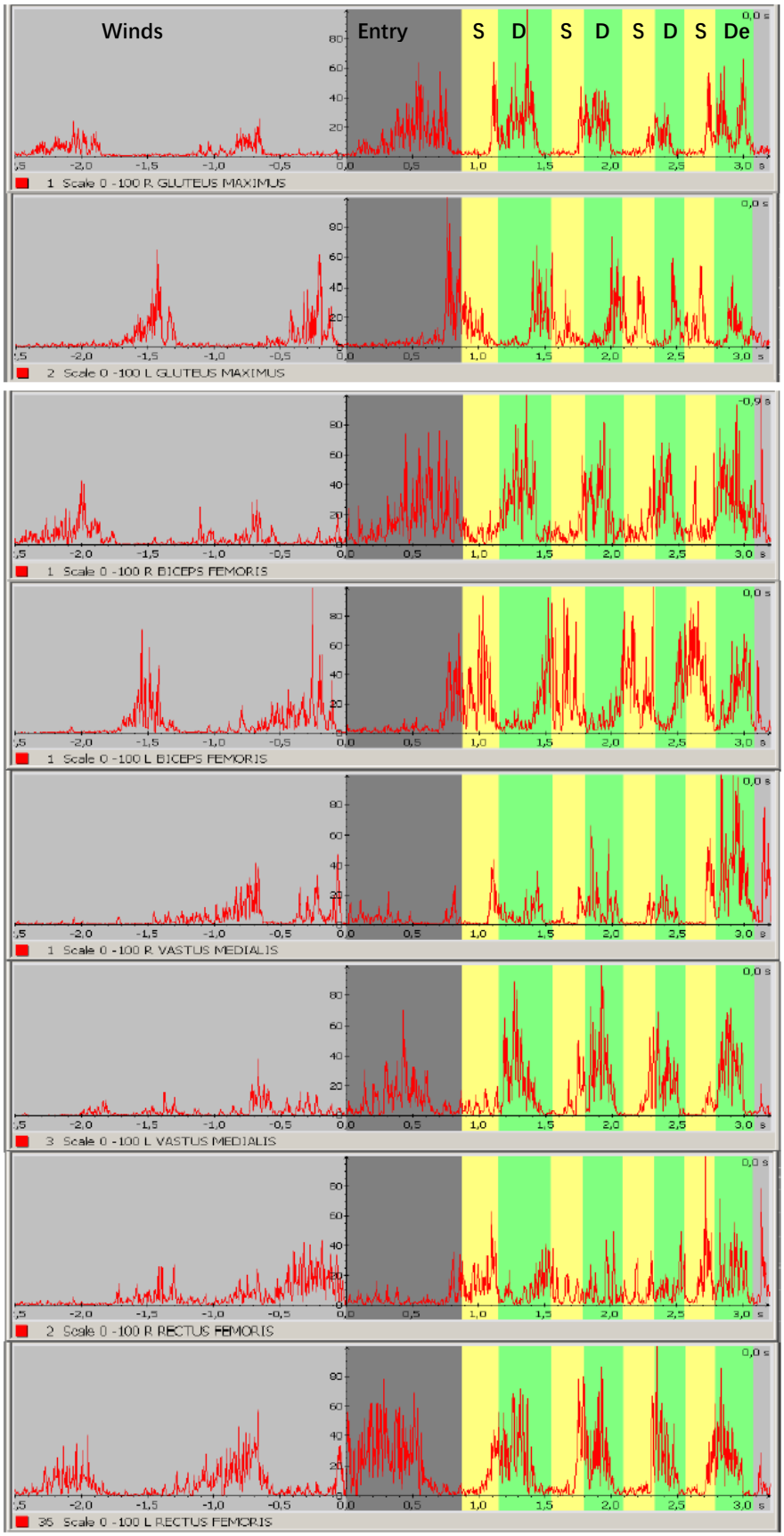
Abstract

The hammer throw is a sport in which a metal ball attached to a steel wire is hurled for the maximum distance using both hands while remaining inside a 2.135m circle (e.g. Judge et al., 2016). No studies were found in the literature search on examining muscle activation pattens in the hammer throw with EMG, although it is one of the most objective and reliable methods available for reflecting muscle functions (Szyszka-Sommerfeld et al, 2020). The purpose of this descriptive case study was to examine the muscle activation patterns of lower body muscles in the hammer throw. An approximately 74 m throw from a right-handed elite male hammer thrower (1.84 m, 115 kg) was measured by using wireless surface electromyographic (sEMG) sensors (Delsys Trigno, USA). The sEMG activities were recorded from seven lower body muscle pairs (right and left): Gluteus maximus, Biceps femoris, Vastus medialis, Rectus femoris, Soleus, Gastrocnemius and Tibialis anterior. The results indicated that most of the right-side muscles were active during the double support phases, whereas the left side demonstrated more variation depending on the muscle. A pre-activation pattern at the end of single support phases was observed in several muscles. It can be concluded that sEMG gives valuable information about the role of different lower body muscles in the hammer throw.

KEYWORDS: EMG, ACTIVATION PATTERN, TRACK AND FIELD


Winds
Entry
S D S D S D S De
1 Scale 0 -100 R GLUTEUS MAXIMUS
2 Scale 0 -100 L GLUTEUS MAXIMUS
1 Scale 0 -100 R BICEPS FEMORIS
1 Scale 0 -100 L BICEPS FEMORIS
1 Scale 0 -100 R VASTUS MEDIALIS
3 Scale 0 -100 L VASTUS MEDIALIS
2 Scale 0 -100 R RECTUS FEMORIS
35 Scale 0 -100 L RECTUS FEMORIS

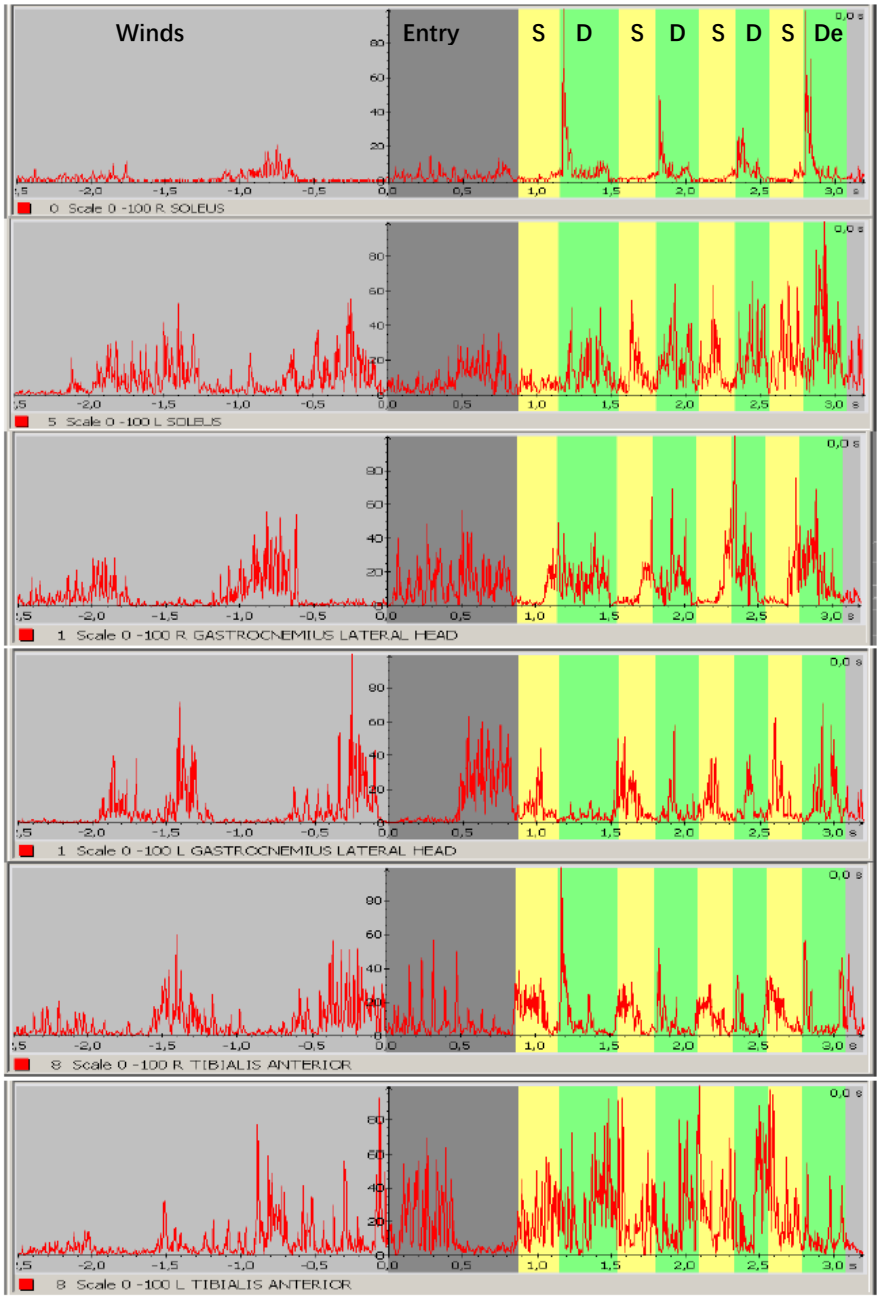


Figure 1: Activation pattern (right and left sEMG) of Gluteus maximus, Biceps femoris, Vastus medialis, Rectus femoris, Soleus, Gastrocnemius and Tibialis anterior. (S = single support phase, D = double support phase, De = delivery phase, L = left, R = right)

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Code 05

A CASE STUDY ON MUSCLE ACTIVATION PATTERNS OF AN ELITE MALE HAMMER THROWER – PART II: CORE AND UPPER BODY MUSCLES

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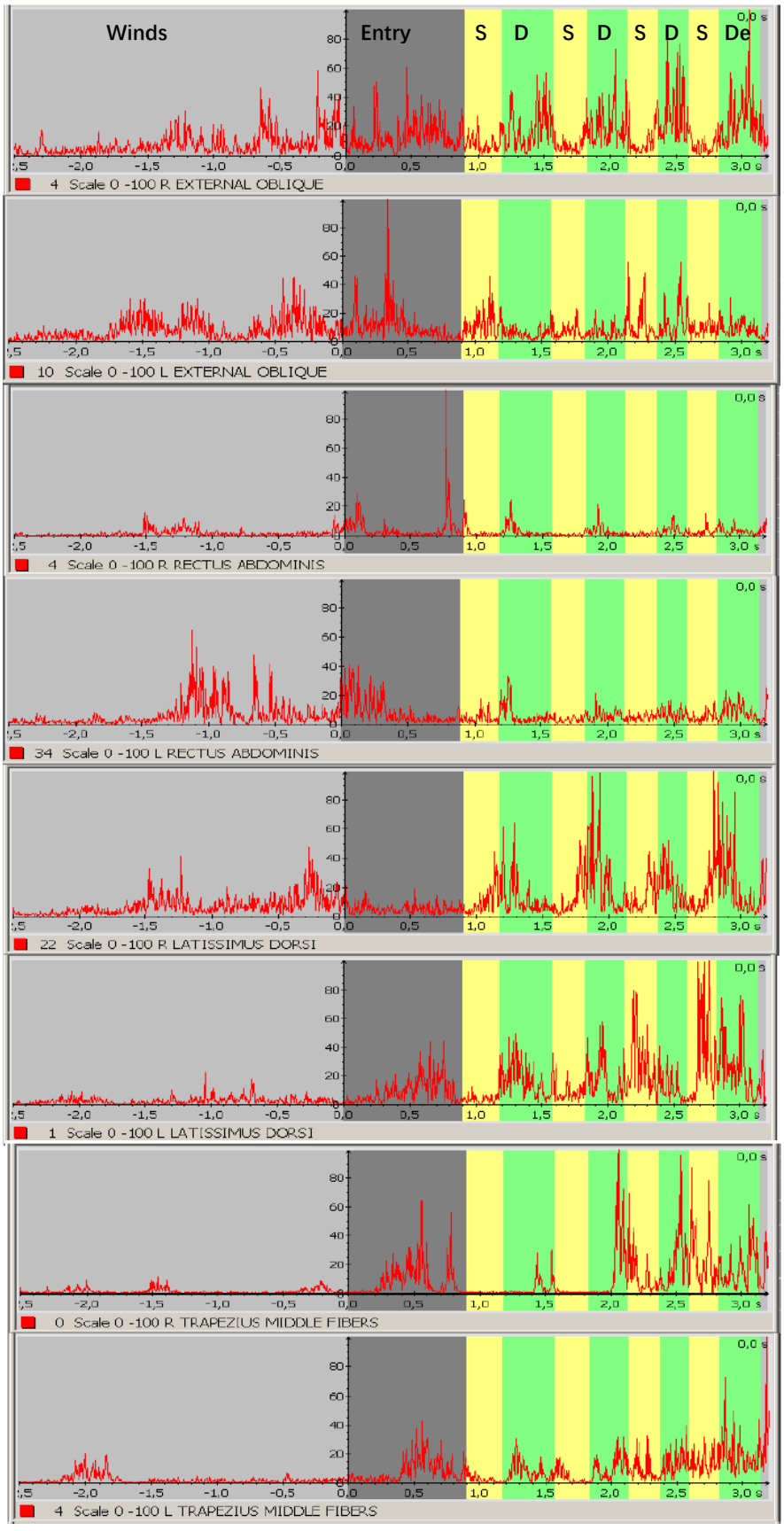
Abstract

The hammer throw is a leg-oriented sport, but power is derived also from the upper body muscles, and especially from the core muscles (Cook, 2006). Therefore, it is not surprising that further research has been warranted in the form of EMG studies to quantify the role of different muscles in the hammer throw (Murosushi et al., 2017). The purpose of this descriptive case study was to examine muscle activation patterns of the core and upper body muscles in hammer throw. An approximately 74 m throw from a right-handed international level male hammer thrower (1.84 m, 115 kg) was measured by using wireless surface electromyographic sensors (sEMG). The sEMG activities were recorded (Delsys Trigno, USA) from seven upper body muscle pairs (right and left): External oblique, Rectus abdominis, Latissimus dorsi, Trapezius, Infraspinatus, Deltoideus and Biceps brachii. The analysis was conducted using qualitative observation. High activity in the External oblique and Latissimus dorsi muscles was observed during the turns, and in upper body muscles (Deltoideus and Biceps brachii) during the delivery. To conclude, sEMG activity particularly in the upper body muscles was found to be less consistent in terms of rhythmicity and amplitude compared to the lower body muscles.

KEYWORDS: EMG, ACTIVATION PATTERN, TRACK AND FIELD


Winds
Entry
S D S D S D S De
4 Scale 0 -100 R EXTERNAL OBLIQUE
10 Scale 0 -100 L EXTERNAL OBLIQUE
4 Scale 0 -100 R RECTUS ABDOMINIS
34 Scale 0 -100 L RECTUS ABDOMINIS
22 Scale 0 -100 R LATISSIMUS DORSI
1 Scale 0 -100 L LATISSIMUS DORSI
0 Scale 0 -100 R TRAPEZIUS MIDDLE FIBERS
4 Scale 0 -100 L TRAPEZIUS MIDDLE FIBERS

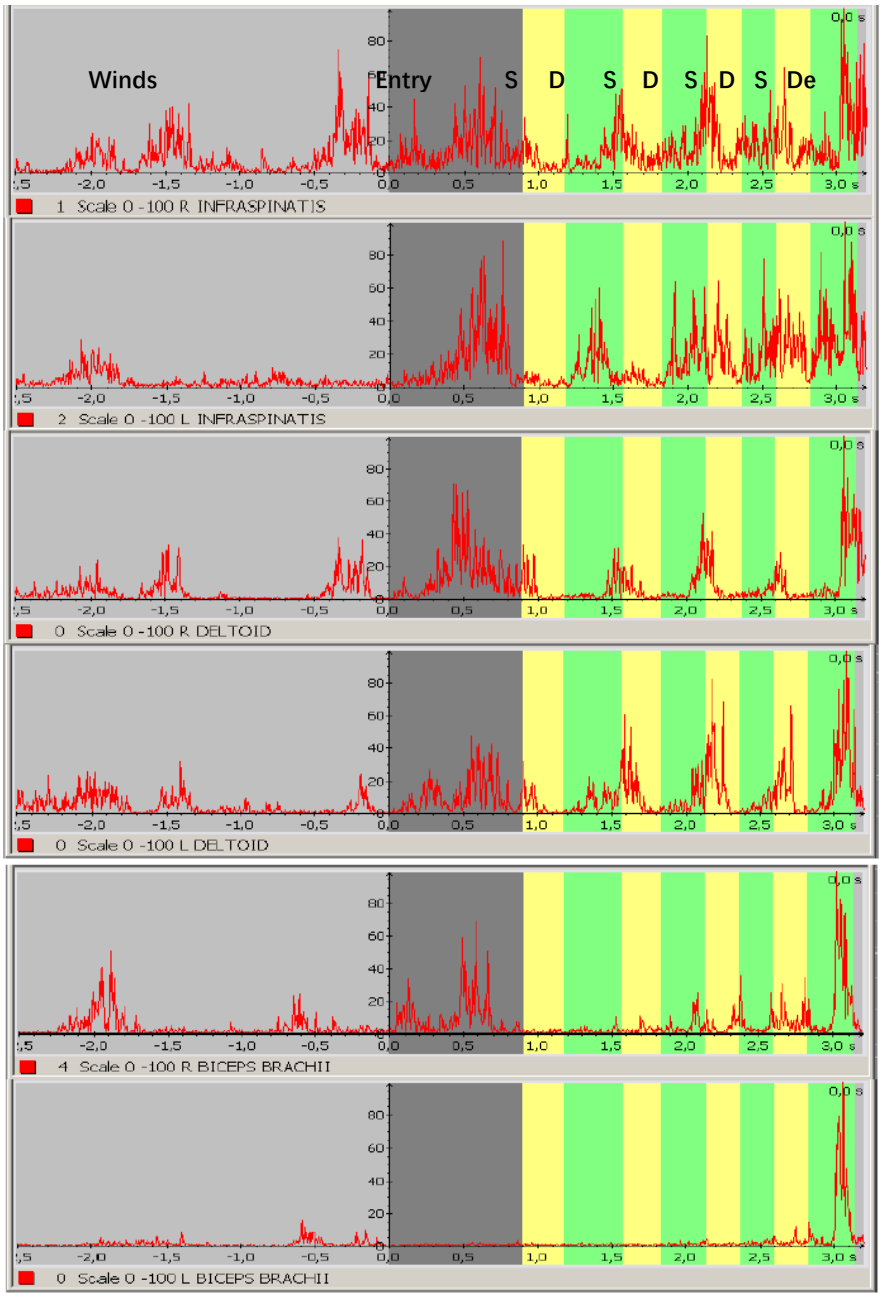


Figure 1: Activation pattern (right and left sEMG) of External oblique, Rectus abdominis, Latissimus dorsi, Trapezius, Infraspinatus, Deltoideus and Biceps brachii. (S = single support phase, D = double support phase, De = delivery phase, L = left, R = right)

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Code 10

Sensory integration processes characterize concussed athletes with balance deficits

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[2]*Smith College*
[3]*University of Regensburg*

Abstract

Introduction: Impaired postural control constitutes a major symptom after mild traumatic brain injuries (mTBI / sport-related concussions (SRC)). In order to uphold cognition and behavior during pathological situations, individuals may be characterized by neuronal upregulation. Because postural control necessitates the integration of sensory information within the somatosensory (/parietal) cortices, we investigated the hypothesis that athletes with ongoing symptoms after SRC are characterized by increased brain activation within these areas in order to compensate for postural deficits.

Methods: 66 athletes (27 ± 13 years; 50 men, 16 women) participated in the study. 22 concussed athletes reported high post-concussion symptoms (PCS; symptomatic group) and 22 concussed athletes reported low PCS (asymptomatic group). 22 healthy non-concussed athletes served as a control group. Postural control was assessed by a pressure distribution measuring plate during four balance conditions, with eyes closed / open whilst either standing on a stable / unstable surface. Brain oxygenation was collected during postural control tasks by functional near-infrared spectroscopy (fNIRS) above pre- and postcentral cortices of both hemispheres.

Results: Increased postural sway was found in symptomatic athletes when compared to control athletes for overall conditions as well as during unstable surface conditions. Symptomatic athletes were characterized by increased brain activation within the parietal cortex for overall balance conditions and when compared to asymptomatic athletes.

Discussion: Increased brain activation within somatosensory and parietal cortices during postural control indicates that sensory integration processes are upregulated in concussed athletes with persisting symptoms. However, such compensatory processes seem to constitute an ineffective neuronal mechanism, as affected athletes cannot mitigate the post-concussion balance deficits.

Conclusion: Athletes with persisting symptoms after an SRC are not effectively controlling posture. The results further indicated that potential compensatory neuronal mechanisms in concussed and symptomatic athletes cannot counteract the post-concussion balance deficits.

KEYWORDS: COMPUTATIONAL SPORT NEUROSCIENCE, MOTOR CONTROL, NEURAL CORRELATES, CLINICAL RESEARCH, SPORT-RELATED CONCUSSION

Code 11

Anticipation Training in Beach Volleyball: Evaluation of a Training Program for the German National Team

Fabian Tobias & Daniel Link

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Abstract

Introduction

Anticipatory skills are crucial for elite beach volleyball players to effectively predict and counter opponent attacks (Schläppi-Lienhard & Hossner, 2015). With increasing competition at the international level, athletes must refine their ability to read attack patterns early and make accurate decisions. Figure 1 illustrates various sources of information over time that influence the subsequent attacking action. The higher the skill level of individual players, the later attack patterns can

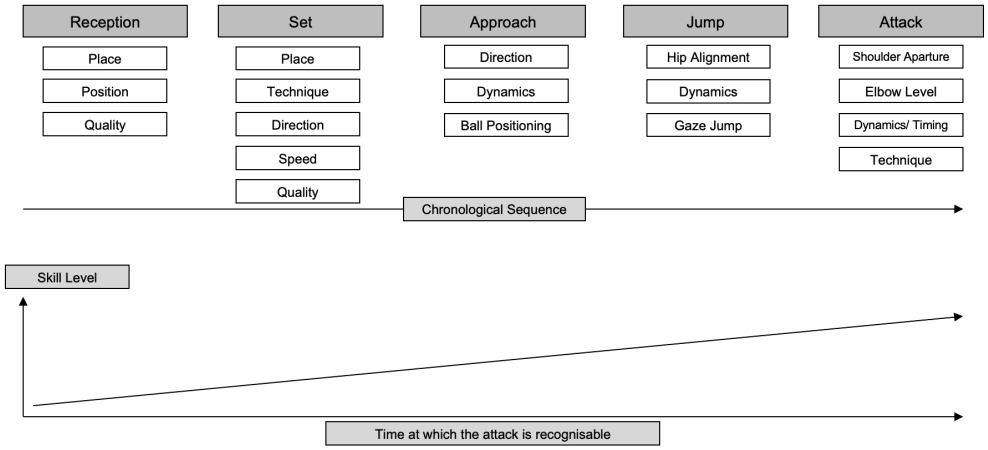

Figure 1. Temporal progression of key cues for attack recognition in beach volleyball based on skill level.

Despite existing research on visual strategies and anticipation training, few studies have explored opponent-specific anticipation training methods in beach volleyball. The program BeachAnticipation, developed in collaboration between the Technical University of Munich (TUM) and the German Volleyball Federation (DVV), aims to enhance anticipatory skills through a gamified, video-based training approach. The software BeachAnticipation builds upon the game analysis tools BeachScouter and BeachViewer (Link, 2014). By utilizing pre-analyzed matches, training sequences can be designed for individual players based on both quantitative and qualitative game analysis. Additional settings can be configured, such as individual adjustments of occlusion timings before hand-ball contact, the response time window for inputting answers, and the resolution of the game sequence after occlusion. This project evaluates the effectiveness of this training method in improving the performance of national team players.

Objective: The study aims to assess the efficacy of the training program with BeachAnticipation in improving anticipation performance of elite beach volleyball

athletes. The findings will inform the development of an optimized, individualized training protocol tailored to specific opponents.

Methods

Two experimental studies will be conducted:

Study 1 – Occlusion Timings for Training: Participants, including TUM sport science students (novices) and German national team players, will watch video clips of professional's beach volleyball attacks. Clips will be occluded at different time intervals (225ms, 200ms, 175ms before hand-ball contact), and participants will be asked to predict attack type (smash, shot) and direction (smash: line, mid, dia; shot: line, dia, cut). Data will be analyzed for skill level differences based on expertise, gender and playing position.

Study 2 - Training Intervention & Retention: National team players will complete at least one training session using a structured pre-test, training intervention, post-test, and 24-hour retention test. The study compares single vs. multiple training sessions to evaluate short- and long-term learning effects.

Results & Implications

Findings from Study 1 will identify optimal occlusion timings for training, with a particular focus on determining the ideal occlusion points for professional players. Additionally, it will examine differences between novices and professionals in anticipatory skills. Study 2 will determine whether training with BeachAnticipation significantly enhances anticipatory skills and retention in skilled beach volleyball players competing at the international Beach Pro Tour level. If successful, the program could be integrated into national team preparation strategies, providing a novel, data-driven approach to skill development. Future research may extend to augmented reality (AR)-based training to simulate real-game conditions more effectively (Cañal-Bruland & Mann, 2024).

KEYWORDS: ANTICIPATION TRAINING, BEACH VOLLEYBALL, GAMIFIED LEARNING

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Code 16

Test-Retest Reliability of HR Model Parameters in Submaximal Rowing Exercise: A Pilot Study

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University of Vienna

Abstract

Introduction
Mathematical modeling of the interaction between workload and heart rate (HR) during physical exercise has been receiving increasing attention. Previous studies suggest that parameters of HR models are associated with athletes' cardiorespiratory fitness (Mongin et al., 2020; De Leeuw et al., 2023; Nazaret et al., 2023). To use these parameters as indicators of fitness, it must be possible to determine them reliably. Therefore, the present study investigates the reliability of HR model parameters in a test-retest scenario.

Methods
Seven Austrian national-level rowers performed two submaximal incremental step tests on a rowing ergometer, separated by three days. Mechanical power and HR were recorded stroke by stroke, blood lactate concentration and rating of perceived exertion (RPE) were captured at the end of each test step. A differential equation HR model (Mongin et al., 2020) was fitted to each pair of power and HR. The model parameters were determined by an evolutionary optimization algorithm. The test-retest reliability of the HR model parameters was assessed via the intraclass correlation coefficient (ICC) (Cohen's kappa for categorical variables) and the standard error of measurement (SEM). Reliability of the traditional metrics RPE, lactate concentration, power and HR per stage served as baseline.

Results
Table 1 summarizes the reliability scores for all metrics. Power showed high reliability, and the traditional metrics were more reliable at the end of the tests. The gain parameter K of the HR model showed good reliability in terms of ICC, exceeding the reliability of traditional HR metrics and being comparable to the reliability of post-test lactate concentration.

Discussion
The results for power and traditional metrics indicate that the athletes were able to consistently produce the predefined power of each test step, and that intra-individual and day-to-day variability have diminishing influence over the course of the test. The good reliability of K suggests that by considering the interaction of workload and HR, parameters of HR models contain additional information which is not captured by traditional HR metrics.

Conclusion

For frequent fitness monitoring, analyzing HR model parameters might be an accessible alternative to metrics that require cumbersome procedures, such as blood lactate concentrations. Further studies are needed to investigate how training interventions influence the HR model parameters and traditional metrics. The presented SEM values can be used in the future to assess if changes in parameters and metrics are meaningful or within the expected measurement error.

KEYWORDS: HR MODEL, ROWING, RELIABILITY, HEART RATE, FITNESS

Table 1. Test-retest reliability scores for repeated submaximal rowing tests, with three incremental steps. S1/S2/S3 stands for the first, second or third step of the test, respectively. Cohen's Kappa was used as alternative to ICC for the categorical metric RPE. All values are rounded to the third decimal.

Group	Metric	ICC / Cohen's Kappa	SEM
HR Model Parameter	HR_0 [bpm]	0.827 **	4.477
	K [bpm/W]	0.95 ***	0.019
	τ [s]	0.879 **	2.791
HR [bpm]	Initial HR	0.343	7.852
	Max HR	0.909 **	2.269
	Mean HR	0.87 **	2.688
	Mean HR S1	0.811 **	3.680
	Mean HR S2	0.924 ***0	2.088
	Mean HR S3	.917 ***0.	2.210
Lactate [mmol/l]	Lactate S1	627 *	0.138
	Lactate S2	0.913 ***0	0.254
	Lactate S3	.957 ****0	0.310
	Lactate Post	.973 ****0	0.310
RPE	RPE S1	.364	0.363
	RPE S2	0.720	0.259
	RPE S3	0.696	0.260
	RPE Overall	1.0	0.000
Power [W]	Power S1	1.0 ****	0.703
	Power S2	1.0 ****	0.950
	Power S3	0.998 ****	2.484

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$, **** $p < 0.0001$

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Code 20

An Analysis of the Running Performance Characteristics of Professional League Referees Across Different Match Contexts

Mu Fan & Hui Zhang

Zhejiang University

Abstract

Objective: This study uses the Chinese Super League (CSL) as a case study to examine the characteristics and patterns of referees' running performance in various situations. Specifically, the study analyzes how referees' performance varies according to their role, the match period, and the game's progression.

Method: This study incorporated ProZone® (Leeds, UK) wearable technology to collect and analyze running performance data from field referees during the 2019 CSL season. The dataset comprises 30 referees across 240 matches, totaling 22,994 minutes of match time. Key metrics analyzed sprinting, high-speed running (HSR), fast running (FR), and total distance (TD). Each match was segmented on a minute-by-minute basis according to different situational contexts. Running performance data were then compared and analyzed against various contextual variables, such as referee nationality, match periods (general and special), and match process (on-field situations and score differences).

Results: (1) Referees from other countries exhibited significantly higher values in FR compared to Chinese referees ($p < 0.001$). (2) Referees exhibited signs of fatigue following a brief period of extensive running, with Sprint, HSR, and TD values significantly lower during the Mean-5min and Next-5min periods compared to the Peak-5min period (all $p < 0.001$). (3) In different match periods, HSR ($p < 0.01$), FR ($p < 0.05$) and TD ($p < 0.001$) were significantly reduced in the second half compared to the first half. Additionally, the 1-15 minutes segment of the match and the additional time periods of both halves had significantly higher Sprint ($F = 1.94$, $p < 0.05$, $\eta^2 = 0.001$), HSR ($F = 7.002$, $p < 0.001$, $\eta^2 = 0.001$), FR ($F = 3.339$, $p < 0.001$, $\eta^2 = 0.002$), and TD ($F = 7.002$, $p < 0.001$, $\eta^2 = 0.001$) values than the other periods. (4) During different match progressions, draws exhibited significantly higher HSR ($p < 0.05$), FR ($p < 0.05$), and TD ($p < 0.001$) compared to when the home team was leading. Additionally, FR ($p < 0.001$) and TD ($p < 0.001$) were significantly lower when the home team was leading than when it was behind. Furthermore, TD increased significantly with the widening score difference ($F = 6.261$, $p < 0.001$, $\eta^2 = 0.001$).

Conclusion: There were no significant differences in running performance between international and Chinese referees. The highest levels of running activity were observed during the first half, the initial 15 minutes of the match, and additional time at the end of each half. During different phases of match

progression, referees exhibited the highest running volumes when the match was tied, when the home team was behind, or when there was a significant score difference. These findings underscore the importance of referees anticipating score changes during pre-match preparations, halftime breaks, and active officiating to maintain optimal physical performance throughout the match.

KEYWORDS: FIELD REFEREES, FOOTBALL, RUNNING PERFORMANCE, SITUATIONAL FACTOR, CHARACTERISTIC

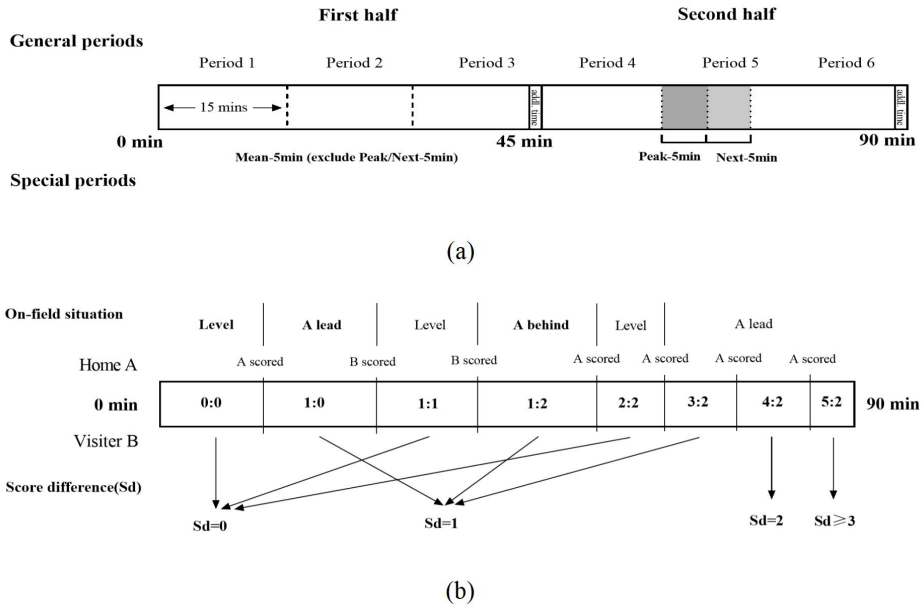

Figure 1. (a)Illustration of the division of match periods; (b)Illustration of the division of the match process.

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Code 23

Recurrence Analysis in Football: Relationship between Recurrence Parameters and Match Results

Sebastian Hermann[1,2], Hendrik Meth[2] & Martin Lames[1]

[1]Technical University Munich

[2]Stuttgart Media University

Abstract

Introduction

Recurrence analysis (RA) has proven to be a valuable tool for capturing dynamic interaction processes in football (Lames et al., 2021). The core element of RA is the recurrence plot (RP), a visual representation of recurring states of a dynamic system (Eckmann et al., 1987). Its patterns and structures are quantitatively recorded in the recurrence quantification analysis (RQA) with firmly defined parameters (Marwan et al., 2007). While previous studies have focussed on methodological issues and full-match analysis, this study analyses the relationship between the RQA parameters and individual team success.

Methods

RPs for 280 matches of the first German Bundesliga of the 2021/2022 season were constructed. The methodological steps considering football-specific characteristics were executed according to Lames et al. (2021). To ensure the comparability of all RPs, overtime trajectories were omitted. For the RP modelling, the average distance matrices of the individual teams are calculated using a threshold of 13 metres. The RQA parameters are calculated according to Marwan et al. (2007) and serve as dependent variables for the statistical analysis of the differences between wins, losses and draws via ANOVA. Match information is obtained from the official Bundesliga website (www.bundesliga.de). In addition to the regular results, expected goals (xG) are included as summative expression of chance quality.

Results

The RPs show discernible differences in the team comparison and the aggregated form of the corresponding matches (Figure 1). The ANOVA of the RQA parameters with the match outcome revealed significant differences between the entropy of the diagonal lines (ENTR; p_{ENTR}=.002) and the entropy of the vertical lines (ENTR-V; $p_{ENTR\text{-}V}$< .001) (Table 1). Successful teams exhibit significantly lower entropy values representing a more homogeneous distribution of vertical and diagonal recurrent structures. The remaining parameters showed no significant differences, although many of them showed a significant tendency (p<.10). The xG tests support this finding, as they show a highly significant difference in both entropy parameters (p_{ENTR}=.001, $p_{ENTR\text{-}V}$<.001) and the recurrence rate (RR; p_{RR}<.001).

Discussion

Team success is closely related to relatively low entropy values but shows no significant differences to other recurrence parameters, such as determinism. Therefore, the frequency of local recurring points that form lines seems to be less relevant for success than the global variation of these line structures. The low entropy values observed with successful teams could be associated with the successful utilisation of repeated tactical movements. In this regard, future studies could use RA tools to specifically look for in-match phases that generate low entropy values and RRs and analyse these in terms of chance frequency and quality.

Conclusion

This study demonstrates the relationship between team performance and RP structures, contributing to a better understanding of team-based dynamics in football matches.

KEYWORDS: PERFORMANCE ANALYSIS, FOOTBALL, MATCH DYNAMICS, RECURRENCE ANALYSIS

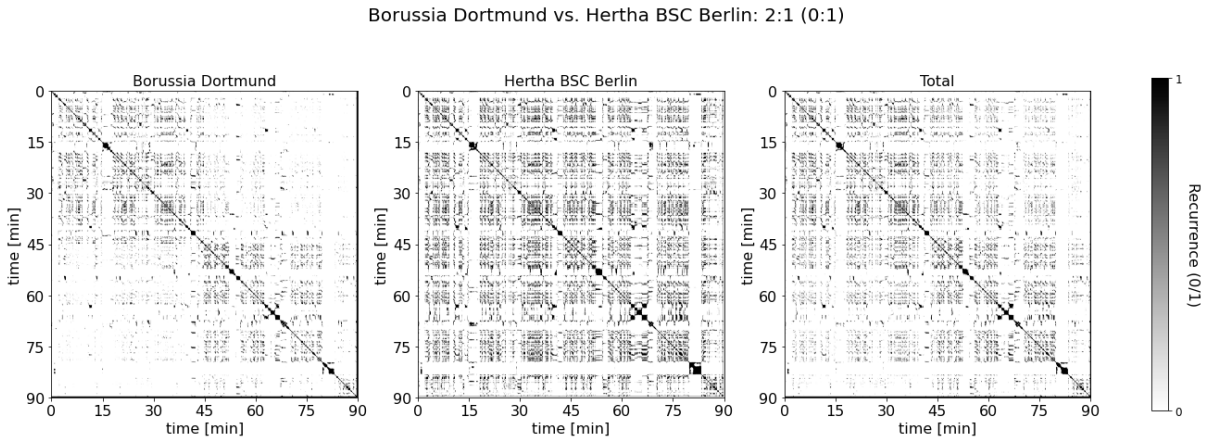

Figure 1. Exemplary comparison of a match team RPs and the aggregated RP, showing clear differences in their patterns (e.g. recurrence density and blocks).

Table 1. ANOVA results (p-values) of the RQA-parameters dependent on different match outcomes and expected goals difference. Double asterisks (**) indicate highly significant results.

RQA-parameter	p_{Result}	p_{xG}
RR	.093	.0001**
DET	.106	.120
LAM	.087	.125
L	.070	.177
TT	.051	.152
ENTR	.002**	.005**
ENTR-V	.0003**	.005**

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Code 35

Influence of horizontal release position and handedness matchups on batter's swing results of fastballs in US Major League Baseball

Mamiko Kato[1] & Toshimasa Yanai[2,3]

[1] Toyo University

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Abstract

Fastballs thrown by right-handed pitchers tend to move across a right-handed batter's field of vision from left to right, whereas the same pitch tends to approach directly toward a left-handed batter in his field of vision. Given this inherent asymmetry in visual information available for batters, fastballs released by right-handed pitchers may create a greater angular displacement of the batter's sightline while tracking the ball in same-side matchups (SSM) than in opposite-side matchups (OSM), potentially making them harder to perceive and predict the ball motion. This study aimed to test the hypothesis that fastballs released from the third/first-base side are harder to hit in SSM than OSM, and to quantify this advantage in SSM in Major League Baseball.

Using 2024 ball-tracking data, we analyzed 28,329 fastballs thrown in SSM and 47,670 in OSM, including fastball kinematics (e.g., position and velocity), situational variables (e.g., ball-strike counts), pitcher handedness and role (starter vs. reliever), and corresponding pitching result. For left-handed pitchers, fastball kinematics were mirror-reversed. All kinematics were standardized. We used generalized additive mixed models to examine whether the interaction between a horizontal release position and matchups was associated with two pitching results: (a) whether a pitch resulted in a missed swing or contact (missed-swing model), and (b) whether contact resulted in a base hit (base-hit model) with covariates. Covariates included fastball kinematics, pitcher handedness and role, situational variables, matchups (0 = SSM, 1 = OSM), and interaction terms as fixed effects, and pitcher and batter IDs as random effects. The model's goodness-of-fit was assessed using marginal and conditional R^2 values (Nakagawa, Schielzeth, & O'Hara, 2012).

Results indicated that fixed effects explained 9% of the variance in both models (marginal $R^2 = 0.09$). The conditional R^2, which indicates the variance explained by fixed and random effects, was 0.19 for the missed-swing model and 0.10 for the base-hit model, suggesting that the random effects contributed more to explaining the variance in missed swings. These metrics indicate that most variance remains unexplained, suggesting that other or unmeasured factors influence pitching results substantially. In the missed-swing model, matchups ($\beta = -0.06$; $p = .026$), horizontal release position ($\beta = -0.19$; $p < .001$), and their

interaction (β = 0.12; p <.001) were significant, after accounting for other covariates, indicating that (i) missed swings are more likely in SSM, (ii) third-base-side releases are likely to increase missed swings, and (iii) this effect are likely to be reduced in OSM. The interaction was not significant in the base-hit model (p = .078). These results provisionally support the hypothesis. Based on the missed-swing model, fastballs released from the 1-m third-base side are 1.35 times more likely to result in missed swings in SSM than OSM. Conversely, fastballs released from the center are 0.83 times less likely to result in missed swings in SSM than OSM. These results suggest that, given the covariates, the same-side advantage in inducing missed swings is evident only for fastballs released from the third-base side, which increases the angular displacement of the batter's sightline.

KEYWORDS: PERFORMANCE ANALYSIS, KINEMATICS, PITCHING, PLATOON EFFECTS

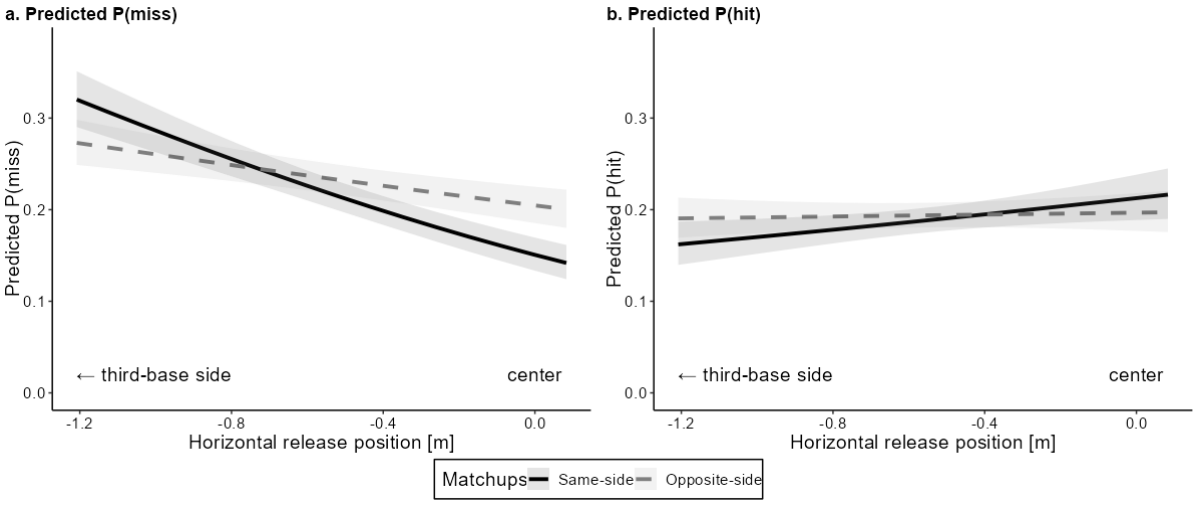

Figure 1. Predicted (a) probability of a missed swing (P(miss)) and (b) probability of a base hit (P(hit)) across various values of horizontal release position by handedness matchups, with all other covariates held at their mean values

Table 1. Fixed effects in constructed generalized additive mixed models for estimating the probability of missed swing and base hits.

Type	Variables	Coefficients in missed-swing model	Coefficients in base-hit model
Linear terms	Matchups: opposite-side	-0.06*	-0.02
	Horizontal release position	-0.19***	0.06*
	Interaction between horizontal release position and matchups	0.12***	-0.06
	Release extension	-0.00	0.04**
	Vertical release position	-0.26***	0.13***
	Ball speed	0.27***	-0.09***
	Spin rate	0.04**	-0.02
	Horizontal spin-induced displacement	0.24***	-0.15***
	Interaction between horizontal spin-induced displacement and matchups	-0.29***	0.19***
	Vertical spin-induced displacement	0.36***	-0.18***
	Pitcher role: starter	0.07*	0.00
	Pitcher handedness: right-handed	-0.25***	0.06
	Ball count: 1	0.06*	0.05
	Ball count: 2	-0.05	0.09*
	Ball count: 3	-0.16***	0.10*
	Strike count: 1	-0.07*	-0.07
	Strike count: 2	-0.55***	0.03
	Outs: 1	0.07*	-0.07*
	Outs: 2	0.09**	-0.07*
Spline function	Horizontal position in same-side matchups	edf = 3.25 χ^2 = 186.4***	edf = 2.28 χ^2 = 9.46**
	Horizontal position in opposite-side matchups	edf = 3.90 χ^2 = 550.5***	edf = 3.64 χ^2 = 76.61***
	Vertical position	edf = 3.93 χ^2 = 2884.0***	edf = 3.42 χ^2 = 434.74***

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Code 37

Coupling load parameters via Kernel Density Estimation – Uncovering underlying patterns for training optimization

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Abstract

Understanding the coupling of internal and external training load is critical for designing effective training programs that maximize athlete adaptation while minimizing injury risk. : Correlating separate traditional summation metrics, such as training impulse (TRIMP) and accumulated PlayerLoad, fails to capture the nuanced relationship between these loads, particularly in intermittent or variable-intensity sports. In this talk, we will demonstrate the utility of bivariate kernel density estimation (KDE) as a superior tool for visualizing and analyzing the complex interaction between internal and external load variables across diverse training sessions and different sports, enabling insights unattainable through conventional metrics.

Two complementary investigations were conducted. The first analyzed on-ice training sessions of 18 junior (sub)elite speed skaters over two seasons, monitoring heart rate (internal load) and velocity (external load). The second observed evaluated 10 male national youth volleyball players across five months of training, pairing heart rate with PlayerLoad. Both studies categorized sessions by type (e.g., endurance, interval, technical drills, game-like exercises) and compared KDE-derived patterns to traditional metrics (TRIMP, intensity zones). Statistical differences were assessed via Kruskal–Wallis, Kolmogorov–Smirnov tests, and effect sizes.

Results consistently revealed that traditional metrics showed limited differentiation between session types. In speed skating, TRIMP scores only distinguished extensive endurance sessions ($P < .001$), while KDE plots of heart rate and velocity highlighted distinct patterns across all session types ($P < .001$). Similarly, in volleyball, TRIMP and accumulated PlayerLoad showed no significant differences between exercises, whereas KDE distributions identified subtle distinctions (effect sizes: 0.01–0.26). Bivariate KDE visualizations further elucidated sport-specific couplings that provide critical information on how internal and external load parameters interact. Within the speed skating cohort, we found clear velocity-heart rate clusters per session type indicating distinct couplings of the load variables. Similarly, in volleyball, KDEs revealed exercise-specific interactions between PlayerLoad and heart rate, undetectable in zone-based analyses. This highlights that simplifying the time

series data within training sessions into one summary score may come at a cost of losing relevant information. By transcending the limitations of aggregate metrics, KDE provides coaches with actionable insights into the dynamic interplay of training loads. This method enhances the ability to tailor session designs, align training stimuli with physiological goals, and mitigate injury risks. Integrating KDE with traditional metrics offers a comprehensive framework for optimizing long-term training planning across sports, from endurance-dominated speed skating to intermittent volleyball drills, ultimately fostering targeted athletic adaptations.

KEYWORDS: DATA MINING, TRAINING LOAD, DISTRIBUTIONS, ATHLETE MONITORING

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Code 51

Modelling Performance Distributions from Multi-trial Athletic Tests

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Abstract

Athlete performance in multi-trial tests (e.g., countermovement jump, drop jump, isometric mid-thigh pull) is typically evaluated using single-value summary statistics, such as the maximum, mean, or trimmed mean of the measured variables. While simple to compute, these point estimates have notable limitations. Maximum values rely on a single observation, disregarding variabability and the remainder of the available data, and potentially misrepresenting the athlete's overall performance profile. Means and trimmed means may understate true capability by diluting maximal efforts, thereby undermining the objective of maximal-output tests (Moir, Shastri, & Connaboy, 2008). Furthermore, the typically small number of trials conducted renders such statistics noisy, unstable, and sensitive to variability (Franks, D'Amour, Cervone, & Bornn, 2016). Previous research has examined the reliability and validity of different summary statistics for representing athletic performance, yet no clear consensus has been reached regarding the most appropriate, and different choices can lead to different conclusions and interpretations (Martin-Rincon et al., 2019; Pedersen & Lorås, 2017). As an alternative, model-based estimates of sport metrics have been shown to offer more reliable assessments of performance (Franks et al., 2016).

This study proposes a novel approach to representing and evaluating multi-trial test results by constructing modelled, athlete-specific performance distributions. Rather than collapsing trials into a single value, distributions capture the full shape, spread, and probability of performance outcomes, therefore offering a more holistic and informative representation of performance. To demonstrate this approach, we analysed physical testing datasets from multiple athletic cohorts. Figure 1 shows an example analysis of isometric mid-thigh pull testing from 32 elite athletes, each completing five trials per day across two days, collected as part of a reliability study. Bayesian multilevel models were fit for each day, with an athlete identifier included as a random effect, and several force-related variables (e.g., peak force, force at 100ms, force at 200ms) as outcome variables. Posterior distributions were generated for each athlete, and plotted alongside the mean and maximum of the observed trials (Figure 1). This figure illustrates the added value of distribution-based representations of performance. The posterior distributions can serve as athlete-specific performance profiles, which provide a more comprehensive and interpretable summary of performance than the point estimates.

This multilevel modelling approach leverages the full data set by incorporating all trials from each athlete, therefore producing more robust and data-informed

estimates of individual performance. Additionally, probabilistic representations of the outcome variable provide greater interpretative value than point estimates.

This method supports a shift from reductionist metrics to a more rigourous, comprehensive and data-informed evaluation of athlete performance. These richer representations can inform better and more evidence-based decision-making in applied settings.

Keywords: BAYESIAN MODELLING, ATHLETIC PERFORMANCE TESTING, PERFORMANCE DISTRIBUTIONS

Figure 1. Posterior predictions for each athlete for Force at 100ms from Day 1 (red) and Day 2 (blue) Bayesain hierarchial models (left). Mean and maximum of each athlete's five observed trials are shown on the right.

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Code 52

Examining the utility of inter-day cerebral haemodynamic measurements in a dynamic motor task using functional near-infrared spectroscopy

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Abstract

This study aimed to assess the test-retest reliability of haemodynamic responses and network connectivity metrics derived from functional near-infrared spectroscopy (fNIRS) across three conditions: resting-state, dynamic, and stable. In the resting-state, participants were required to sit in the dark with their eyes closed for 7 minutes, this served to produce the baseline cerebral haemodynamics. Further, the dynamic and stable conditions required participants to engage in a five-minute table tennis serve interception task where they were required to return the serves from the ball launcher machine into a designated zone while they had the fNIRS on to measure their cerebral haemodynamics (Figure 1). In the stable condition, balls were alternately fired to the same positions on the left and right. In the dynamic condition, the balls were fired to random positions towards the participant.

Using a five-session repeated measures design, data were collected from 10 regions of interest over five different days. Key measures included mean and peak values of the haemodynamic response function (HRF), functional connectivity (FC), and both global and nodal network metrics derived via GRETNA. Finally, the inter-session reliability was measured using intra-class correlation coefficients (ICC) via a two-way mixed effects model (Koo & Li, 2016) applied to each of the metrics mentioned prior. ICCs for 3 different permutations of sessions were measured: ICC between days 1, 2 and 3, days 1, 4 and 5, as well as days 3, 4 and 5 (Figures 2, 3 and 4).

Briefly, HRF signals were preprocessed using the Homer3 toolbox, this included channel pruning, motion artifact correction and block averaging in line with best practices for fNIRS data (Huppert et al., 2009). Functional connectivity was derived through NIRS-KIT, while the network metrics were derived using the NIRS-KIT extension for GRETNA.

While mean group data showed relative stability, individual data demonstrated substantial variability, contributing to low ICCs across most regions. Interestingly, peak HRF values tended to yield higher ICCs and Cronbach's alpha scores than mean values, suggesting more consistent maximal activation across sessions. Certain regions (e.g., PFC_L/R, PMC, M1) showed comparatively better internal consistency, though still exhibited low to fair ICCs.

Network metrics derived from GRETNA revealed similar trends. Despite the visual stability of mean global metrics, individual plots highlighted considerable variability across sessions. Nodal metrics suffered particularly low reliability, with

Betweenness Centrality showing the poorest ICC. Comparatively, metrics such as Nodal Efficiency and Cluster Coefficient demonstrated higher consistency in specific nodes.

Functional connectivity analysis further supported these findings, with resting-state conditions consistently producing higher ICC and Cronbach's alpha values than task conditions. Notably, shorter test-retest intervals were associated with improved reliability in resting-state metrics, but this pattern did not hold for the task-based measurements.

A possible takeaway from this would be that fNIRS has low resting-state inter-day reliability and even poorer inter-day reliability for dynamic tasks, however it is worth noting a few key limitations. These include possible confounds from caffeine intake and sleep quality, region of interest approximations from cap-based mapping, and the absence of short-channel regressors. Despite these constraints, the findings provide important stepping stones for further work on the interpretation of session-to-session variability in fNIRS research, particularly in studies involving dynamic motor tasks.

Overall, our results underscore the need for cautious interpretation of fNIRS-derived metrics in longitudinal studies and highlight specific parameters (e.g., peak HRF, resting-state FC) that may serve as more reliable indicators of brain activity over time.

KEYWORDS: fNIRS, METASTABILITY, NEUROSCIENCE

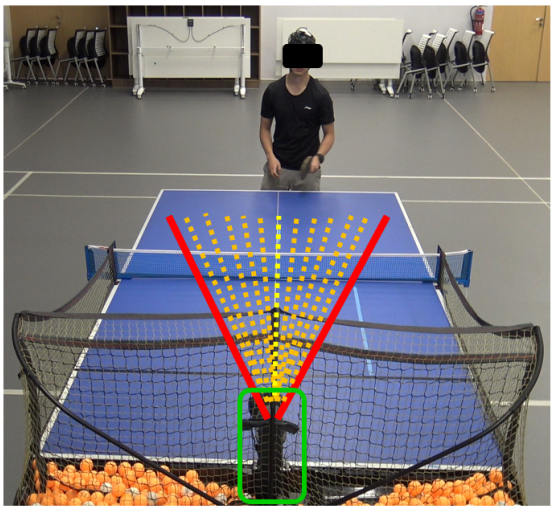

Figure 1. The setup for each testing session. The participant is wearing the fNIRS cap. Highlighted in green is the table tennis ball feeder robot. The red lines delineate the left and right bounds for where the table tennis ball will be served; total angle of fire (60°). The yellow centre dotted line delineates the centre of the angle of fire. The orange dotted lines between the two red lines depict all other positions that the ball will be served to within the left and right bounds; starting from the yellow centre dotted line, moving clockwise, each line represents a 5° increment.

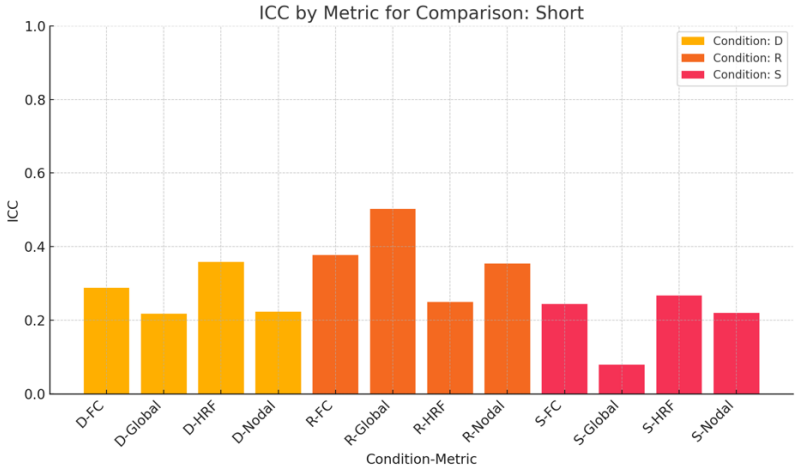

Figure 2. Intraclass Correlation Coefficients (ICC) for each metric under Condition D, R and S in the “Short” comparison. This figure presents ICC values for different metrics (e.g., Global, FC, HRF, Nodal) grouped by condition for the "Short" comparison. Higher ICC indicates greater reliability.

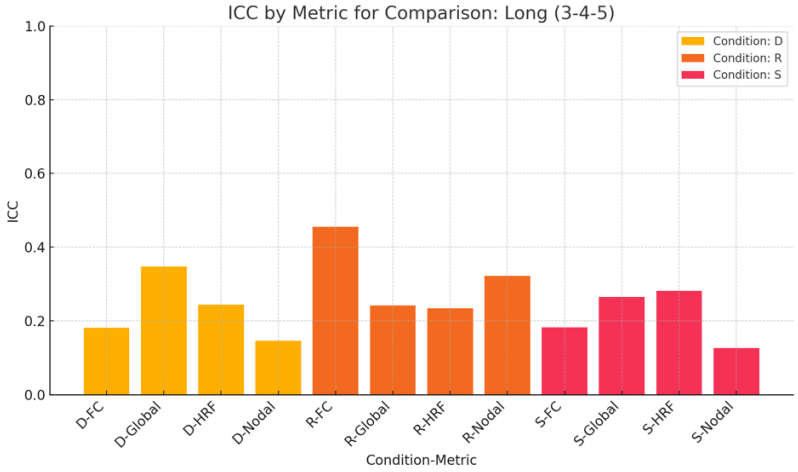

Figure 3. Intraclass Correlation Coefficients (ICC) for each metric under Condition D, R and S in the “Long (3-4-5)” comparison. This figure presents ICC values for different metrics (e.g., Global, FC, HRF, Nodal) grouped by condition for the "Long (3-4-5)" comparison. Higher ICC indicates greater reliability.

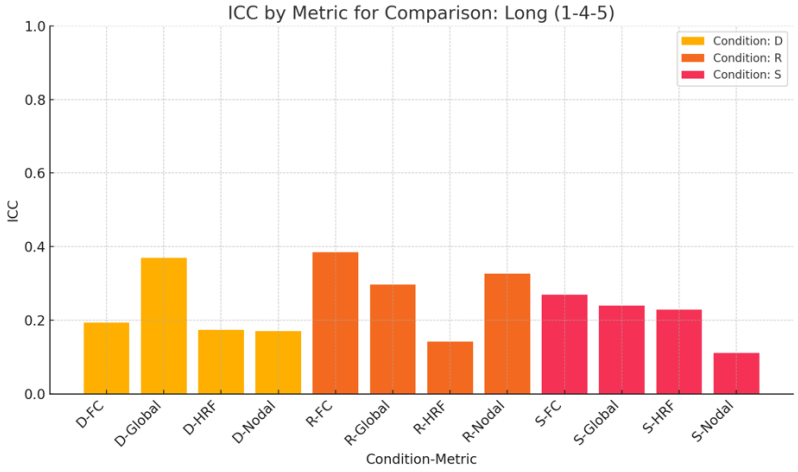

Figure 4. Intraclass Correlation Coefficients (ICC) for each metric under Condition D, R and S in the “Long (1-4-5)” comparison. This figure presents ICC values for different metrics (e.g., Global, FC, HRF, Nodal) grouped by condition for the " Long (1-4-5)" comparison. Higher ICC indicates greater reliability.

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Code 54

Examining dropout risk and predicting sporting success in swimming using competition participation history during youth

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Abstract

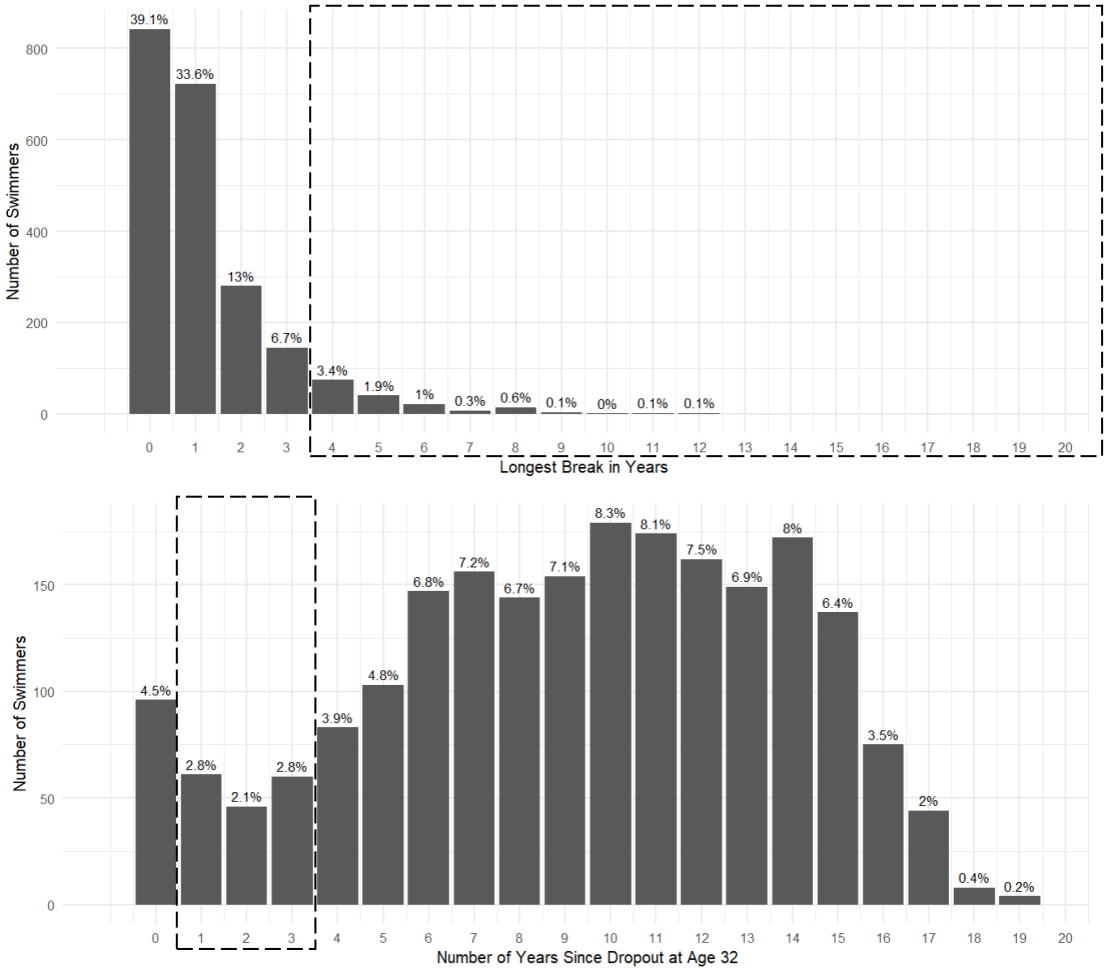
Dropout is a persistent challenge in sport talent development, with the retention of athletes through to peak performance age being crucial for maintaining a robust talent pool capable of achieving international medal success. One of the key difficulties in studying dropout lies in its inconsistent definition, compounded by the fluid nature of athlete participation in sports, where individuals may take breaks and later return. Numerous factors have been proposed as contributors to dropout, but to our knowledge, no study has specifically examined how competitive participation during youth influences the likelihood of dropout in swimming. Understanding this relationship could provide valuable insights into how youth sport participation can be better managed to facilitate athletes' transition to senior levels and reduce the risk of dropout. Thus, this study investigated how biological sex, continent, and debut age, medal success, race volume and engagement in multiple swim disciplines between ages 13 and 18, relates to dropout risk via a survival analysis. A secondary aim was to examine whether these same variables can predict additional sporting success outcomes: (a) effective career length of the athlete, (b) active competition status between the peak swimming performance ages 23 and 25, (c) participation in World Championships and Olympic Games, and (d) highest status achieved at those meets as either a medallist, non-medallist or non-participant. Data from 2,154 international swimmers (F = 1,197; M = 957) were obtained from the World Aquatics database covering participation from 1980 and 2019 over 20 years from age 13 up to 32. This study employed a novel sensitivity analysis to define dropout ultimately determining that four consecutive years without results following debut was the most scientifically valid criterion based on the available data (Figure 1). A Cox proportional hazards model was constructed systematically incorporating various combinations and permutations of 12 predictors and permitting a single two-way interaction term to maintain interpretability. The model with the highest concordance index (C-index = 0.644) was selected. Median time to dropout was six years for men and five years for women. Key results from the survival model are presented in Table 1. Female athletes were 1.47 times as likely as male athletes to drop out. Asians were more likely to drop out than athletes from Europe, Oceania and South America. Lower dropout risk was associated with older debut age, greater youth medal success, higher total race count (but lower average annual races), and broader discipline diversity. For the secondary aim, Random Forest and XGBoost models were

trained using a standardised set of the earlier 12 variables and an additional index of discipline specialisation. Across all four sporting success outcomes, model accuracy exceeded chance levels; however, Brier scores suggest limited discrimination ability, indicating that model performance could be improved with additional predictor variables. Findings support encouraging multi-discipline engagement and careful management of competition load during youth to mitigate dropout. Moreover, the use of publicly available competition data offers a promising foundation for predicting long-term athlete outcomes, particularly in contexts where bespoke tracking systems are unavailable.

KEYWORDS: DROPOUT, YOUTH SPORT, SURVIVAL ANALYSIS, SWIMMING

Table 1. Results for the Cox Proportional Hazards Model predicting dropout risk. Hazard ratios (HR), regression coefficients (B), standard errors (SE), Wald statistics, p-values, and 95% confidence intervals are reported for each predictor. A positive B indicates increased dropout risk, while a negative B indicates reduced risk. The model includes main effects and a single interaction term with highest concordance.

						95.0% CI for Hazard ratio	
Variables	**B**	**SE**	**Wald**	**p-value**	**HR**	**Lower**	**Upper**
sexWomen	0.3827	0.0511	7.435	<0.001*	1.4662	1.3255	1.6218
continentAfrica	-0.0211	0.1072	-0.158	0.8748	0.9791	0.7532	1.2729
continentEurope	-0.5052	0.0634	-7.268	<0.001*	0.6034	0.5265	0.6915
continentNorth America	-0.1497	0.0761	-1.868	0.0618	0.861	0.7358	1.0074
continentOceania	-0.3319	0.0914	-3.596	<0.001*	0.7176	0.5988	0.8599
continentSouth America	-0.7322	0.1106	-5.893	<0.001*	0.4808	0.3769	0.6134
WA_debut	-0.2297	0.0277	-6.904	<0.001*	0.7948	0.7446	0.8483
noOfMedals_youth	-0.1087	0.0165	-6.884	<0.001*	0.897	0.8696	0.9252
totalRaces_youth	-0.041	0.0086	-4.305	<0.001*	0.9598	0.9421	0.9779
meanRaces_youth	0.1027	0.0178	5.036	<0.001*	1.1082	1.0648	1.1534
noOfDisciplines_youth	-0.0872	0.0344	-2.462	0.0138*	0.9165	0.855	0.9824
backstroke_youth	-0.0072	0.008	-0.929	0.3528	0.9928	0.9779	1.008
butterfly_youth	-0.0051	0.0113	-0.445	0.6563	0.9949	0.9728	1.0175
medley_youth	-0.0145	0.0114	-1.363	0.1728	0.9856	0.9652	1.0064
noOfMedals_youth:totalRaces_youth	0.0021	0.0003	7.074	<0.001*	1.0021	1.0016	1.0027



Threshold for dropout (consecutive years of inactivity)	FP%	FN%	Sum of FP% & FN%
1	60.8	0	60.8
2	27.2	2.8	30.0
3	14.2	4.9	19.1
4	7.5	7.7	15.2
5	4.1	11.6	15.7
6	2.2	16.4	18.6
7	1.2	23.2	24.4
8	0.9	30.4	31.3
9	0.3	37.1	37.4
10	0.2	44.2	44.4
11	0.2	52.5	52.7
12	0.1	60.6	60.7

Figure 1. Derivation of appropriate dropout criteria in terms of consecutive years of inactivity was based on calculating the percentage of false positives (FP%; top chart) and false negatives (FN%; bottom chart) and selecting the lowest sum percentage (table). The threshold was set at 4 consecutive years of inactivity; the percentage of swimmers falsely identified as dropouts when they were in fact in-between periods of activity was 7.5% while the percentage of swimmers who had dropped out for 1 to 3 years but had not been classified as such because they had not met the required threshold was 7.7%.

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Code 59

Game, Set, Match — A Finite Stochastic Markov Chain Approach for In-Match Win Predictions in Professional Tennis

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Abstract

In-game win probability (IGWP) models in sports estimate the likelihood of an athlete or team winning a match at any point during a match using historical and real-time data (Robberechts, Haaren, & Davis, 2021). While widely used in the betting industry, academic interest in performance-applications of IGWP models has grown recently (e.g. soccer (Robberechts et al., 2022), American football (Lock & Nettleton, 2014), or basketball (Maddox, Sides, & Harvill, 2022)). Morris (1977) introduced the concept of point importance, defined as the match-win probability when winning the respective point minus the match-win probability when losing it using static point win rates of the server. This framework has been adapted to study pressure performance using rule-based IGWP models (González-Díaz, Gossner, & Rogers, 2012; Kovalchik & Reid, 2018). However, these studies lack rigorous validation of the used IGWP models based on real-world datasets.

Tennis' hierarchical scoring system naturally allows the modeling of a tennis match through discrete hierarchical Markov chains (Barnett & Clarke, 2002). Our approach extends this framework to an IGWP model using point-by-point data for 3,587 ATP best-of-three matches played between 1991 and 2024 (with a total of 513,055 points played. Following the methodology from Barnett and Clarke (2005) we used the return-adjusted serve point-win rates to predict the winner of the next point. The match context was also considered by adjusting the model to the current match state (e.g. updating state transitions to the likelihoods of winning the current game, set, and tiebreak) and other factors (e.g. surface). These factors were translated into dynamic player-specific probabilities of winning a point (dependent on the server) to predict the outcome of a game or tiebreak. The resulting game and tiebreak probabilities were taken as input to predict the set outcome. Finally, the set probabilities were taken to predict the match (González-Díaz et al., 2012).

Our model provides game-win probabilities at any time points in the match, with an increasing prediction Brier Skill Score over the course of the match. To validate its performance it is compared against baseline models with static point win-rates as in Morris (1977).

Figure 1 visualizes the implementation of our IGWP model during the Six King Final between Jannik Sinner and Carlos Alcaraz, where Table 1 shows the input parameters of the historic rates of points won on serve and return. The match saw multiple momentum shifts – Sinner's early 4-1 lead in the first set, Alcaraz's

comeback to win the set in a tiebreak, and a tightly contested second and third set until Sinner secured the match-win in the last three games of the third set.

The match illustration shows that our model can be applied to accurately identify the most relevant points in a tennis match, giving prospects to further investigate the issues of clutch performance, choking, and momentum. Moreover, an accurate IGWP model allows evaluating risky behavior and decision-making (e.g. comparing behavior on first and second serve) and its effect on the outcome of a match (e.g. see clutch performance in tennis: Kovalchik & Reid, 2018).

KEYWORDS: IN-GAME-WIN-PROBABILITY, TENNIS, WIN PREDICTION, MATCH FORECASTING, MARKOV CHAIN

Table 1. Historic serve and return point-win percentages and winning probabilities of an exemplary match between Jannik Sinner and Carlos Alcaraz in the Final of the Six Kings Slam.

Player	Serve %	Return %
Jannik Sinner	0.68	0.41
Carlos Alcaraz	0.67	0.43

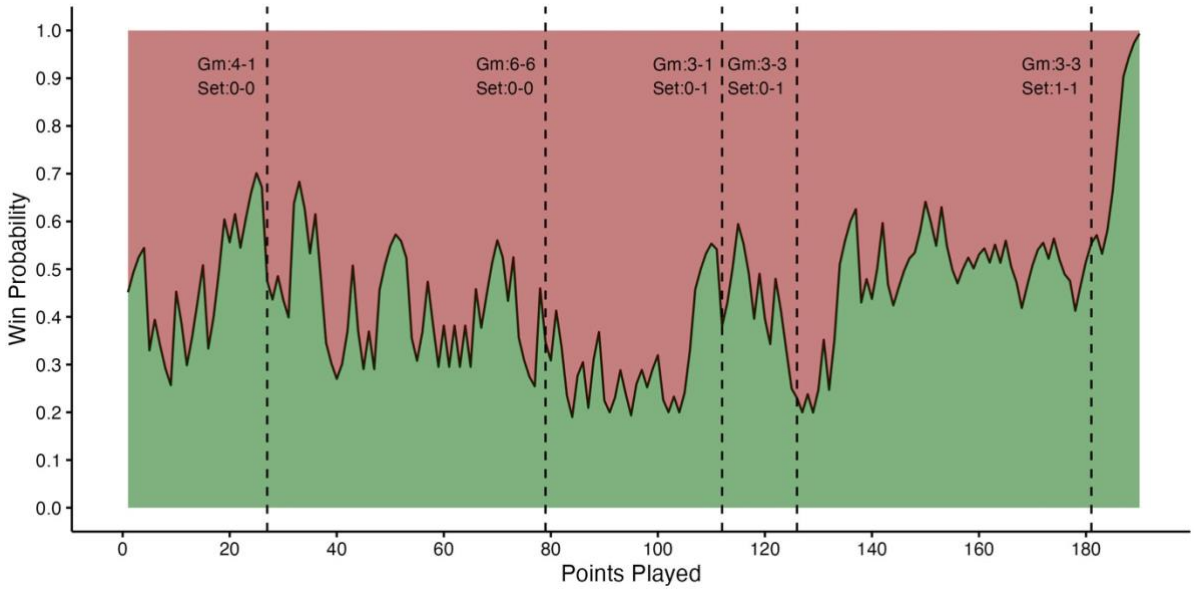

Figure 1. In-game win probability illustration of an exemplary match between Jannik Sinner (green) and Carlos Alcaraz (red) during the Six Kings Slam Final.

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Code 60

Impact of PyzoFlex® Sensor Integration on the Dynamic Properties of Alpine Skis in Laboratory Conditions

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Abstract

The interaction between ski and snow is crucial to skiing technique and performance, with ski deflection characteristics offering valuable insights into the complex dynamics of this process. For this purpose, a sensor ski based on PyzoFlex® technology was developed and validated in extensive investigations and tested in application-oriented field settings (Thorwartl et al. 2022; Thorwartl et al. 2023). The PyzoFlex® sensor system has been used on recreational skis, but for racing skis, it is crucial that the sensors have minimal impact on performance. Therefore, this research aims to evaluate the impact of PyzoFlex® sensor foils on the dynamic properties of skis by comparing an instrumented and non-instrumented ski through free vibration testing, following ISO 6267 standards. Key metrics assessed include the time for 30 complete vibrations (t_{30}), natural frequency (f_n), vibration period (T), and half-life ($t_{1/2}$).

To investigate this, a ski (Atomic Redster G7; length: 1.82 m; radius: 19.6 m), initially in its original state, and then subsequently instrumented with the PyzoFlex® ski sensor system (Thorwartl et al. 2021) underwent free vibration testing in accordance with ISO 6267 to derive various dynamic parameters (Figure 1). Vibration data were collected using a capacitive sensor (HBM 25321A B12/200, Hottinger Baldwin Messtechnik, Darmstadt, Germany) which was mounted on the ski shovel, and the data were processed and visualized using LabVIEW (National Instruments, Austin, Texas, USA). By calculating both absolute differences (diff) and relative differences (% diff) between the two configurations, a detailed comparison of dynamic properties was made.

The test results revealed that the corresponding values of $t_{1/2}$, T and t_{30} did not change by more than 1.8% (max. 0.02 s) compared to the initial non-instrumented ski (Table 1). The variation in f_n is 0.07 Hz (% diff: 0.6%).

Based on the free vibration measurements, it can be concluded that the foils have minimal influence on the dynamic properties of the ski due to the flexibility and low mass of the sensors. This is in contrast to a prototype utilizing strain gauges, which significantly affected the ski's behavior, with t_{30} reduced by 100% (Yoneyama et al. 2008). In the case of the PyzoFlex® ski, t_{30} showed a change of less than 1%. While other prototypes exist, they either did not assess such dynamic impacts or have not published results on this aspect.

This study is limited to laboratory vibration tests; effects during dynamic skiing and under varying snow conditions remain to be explored.

In summary, the integration of PyzoFlex® sensor foils does not appear to compromise ski dynamics, making them suitable for use in racing skis. The first prototype has already been developed and will soon be tested under laboratory and field conditions.

KEYWORDS: FREE VIBRATION TESTING; SENSOR INTEGRATION; SKI DYNAMICS; SPORTS EQUIPMENT

Table 1. Results of the free vibration test. $t_{1/2}$: half-life; T: vibration period; t_{30}: time taken for 30 complete vibrations; f_n: natural frequency. Absolute differences (diff) and relative percentage differences (% diff) are also included.

	Non-instrumented ski	**PyzoFlex® ski prototype**	**diff**	**% diff**
$t_{1/2}$	1.12 s	1.14 s	-0.02 s	-1.8%
T	87.0 ms	87.6 ms	-0.6 ms	-0.7%
t_{30}	2.61 s	2.63 s	-0.2 s	-0.8%
f_n	11.49 Hz	11.42 Hz	0.07 Hz	0.6%

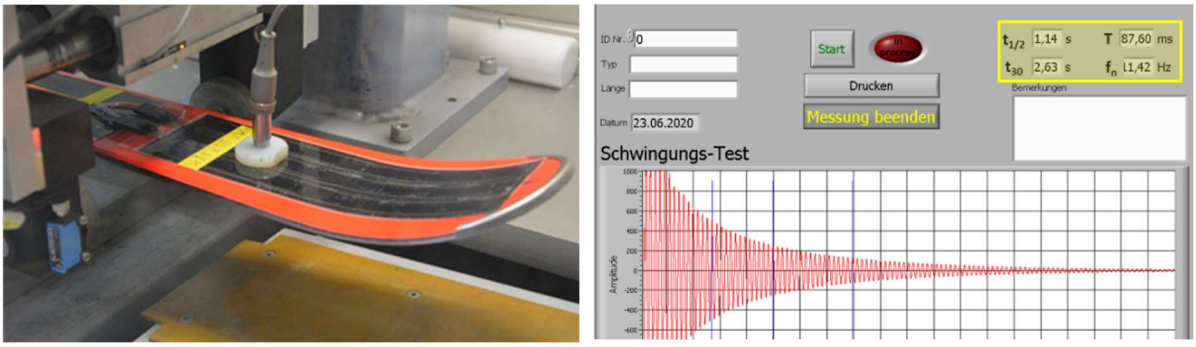

Figure 1. The setup on the free vibration machine is shown on the left, while the calculation results are displayed in the LabVIEW program on the right, with the data value highlighted in yellow.

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Code 63

Exploration of athlete step side patterns using IMU data – a UMAP clustering approach

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Abstract

Biomechanical data analysis is essential for understanding and enhancing sprint performance (Blauberger et al., 2021; Valamatos et al., 2022) with IMUs widely used to capture key running metrics such as foot touchdown, ground contact time, and flight time (Blauberger et al., 2021; Lee et al., 2010; Schmidt et al., 2016; Strohrmann et al., 2012). While these parameters were traditionally identified using rule-based methods, machine learning approaches now offer deeper and more flexible analysis (Prasanth et al., 2021), enabling enhanced movement insights to optimize training, improve performance, and reduce injury risk (Cui & Wang, 2025; Tam & Yao, 2024; Wang & Wang, 2021; Yan, 2024). Notably, analyzing kinematic asymmetries in running has been shown to provide valuable information related to both performance outcomes and injury risk (Carpes et al., 2010; Ciacci et al., 2013). This study investigates the use of IMUs combined with machine learning to identify step-specific leg asymmetries by clustering biomechanical patterns at the individual step level during running.

Methods: Twelve sprint-trained athletes (19.7 ± 3.7 yrs; 1.78 ± 0.11 m; 68.6 ± 9.5 kg; 6 female) completed three 60 m sprints with 20-minute rest intervals. A custom algorithm extracted 15 steps per foot per run (excluding block starts) using shank-worn 9-axis IMU signals in world frame— accelerometer (ax, ay, az, resultant) and gyroscope (gx, gy, gz, resultant). A UMAP was fitted per athlete to preserve individual movement patterns and cluster for foot side. A Weights & Biases sweep optimized hyperparameters across 511 axis combinations ($2^9 - 1$), n_neighbors $\in$ [10, 1000], min_dist $\in$ [0.01, 1.0], and metrics $\in$ {euclidean, cosine, correlation, manhattan}. Silhouette and Davies-Bouldin scores were computed per athlete and averaged to assess clustering quality.

Results: Athletes' left and right steps were clustered with varying clarity and scores while on average, clustering metrics suggest a general tendency toward separability (Table 1). The 3D visualizations (Figure 1) further illustrate step-specific variability.

Discussion: The results indicate that clusters can be identified at the individual step level across athletes. Clustering scores vary between athletes, possibly reflecting differing levels of asymmetry between the left and right step patterns. Also within athletes the clustering approach is not uniformly effective across all steps, suggesting that asymmetries may differentiate during certain run phases. The probable existence and pattern of asymmetries intra-step and interstep for left and right warrants further investigation. The successful detection of patterns using shank-worn IMUs with the UMAP clustering method highlights the potential of this approach for nuanced athlete analysis.

KEYWORDS: BIOMECHANICS, RUNNING, UMAP, MACHINE LEARNING

Table 1: UMAP performance scores for best performing hyperparameter setting: axis_combination: az_gz metric: cosine; min_dist; 0.225392; n_neighbors: 855

Subject	Silhouette Score	Davies-Bouldin Score
1	0.360294	1.125766
2	0.675611	0.435183
3	0.355789	1.226088
4	0.739554	0.384088
5	0.644067	0.480205
6	0.645343	0.509411
7	0.674019	0.430497
8	0.675798	0.433941
9	0.455527	0.901814
10	0.763051	0.343339
11	0.281184	1.477205
12	0.337144	1.206047
Overall average	**0.550615**	**0.746132**

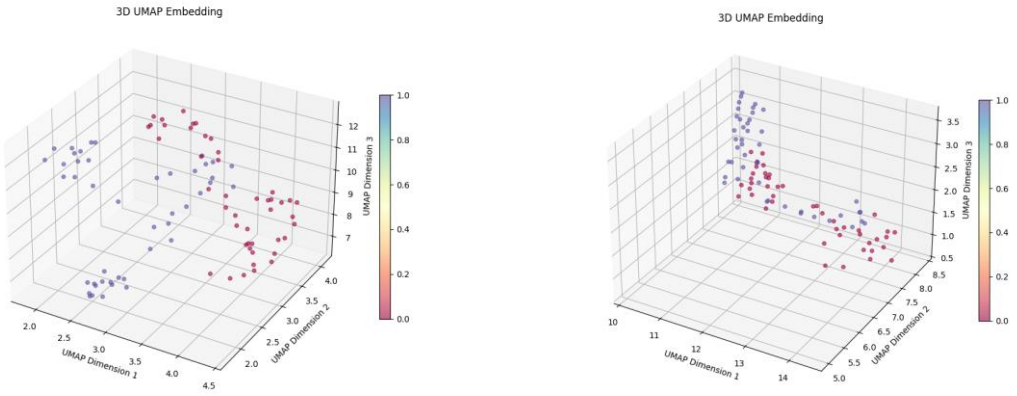

Figure 1. Visualisation for each athlete step in UMAP clustering. Left: athlete 10; best clustering results; right: athlete 11, worst clustering results. Red dots represent left foot (value 0), and blue dots right foot (value 1).

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Code 66

A Novel Fatigue Detection Method for Table Tennis Specific Aerobic Testing Using 3D Human Pose Estimation Approach

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Abstract

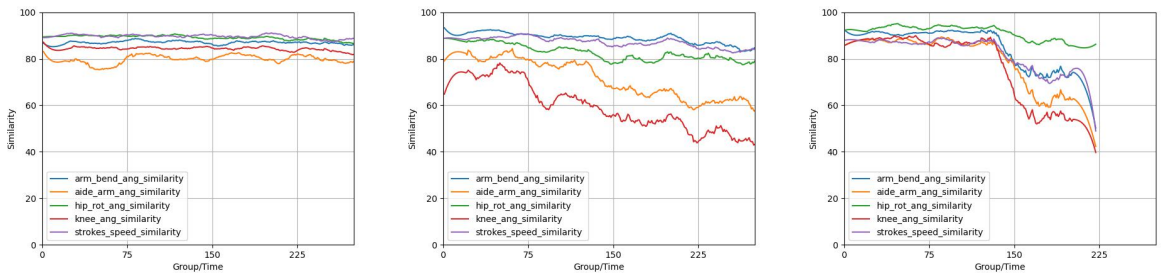
This paper presents a novel method for detecting physical fatigue during table tennis specific aerobic testing, it is based on the 3D human pose estimation approach from the single-view video input. The table tennis specific aerobic test is a physical fitness assessment for athletes. During the test, athletes perform continuous two-position forehand strokes with the assistance of a table tennis ball serving machine. The test is conducted in multiple stages and continues until the athlete reaches physiological exhaustion. The proposed system employs advanced pose estimation algorithms to extract skeletal joint data, enabling continuous monitoring of key kinematic indicators. Fatigue-related changes are identified by analyzing temporal and spatial variations in body posture and motion dynamics.

This paper first introduces an improved multi-hypothesis generation transformer network for 3D human pose estimation. This network can generate multiple 3D pose hypotheses from a single 2D input and leverages spatial and temporal semantic cues to enhance pose representation, thereby reconstructing accurate 3D human poses. We then apply the proposed 3D pose estimation method to fatigue detection. Five technical features—including the dominant hand's swing angle, balance control of the non-dominant hand, knee flexion angle, hip rotation angle, and ball-striking speed—are derived from the estimated 3D human key-points. All strokes performed during the test are grouped into pairs for motion comparison. The first three-stroke pairs from the initial stage are designated as the reference set, representing the athlete’s standard performance. Subsequent stroke data from later stages are temporally aligned with this reference set, and dynamic time warping is used to evaluate the similarity between the motion features. A substantial drop in the similarity between mid- or late-stage movements and the initial reference strokes indicates physical fatigue.

The proposed 3D human pose estimation method was evaluated on the public Human3.6M dataset, achieving a mean per-joint position error (MPJPE) of 40.75 mm—an improvement of 11.2 mm over the classic PoseFormer (Zheng et al., 2021) and 0.26 mm over the state-of-the-art D3DP (Shan et al., 2023), it demonstrates the effectiveness of the proposed method in complex pose estimation tasks.

In the experiments of fatigue detection, forehand stroke data were collected from three athletes, each performing a specific aerobic test. The three participants represented different performance levels: a national team player, a university-level elite athlete, and a collegiate club-level athlete. The feature curve variation graphs of the three athletes during the multi-stage aerobic test is illustrated in Figure 1. We aslo proposes an evaluation index for fatigue detection. By calculating the average decline rate of each feature and assigning weights according to their relative importance, which serves as a reliable fatigue index, the result is listed in Table 1. Experimental results showed that the top-level athlete—representing the national team—demonstrated significantly greater stroke consistency than the other two participants. Furthermore, signs of fatigue in this athlete were minor and occurred later during the aerobic test, indicating superior physical endurance and movement control under prolonged exertion. The proposed system offers valuable insights for training optimization and skill development.

KEYWORDS: DEEP LEARNING, 3D HUMAN POSE ESTIMATION, DEPTH AMBIGUITY, FATIGUE DETECTION , SPECIFIC AEROBIC TESTING



(a) (b) (c)

Figure 1.The feature curve variation graphs of the three athletes during the specific aerobic test. (a) Athlete ID 1 (national team player); (b) Athlete ID 2 (university-level elite athlete); (c) Athlete ID 3 (collegiate club-level athlete)

Table 1. The result of the declining trend during the specific aerobic testing in table tennis.

Athlete ID	Dominant hand's swing angle	Balance control of the non-dominant hand	Hip rotation angle	Knee flexion angle	Ball striking speed	**Fatigue index**
1	2.76 %	10.37 %	2.65 %	6.72 %	0.73 %	**3.671**
2	11.36 %	16.49 %	7.42 %	19.19 %	5.75 %	**10.574**
3	41.63 %	19.16 %	21.91 %	50.09 %	6.34 %	**24.572**

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Code 68

Predicting Stroke Types in Table Tennis Using Sequence-to-Sequence Models

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Abstract

Table tennis is renowned for its rapid pace and diverse shot types, posing unique challenges for predicting players' strokes during a match. This study introduces a deep learning approach to predict the types of upcoming shots in table tennis rallies based on the sequence of previous shots, aiming to enhance strategic analysis and player performance. Our methodology uses a dataset derived from table tennis matches, where each shot is labeled with its type, such as forehand, backhand, or shot type, and associated contextual data, including the player executing the shot, ball's landing area, and shot type. We use deep learning architectures with Transformer models to tackle this sequence prediction task. Preliminary evaluations indicate that our models successfully identify shot sequences, with the Transformer-based architecture demonstrating superior capability in modeling temporal dependencies. The implications of this research are profound for table tennis. Accurate prediction of shot types can empower players to anticipate opponents' moves more effectively, refining their reaction times and tactical decisions. Future efforts will focus on expanding the model to incorporate additional variables, such as ball spin and player positioning, to further elevate prediction precision and extend applicability to other fast-paced sports.

KEYWORDS: TABLE TENNIS SEQUENCE MODELING SPORTS ANALYTICS

Code 69

Technical and tactical analysis of the winning and losing game between Miwa Harimoto and Sun Yingsha

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Shanghai University of Sport

Abstract

Miwa Harimoto is a key player of the new generation of Japanese women's table tennis and currently the main opponent of Chinese women's table tennis. This article uses methods such as literature review, four stage indicator evaluation, and video observation to analyze the technical and tactical aspects of the four matches between Miwa Harimoto and Sun Yingsha from different perspectives of winning and losing, aiming to provide theoretical reference and research support for the training and preparation of Chinese women's table tennis. The research results indicate that: 1. The usage rates of Miwa Harimoto and the fourth segment are relatively low; 2. The serving and attacking section does not have a significant advantage; 3. The connection between serving and the fourth racket has a certain impact on the outcome of the game; 4. The stalemate of the serve has a significant impact on the outcome of the game; 5. The receiving and serving stages are relatively passive; 6. Miwa Harimoto has a tendency to lead in the middle of the game at the beginning, but there is a high possibility of a comeback in the end. It is suggested that Sun Yingsha can seek breakthroughs in receiving and attacking in the match against Miwa Harimoto, pay attention to Miwa Harimoto's strong topspin serve, improve quality and increase landing point changes, suppress Miwa Harimoto's large angle lane changing and continuous defense in the stalemate, and actively attack in the serving and attacking tactics to gain a competitive advantage. Control the score at the beginning of the game, do not keep falling behind and try to regain the lead.

KEYWORDS: TABLE TENNIS,MIWA HARIMOTO,TECHNICAL AND TACTICAL ,FOUR STAGE INDICATOR EVALUATION METHOD

Table 1. Observation Sample of the Match between Miwa Harimoto and Sun Yingsha.

Number	Competition Information	Match players	Score
1	2023 World Table Tennis League Finals Round of 16	Miwa Harimoto vs Sun Yingsha	2：3
2	2024 WTT Macau Championship Women's Singles Semifinals	Miwa Harimoto vs Sun Yingsha	2：4
3	2024 Asian Championship Team Finals	Miwa Harimoto vs Sun Yingsha	3：2
4	2024 Asian Championships Women's Singles quarterfinals	Miwa Harimoto vs Sun Yingsha	2：4

Table 2. Overall data of Miwa Harimoto's 4 matches against Sun Yingsha.

Miwa Harimoto	Serve and attack section			Serve stalemate segment		Receiving and attacking section		Receiving and serving stalemate segment	Total
	serve	Third shot	Fifth shot	Fifth shot	Confrontation I	receive	Fourth shot	Confrontation II	
Score	22	25	-	26	33	21	38	41	206
Lose points	4	24	32	-	41	20	45	45	211
Scoring rate	43.93%			59.00%		47.58%		47.67%	49.40%
Usage rate	25.66%			23.98%		29.74%		20.62%	100.00%

Table 3. Statistics of 4 matches between Miwa Harimoto and Sun Yingsha.

Miwa Harimoto	Scoring rate	Assessment	Usage rate	Assessment
Serve and attack section	43.93%	pass	25.66%	low
Receiving and attacking section	47.58%	good	29.74%	low
Serve stalemate segment	59.00%	good	23.98%	low
Reserve stalemate segment	47.67%	good	20.62%	low

Table 4.Miwa Harimoto and Sun Yingsha's 4 match match grabbing data statistics.

Miwa Harimoto	Winning game serving and attacking section			Failed game serving and attacking section		
	serve	Third shot	Fifth shot	serve	Third shot	Fifth shot
Scoring rate	10.83%	13.46%	-	10.16%	14.16%	-
Loss rate	2.5%	10.58%	20.25%	1.6%	15.04%	26.25%
Scoring rate		47.37%			42.03%	
Assessment		pass			pass	
Usage rate		23.46%			26.95%	
Assessment		low			low	

Table 5.Miwa Harimoto and her match against Sun Yingsha in 4 games: statistics of the grabbing segment data .

Miwa Harimoto	**Winning game rserving and attacking section**		**Failed game rserving and attacking section**	
	rserve	Fourth shot	rserve	Fourth shot
Scoring rate	12.20%	27.55%	8.40%	20.19%
Loss rate	8.13%	28.57%	11.76%	32.69%
Scoring rate	54.41%		39.24%	
Assessment	good		pass	
Usage rate	27.98%		30.86%	
Assessment	low		low	

Table 6. Miwa Harimoto and Sun Yingsha 4 matches serve stalemate data statistics.

Miwa Harimoto	**Winning game serve stalemate segment**		**Failed game serve stalemate segment**	
	Fifth shot	Confrontation I	Fifth shot	Confrontation I
Scoring rate	24.06%	56.82%	17.72%	28.29%
Loss rate	-	43.18%		71.11%
Scoring rate	69.84%		45.76%	
Assessment	good		fail	
Usage rate	25.93%		23.05%	
Assessment	low		low	

Table7. Miwa Harimoto and Sun Yingsha have 4 matches of receiving and serving stalemate data statistics.

Miwa Harimoto	**Winning game receiving and serving stalemate segment**	
	Confrontation II	Confrontation II
Scoring rate	49.09%	38.78%
Loss rate	50.91%	61.22%
Scoring rate	49.09%	38.78%
Assessment	good	pass
Usage rate	22.63%	19.14%
Assessment	low	low

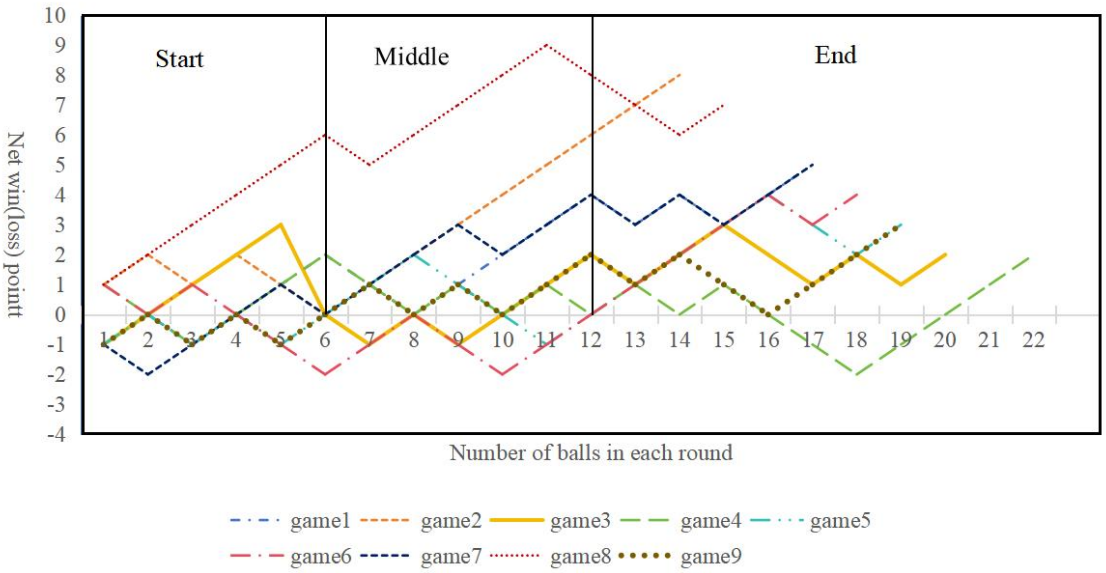

Figure 1. Discount chart of the score trend of the winning games between Miwa Harimoto and Sun Yingsha in 4 matches.

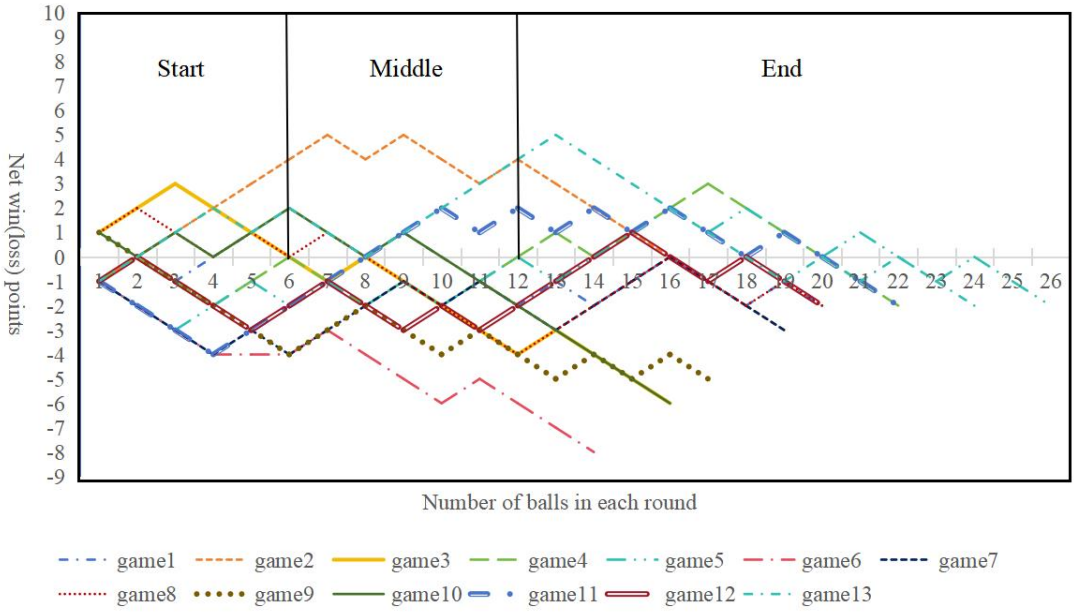

Figure 2. Discount chart of the score trend of Miwa Harimoto'

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Code 73

Comprehensive Analysis of Key Motion Parameters in Speed Climbing Performance

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Abstract

Speed climbing has transformed from a niche discipline into one of the most dynamic and widely recognized forms of competitive sport climbing. Its international appearance reached without doubt a peak with its Olympic debut at the Tokyo 2020 Summer Games, where it was initially included as part of a combined discipline alongside bouldering and lead climbing. This milestone brought unexpected visibility and media attention and promoted the development of training methods. The Paris 2024 Olympics marked another historical highpoint, featuring speed climbing as a standalone event and showcasing record-breaking performances as athletes continued to push boundaries of what is possible on the standardized 15m wall. This separation served as role model for the following Olympic games in Los Angeles 2028, where sport climbing will be given three independent disciplines. As speed climbing continues its ascent on the world stage, the application of technology is inevitable to meet the sport's evolving demands and to reach new levels of human performance.

Therefore, this research deals with a comprehensive performance analysis of speed climbing athletes by evaluating motion describing parameters. Based on a collection of almost 900 recordings from 29 speed climbing competitions, a data set consisting of several key parameters was generated to identify movement sequences of around 250 athletes. This was enabled by the application of a CNN-based framework for the automated detection of human key points and features on single frames. In addition to quantitative evaluation of the filtered data set to analyze possible correlations with the finishing time of each athlete, individual parameters can be examined in a targeted manner. Accordingly, a detailed analysis of limb movements and velocities was carried out to link synchronized motions and coordination with an athlete's performance. To assess the harmonic coordination of athletes' limb movements, velocity trajectories of hands and feet were analyzed. Our study hypothesizes that the closer these characteristics follow a mono-frequent sinusoidal signal, the better the athlete's performance and the better their end times. This relationship suggests that mono-frequent kinematic patterns may serve as an indicator of optimal movements in speed climbing.

The results reveal that this hypothesis primarily applies to lower extremities. Due to the unique route map and the resulting movement patterns, hand kinematics could not be adequately approximated by a single sinusoidal fit due to anti-symmetric motions. However, significant insights emerged for the feet: a correlation was observed between deviations from an ideal mono-frequent signal

and the athletes' end times. Thereby, these deviations from the actual velocity profiles were quantified by calculating R^2 values (sinusoidal fit accuracy) and peak differences (absolute mean horizontal deviation of data and fit peaks). Additionally, the sinus fit frequency was extracted and evaluated for each left and right foot.

The analysis of Figure 1 confirms harmonic lower-limb motion (high R^2, minimal Peak Diff) correlates with lower end times, while the fit frequency shows no significant influence. The near-zero frequency correlations indicate athletes tend towards a median rate balancing speed and controlled foot placement, prioritizing movement precision over high step frequencies.

KEYWORDS: COMPUTER SCIENCE IN SPORTS, SPORTS SCIENCE, PERFORMANCE ANALYSIS, SPEED CLIMBING

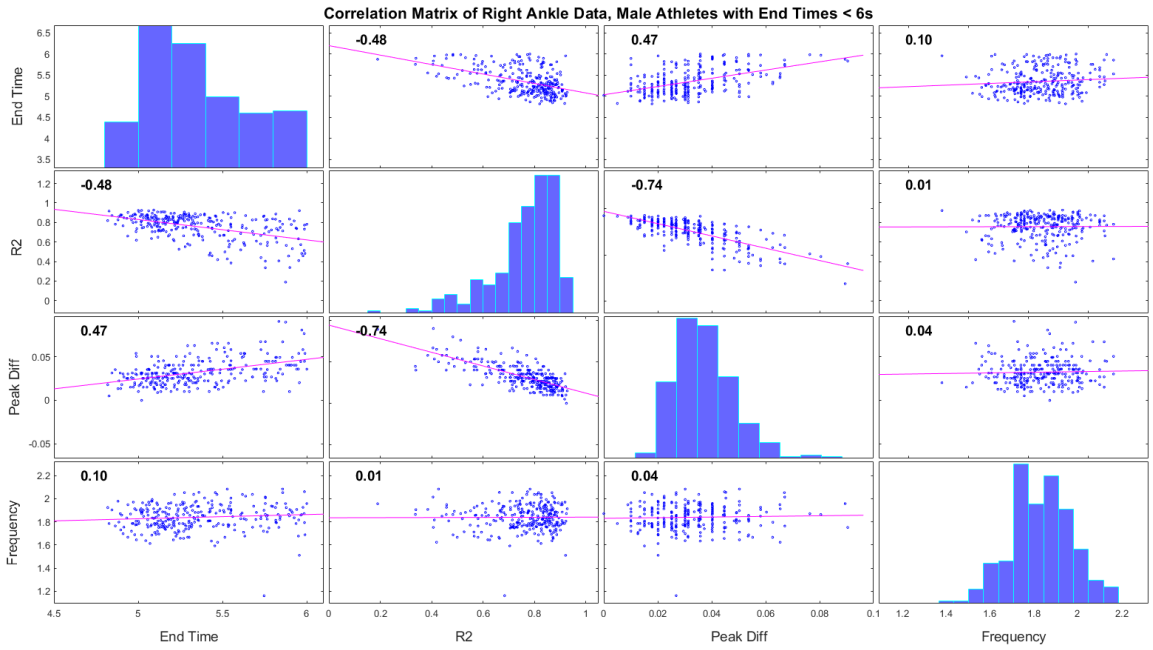

Figure 1. Correlation matrix of right ankle kinematics (male athletes with end times < 6s) analyzing the relationship between the achieved end time and these performance metrics: R^2 (sinusoidal fit accuracy), Peak Diff (horizontal signal to fit peak deviation) and Frequency (of the fitted sinus signal).

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Code 80

Understanding Team Dynamic Behaviours through the Temporal Evolution of Passing Networks in Football

Runqing Ma[1], *Ricardo da Silva Torres*[2], *Arnold Baca*[1] & *Juliana Exel*[1]

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[2]*Wageningen University & Research*

Abstract

Introduction

In football match performance evaluation, various indicators can be taken into consideration, such as the number of crosses, assists, pass accuracy or any other key indicators. However, these indicators fail to capture the collective behaviour information which is reflected through player interactions. Understanding these interactions is crucial for analysing how the game plays, with passing being a fundamental event of team interactions. To analyse these interactions, social network analysis (SNA) is used to capture the relation between players. However, traditional network approaches treated the entire 90-minute match as one entity with limited temporal variation information during the game, resulting in the dismissal of dynamic changes over the match. To overcome this limitation, this study analysed the dynamic evolution of passing networks over time, to explore how teams' behaviours change during a match and how such dynamics affect the match outcomes.

Method

A total of 64 matches of World Cup 2022 from Statsbomb were analysed by dividing each match into 15-minute time intervals to construct the player passing networks, where players are the nodes with multiple spatial features, edges are directed and weighted counted by the number of passes and the value of passes, and network-level features such as network entropy and graph edit distance are also considered.

To model the progression of passing network dynamics over time, each passing network interval is represented as a graph. Graph Neural Networks (GNNs) are utilized to process these graphs, exploring their spatial information, while a Long Short-Term Memory (LSTM) is used to maintain the critical temporal dependencies. The entire workflow is shown in Figure 1. This hybrid architecture integrates the spatial information within each 15-minute graph and the temporal relationships between consecutive graphs, enabling dynamic pattern recognition and comprehensive understanding of the evolving match dynamics.

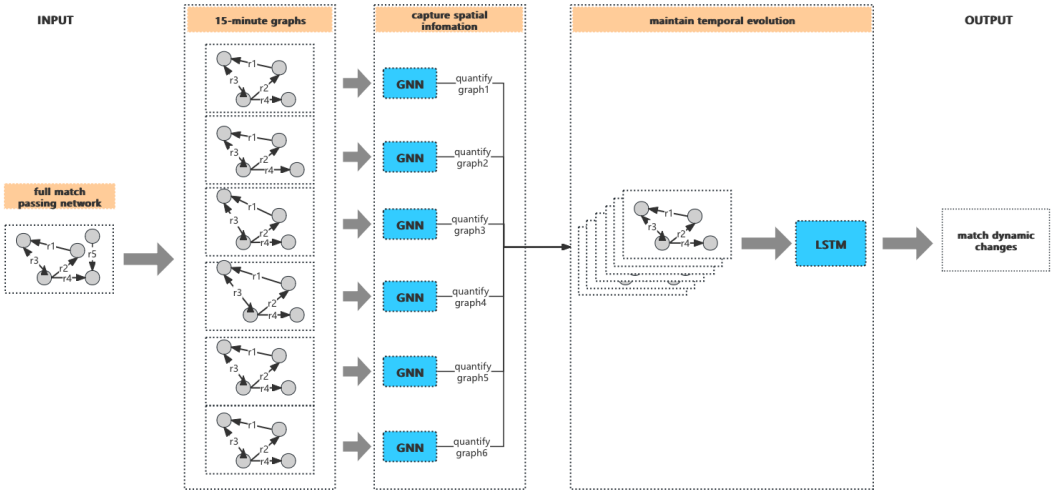

Figure 1. The flowchart of the spatio-temporal analysis for dynamic passing networks

Expected result and applications

Compared to traditional methods, GNNs provide a systematic and multi-dimensional framework that is essential for analysing the evolving dynamics of football matches. In the expected results, variations between dynamic might be associated with the match status (leading, drawing or trailing) during the game. These findings will offer insights into how dynamic passing networks evolve and contribute to team success. Potential applications include performance analysis, tactical optimization, and real-time decision support for coaches and analysts. By shifting the focus from a purely spatial approach to a spatio-temporal perspective, this study seeks to provide deeper insights into how passing dynamics evolve and impact match outcomes.

KEYWORDS: SOCIAL NETWORK ANALYSIS, COLLECTIVE BEHAVIOURS, SPORTS PERFORMANCE ANALYSIS, TEAM SPORT, MATCH DYNAMICS

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Code 84

Match Analysis in German Badminton based on Perturbations - Technical Workflow and Performance Analysis

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Abstract

Data-driven match analysis is essential in preparing the German national badminton team for competitions. We developed a standardized workflow for tactical match analysis in the singles disciplines, which inclcudes automatic–supported by Computer Vision technology and manually executed tasks. Computer Vision technology is used to identify the rally's starting and ending point so the matches' video recordings can be cut into net playing time. Depending on the discipline and dynamics of the video recording–static or TV images with replays–rallies are correctly classified by our developed software with F1-Scores between .79 (doubles, static camera) and .91 (singles, TV image). With the preprocessing of the video record, a time saving of up to 30% was observed in the manual analysis process afterward.

Based on this workflow we collected data of 60 matches and performed a study that examines how perturbations in badminton singles are created. Therefore, we analyzed the shots that create an advantage for one player, the so-called Impulse. We explore four aspects, including the quality—Positive vs. Negative—of the Impulse, the technique used, the Shot Number, and the conversion rate, all according to the factors of Gender and Age. Results indicate that Impulses were 64.8% Negative and 35.2% Positive, with no significant Gender or Age differences. Positive Impulses mainly comprise Net shots (Women: 30.1%, Men: 29.8%, Elite: 31.4%, U19: 27.6%, U15: 30.8%), while Negative Impulses predominantly involve Lobs (Women: 26.3%, Men: 29.5%, Elite: 26.0%, U19: 27.4%, U15: 30.3%). In contrast to male players, poor Clears play an essential role in losing a rally in Women's badminton (Women: 21.3%, Men: 13.1%). Temporally, Impulses occur later in Men's and Elite matches than in Women's and Youth's matches (Women: 6.8 (± 5.8), Men: 8.9 (± 8.2), Elite: 10.2 (± 8.8), U19: 7.4 (± 6.3), U15: 5.7 (±4.8)). For Positive Impulses the conversion rate to point gain is 70.7%, for Negative Impulses the conversion rate to point loss is 86.7%.We conclude that success in badminton singles seems more reliant on avoiding bad shots than executing good ones. Gender and Age differences in shot techniques and timing of Impulses likely stem from the different physical abilities of Men and Elite players compared to the other examined categories.

KEYWORDS: BADMINTON, COMPUTER VISION, KEYPLAYS, PERTURBATIONS

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Code 88

Shot Detection in Table Tennis - A Velocity-Based Approach Using Markerless Motion Capture Data

Schumann Eric[1], Freude Felix[1], Müller Gabriel[1], Slijepčević Djordje[2] & Horst Fabin[1]

[1] Johannes Gutenberg-University Mainz
[2] St. Pölten University of Applied Sciences

Abstract

Introduction

Advances in markerless motion capture, driven by video-based human pose estimation, are enabling new possibilities for automated sports performance analysis (Colyer et al., 2018; Noorbhai et al., 2025). Such automated analysis could support tasks such as opponent scouting, load monitoring, and technique feedback in practice and competition settings across various sports, including table tennis (Wu et al., 2023). A key challenge lies in detecting sport-specific movements (e.g., shots) while filtering out unrelated movements (e.g., picking up a ball). Previous studies have used machine learning for automated shot detection in table tennis (Kulkarni & Shenoy, 2021), but these approaches are often computationally intensive and lack interpretability. We propose a heuristic approach for automated shot detection using the hand segment velocity from markerless motion capture data.

Methods

We analyzed data from 36 healthy, physically active adults (19 females, 17 males; age: 20-38 years), including 14 beginners, 10 advanced, and 12 expert table tennis players. In a standardized practice setting, participants performed 10 shots of six table tennis techniques (backhand/forehand drive, push, and topspin) in counterbalanced order. Ball delivery was standardized using a Donic Newgy Robo-Pong 2055 (Newgy Industries, USA). In a competition setting, 13 out of the 36 participants played three 60-second games against opponents of same sex and playing level.

Data were collected in an indoor laboratory using eight synchronized Miqus video cameras (Qualisys, Sweden; 1920×1080 Pixels; 85 Hz). Videos were processed in Theia3D 2023.1 (Theia Markerless, Canada), body segments modeled in Visual3D Professional 2023.1 (C-Motion, USA), and signals processed in MATLAB 2024b (MathWorks, USA). We extracted the filtered one-dimensional velocity of the hand segment's center of gravity along the table's long axis, using a fourth-order low-pass Butterworth filter (cutoff: 6 Hz).

Ground truth annotations were provided by an experienced table tennis player. Shot detection relied on velocity peaks identified via MATLAB's *findpeaks* function, using thresholds for peak height (>0.9 m/s), prominence (>1.4 m/s), width (0.085–

0.429 s), and inter-peak distance (>0.858 s, twice the maximum peak width). Thresholds were derived from the annotated peaks in the standardized practice setting (Figure 1).

Results

Our heuristic approach achieved an accuracy of 99.9% in the standardized practice setting (True Positives: 2157; True Negatives: 2366; False Positives: 7; False Negatives: 0) and 95.0% in the competition setting (True Positives: 933; True Negatives: 950; False Positives: 61; False Negatives: 39).

Discussion

Our results show that a heuristic approach based on hand velocity enables near-perfect shot detection in standardized practice settings. In the competition setting, accuracy decreased, particularly for "other" shots (Table 1), which included techniques not considered during threshold definition, and those performed by expert players. Future work should focus on optimizing thresholds for specific shot techniques and playing levels, as well as comparing performance with machine learning approaches.

Conclusion

A velocity-based heuristic approach using the player's hand segment provides transparent, efficient, and accurate automated shot detection in table tennis. The approach has potential for practical use in research, training, and competition settings, and might be applicable to other sports.

KEYWORDS: SPORTS PERFORMANCE ANALYSIS, EVENT DETECTION, HUMAN POSE ESTIMATION, SEGMENTATION, PEAK DETECTION

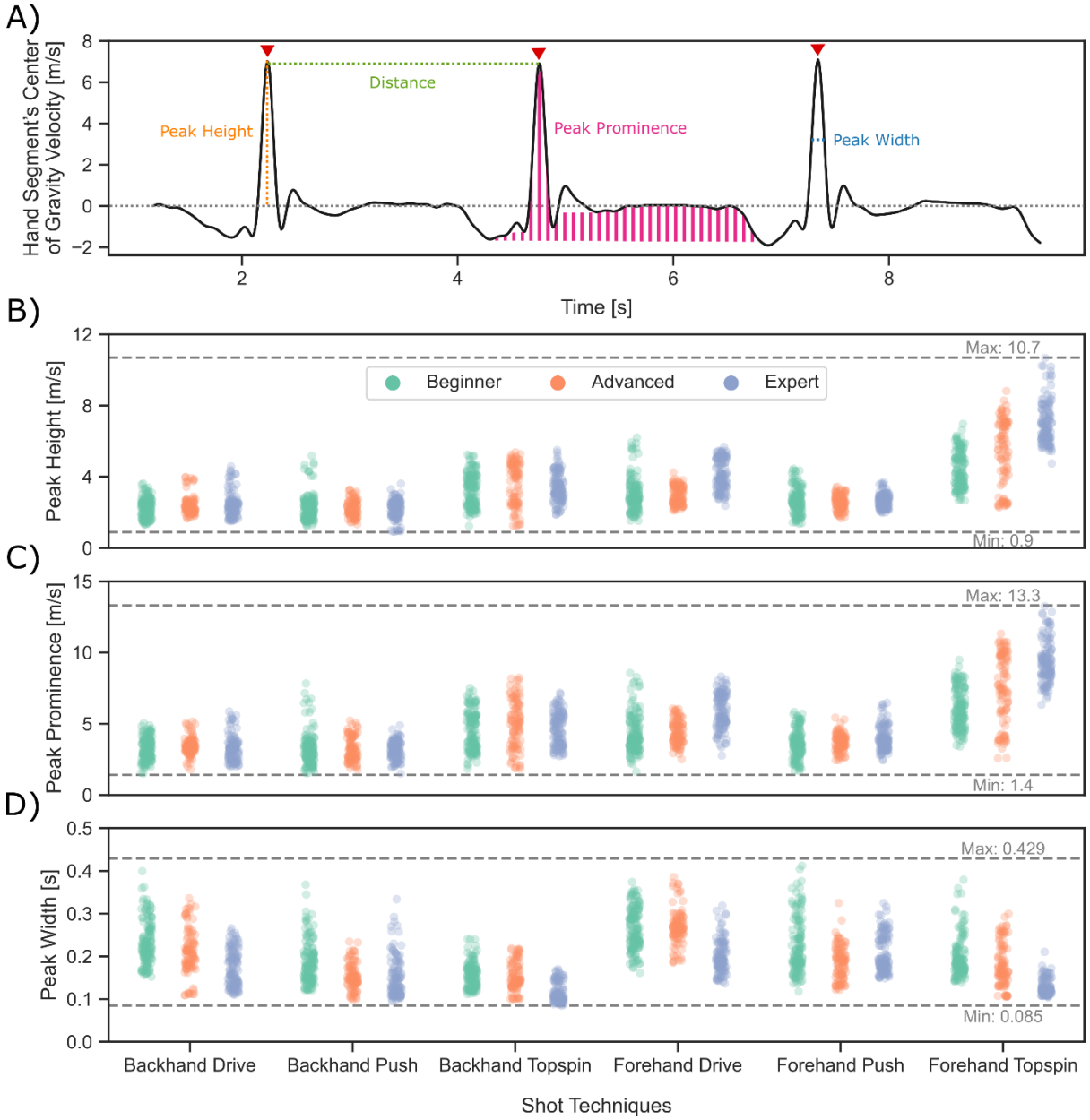

Figure 1. Velocity characteristics of the hand segment's center of gravity for automated shot detection in table tennis. (A) Example time series of the hand segment's center of gravity velocity with peak features used in our detection approach: peak height (orange), peak prominence (magenta), peak width (blue), and inter-peak distance (green). (B–D) Distribution of peak characteristics across shot techniques and playing levels (Beginner, Advanced, Expert): (B) Peak height, (C) Peak prominence, (D) Peak width. Each dot represents one annotated peak, grouped by shot technique and color-coded by playing level. Dashed lines indicate the global minimum and maximum values used in our automated detection approach.

Table 1. Post-hoc analysis of the shot detection results in the non-standardized competition setting. The table shows the number of true positives (TP) and false negatives (FN) for each shot technique, along with the corresponding sensitivity (TP / [TP + FN]) across playing levels: beginner, advanced, expert. In addition to the six shot techniques assessed in the standardized practice setting, annotations were also made for serves and other shot techniques.

Shot technique	**Beginner**		**Advanced**		**Expert**	
	TP / FN	Sensitivity	TP / FN	Sensitivity	TP / FN	Sensitivity
Backhand Drive	81 / 0	100,0%	63 / 0	100,0%	36 / 6	85,7%
Backhand Other	1 / 0	100,0%	6 / 3	66,7%	2 / 6	25,0%
Backhand Push	14 / 0	100,0%	37 / 1	97,4%	23 / 1	95,8%
Backhand Serve	18 / 0	100,0%	55 / 0	100,0%	15 / 0	100,0%
Backhand Topspin	0 / 0	-	9 / 0	100,0%	30 / 1	96,8%
Forehand Drive	72 / 3	96,0%	66 / 1	98,5%	15 / 2	88,2%
Forehand Other	1 / 0	100,0%	15 / 8	65,2%	7 / 3	70,0%
Forehand Push	6 / 0	100,0%	10 / 0	100,0%	9 / 2	81,8%
Forehand Serve	60 / 0	100,0%	106 / 0	100,0%	75 / 0	100,0%
Forehand Topspin	0 / 0	-	50 / 2	96,2%	51 / 0	100,0%

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Code 91

Table tennis profiling with first offensive shot transitions

Ruizhi Liu[1,2], Frederic Rothe[2] & Martin Lames[2]

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Abstract

Introduction: Technique and tactics are pivotal in table tennis performance analysis, yet existing methods often classify shots solely by sequence, neglecting tactical attributes and their impact on rally outcomes. The First Offensive Shot (FOS) model addressed this but remained coarse-grained. This study introduces the Enhanced FOS (EFOS) model, integrating shot type and number into a refined state-transition framework to better capture rally dynamics.

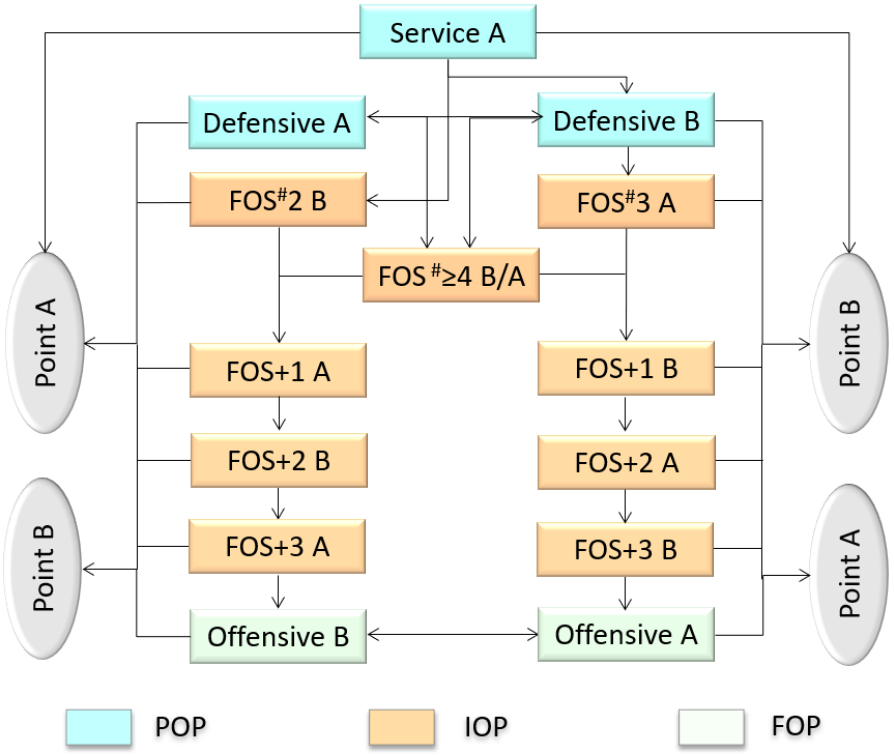
Methods: The EFOS model divides rallies into three phases: pre-offensive (POP), initial-offensive (IOP), and final-offensive (FOP) (Figure 1). Each phase was further categorized by shot type and number, with transition probabilities computed between states. Data from 105 men's and women's singles matches at the Tokyo 2020 Olympics were analyzed, with gender, ranking, and match results as independent variables. Nonparametric tests (Mann-Whitney U, Kruskal-Wallis H) were used for statistical analysis.

Results: The IOP accounted for 70.6% of rallies, highlighting its critical role. Male players favored defensive returns before attacking ($FOS^{\#} \geq 4$: 21.0%), while females attacked earlier ($FOS^{\#}3$: 51.7%). High-ranked players (≤40) exhibited superior transition efficiency and lower error rates, especially in the IOP. Winners consistently showed higher transition rates and fewer errors across phases. Attacking defensive shots (FOS#3, $FOS^{\#} \geq 4$) proved more effective than attacking serves ($FOS^{\#}2$), with higher direct winning rates (6.7%, 7.0% vs. 4.0%, $p = 0.002$).

Discussion: The EFOS model underscores the IOP's dominance in rally outcomes and reveals gender-specific strategies. Male players excelled in later attacks, while females prioritized early aggression. The model's state-transition approach offers deeper tactical insights than traditional methods, aligning with findings in tennis and badminton. Limitations include its focus on offensive players and Olympic-level data, which may not generalize to all tournaments.

Conclusion: The EFOS model advances table tennis performance analysis by emphasizing the IOP's importance and differentiating tactical efficiencies. Coaches should prioritize IOP training and error reduction, with gender-specific adaptations. Future research could extend this framework to defensive players or other racket sports.

Keywords: TABLE TENNIS, PERFORMANCE ANALYSIS, STATE-TRANSITION MODEL, GENDER DIFFERENCES, TACTICAL EFFICIENCY



Legend: “A” or “B” appended at the end of each frame denotes which player executed the shot.

Figure 1 Enhanced First Offensive Shot Model for Service Player A.

Code 92

A Comparison of Table Tennis Player Performance Between China and Other Countries Based on Stroke Effectiveness

Zheng Zhou & *Jie Zhao*

Zhejiang University

Abstract

As a highly interactive dyadic sport, the results of table tennis not only depended on the performance of own side, but also the performance by the opponent. This study introduced a novel analytical method incorporating weighted coefficients for consecutive two strokes by same sider to assess stroke effectiveness (SE) among elite shake-hand offensive players. The dataset comprised 20 matches between the top 30 male players (7 from China and 15 from other countries) were selected (based on the world rankings for 2023 to 2024) as samples, with deliberated balancing Chinese winners (n=10) and other countries winners (n=10). All match videos were sourced from broadcasts or online platforms. Then, a reliable data collection system of table tennis matches was used for the data collection, and the stroke observation indices included of strike consequence and rally results. The results showed that (1) Chinese players demonstrated significantly better performance in the first, second, after sixth stroke ($P < 0.05$) and after fifth stroke ($P < 0.01$) compared to other countries players. (2) Non-significant advantages were observed in the third and fourth stroke. (3) Notably, players from other countries only showed numerically superior outcomes in the after fifth and after sixth strokes ($P > 0.05$).The proposed method in this study can quantify and analyze the impact of current and next strokes by own side with different coefficients α and β, enhancing players' and coaches' strategical cognition of inter-stroke dynamics.

KEYWORDS: TABLE TENNIS, MATCH ANALYSIS, STROKE EFFECTIVENESS

Code 94

Analysis of the Differences Between Teaching Competitions and International Competitions for Elite Chinese U15 Table Tennis Players

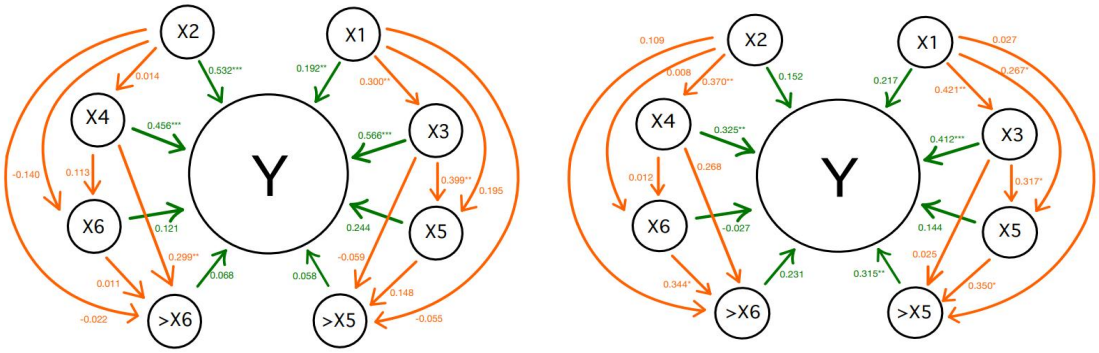
Shuangying Wang & *Zheng Zhou*

Zhejiang University

Abstract

To explore the differences in technical and tactical applications between training and competition, this study selected 80 matches (40 teaching matches and 40 international matches) played by five elite Chinese U15 female table tennis players as the sample. Using regression models and path analysis, the following conclusions were drawn: 1) In teaching matches, the effectiveness of strokes from the 1st to the 4th shot was significantly associated with the probability of winning. In international matches, the effectiveness of the 3rd, 4th, and post-5th shots was significantly related to winning probability (see Figure 1). 2) In teaching matches, the top four strokes in terms of importance were ranked as follows: 3rd shot > 2nd shot > 4th shot > 5th shot. In international matches, the ranking was: 3rd shot > 4th shot > 8th shot > 7th shot. 3) Path analysis showed that, in both teaching and international matches, the 3rd shot had the most positive impact on the probability of winning by the 5th shot, while the 4th shot had the most negative impact on the probability of winning by the 6th shot. However, the magnitude of these effects was greater in teaching matches than in international matches.

KEYWORDS: TABLE TENNIS PLAYER, TEACHING COMPETITION, INTERNATIONAL COMPETITION, REGRESSION MODEL, PATH ANALYSIS



A: Teaching competition B: International competition

Note: Y represents the scoring probability, X denotes the shot sequence, orange indicates the correlation coefficient, and green indicates the path coefficient.

Figure1. Correlation and path coefficients between shot sequence and scoring probability in U15 elite female players' matches

Code 96

Development of a Perturbation in Performance Scale: An Approach Using EPL Soccer Positional Coordinate Data

Choi Hyongjun

Dankook University

Abstract

This study aims to develop a new scale for measuring and evaluating Perturbation in Performance (PiP) in sports. Specifically, we propose a methodology for objectively measuring performance perturbation using positional coordinate data from English Premier League (EPL) soccer matches. The study develops a method that measures performance perturbation from multiple perspectives based on three key indicators: team centroid displacement, spatial entropy, and formation stability, which are integrated to calculate a Perturbation in Performance Index (PiP Index). When applied to actual EPL match data, the proposed methodology effectively detected performance perturbations occurring during matches and quantitatively evaluated their intensity. The significance of this study lies in providing a tool for objectively measuring performance perturbation, thereby expanding the theoretical foundation of sports performance analysis and enhancing the practical applicability of data-driven sports analysis.

KEYWORDS: PERTURBATION IN PERFORMANCE, POSITIONAL COORDINATE DATA, SOCCER ANALYSIS, TEAM CENTROID, SPATIAL ENTROPY, FORMATION STABILITY

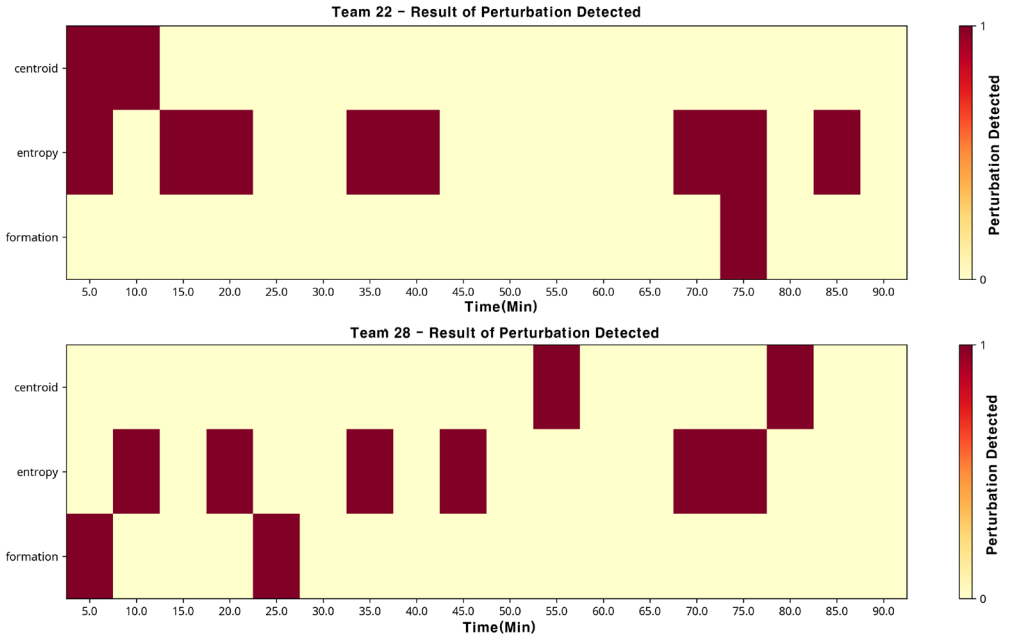


Figure 1. Results of Perturbation Detected

Code 98

Impact of Resistance Training on Physical Fitness Parameters in Kabaddi and Wrestling Players

Sagar Dalal, Sanyam Malik & *Yogesh Chander*
Sports University Of Haryana

Abstract

This study examines the impact of a structured resistance training program on the physical fitness of intercollegiate Kabaddi and Wrestling players in Jhajjar, Haryana, India. Both sports, deeply rooted in Indian culture, require strength, endurance, and agility. Addressing a significant gap in empirical research, the study evaluates the effects of a four-week resistance training intervention on athletic strength and endurance. Twenty male athletes (ten from each sport), aged 18-25, participated in a program consisting of ten targeted resistance exercises. Data were analyzed using SPSS 20, with pre- and post-training tests. Across all ten variables, post-test mean scores were significantly higher than pre-test scores. The t-values ranged from 3.96 to 6.15, all significant at the 0.05 level, confirming that the observed changes were not due to chance. The results indicated improvements in upper and lower body strength, muscular endurance, and explosive power. Kabaddi players showed gains in agility and explosive strength, while wrestlers demonstrated notable improvements in muscular endurance and overall power. While the findings highlight the effects of resistance training on performance, the study also recognizes several limitations, including a small sample size, a brief intervention period, and uncontrolled factors such as nutrition and recovery. It recommends future research with larger, more diverse samples, including female athletes, and the use of advanced assessment tools. The study also suggests a holistic training approach that combines resistance training with psychological, nutritional, and tactical components. It emphasizes the potential of evidence-based conditioning programs to enhance performance in traditional Indian sports, providing practical insights for coaches, strength and conditioning professionals, and physical education practitioners aiming to support athlete development at both national and international levels.

KEYWORDS: RESISTANCE TRAINING, TRADITIONAL SPORTS, PHYSICAL FITNESS PARAMETERS

15th International Symposium on Computer Science in Sport

IACSS 2025

September 12 - 15, 2025

Tokyo Gakugei University
Tokyo, Japan

Theme:
Data Analysis

Code 14

The Centre That Moves: A Data-Driven Perspective on Spatial Adaptations in Men's Singles Badminton

Julian Quah Jian Tan, Chaitanya Dhanajay Jadhav & John Komar

Nanyang Technological University

Abstract

The centre of the court presents itself as a key constraint in badminton. Players return to the centre after playing a shot, positioning themselves optimally to respond to the next return. This study aims to determine the extent of a central zone where players position themselves according to the theory of angles. Pose estimation and object detection algorithms were employed to automatically extract multivariate features from over 40,000 shots across fifty professional men's singles matches. Specifically, human skeletal landmarks and shuttlecock coordinates were used to derive features such as joint projection angles, inter-landmark distances and temporal derivatives of the shuttlecock's movement. Hitting events were detected by a custom trained bidirectional LSTM model. The locations of shuttlecock and players centre of mass (COM) position during impact were projected onto the ground on a 4 × 4 grid for each court half. The angle of shot trajectories was identified from the shots executed within each grid, then the bisector, mean and median angles were computed, following Benguigui et al. (2024). Within each court zone, paired t-tests were conducted to compare the Euclidean distances between the receiving player's COM, the bisector, and the court's centre point. The results showed that players were consistently closer to the bisector than to the centre point across all zones ($p < 0.00$), supporting the findings of Benguigui et al. (2024). While players frequently returned to a general central area on the court, their exact positioning within this space varied depending on the previous shot. These findings indicate that the centre is a dynamic space that shifts based on performance context to optimise shot return efficiency. Consequently, we propose redefining the centre as a zone instead of a point, acknowledging its dynamic nature and dependence on contextual factors in player positioning.

KEYWORDS: PERFORMANCE ANALYSIS, BIG DATA, COMPLEX SYSTEMS, AFFORDANCE, ARTIFICIAL INTELLIGENCE

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Code 19

Big Three 100 - An Open Access Movement Data Set of over 100 People Doing Bench Press, Squats and Deadlifts

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University of Bremen

Abstract

Introduction

Looking into movement data in strength sports is essential for different purposes like teaching and reviewing movements (Liebermann et. al., 2002; O'Donoghue, 2006), as well as analyzing various aspects like exercise execution form or workout intensity (Dorschky et al. 2023; Dänekas et al. 2022). Most researchers record their own data to investigate specific aspects like exercise execution form (Lee, Joo, Lee, & Chee, 2020; Chern et al. 2025). This process is not only very time-consuming, but also creates a data set that is usually very specific in terms of used sensors or positions and, therefore, not reusable for other studies. The scientific community needs a standardized data set that covers different strength exercises, uses a simple and realistic setup, has a huge sample size, and covers video and internal measurement unit (IMU) data measured in acceleration and rotation. We created the Big Three 100 data set for precisely this purpose.

Methods

The data set consists of 101 athletes with various backgrounds in exercise expertise, sex, and body proportions. Each participant did four sets of the big three strength exercises: bench press, deadlift, and squats in a self-chosen order. They could freely choose weight and the amount of repetitions per set, ranging between five and 40. We recorded movement with two 2D cameras capturing the front and side view, and with one smartwatch capturing the acceleration and rotation at 100Hz from the right wrist of the athlete. We asked participants for demographic data, such as self-rated exercise expertise on a scale from one (lowest) to five (highest) for each exercise, measured their body part length (height, upper body, lower body, extremities), and asked them about gender and sex. The results are shown in Table 1.

Results

We cut the two videos into one and anonymized participants by pixelating their faces. We also cut the IMU data to make it fit the video. Additionally, we built a website to visualize the video and IMU data to make the data as understandable and accessible as possible (see screenshot in 'Figure 1'). The whole data set can also be downloaded from that same webpage.

Discussion

The Big Three 100 data set is the first known open access data set reflecting over 100 athletes doing bench presses, deadlifts, and squats. We recorded IMU data with a smartwatch on the athletes' right wrists, a setup that closely resembles practice. Future researchers can test algorithms to predict important exercise variables such as exercise intensity, exercise execution form, and length of concentric and eccentric phases. The set can also be used to develop live feedback systems for athletes.

Conclusion

With the Big Three 100 data set, future researchers have a standardized set of 1200 videos and IMU sequences. The data set can be used for multiple purposes like teaching, machine learning, or creating feedback systems. This contribution to the research community enriches future research and creates a gold standard data set for a multitude of research areas in the domain of computer science in sports in strength sports.

KEYWORDS: SPORTS, MACHINE LEARNING, BIOMECHANICS, WEARABLE SENSORS, DATA COLLECTION

Table 1. Demographic Distribution of the Big 3 100 data set. mean values (m) and standard deviation (sd) are displayed for females, males and the whole distribution of athletes in regards to height and different self-rated exercise expertise measured from one (lowest) to five (highest).

Sex	Amount	Height	Bench Press Expertise	Squat Expertise	Deadlift Expertise
Female	48	m = 167.6cm sd = 6.9cm	m = 1.96 sd = 1.05	m = 2. 83sd = 1. 17	m = 1.98 sd = 1.10
Male	53	m = 181cm sd = 6.6cm	m = 3.04 sd = 1.30	m = 2.85 sd =1.23	m = 2.09 sd = 1.15
Total	101	m = 175cm sd = 9.8cm	m = 2.53 sd = 1.30	sd = 1.80	m = 2.04 sd = 1.12

Figure 1. Demonstrating the Big Three 100 website. Video is played in parallel to the selected IMU data. Over 1200 different exercise sets distributed equally into squats, bench press and deadlifts are available. Link: https://digital-media-lab.uni-bremen.de/BigThree100/

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Code 26

An Automatic Segmentation and Highlight Extraction System for Table Tennis Videos Using The Bimodal-Based Deep Neural Networks

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[2]Ming Chuan University

Abstract

This paper presents an automatic segmentation and highlight extraction system for table tennis videos, it is based on a bimodal deep neural network architecture. We propose a novel framework that integrates a convolutional neural network for visual feature extraction with a pose estimation module to obtain the skeletal key points of each player, enabling precise, player-specific action recognition. The overall architecture of the proposed system is illustrated in Figure 1. In the RGB image analysis modality, we adopt the classic and effective SlowFast network (Feichtenhofer et al., 2019) as the backbone for feature extraction. By simultaneously processing video frames at both slow and fast temporal resolutions, the SlowFast network enhances the understanding of motion across multiple time scales. For feature fusion, we design an Attentive Fusion module that first concatenates the visual and pose-based features, followed by a self-attention mechanism to refine the combined representation. A two-layer fully connected (FC) classifier performs the final action classification. Thus, the action recognition component leverages the fusion of raw visual features and pose-based temporal dynamics, enabling accurate identification of key actions, such as serves and strikes.

Additionally, by incorporating ball trajectory analysis, the system robustly detects the start and end of each rally. The dataset used in this study was collected from table tennis matches played by the National Chung Hsing University varsity team. The videos were recorded from a consistent side view of the table, capturing six matches in total—three from the men's team and three from the women's team—under identical environmental conditions. Each video was recorded at 60 frames per second (FPS) with a resolution of 1920×1080 pixels. As shown in Table 1, we conducted a comparative analysis of action recognition and classification performance across different models. The comparison includes unimodal approaches and prior multimodal models from related studies. We implemented and evaluated methods based solely on the backbone network for unimodal baselines.

Furthermore, we extended these methods by incorporating ball trajectory data as an additional modality to assess its impact. The results indicate that integrating an

additional data source significantly enhances classification performance. Compared with previous multimodal approaches, our use of a dynamic Region of Interest (dynamic RoI) strategy leads to consistently improved performance across multiple evaluation metrics. Experiments on our curated dataset demonstrate that our proposed method achieves an action recognition accuracy of 88.89%, representing an approximate 9% improvement over unimodal baselines. Moreover, the proposed approach significantly enhances processing speed, achieving 29.54 frames per second (FPS)—a 196% increase over previous action recognition systems. The results demonstrate the effectiveness of the proposed multimodal framework in segmenting match footage and extracting highlights, offering a scalable solution for sports media automation and performance analytics in table tennis. Currently, the system focuses on detecting general stroke actions in table tennis. However, such actions can be further subdivided into more specific categories, such as push, chop, and block techniques. A more fine-grained stroke classification will be a focus of our future work.

KEYWORDS: TABLE TENNIS, VIDEO SEGMENTATION, HIGHLIGHT EXTRACTION, BIMODAL DEEP LEARNING NETWORK, ACTION RECOGNITION

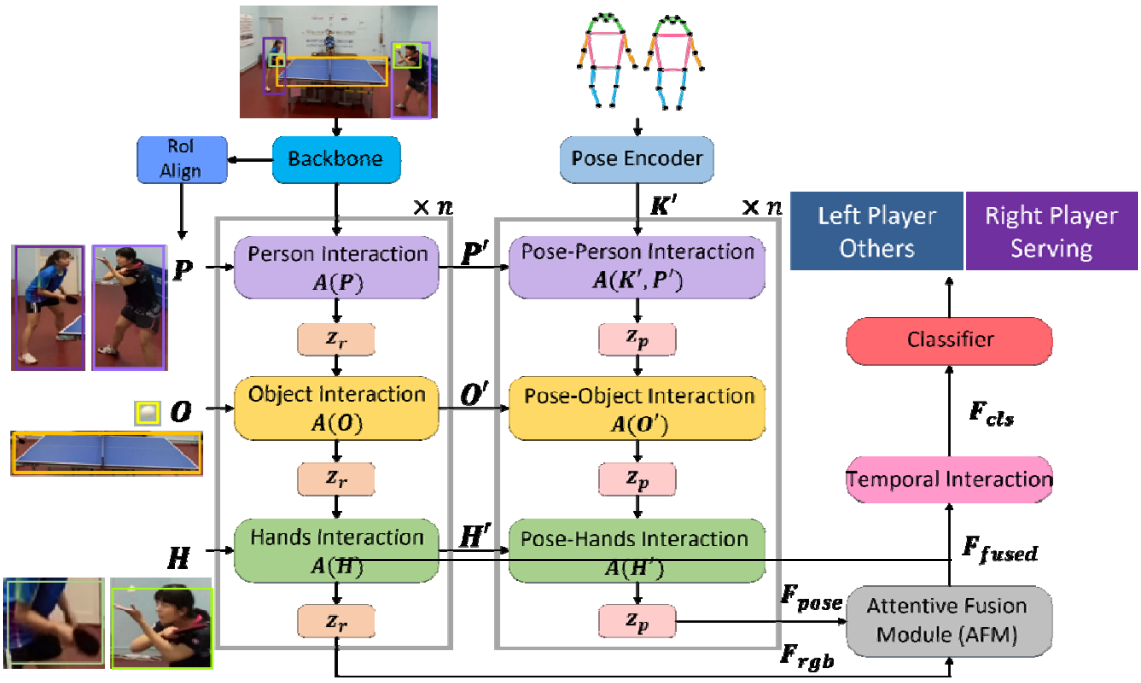

Figure 1.The network architecture diagram of the proposed method.

Table 1. Performance comparison between the proposed method and other state-of-the-art approaches.

Method	Accuracy	Precision	Recall	F1-measure
Skeleton-Based (Martin et al., 2021)	73.66%	81.00%	89.05%	84.83%
Skeleton-Based with Ball Trajectory	79.91%	88.18%	89.50%	88.83%
Bimodal-Based(Faure et al., 2023)	85.58%	94.85%	89.76%	92.23%
Proposed Method	**88.89%**	**96.34%**	**92.00%**	**94.12%**

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Code 28

Research on the Correlation Between Sports State Anxiety and Athletes' Competition Performance Based on Big Data Analysis

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Abstract

Background and Objectives

Current research predominantly examines single anxiety dimensions' isolated effects on athletic performance, neglecting synergistic interactions of multidimensional anxiety indicators and group heterogeneity stemming from gender and skill level variations. This study integrates cognitive anxiety, somatic anxiety, and self-confidence metrics with multivariate statistical analyses to systematically elucidate dynamic mechanisms linking anxiety profiles to competition outcomes. By identifying population-specific regulatory effects and multidimensional anxiety-performance pathways, it aims to establish a refined framework for optimizing personalized psychological interventions tailored to athletes.

Methods

This study recruited 128 athletes from Wuhan Sports University ’s School of Sports Training, with 72.66% male, 27.34% female, and 64.06% classified as first-level athletes. Cognitive anxiety, somatic anxiety, and self-confidence were measured using the CSAI-2 scale, while competition rankings were quantified as 1-5 scores. SPSS 26.0 performed reliability validation through Cronbach ’s alpha coefficients ranging from 0.78 to 0.85 and KMO tests, followed by Pearson correlation analysis, multivariate linear regression, and multifactorial ANOVA to examine anxiety-performance relationships and subgroup differences.

Results

Reliability analyses demonstrated strong internal consistency for CSAI-2 dimensions: cognitive anxiety $\alpha=0.82$, somatic anxiety $\alpha=0.78$, and self-confidence $\alpha=0.85$, with structural validity confirmed by KMO=0.81 and Bartlett ’ s test $p<0.001$. Pearson correlations revealed somatic anxiety negatively correlated with performance ($r=-0.37$, $p<0.01$), self-confidence showed a positive association ($r=0.42$, $p<0.001$), and cognitive anxiety exhibited weaker negative linkage ($r=-0.23$, $p<0.05$). Multivariate regression indicated anxiety dimensions collectively explained 31% of performance variance ($R^2=0.31$), with self-confidence as a positive predictor ($\beta=0.39$, $p<0.001$) and somatic anxiety as a negative predictor ($\beta=-0.28$, $p<0.01$). ANOVA results highlighted elite athletes ’ lower somatic anxiety versus first-level ($p=0.018$) and second-level athletes ($p=0.003$), alongside higher cognitive anxiety in females than males ($p<0.05$).

Table 1. Key Statistical Results of Competitive State Anxiety and Athletic Performance

Analysis Type	Key Variables	Statistical Values	Significance (p-value)
Correlation Analysis	Somatic Anxiety vs. Performance	r = -0.37	0.003
	Self-Confidence vs. Performance	r = 0.42	< 0.001
Regression Analysis	Self-Confidence (β)	0.39	< 0.001
	Somatic Anxiety (β)	-0.28	0.008
ANOVA	Elite vs. First-Level Athletes	F = 4.32	0.018
	Gender Difference (Cognitive)	Mean Δ = 2.15	0.024

Note: β = standardized regression coefficients; Δ = mean difference.

Discussion and Conclusion

This study systematically elucidates the intricate mechanisms linking competitive state anxiety to athletic performance. Somatic anxiety significantly impaired performance, likely due to physiological interference with technical execution, while self-confidence enhanced outcomes through strengthened psychological resilience. Elite athletes demonstrated superior anxiety management capabilities, potentially attributable to long-term systematic training and adaptive psychological conditioning. Notably, female athletes exhibited higher cognitive anxiety levels than males, highlighting the necessity for gender-specific intervention strategies. These findings advocate integrating anxiety monitoring into training systems via wearable devices for real-time physiological tracking or regression-based early-warning models. Future research should expand to dynamic anxiety profiling by incorporating physiological metrics such as heart rate variability and neuromuscular feedback, fostering interdisciplinary exploration of anxiety-performance mechanisms.

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Code 40

Using Machine Learning for identifying soccer in-possession match phases based on their tactical intention

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Abstract

Introduction

This study aims to identify and categorise match phases based on their tactical intention through AI techniques on a large-scale spatiotemporal tracking dataset from the German Bundesliga. In modern football, understanding the flow and structure of a match beyond isolated events is essential for both performance analysis and tactical planning. By segmenting matches into different phases of play with specific tactical intentions, our model provides a deeper context to individual and team actions. The results can also provide a foundation for developing new products to enhance athletes' performance and other sports industry fields.

Match phase model

Match phases are defined as periods of stable ball possession with different tactical intentions or the same intention but different behaviour on fulfilling it. We defined three tactical intentions: Keep possession, Invade the opponent space and Scoring, and 6 phases inside these intentions: Maintenance, Build Up, Progression, Counter Attack, Sustained Threat and Finishing. Figure 1 provides an overview of the definitions of the match phase and their transitions.

Computational approach

We propose a novel approach integrating Graph Neural Networks (GNNs) with Transformers to derive these match phases from spatiotemporal tracking data. GNNs model the dynamic interaction and spatiotemporal dependencies among players, capturing the implicit graph-structured features of the game. Each frame of possession is represented as a graph where nodes correspond to players and edges encode player relationships and distances. Ball states are calculated as global features. Transformers, known for their proficiency in handling long-term dependencies, are used to process and separate sequential tracking data into phases. This combination allows our model to learn spatial interactions and temporal sequence patterns, leading to a robust phase segmentation capability.

Expected Results

We expect our model to demonstrate high alignment with human judgments by validating its performance at the time series level and having domain experts identify the corresponding match phase segments. Furthermore, we will provide practical application examples to highlight the model's utility in performance

analysis. For instance, quantifying how match phase distribution affects physical and tactical performance or profiling a team's playing style based on phase frequency.

KEYWORDS: SOCCER ANALYTICS, MATCH PHASE, TACTICAL INTENTION, GRAPH NEURAL NETWORKS, TRANSFORMER

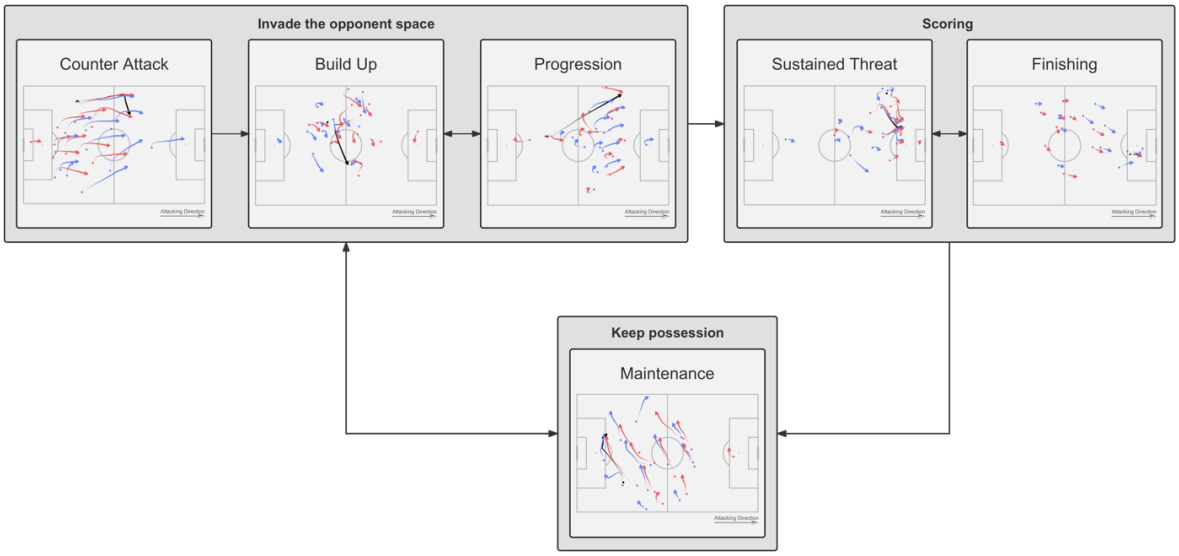

Figure 1. Connections between Intentions and Phases

Code 50

Clustering AFL Players Using Factorisation of Spatial Data

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Abstract

In Australian Football, like other team invasion sports, players are commonly assigned different roles within a team. These roles influence the types of actions players perform in a match (e.g., kicks, handballs, marks, goals, intercepts), and the distributions of player actions have been used to characterize playing styles and detect player roles in previous research (Jackson, 2016; Moffatt, 2025). Event data in elite Australian Football also contains spatial information about where a player is involved in the game (i.e. the locations on the field where the player received or passed the ball or performed other actions). This spatial information has not typically been included in previous analyses of player and team styles and roles. The spatial information contained in shot location data has been used to create a low-dimensional representations of offensive player types in basketball (Miller, 2014). This study aimed to evaluate the feasibility of characterizing and clustering player and team styles in Australian Football using spatial event data.

Six seasons (2018-2023) of play-by-play event data from the AFL (premier men's competition) were analysed (n=1,197 matches). In each match the spatial location of player actions was recorded by a commercial data provider. Non-negative matrix factorization (NMF) was used to estimate spatial basis vectors representing common co-occurring action locations. Players were represented by their basis vector loadings and clustered using hierarchical clustering. The effects of field grid size, spatial smoothing, NMF loss function, and match action types included in the analysis were investigated.

Spatial dimensionality reduction using NMF was able to partition the field into logically distinct regions based on where players typically performed different types of actions (Figure 1 shows an example for kicks). Allowing for the representation of players with respect to their basis vector weightings (Table 1). Spatial information leveraged from only a small number of action types (kicks, marks, handballs) was able to identify domain accurate player types.

Player profiling and grouping systems have applications in team selection, opposition preparation, and list management (trading, drafting, and contracting). Incorporating spatial information into existing player event datasets in Australian Football provides a valuable contextual layer of information that can enhance this type of analysis.

KEYWORDS: AUSTRALIAN FOOTBALL, SPATIAL DATA, DIMENSIONALITY REDUCTION

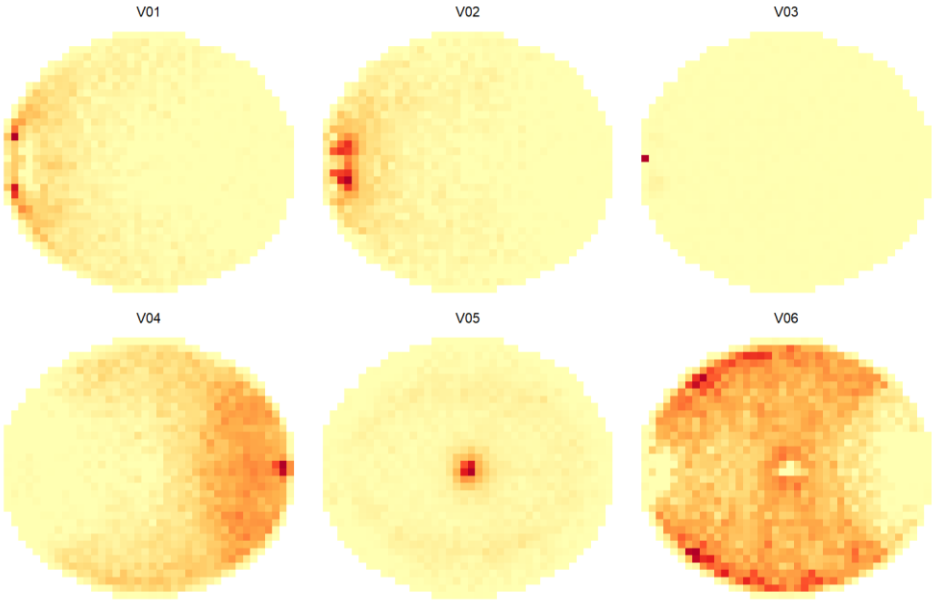

Figure 1. Spatial basis vectors for kicks using Frobenius norm, 4x4m grid size, non-smoothed spatial intensities, and k=6 basis vectors.

Table 1. Example output of player basis vector loadings across three different types of action (kick, handball, mark).

Player	Kick 1	Kick 2	Kick 3	Kick 4	Kick 5	Kick 6	Handball 1	Handball 2	Handball 3	Handball 4	Mark 1	Mark 2	Mark 3
Jack Macrae	0.00	0.00	0.00	0.02	0.05	0.25	0.05	0.05	0.13	0.11	0.06	0.25	0.03
Jake Lloyd	0.00	0.22	0.06	0.00	0.01	0.04	0.26	0.00	0.07	0.01	0.21	0.10	0.01
Lachie Neale	0.00	0.01	0.00	0.04	0.10	0.20	0.04	0.02	0.13	0.14	0.08	0.22	0.03
Clayton Oliver	0.00	0.00	0.00	0.03	0.13	0.17	0.03	0.05	0.13	0.13	0.02	0.28	0.03
Rory Laird	0.06	0.03	0.01	0.01	0.06	0.16	0.07	0.01	0.17	0.08	0.12	0.21	0.00
Zach Merrett	0.00	0.01	0.00	0.02	0.08	0.21	0.04	0.00	0.21	0.09	0.05	0.27	0.01
Jack Crisp	0.04	0.03	0.01	0.01	0.05	0.18	0.11	0.01	0.19	0.03	0.13	0.21	0.00
Christian Petracca	0.00	0.00	0.00	0.15	0.08	0.10	0.00	0.10	0.12	0.12	0.00	0.15	0.17
Tom Stewart	0.10	0.20	0.04	0.00	0.01	0.00	0.23	0.00	0.10	0.00	0.25	0.07	0.01
Marcus Bontempelli	0.00	0.01	0.00	0.07	0.10	0.16	0.03	0.07	0.13	0.12	0.05	0.16	0.12

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Code 55

Data-Driven Evaluation and Improvement of Rugby Teams: A PCA and DEA-Based Analysis

Keita Inoue[1], Makoto Kiuchi[2], Nobuyoshi Hirotsu[3] & Kazuyuki Sekitani[4]

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[2]Sayama Secom Ruggut's
[3]Juntendo Universityÿ
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Abstract

This study presents a data-driven approach to evaluating and improving the performance of rugby teams using a combination of Principal Component Analysis (PCA) and Data Envelopment Analysis (DEA). The dataset consists of detailed performance statistics from five teams in the Japan Rugby League One Division 3, encompassing 29 distinct play-related metrics. Due to the high dimensionality and complexity of the data, PCA was applied to extract key underlying performance dimensions. This dimensionality reduction technique successfully identified 9 principal components that capture the essential variance of the original dataset, effectively summarizing performance areas such as offense, defense, competes for the ball, and set play. The reduced data were then assessed using two DEA models—maxRAM and minRAM—to measure team efficiency from both short-term and long-term perspectives. The maxRAM model emphasizes immediate performance enhancement, while the minRAM model focuses on sustainable, long-term development. Through this dual-model analysis, the study identified inefficiencies in specific teams and proposed tailored improvement strategies accordingly. Short-term recommendations included tactical refinements, adjustments in training focus, and targeted player recruitment. Long-term plans involved the development of structured training programs, player development pipelines, and strategic roster planning to foster continued growth. This integrated PCA-DEA framework provides valuable insights for coaches, analysts, and team managers, offering a systematic method to diagnose inefficiencies and implement performance improvements based on empirical data.

KEYWORDS: DATA ENVELOPMENT ANALYSIS (DEA), PRINCIPAL COMPONENT ANALYSIS (PCA), RUGBY, PLAYER REINFORCEMENT

Code 58

AI Applications in China's Physical Education Classes: A Systematic Review of Innovations and Trends

Di Feng, Zan Liu & Jie Qu
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Abstract

This systematic review examines the integration of artificial intelligence (AI) into China's physical education (PE) sector, synthesizing empirical studies from 2015–2023. Under national initiatives like the New Generation AI Development Plan, AI tools—wearables (e.g., Xiaomi Smart Bands), VR coaching platforms (e.g., Tencent's VR Basketball Trainer), and computer vision systems (e.g., Huawei's Motion Analysis Toolkit)—demonstrate efficacy in personalized fitness programs (23% student fitness gains), skill retention (40% improvement), and posture recognition (92% accuracy). Emerging trends include IoT-enabled smart facilities and predictive health analytics, reducing injuries by 18%. However, challenges persist: 65% of educators report data privacy concerns under China's Data Security Law, while rural schools lag in AI adoption (12%) due to infrastructural disparities. Despite scalable IoT deployments nationwide, China's ethical frameworks trail EU GDPR standards. The findings underscore the need for equitable resource allocation, teacher AI literacy programs, and collaborative policymaking to align technological innovation with educational and health objectives.

Introduction

The integration of artificial intelligence (AI) into China's education system has gained momentum under national initiatives like the New Generation AI Development Plan[1]. Physical education (PE), traditionally reliant on manual instruction, is undergoing transformation through AI-driven tools aimed at enhancing pedagogical efficacy, student engagement, and health outcomes. Despite growing interest, a systematic synthesis of AI applications in Chinese PE remains limited. This review addresses this gap by examining current AI implementations, emerging trends, and challenges in adoption. The findings aim to inform educators, policymakers, and technologists on optimizing AI's role in PE.

Methods

A systematic literature review was conducted using peer-reviewed articles, government reports, and case studies (2015–2023) from databases including Web of Science, PubMed, and CNKI. Keywords included AI in PE, wearable technology, and smart education in China. Inclusion criteria prioritized empirical studies on AI tools deployed in Chinese K–12 and college PE programs. Data were thematically categorized into applications, trends, and challenges.

Results

1. AI-Driven Pedagogical Tools

- **Personalized Fitness Programs**: Wearable devices (e.g., Xiaomi Smart Bands) collect real-time biometric data (heart rate, BMI) to tailor exercise regimens. A 2022 Beijing pilot study reported a 23% improvement in student fitness scores using AI-generated plans.

- **Virtual Coaching**: VR systems (e.g., Tencent's VR Basketball Trainer) employ machine learning to simulate sports scenarios. Trials in Shanghai schools showed a 40% increase in skill retention compared to traditional methods.
- **Automated Skill Assessment**: Computer vision systems (e.g., Huawei's Motion Analysis Toolkit) evaluate techniques like gymnastics routines, achieving 92% accuracy in posture recognition.

2. Emerging Trends

- **Smart Campus Integration**: IoT-equipped facilities (e.g., Alibaba's AI-powered gyms) autonomously adjust environmental conditions (lighting, temperature) to optimize training.
- **Predictive Health Analytics**: AI models predict overtraining risks by analyzing fatigue patterns, reducing student injuries by 18% in Guangzhou trials.

3. Adoption Challenges

- **Data Privacy**: 65% of surveyed educators expressed concerns about biometric data misuse.
- **Urban-Rural Disparities**: Only 12% of rural schools utilize AI tools due to infrastructure gaps.

Discussion

AI's integration into PE aligns with China's dual goals of educational modernization and health promotion. Key innovations—such as VR coaching and predictive analytics—demonstrate efficacy in skill development and safety. However, disparities in resource allocation risk exacerbating educational inequalities, echoing findings by Wang et al. (2022) on technology gaps in rural China[2]. Ethical concerns, particularly under China's *Data Security Law*, necessitate stringent encryption and transparent data policies. Furthermore, teacher training programs must evolve to address AI literacy gaps, as highlighted by the Ministry of Education's 2023 report [3].

Comparatively, China's AI adoption in PE surpasses global counterparts in scalability (e.g., nationwide IoT deployments) but lags in ethical frameworks, unlike the EU's GDPR-focused approaches. Future research should explore AI's long-term impacts on student motivation and mental health.

Conclusion

This review underscores AI's transformative potential in Chinese PE, from personalized training to predictive health management. While technical advancements are robust, equitable access and ethical governance remain critical hurdles. Collaborative efforts between policymakers (e.g., Ministry of Education) and tech firms (e.g., Baidu, SenseTime) could drive inclusive innovation. Future directions include AI-augmented mental health support and adaptive exoskeletons for mobility training. As global AI education markets expand, China's PE reforms offer a blueprint for merging technology and pedagogy.

KEYWORDS: ARTIFICIAL INTELLIGENCE; LIMITATIONS; TREND

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Code 62

Smart Sport Assistance: Low-Cost Intelligent Systems for Inclusive Physical Education

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Abstract

Introduction

Students with visual impairments or blindness encounter significant challenges in physical education (PE), often leading to exclusion and reduced engagement. These barriers may include limited spatial orientation, lack of adapted feedback systems, and general misconceptions among educators regarding the capabilities of visually impaired learners. The “Smart Sport Assistance” project was initiated to address these challenges through the co-development of low-cost, intelligent assistive systems that aim to improve inclusion, spatial awareness, and active participation in PE settings. The project employed a user-centered Open Innovation framework, integrating the expertise of PE teachers, researchers, and students from Austrian higher technical schools (HTLs), who collaborated directly with visually impaired and sighted pupils throughout all development stages.

Methods

Using agile development methods, multiple prototypes were created using ESP32-based microcontroller platforms. These systems integrate a range of sensors including inertial measurement units (IMUs), LiDAR and Time-of-Flight (ToF) distance sensors, and pressure-sensitive mats. The hardware configurations are optimized for real-time feedback via auditory, haptic, or visual cues, tailored to the specific needs of users with varying levels of visual perception. Emphasis was placed on maintaining low material cost, ease of use, and reproducibility across diverse educational environments.

Results

The prototypes developed include: (a) a re-engineered bell ball equipped with an IMU and LED/buzzer system, enabling it to emit speed-related acoustic and optical signals even when stationary - overcoming a critical limitation of conventional bell balls; (b) two swimming feedback solutions - one using computer vision for swimmer tracking and auditory alerts, the other using an underwater bubble stream to provide tactile feedback near the lane's end; (c) soft pressure-sensitive mats combined with an accessible app that enable various movement games; and (d) a basketball hoop with a metronome-based acoustic orientation system and a light barrier for real-time scoring feedback. Pilot trials conducted in inclusive PE settings showed high acceptance among visually impaired students, who reported increased engagement, greater confidence, and reduced frustration during activities that previously posed challenges. Teachers

and peers also reported a stronger inclusive dynamic, facilitated by the visibility and functionality of the assistive systems.

Discussion & Conclusion

The low-threshold design ensures that the solutions can be replicated in other contexts using open-source documentation. To support dissemination and awareness, a “Sensitization Box” was compiled, combining the technical systems with inclusive teaching materials and training guides for educators and peers. This package not only promotes sustainable implementation but also enhances awareness of inclusive practice in school sports environments. In conclusion, the project highlights how co-designed, technologically intelligent systems can effectively reduce access barriers and promote equal participation in PE for students with visual impairments.

KEYWORDS: ASSISTIVE TECHNOLOGIES, VISUAL IMPAIRMENT, PHYSICAL EDUCATION, SENSOR SYSTEMS, OPEN INNOVATION

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Code 82

A Deep Learning based Basketball Game State Reconstruction System

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Abstract

Advances in deep learning are transforming sports analytics into a multidisciplinary field integrating sports science and computer science. Traditional methods relying on manual reviews or specialized hardware often face scalability challenges due to their labor-intensive workflows and high infrastructure costs. This paper presents an end-to-end basketball analytics system using computer vision to detect and track players and ball location in the court in real time, enabling tactical and performance evaluation. The platform delivers valuable insights for in-game decisions and post-game strategy while remaining adaptable to resource-constrained environments.

KEYWORDS: SPORTS ANALYTICS, DEEP LEARNING, GAME STATE RECONSTRUCTION

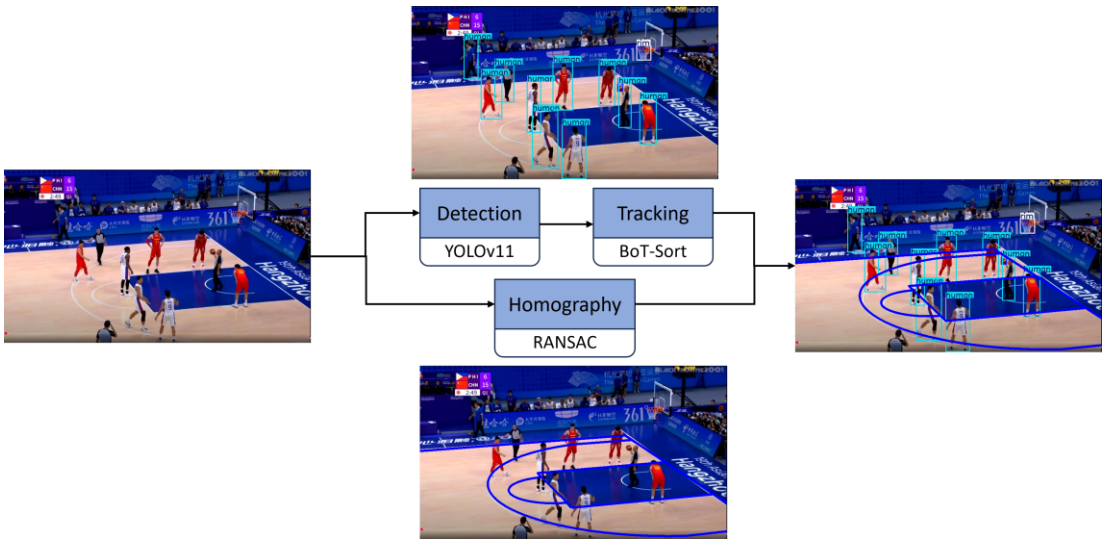

Figure 1. The flowchart of game state reconstruction system.

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Code 83

An AI-assisted Basketball Tactical Decision Support System for Effective Coaching

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Abstract

In recent years, the integration of data analysis and artificial intelligence (AI) has significantly reshaped basketball training and tactical decision-making. As a team sport emphasizing collaboration, real-time decisions, and situational adaptation, basketball offers an ideal context for applying intelligent systems to enhance coaching strategies. To comprehensively understand the development and application of AI and data analysis in basketball tactical decision-making, a systematic literature review was conducted using Web of Science, Scopus, and Google Scholar databases. Keywords including "basketball tactical decision support system," "artificial intelligence in sports," "basketball data analysis," "machine learning in basketball," and "training optimization" were used, with a publication date range from 2015 to 2024. An initial retrieval identified 98 articles. Following a screening process based on titles, abstracts, and full-text reviews, 19 studies focusing on empirical research, system development, and real-game applications were selected for detailed analysis.

Key references included studies on player performance evaluation (Sicilia et al., 2019; Martonosi et al., 2023), computer vision-based game video analysis (Chen & Wang, 2020; Mendes-Neves et al., 2023), tactical modeling (Wang et al., 2024; Tian et al., 2019), and injury prediction frameworks (Phatak et al., 2021; Sarlis et al., 2021). Findings show that AI and advanced data analysis have significantly contributed to enhancing tactical efficiency, accelerating decision-making, and optimizing lineup management. Early research mainly focused on isolated player performance metrics, whereas more recent studies have adopted comprehensive tactical modeling by integrating multi-source data such as player movements, game context, and opponent tendencies.

Nonetheless, several limitations persist. Many studies heavily rely on structured datasets, with limited integration of unstructured video data or real-time sensor information. Additionally, there is a predominant focus on individual-level analysis, while team-level tactical interactions and dynamic opponent modeling are less explored. Furthermore, empirical validation through intervention experiments remains scarce, limiting the practical relevance of many proposed systems.

Overall, data-driven tactical support systems have demonstrated benefits such as improved scoring efficiency, targeted defensive strategies, and enhanced player role assignments. However, inconsistencies in data sources, insufficient integration of collective team behaviors, and a lack of research on long-term training outcomes highlight areas for further development.

In response to these gaps, this study proposes a new tactical decision support framework based on comprehensive professional basketball game data. The framework involves collecting player and team statistics, preprocessing and feature extraction, and applying statistical models to identify key tactical indicators. Emphasizing both individual and collective tactical behaviors, the system's effectiveness will be validated through collaboration with a professional basketball team. Empirical data from training and competition environments will be collected to assess the practical utility and impact of the system on tactical outcomes and training efficiency.

KEYWORDS:BASKETBALL, TACTICAL DECISION,DATA ANALYSIS,

PERFORMANCE SUPPORT, AI-ASSISTED

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Code 87

Multi-modal Machine Learning Models for The Prediction of Overuse Injuries in Sports

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Abstract

Overuse injuries occur without a traumatic cause (Aicale, Tarantino, & Maffulli, 2018). Contributing factors include insufficient recovery, overloading and lack of fitness (Aicale et al., 2018). Training load is the summation of internal and external load. External load is the work done by the athlete (Halson, 2014), frequently measured with Inertial Measurement Units (IMU). IMUs typically include: an accelerometer, a magnetometer, and a gyroscope. Internal load is the physiological and psychological stress imposed by exercise (Halson, 2014). Biomarkers, such as Heart Rate (HR), biochemical markers and endocrine markers track physiological changes in response to load (Bestwick-Stevenson, Toone, Neupert, Edwards, & Kluzek, 2022). However, the most common method is using the Rate of Perceived Exertion (RPE) with Borg rating (Scherr et al., 2012). RPE is a subjective method, as it reflects the internally experienced effort without direct physiological measurement.

This study aims to improve athlete monitoring by predicting RPE using HR, IMU-derived metrics, and flywheel force data. It also examines the potential of load metrics to predict changes in blood lactate concentration, assessing lactate as an objective marker of exertion and overload alongside subjective measures.

Twelve male participants (23.3 ± 2.9 years old) performed squats on a flywheel machine (Albert, Herdick, Brahms, Granacher, Arnrich, 2023). Acceleration, orientation, heart rate and force metrics are collected with initial and final lactate concentration. Machine learning models were developed to predict session RPE values: using HR and IMU metrics only, and then with the addition of flywheel metrics. Model performances were compared to assess the effect of added external load data on RPE prediction. In parallel, regression models were created to predict changes in blood lactate concentration using HR and IMU metrics.

We developed and compared six machine learning models: Linear Regression (LR), Support Vector Regression (SVR) with linear kernel, Gradient-Boosting Regression Trees (GBRT), Random Forest (RF), Multi-Layer Perceptron (MLP) and residual network (ResNet).

Table 1 shows the models' performance when flywheel force metrics were included. All algorithms showed fewer errors with the added metrics. In lactate prediction, LR had the highest Mean Squared Error (MSE) (35.69). SVR had the lowest Root Mean Squared Error (RMSE) (1.69) and the lowest MSE (4.84).

Including flywheel-derived force metrics improved predictive accuracy, supporting our hypothesis that more detailed training load information enhances RPE prediction. For lactate prediction, non-linear models outperformed linear models, suggesting lactate changes do not follow a linear pattern, aligning with literature showing lactate increases gradually first, then exponentially (Goodwin, Harris, Hernández, & Gladden, 2007). SVR was the better-performing model to

predict lactate change with exercise due to its ability to capture non-linear patterns and manage small datasets. However, the generalisation ability of our predictive models is limited by having only two lactate time points per participant.

These findings show the value of integrating diverse load measures to improve overload monitoring in athletes. Future research should focus on increasing the dataset size and the time points for lactate measurements while leveraging advanced deep-learning architectures to improve predictive accuracy.

KEYWORDS: INJURY, TRAINING LOAD, RPE, LACTATE, IMU, HR

Table 1: The results of the models including both IMU + HR features, with and without flywheel-derived variables (F). Model performance is reported using Mean Squared Error (MSE), Root Mean Square Error (RMSE), and Mean Absolute Percentage Error (MAPE). (GBR = Gradient Boosting Regressor; LR = Linear Regression; MLP = Multi-Layer Perceptron; RF = Random Forest; SVR = Support Vector Regression.)

Model	F + IMU + HR			IMU + HR		
	MSE	RMSE	MAPE (%)	MSE	RMSE	MAPE (%)
GBR	3.32	1.72	9.31	3.89	1.79	9.91
LR	4.16	1.95	11.07	5.53	2.26	12.27
MLP	3.56	1.82	9.88	3.83	1.88	10.39
RF	2.83	1.59	8.76	3.24	1.67	9.34
SVR	3.05	1.67	9.63	3.45	1.77	9.92

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Code 90

The Correlation between Sports Fatigue and Lower Extremity Joints Angular Velocity in Women Weightlifting Athletes by Utilizing Open AI Skeleton

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Abstract

Sports fatigue leads athletes to a potential risk of injuries and also affects athletes' sports performance. Monitoring sports fatigue in athletes' states is a critical issue for coaches and athletes. (Guan, X., Lin, Y., Wang, Q., Liu, Z., & Liu, C., 2021, Halson, S. L., 2014 and Allen, T. J., & Proske, U. 2006) Moreover, Open AI Sekleton has become more popular in the sports field. (Osokin, D., 2018 and Toshev, A., & Szegedy, C. 2014) Therefore, we aim to find the relation between sports fatigue and the lower extremity joints' angular velocity on women's weightlifter movements by utilizing an Open AI skeleton model. We recruited 10 participants, who are college weightlifting athletes, and each athlete lifted the snatch lifts during their daily training for a total of 360 snatch lifts. The surface electromyography (EMG) signal for the athletes both legs of the hamstring muscles to indicate sports fatigue in these athletes. The athletes' lower extremity joint positions, which were gathered by the open-source Intel OpenVINO with COCO model skeleton, furthermore, the Mann-Whitney U test is considered to obtain the correlation between pre-fatigue and fatigue of weightlifter movement. The experimental results shown in Table 1 indicate that in the athlete's lower extremity of four joints, the median of their angular velocity in fatigue is higher than in the pre-fatigue state. Therefore, from the experimental results, the athletes' conditions in sports fatigue can be monitored by the joints' angular velocity with an open AI skeleton.

This research is funded by the National Science and Technology, Taiwan, R.O.C. (MOST 107-2410-H-845-026-)

KEYWORDS: OPEN AI SKELETON, SPORTS FATIGUE, WEIGHTLIFTING SNATCH, JOINT ANGULAR VELOCITY

Table 1. The results of the pre-fatigue and fatigue on weightlifters' lower extremity joints.

	statistic	p	Pre-fatigue median (rad/s)	Fatigue median (rad/s)
Right Hip	18559	0.014	-25.79	-31.77
Right Knee	18781	0.007	-7.37	-43.46
Left Hip	12466	<0.001	16.36	34.07

Left Knee	13711	0.014	28.7	49.58

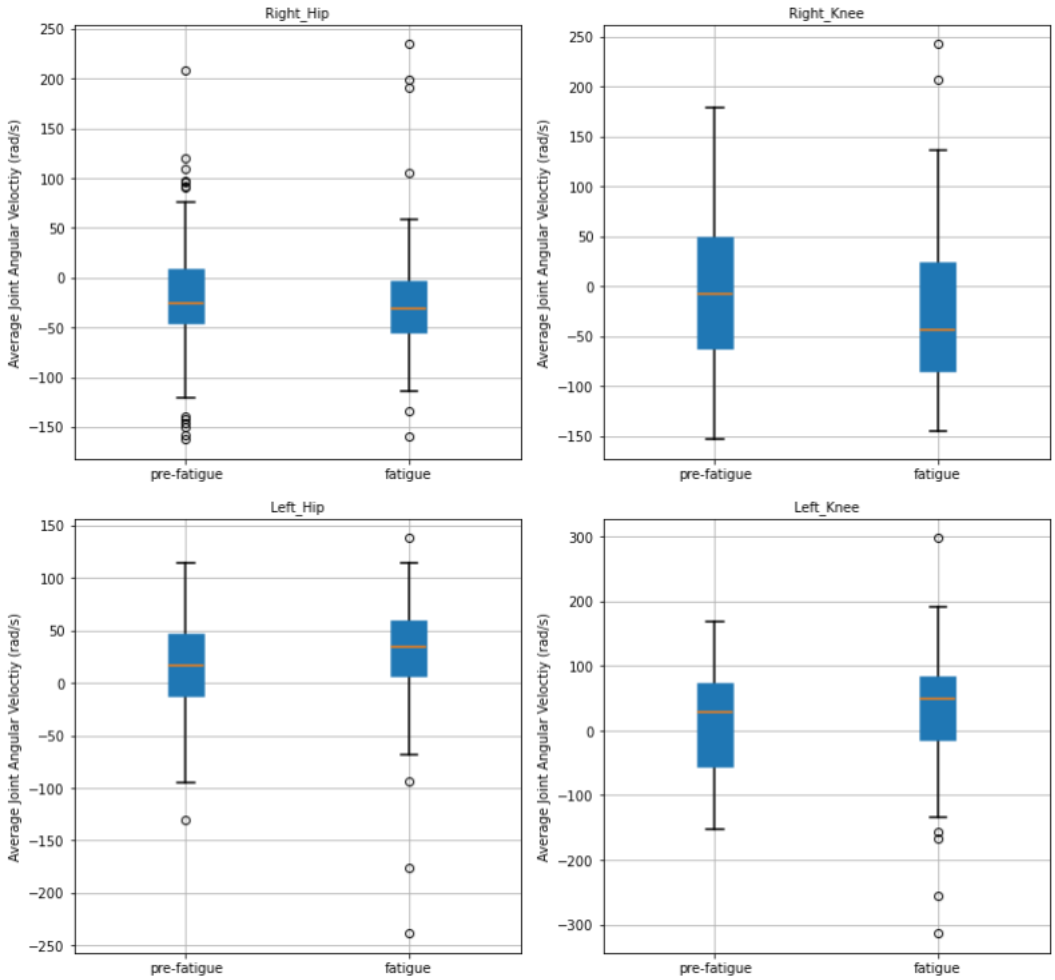

Figure 1.The average joint angular velocity comparison of four joints in the pre-fatigue and fatigue states.

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Code 97

Use of Digital Tools in Pre-Service Coaching Practices: A Case Study of the Sports University of Haryana

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Abstract

This research surveys the integration of digital tools in pre-service coaching programs, specifically the Postgraduate Diploma in Sports Coaching at the University of Haryana. It examines the current status of digital tool usage and technology in pedagogical and practical applications for future sports coaches. The study explores issues such as the digital divide, internet connectivity, time management, cyberbullying, cybersecurity, online learning etiquette, motivational challenges, online distractions, pedagogical problems, digital literacy, teachers' skills for remote teaching, communication gaps, practical arrangements, urgent daily communication, evaluation and criticism, platform availability for online education, electricity supply, resource access, digital attendance reporting, curricular updates, internship communication, digital notices, learners' dedication, teaching quality, ongoing professional development, cognitive health, online admission procedures, university payment gateways, deposit fee verification, mess dues clearance, user-friendly and updated websites, professional recognition, self-learning materials, MOOC course agreements, digital resource maintenance, university initiatives for procuring digital tools, video analysis platforms, wearable performance trackers, mobile coaching apps, real-time feedback, personalized training strategies, and data-driven decision-making/teaching. Responses were collected from 100 pre-service coaching students (23 females and 77 males) enrolled in the Postgraduate Diploma in Sports Coaching program for the 2024-25 academic year. The participants represented disciplines including Athletics (19), Badminton (6), Basketball (6), Boxing (10), Cricket (4), Football (5), Handball (2), Kabaddi (17), Lawn Tennis (6), Volleyball (7), Wrestling (13), and Yogasana (5) at the Sports University of Haryana. Findings suggest that digital and virtual learning environments, along with reflective practice, are incorporated within the university. The study highlights both opportunities and challenges associated with digital integration. Overall, students called for ongoing updates, feedback systems, and investment in tools like smartboards, digital performance tracking, and performance-analysis software to modernise coaching practices and align with global sports-tech trends. These insights provide valuable implications for sports education institutions seeking to modernise their coaching curricula in line with current digital advancements.

KEYWORDS: DIGITAL TOOLS, PRE-SERVICE COACHING, SPORTS-TECH TRENDS.

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15th International Symposium on Computer Science in Sport

IACSS 2025

September 12 - 15, 2025

Tokyo Gakugei University
Tokyo, Japan

Theme:
Physiology & Biomechanics

Code 03

Design of an Integrated System Combining a Six-Axis Sensor and OpenPose for Forehand Stroke Analysis

Yung Hoh Sheu[1], *Li Wei Tai*[1], *Sheng K Wu*[2], *Tz Yun Chen*[1], *Tzu Hsuan Tai*[1] & *Cheng You Huang*[1]

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Abstract

This study aims to explore the integrated application of a six-axis sensor and OpenPose technology to quantify the racket-swinging motions of table tennis players and analyze their athletic performance. Furthermore, it investigates the relationship between body movement and changes in joint angles. The six-axis sensor, embedded in the racket handle, is used for testing and analyzing forehand strokes. It accurately measures angular variations, velocity, and acceleration during the swinging process, comprehensively capturing the motion's characteristics. Additionally, OpenPose technology is employed to extract joint angle variations, which are then compared with data obtained from the six-axis sensor. By analyzing waveform similarities from these two distinct data sources, the study explores the correlation between joint movements and racket motion parameters, providing a more precise basis for technical evaluation and motion optimization.Moreover, the data from both the sensor and OpenPose are displayed in real time through the HoloLens Mixed Reality (MR) system, offering coaches immediate and intuitive visual feedback to facilitate training adjustments and technique refinement. Motion data were collected from 100 table tennis players (90 male and 10 female), covering a range of skill levels from amateur to professional. Each player performed at least 20 forehand stroke tests, resulting in the analysis of over 2,000 sets of swing data, thereby ensuring the representativeness and accuracy of the research findings.The experimental results indicate that the integration of OpenPose and the six-axis sensor achieved a recognition accuracy of over 90%. The efficiency calculations reveal that players with more stable waveforms exhibit an overall joint variation error of less than 10% in their dominant-side shoulder and axis joints, suggesting that higher correlations in these parameters are associated with more stable swings during actual matches.The findings of this study can serve as a foundation for personalized training programs and assist coaches in formulating optimized training strategies, ultimately enhancing players' technical performance and competitive abilities..

KEYWORDS: SIX-AXIS SENSOR, OPENPOSE, MIXED REALITY

Code 09

Assessment of performance during penché rotation in rhythmic gymnastics using statistical parametric mapping

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Abstract

Rhythmic gymnastics (RG) is a highly technical and artistic sport that requires athletes to integrate strength, flexibility, coordination, and precise execution of complex movements. In RG, gymnasts perform balance exercises by standing on one leg while the free leg is raised in different positions, which is an extreme challenge in terms of postural balance. Balance exercises can generally be categorized into static and dynamic balance. Several studies have examined the kinematics of various gymnastics movements, focusing on flexibility, muscle activation, and balance control (Donti, Bogdanis, Kritikou, Donti, & Theodorakou, 2016). Performance variability in balance tasks was twice as high in the younger gymnast compared to the older one (Rutkowska-Kucharska, Szpala, Jaroszczuk, & Sobera, 2018). Sobera et al. (Sobera & Rutkowska-Kucharska, 2019)noted that balance abilities vary significantly across different age groups, making it difficult to generalize results across all skill levels. However, balance stability in RG remains a complex task.

Differences in kinematic variables between sports activities have been assessed using statistical parametric mapping (SPM), which evaluates movement and improves the understanding of strategies employed to achieve the various tasks (Martonick et al., 2022). This can lead to enhanced performance, effective treatment approaches for sports injuries, precise strength and conditioning programs (Yona, Kamel, Cohen-Eick, Ovadia, & Fischer, 2023). A number of studies have applied SPM to the field of sports biomechanics (Morais, Barbosa, Lopes, Moriyama, & Marinho, 2024). Therefore, we assessed performance in the penché rotation in RG using SPM by comparing it with the static balance exercise.

Six female gymnasts participated in this study. The Xsens wearable motion capture system was used to capture full-body joint kinematics during static balance and penché rotation in RG. All subjects were asked to perform three static balance tests and penché rotations technique. Hip, knee, and ankle joint ROM for supporting and lifted the leg were calculated. Motion data were normalized into 100 steps prior to statistical analysis. SPM was used to assess performance in the penché rotation by comparing the statistical significance between the static balance test and the rotation technique. The significance level for all statistical tests was set a priori to $p < 0.05$.

During the penché rotation, gymnasts exhibited increased plantarflexion of the ankle (p=0.001, 0-27%) and hyperextension of the knee (p=0.024, 0-21%) and hip (p=0.046, 0-10%) in the supporting leg, while demonstrating a more flexed knee (p<0.001, 0-100%) in the lifted leg throughout the entire execution phase compared to the static balance test (Figure 1).

This study applied SPM analysis to assess the performances in penché rotation in RG by comparing lower extremity kinematics against a static balance pose. Results showed a difference in joint kinematics for supporting and lifted legs during static balance and dynamic rotation techniques. This could indicate what specific joint motions do not fit with threshold values in the movement patterns of the static balance test, which can then be interpreted as performance in dynamic rotation. Assessing the overall movement patterns revealed that performing the rotation technique caused the supporting leg's ankle and knee joints to be more extended at the start of the movement while having greater flexion of the lifted leg's knee. Therefore, SPM analysis can be used to evaluate performance and movement patterns during routines in RG.

KEYWORDS: RHYTHMIC GYMNASTICS; PERFORMANCE; INERTIAL SENSORS; STATISTICAL PARAMETRIC MAPPING

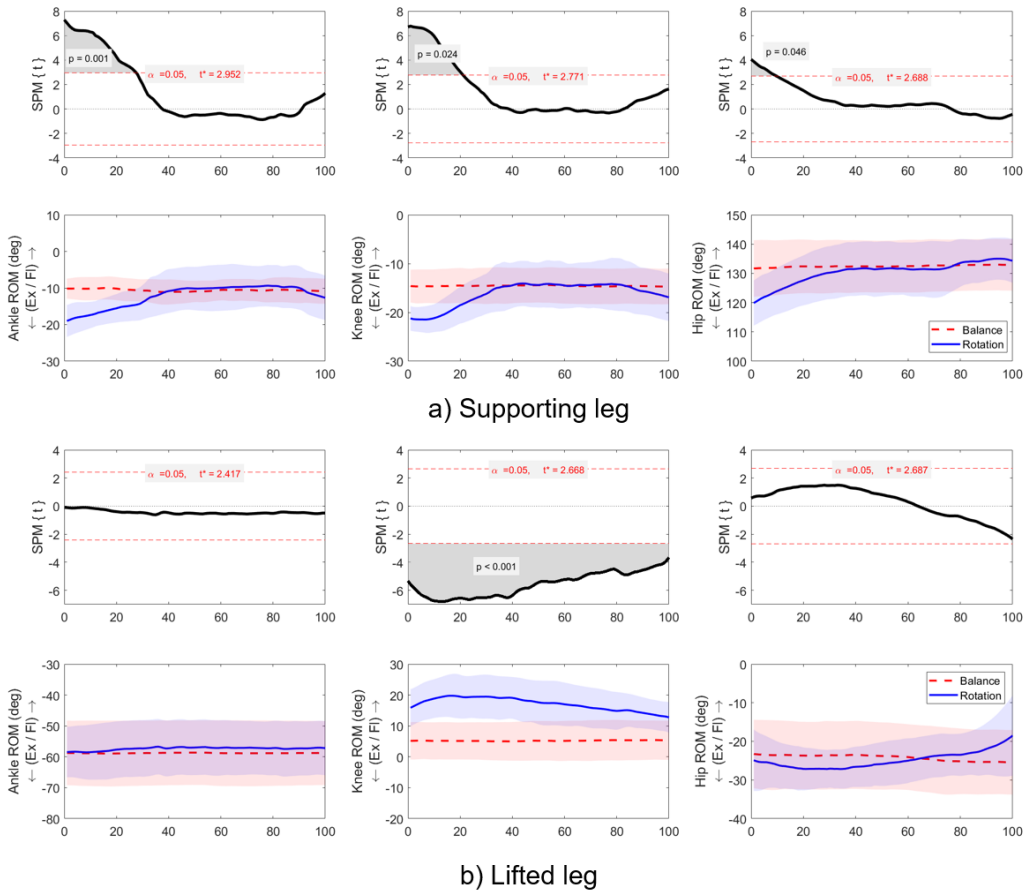

Figure 1. SPM analysis between static and rotation for supporting and lifted leg.

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Code 13

Investigation of the Effect of Vibration Amplitude and Frequency on Muscle Contraction Patterns

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Abstract

One of the training methods believed to increase athletic performance is vibration approaches. There are two types of vibration depending on the application method: Local Vibration (LV) and Whole-Body Vibration (WBV). The aim of the study is to evaluate the effects of vibration on muscular activation strategies through kinetic and kinematic means.

The aim of this scientific research project was to investigate of muscular activation respond to whole body vibration (WBV) through 30 second at different frequency and amplitude of participants from different sports branches. These responds to WBV were recorded by Electromyography device. Active atheletes were participate in this project named "Evaluation of vibration frequencies and amplitudes effects on muscular activation strategies" from football (n=14), basketball (n=14) and swimming (n=12) who had no injury for the last six months. In scientific research project, EMG values of participants were recorded during WBV treatments at squat position. The recorded EMG values were normalized to maximal voluntary contraction values which were recorded before WBV exercises. The level of statistical significance was determined as $p \leq 0.005$. When the results compared between participants from different sports branches statistically, the study design of our project was indicated that basketball players and swimmers had more affected according to football players during WBV treatments and there was not statistically significant difference between basketball players and swimmers.

Within the framework of our scientific research project it could be said that WBV treatments is an efficient method to increase the level of muscular activation of well trained athletes and this efficient method can use during recovery period, rehabilitation in the disability process or off-season period.

KEYWORD: WHOLE BODY VIBRATION, MUSCULAR ACTIVATION, EMG, DIFFERENT SPORTS BRANCHES

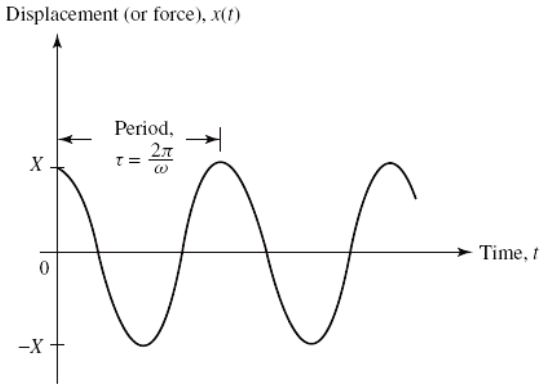

Figure 1: Spring Motion Formula and Wave Graph

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Code 15

Correlation between ground reaction force and kinematics during sprint acceleration using wearable sensors

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Abstract

Many studies have investigated biomechanical factors in the various phases of sprinting using force platforms, optical motion capture, video cameras, inertial measurement unit (IMU) sensors, and in-shoe pressure systems (Fraeulin, Maurer-Grubinger, Holzgreve, Groneberg, & Ohlendorf, 2021). The kinematics and kinetics were shown to be associated with maximal sprint performance. Typically, 70% of maximum velocity is reached by the end of the fourth step in the acceleration (Nagahara, Kanehisa, & Fukunaga, 2020). Also, peak vertical force is a key element of high performance during acceleration (King, Burnie, Nagahara, & Bezodis, 2022). However, no study has used both IMU and in-shoe pressure insole sensors to examine ground reaction force (GRF) and joint kinematics in sprinting. This study aimed to investigate the correlation between GRF and joint kinematics during the acceleration by using Xsens MVN and F-scan wearable systems.

In this study, 10 male junior athletes participated. The Xens MVN (Xsens MVN Analyze, Movella, Netherlands) and F-Scan research (Tekscan Inc, MA, USA) wearable systems were simultaneously used to capture full-body joint kinematics and GRFs during sprinting at a 60 Hz sampling rate. After completing the calibrations for the Xsens and F-scan systems, all sprinters ran three sets of 30-meter sprints on an indoor track under the guidance of an experienced coach while wearing both systems. From the Xsens MVN system, the joint kinematics in a front leg over time, were calculated and exported (Dambadarjaa et al., 2024). Meanwhile, vertical GRFs in the front leg were calculated and exported from the F-Scan research (Chen & Bates, 2000). Then, the data (ankle, knee, and hip joint angles in sagittal planes, GRF in the vertical direction) were divided into two phases: block clearance and the first four steps. Kinematics in the first four steps or during acceleration were averaged and normalized into 100 steps for further analysis. Pearson correlation coefficients were used to analyze the relationship between GRF and joint kinematics for normally distributed data, while Spearman rank correlation coefficients were applied for non-normally distributed data. A p-value of less than 0.05 was interpreted as statistically significant.

The vertical GRF and lower extremity joint angles are shown in Fig 1. The mean of peak GRF was 1593.3±347.6N. The maximum flexion of the ankle, knee, and

hip was 21.2±6.9°, 139.5±9.6°, and 80.1±5.8°, respectively (Figure 1). Correlation analysis showed that peak GRF was correlated with ankle dorsiflexion, knee extension, and hip extension (Table 1). This study investigated the kinematics and GRF during sprint acceleration using wearable systems, such as inertial measurement and insole pressure sensors. Future studies will investigate the relationship between GRF, center of mass velocity and whole-body kinematics during both block clearance and acceleration phases.

KEYWORDS: GROUND REACTION FORCE, KINEMATICS, SPRINTING, SENSORS

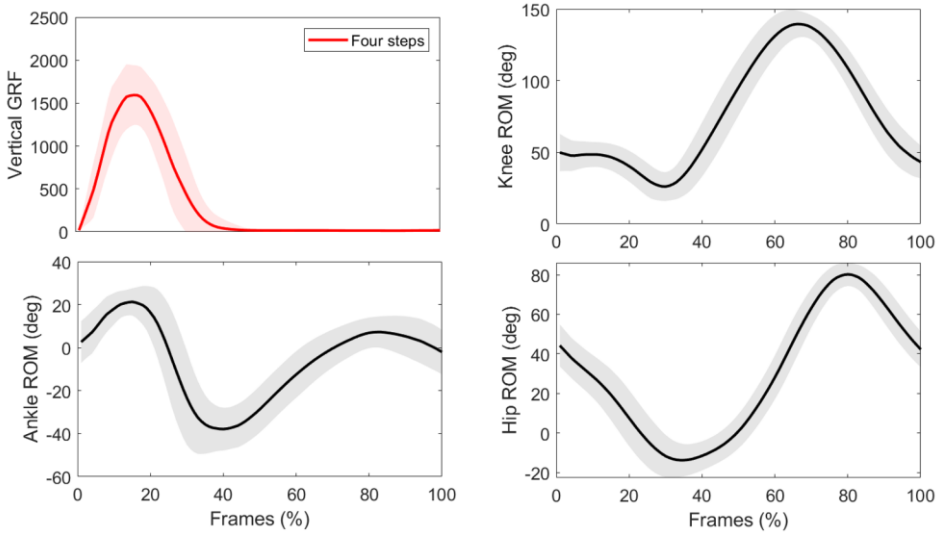

Figure 1. GRF and joint kinematics

Table 1. Correlation between GRF and joint kinematics		
Ankle dorsiflexion	-0.29	0.01
Knee extension	-0.26	0.02
Hip extension	-0.44	<0.0001

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Code 18

Identifying technique differences in professional alpine skiing based on Human Pose Estimation models

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Abstract

Introduction

In many professional sports, analyzing training and competition with video material ishighly relevant in order to achieve good results in the competition (Zheng and Zhang, 2022). Manual video analysis can be cumbersome, error-prone and inappropriate for more advanced analysis. Although modern video analysis algorithmscan be used to support this process,few works applied thoseto alpine skiing data yet. We usedmethods for automated preprocessing, human pose estimation and machine learningto analyze video capture of alpine sking races, aimingto investigate ifsimilarclustersofskiierscanbeidentifiedbased on curving technique.

Methods

In this study, a prototype was developed that groups professional skiers with clustering algorithms based on their pose, using a dataset with video capture of the 2021 downhill ski race in Kitzbühel, Austria. To ensure comparability, all 34 runs have been semi-automatically preprocessed, including cutting, scene selection and the training of a custom object detection model to recognize ski flags and skiers. For each run 100 frames in immediate vicinity to a defined ski flag were selected to apply a human pose estimation model (see Figure 1).

The generated human pose data was checked using predefined rules and outlier detection algorithms to ensure, that only correctly processed frames were used for subsequent steps. Human pose data remaining after this filtering process was fed in different representations into various clustering algorithms. Once the final clustering model had been selected, the different poses were visualized in order to draw conclusions about skiing poses. For the visualizations, prototypical athletes per cluster were identified based on cluster centroids and their poses were shown in comparison using an animated frame by frame diagram.

Results

The results show, that it is possible to group skiers based on their pose. In the dataset and course segment used, three distinct clusters were identified representing different techniques to master this segment. (see Table 1).

The derivation of clearly distinguishable clusters shows that the chosen procedure for processing the given data is suitable for analyzing skiing technique differences.

Discussion and Conclusion

Our work enables skiiers and their coaches to partially automate video analysis of training and race runs and compare to other athletes. Additionally, it describes the exact technical steps required to reproduce this analysis. Limitations were recognized in the application of the human pose estimation model, as some complex skiing poses were not correctly recognized and therefore the original dataset had to be reduced to those frames usable for further processing. Also, as the preprocessing involved to a small extent heuristics and manual steps, processing efficiency and flawlessness can still be optimized. Future research could address these issues on the one hand side and apply the shown methodology to a larger dataset on the other.

KEYWORDS: SKIING, MACHINE LEARNING, HUMAN POSE ESTIMATION, CLUSTERING

Figure 1. Human Pose Estimation results.

Table 1. Excerpt of clustering results show skier and cluster id

Skier	Skier Name	Cluster
1	Muzaton	1
2	Baumann	1
3	Cater	2
4	Clarey	2
5	Innerhofer	3
…		

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Code 25

The Demand for Over-the-Top Basketball Broadcasts: Substitution Effects and Viewer Preferences

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Abstract

Despite the rapid proliferation of over-the-top (OTT) streaming platforms in the sports broadcasting landscape, empirical research on the demand for OTT sports content remains sparse (Nalbantis & Kühne, 2024; Baecker et al., 2024). Even more limited is our understanding of basketball viewership dynamics, particularly within European markets (see Di Mattia & Krumer, 2023; Schreyer & Ansari, 2022; Nalbantis & Pawlowski, 2016). This study addresses this gap by examining the determinants of demand for live broadcasts of the Greek Basket League (GBL) on a major OTT platform.The GBL is the top-tier professional basketball league in Greece and one of the most historic domestic basketball competitions in Europe. Drawing on comprehensive viewership data from two GBL seasons (2022/23 and 2023/24), we investigate a wide array of potential drivers of audience demand. These include variables related to game attractiveness (e.g., expected closeness, ELO ratings), scheduling features (e.g., day of the week, time slot), and potential substitution effects . We focus especially on the effects of competition from domestic football broadcasts, as well as substitution that may occur when the same basketball game is simultaneously broadcast on linear television.We begin our empirical analysis by estimating an ordinary least squares (OLS) regression to explore the association between these factors and OTT viewership levels.

However, the broadcaster's endogenous decision to select certain games for linear TV coverage introduces potential selection bias. Games chosen for television are likely to be the most attractive to audiences, meaning simple OLS estimates may conflate the effect of TV coverage with underlying game appeal.To address this concern,similar to previous work (e.g., Wallrafen et al., 2022),we apply an Endogenous Treatment Regression (ETR) model, using the maximum likelihood estimation approach developed by Maddala (1983) and grounded in the selection model framework proposed by Heckman (1976, 1978). This model allows us to account for the non-random treatment assignment—here, the likelihood of a game being broadcast on linear television—and isolate the true effect of simultaneous TV coverage on OTT demand.Across both modeling approaches, our findings consistently highlight a strong viewer preference for close and competitive games. Moreover, we find clear evidence of substitution between linear and OTT broadcasting platforms: games aired simultaneously on traditional television attract significantly lower viewership on the OTT platform, all else equal. In addition, we observe substantial cross-sport competition effects—high-profile Greek football broadcasts significantly reduce OTT basketball viewership, indicating overlapping fanbases and intense competition for viewer attention during concurrent time slots.These findings contribute to a deeper understanding of consumer behavior in contemporary sports media markets and provide valuable insights for rights holders, broadcasters, and league administrators seeking to optimize exposure and maximize audience reach across platforms.

KEYWORDS: DEMAND, MEDIA, SPORTS BROADCASTING, SUBSTITUTION

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Code 45

Development of an AI-based Online Sports Injury Assessment System: Athlete Self-Monitoring and Injury Management

Shuya Chen[1], Yi-Shen Chou[1], Chen-Yu Sun[2], Sheng-Kuang Wu[2] & Wen-Dien Chang[2]

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[2] *National Taiwan University of Sport*

Abstract

Athletes often struggle to accurately identify and manage sports injuries due to the ambiguous nature of symptoms, which can result in missed opportunities for early intervention. This study focused on the development of an AI-based online system for sports injury assessment and the validation of the system's performance in responding to injury-related inquiries.

Experiment 1: Development of an AI-based online sports injury assessment system

The system developed in this study enables athletes to conduct self-assessments targeting muscle tightness, tenderness, and special physical examinations across various body regions, including the head and neck, shoulders, elbows, wrists, hips, knees, and ankles. Upon completing the assessment, users were able to input their results into a self-assessment processing application (APP), which utilized a question-answering (Q&A) model trained via transfer learning on a corpus of sports injury management strategies. The AI assistant powered by Retrieval-Augmented Generation (RAG) retrieved relevant information from the knowledge base and generated real-time, evidence-based recommendations. To enhance accessibility, the system supports Application Programming Interface (API) calls to retrieve instructional images and videos stored in Azure Blob Storage, allowing athletes to intuitively understand the injury assessment procedures.

Experiment 2: Validation of the system response

Using the NotebookLM platform supported by Gemini 1.5 Pro, 20 sports injury-related test questions were randomly generated. From these, 10 key questions were selected by experts, covering issues such as temporomandibular joint dysfunction, cervical mobility, shoulder function, elbow tenderness, wrist movement, hip flexibility, and knee stability. The AI system underwent 5 rounds of testing, during which it demonstrated 100% consistency in its responses. These results provide strong evidence of the system reliability in the detection and management of sports injuries.

In conclusion, the AI-based online sports injury assessment system developed in this study offers an innovative approach to the prevention, evaluation, and management of athletic injuries, with the potential to enhance early detection and individualized care strategies in sports medicine.

KEYWORDS: SPORTS MEDICINE, ARTIFICIAL INTELLIGENCE, LARGE LANGUAGE MODELS, RETRIEVAL-AUGMENTED GENERATION, SELF MANAGEMENT

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Code 46

Comparison of different pose estimation models: A validation study

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[2] *University of Brasilia*

Abstract

As pose estimation has been gathering a lot of attention for kinematic analysis, many pose estimation models have been developed in recent times. A pose estimation model is a trained neural network or algorithm that takes input images or videos and predicts keypoints or body poses. Each model contains different strong and weak points, which make it difficult for users to decide which model to use for kinematic analysis. The accuracy of the model can be one big factor for the model selection, but there are not many studies investigating this critical issue. Therefore, this study aims to investigate the accuracy of different models by comparing the measurements from the models against reference measurements. Five male participants were invited to this study. Each participant was asked to perform five exercises: squat, squat jump, counter movement jump, walk, and jog while being recorded by normal RGB cameras (Contemplas) and marker-based tracking cameras (VICON). The video recordings from the normal RGB cameras were processed by six different pose estimation models: Mediapipe, MeTRAbs Small, MeTRAbs X Large, Yolo, MoveNet Lightning, and MoveNet Thunder to detect joint positions. From the detected joint positions, four joint angles, left hip, right hip, left knee, and right knee were calculated. Three-way repeated measures ANOVA and Tukey HSD post-hoc analysis were applied to the joint angle comparison between pose estimation models and marker-based motion capture system. The ANOVA result showed that factors exercise and model had a significant impact on the measurement errors although factor angle did not. In the post-hoc analysis, knee joint angles errors from Yolo, MoveNet Lightning, and MoveNet Thunder in jog and walk were significantly higher than those from Mediapipe, MeTRAbs Small, and MeTRAbs X Large. In conclusion, differentiated recommendations can be given for optimum model choice in different conditions in kinematic analyses. In addition, it must be considered that Yolo contains an option to actively improve its accuracy by fine-tuning.

KEYWORDS: POSE ESTIMATION, COMPUTER VISION, VALIDATION, ARTIFICIAL INTELLIGENCE, SPORTS INFORMATICS

Code 47

Improving the Estimation Accuracy of a Pose Estimation Model Using Time-Series Data Correction with the K-Nearest Neighbors Method

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[1] Tokyo University of Science

[2] Yamanashi Gakuin University

[3] Ventforet Kofu

Abstract

Pose estimation models such as BlazePose (Bazarevsky et al.) are widely used to identify human skeletal and joint coordinates from images or videos, enabling analyses in sports, medicine, and various industrial fields. However, these models often exhibit decreased accuracy when confronted with occlusions, background similarities, or fast movements, leading to occasional misestimations of body-part positions. The purpose of this study was to improve the estimation accuracy of such models by treating the predicted joint coordinates as time-series data and detecting anomalies via a k-nearest neighbors (KNN) algorithm.

Introduction: We focused on sprint videos in which subjects ran from left to right. Using annotated "correct" pose coordinates (ground truth) from adult sprint videos, we trained a KNN model to learn the normal spatiotemporal patterns for each body part of interest (e.g., shoulders, elbows, knees, ankles). Our approach did not require refining the pose estimation model itself; instead, it leveraged post-processing of its output.

Methods: First, we extracted time-series features by converting each body part's x- or y-coordinate into sliding-window vectors. These vectors, derived from correctly annotated data, served as the training set for our anomaly detection KNN model. When BlazePose was applied to new sprint videos, estimated coordinates were fed into the KNN model to detect outliers by measuring distances to the nearest training vectors. Frames flagged as anomalous were deleted, and missing coordinates were subsequently corrected via cubic spline interpolation of the third degree.

Results: Experiments on four sprint videos (two adults, two children) showed that the average error distances (in pixels) to the annotated ground truth decreased for most body parts. Notably, for certain leg coordinates, errors dropped by up to 15 pixels on average per frame. Even when applied to videos featuring children, which differed from the training set of adult videos, the proposed method demonstrated improvements in accuracy.

Discussion: While the KNN-based correction generally outperformed the raw BlazePose estimates, occasional overcorrection or missed anomalies were observed. These limitations suggest that further optimization of hyperparameters and expansion of the training dataset can increase robustness. Nevertheless, the

study confirms that focusing on the motion trends in time-series data effectively mitigates sporadic, severe misestimations.

Conclusion: The proposed post-processing approach substantially reduces pose estimation errors for sprint videos, demonstrating good potential for broader applications and for other pose estimation models. Future work includes refining the anomaly detection thresholds, extending the training data, and testing on more diverse movements to ensure generalizability.

KEYWORDS: POSE ESTIMATION, K-NEAREST NEIGHBORS, TIME SERIES, VIDEO ANALYSIS, ANOMALY DETECTION

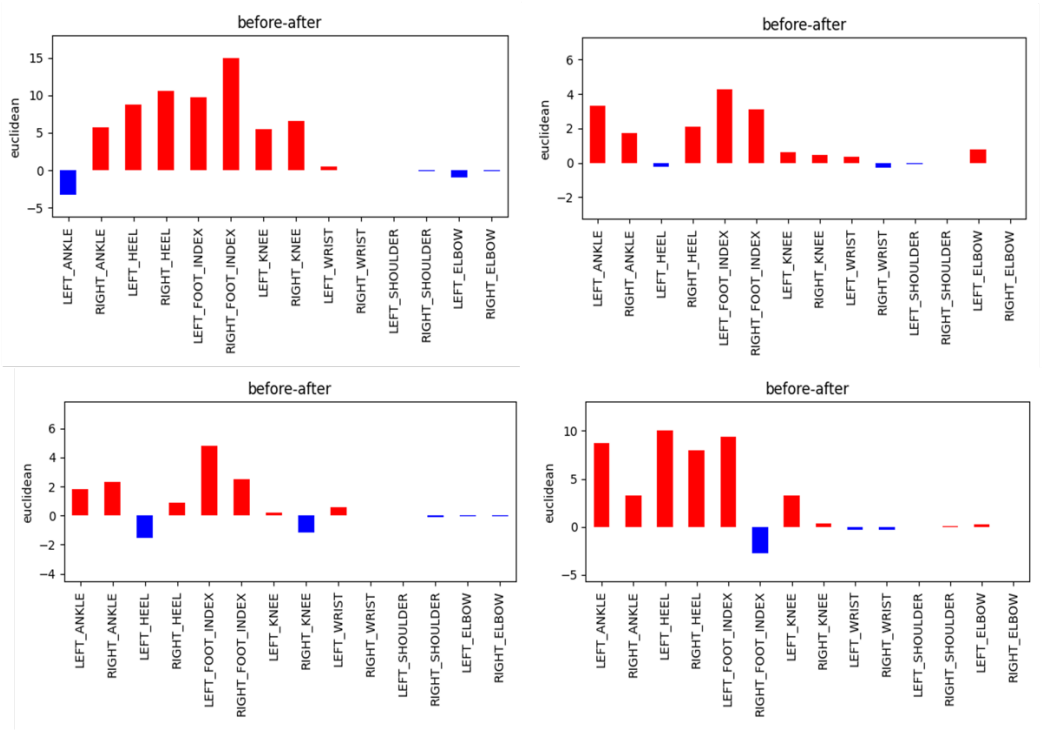

Figure 1 Average number of corrected pixels per frame after applying the proposed method. The top chart refers to adults (≥170 cm), and the bottom chart refers to children (<160 cm). Positive bars indicate improved estimation accuracy, while negative bars indicate slight decreases.References

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Code 49

Classification and Evaluation of Road Bike Riding Posture Using Pose Estimation

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Abstract

Road cycling has become increasingly popular in recent years. However, prolonged pedaling with improper posture can lead to chronic pain in the knees and lower back (Castronovo et al.). While there is growing demand for bike fitting to ensure appropriate posture, current practices rely heavily on subjective evaluation by coaches or athletes themselves. These methods are often inconsistent and difficult to apply across larger groups. To address this issue, we propose an objective and quantitative method to assess road cycling posture using pose estimation technology.

In this study, we employed RTMPose, a high-accuracy pose estimation model trained on the COCO dataset, to extract skeletal joint coordinates from side-view cycling videos (OpenMMLab, 2023). From the estimated joint positions, we calculated joint angles over time, focusing on key joints such as the right elbow, hip, knee, and ankle. Since cycling motion involves continuous pedaling with varying cadence and frame counts across individuals, we adopted Dynamic Time Warping (DTW) to align the time-series angle data. This method enables fair comparison between subjects by reducing the influence of temporal variations (Jang et al.). The aligned data was then subjected to k-means clustering to categorize posture patterns.

A preliminary study involving two participants was conducted to verify the reliability of the clustering method. The results showed that elbow and ankle data yielded high consistency across repeated trials, indicating these joints are suitable indicators for posture classification. On the other hand, hip and knee joints displayed lower consistency, suggesting further refinement of features or inclusion of additional parameters such as motion stability or torque may be beneficial.

In the main experiment, we collected and analyzed video data from 13 participants, including beginners to advanced-level cyclists. As a result, joint angle statistics for the right elbow, hip, knee, and ankle were calculated for each cluster, enabling a detailed comparison of posture characteristics. For instance, the right elbow in Cluster 0 showed the highest average angle (155.2°), representing an extended posture, while Cluster 1 showed the lowest average (124.9°), indicating a more flexed and potentially relaxed form. Cluster 2 exhibited the largest variability. Similar trends were observed in the ankle, where greater range of motion in Cluster 1 suggested improved lower-body fluidity.

This study demonstrates the potential of combining pose estimation and clustering to quantitatively evaluate cycling posture without requiring any physical markers on the subject. Our approach provides an efficient and scalable method for analyzing riding form, which can contribute to improved training guidance, personalized bike fitting, and injury prevention. Future work may include incorporating additional biomechanical parameters or using larger datasets to enhance classification performance.

This study demonstrates the potential of combining pose estimation and clustering to quantitatively evaluate cycling posture without requiring any physical markers on the subject. Focusing on joints such as the ankle and elbow provides practical insights for improving posture and enhancing bike fitting techniques.

KEYWORDS: POSE ESTIMATION, ROAD CYCLING, CLUSTERING, JOINT ANGLE ANALYSIS, BIKE FITTING

Table 1. Mean joint angle statistics for each cluster in male subjects, including range (min–max) values, based on pose estimation.

Cluster	Joint	Mean Angle (°)	Angle Range (Min–Max)
0	Elbow	155.	143.0-162.6
1	Elbow	2124.	111.2–134.6
2	Elbow	9145.	127.1–168.8
0	Hip	3	53.6–110.8
1	Hip	84.9	54.9–112.8
2	Hip	85.0	51.0–109.5
0	Knee	78.1	67.1–150.4
1	Knee	104.	71.1–158.9
2	Knee	7109.	64.5–155.5
0	Ankle	5107.	118.8–153.1
1	Ankle	6135.	126.5–158.0
2	Ankle	0140.	119.3–158.9
		0136.	
		0	

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Code 53

Data-driven Error Correction of MediaPipe Outputs for Football Kicking Pose Estimation

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Abstract

This study proposes an algorithm for detecting and correcting errors in time-series landmark data estimated from monocular video using MediaPipe, a markerless pose estimation framework. We focus on a single-camera setup for pose estimation during soccer kicking motion, where accurate tracking of the left and right heel landmarks is crucial for analyzing the kicking behavior. The single-camera setup offers high versatility and holds great potential for widespread applications in consumer-level scenarios. Although MediaPipe, developed by Google, is widely accessible and capable of estimating human pose landmarks from RGB video, its accuracy significantly degrades in monocular settings, often resulting in erroneous landmark estimations since monocular input may not have enough degree of freedom to estimate the depth of the movie. To address this limitation, we investigated the error trends in the estimated left and right heel landmarks. The analysis revealed that the predominant error was the flipping of heel positions between the left and right sides. Based on the classification of such characteristic error patterns, we developed a novel algorithm called EDaCC (Error Detection and Correction by Chaining), which performs data-driven error detection and correction grounded in statistical tendencies. For performance evaluation, we compared the proposed EDaCC algorithm with a conventional baseline method, the Speed Threshold Correction Method (1). Figure 1 illustrates the overall system model. The evaluation was conducted by comparing three types of heel coordinate data: p(x, y) (raw MediaPipe output), f(x, y) (corrected output by EDaCC), and c(x, y) (ground truth manually annotated by a human). Table 1 presents the error rates across multiple error categories for each method. Experimental results demonstrate that the EDaCC algorithm significantly reduces the most prevalent error type—left-right heel inversion—leading to a substantial improvement in pose estimation accuracy. These results validate the effectiveness of the proposed approach for enhancing pose estimation in monocular video settings.

KEYWORDS: MEDIAPIPE, 2D POSE ESTIMATION, MARKERLESS, SINGLE CAMERA

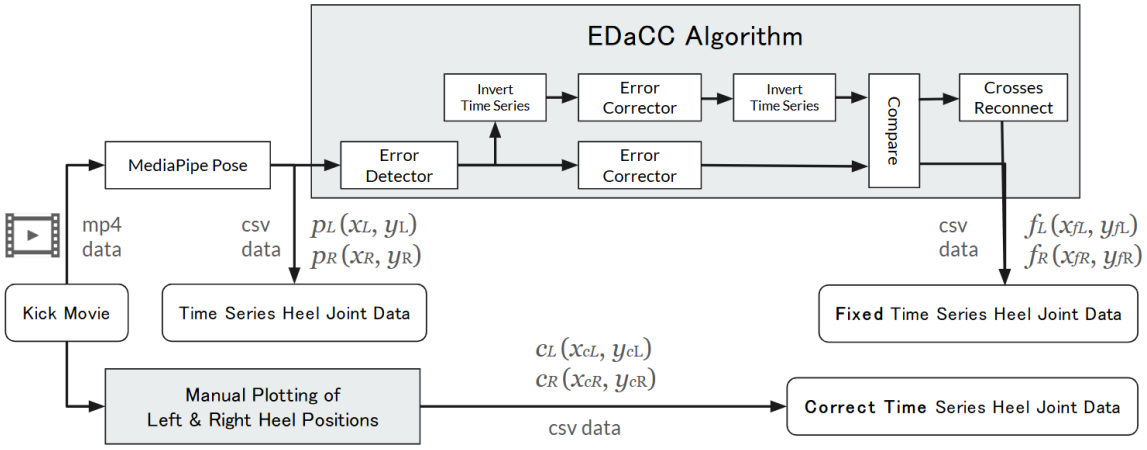

Figure 1. System Model

Table 1. Percentage of error classifications for MediaPipe heel coordinates, heel coordinates after the EDaCC algorithm, and heel coordinates after the velocity threshold correction method for 4 seconds x 10 kick videos.

		Right Heel		
		correct pos	frip to left heel pos	error pos
Left Heel	correct pos	MediaPipe: 91.85% EDaCC: 96.89% Velocity: 78.32%	MediaPipe: 0.00% EDaCC: 0.00% Velocity: 0.00%	MediaPipe: 0.17% EDaCC: 0.34% Velocity: 7.90%
	frip to right heel pos	MediaPipe: 0.50% EDaCC: 0.17% Velocity: 0.17%	MediaPipe: 5.46% EDaCC: 0.67% Velocity: 2.94%	MediaPipe: 0.67% EDaCC: 0.17% Velocity: 0.08%
	error pos	MediaPipe: 0.50% EDaCC: 1.60% Velocity: 4.79%	MediaPipe: 0.42% EDaCC: 0.00% Velocity: 0.25%	MediaPipe: 0.42% EDaCC: 0.17% Velocity: 5.55%

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Code 57

Exploring the perception of esports participation among Chinese young adults - A qualitative study informed by the theory of planned behavior

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Abstract

Esports has gained widespread popularity in China, captivating millions of young adults. This study aims to explore their perception on participation in esports and identify facilitators and barriers shaping their participation using a qualitative study through the lens ofthe theory of planned behavior. Eighteen esports players (male = 13, female = 5) aged between 18 to 36 years were recruited using purposive sampling. Thematic analysis was used to explore participants' perception and experience in relations to participation in esports. Our results indicated that Chinese young adults hold behavioral beliefs that esports participation has negative effects on physical health (i.e., eye fatigue, sleep deprivation, dizziness), dual effects on psychological health (i.e., psychological regulation or inducing mental fatigue and stress), and behavior addiction. These normative beliefs including peer effect, parent's stigmatizing attitudes, academic and occupational pressure, and social norm bias could influence their participation intention. Additionally, they recognized esports as ease of participation. These factors could facilitate their participation intention in esports, including social interaction need, interest, competition need, victory need, stress coping, information regarding esports events and gaming-skill teaching, audiovisual stimulation, and in-game reward mechanism. These factors could inhibit their participation intention in esports, including hardware constraints, learning or working intensity, gaming-skill bottleneck, physical and psychological conditions, and in-game matching mechanism. This study also revealed that the impact mechanism of esports participation behavior is constrained by the inherent attributes of esports, namely synergy, competition, social interaction, entertainment, and value, combined with participants' gaming skills, and physical and psychological conditions.

KEYWORDS: PERCEPTION, ESPORTS PARTICIPATION, CHINESE YOUNG ADULTS, THEORY OF PLANNED BEHAVIOR

Code 86

Modelling Defensive Behaviour and Predicting Corner Outcomes Using Hidden Markov Models and Graph Neural Networks

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[2] *Nottingham Forest Football Club*

Abstract

Introduction

Corner kicks are among the most structured and rehearsed phases in football, offering insight into team tactics and individual responsibilities. Prior studies have analysed set-piece strategies using supervised learning or clustering on tracking data, often requiring analysts to generated labels (Shaw, Gopaladesikan, 2020; Bauer, Anzer, Wyatt Smitt, 2022). While informative, these methods are limited by reliance on proprietary or labour-intensive datasets.

We propose an unsupervised Covariate Dependent Hidden Markov Model (CDHMM) framework to infer defenders' marking responsibilities—distinguishing between man-marking and zonal defending—through latent state estimation during corners. HMMs have previously been applied in basketball to infer man-marking (Franks, Miller, Bornn, Goldsberry, 2015; Keshri, Oh, Zhang, Iyengar, 2019). We extend this to football by incorporating zonal defending and using a covariate-dependent transition model, which reveals how contextual features shape team-specific behaviours. Beyond behaviour modelling, we integrate these inferred tactical descriptors into downstream predictive tasks. This allows us to examine not only *what* defenders are doing, but also *how* those behaviours influence corner outcomes. This dual approach enables both tactical interpretation and higher accuracy outcome prediction.

Methods

Our dataset includes four full seasons (2020/21–2023/24) of English Premier League spatiotemporal tracking and aligned event data, yielding 14,678 corner kick sequences. For each defender, we construct a CDHMM with eleven hidden states: ten corresponding to marking a specific attacker, and one for zonal defending. State transitions depend on contextual features such as defender–attacker distance and relative velocity.

To assess predictive utility, we derive features like expected state occupancy counts and integrate them into graph-based representations of each corner. These features are used as edge and aggregated node inputs for a set of GNN models, including the TacticAI architecture (Wang et al, 2024). We evaluate performance on the task of predicting the corner's receiver and are currently extending the framework to predict shot outcomes.

Results

Models enhanced with CDHMM-derived features achieved higher top-3 accuracy

on the reception prediction task compared to baselines using only positions, velocities, heights and weights, as shown in Table 1. This indicates that latent tactical structure—captured via defender state assignments—adds predictive value not previously evident.

Discussion

Beyond predictive accuracy, the CDHMM outputs provide a rich layer of tactical insight. Each defender's inferred hidden state—whether marking a specific attacker or occupying a zone—offers an interpretable, time-resolved characterization of the defensive strategy throughout a corner. Additionally as seen in figure 1, team's zonal structure can be visualised with the CDHMM. When combined with deep learning-based predictors, these features act as informative priors that improve model accuracy while retaining tactical interpretability—an important consideration for practical adoption by coaches and analysts.

Conclusion

We present a novel approach that bridges interpretable behavioural modelling and outcome prediction for set-piece analysis. By inferring marking responsibilities without manual labels and embedding them into GNN-based predictive pipelines, our method improves both tactical understanding and model performance. Future work will extend this framework to shot prediction tasks and explore its application in performance analysis and tactical feedback workflows.

KEYWORDS: SPORTS ANALYTICS, ASSOCIATION FOOTBALL, SET-PIECE ANALYSIS, TACTICAL BEHAVIOUR MODELLING, SPATIOTEMPORAL DATA ANALYSIS

Model	Average Top-3 Accuracy	Improvement vs Human Experts
Random	0.136	-42.57%
Human Experts	0.238 ± 0.045	-
Deep Sets	0.421 ± 0.017	+76.89%
GATV2	0.442 ± 0.005	+85.71%
GATV2 + D_2 group convolution	0.474 ± 0.004	+99.16%
GATV2 + Canonicalization	0.486 ± 0.012	+104.20%
GATV2 + Canonicalization + HMM features	0.493 ± 0.004	+107.14%

Table 1. Comparison of model performance on the corner recipient prediction task, reported as average top-3 accuracy across 5 random seeds. Human expert performance reflects predictions from 9 analysts at Nottingham Forest FC's first team and academy. Canonicalised models standardise corner

data by reflecting it such that all corners appear to be taken from the same corner of the pitch. In these modelsd, node features are first preprocessed using a two-layer MLP with a hidden layer of size 16 and input/output dimensions equal to the original node feature size. HMM features are node-level aggregations of expected state occupancies and man-marking assignments (Viterbi edges) across all incoming edges. The combination of canonicalisation and HMM features outperforms the D_2-equivariant GATv2 model (TacticAI) on our dataset.

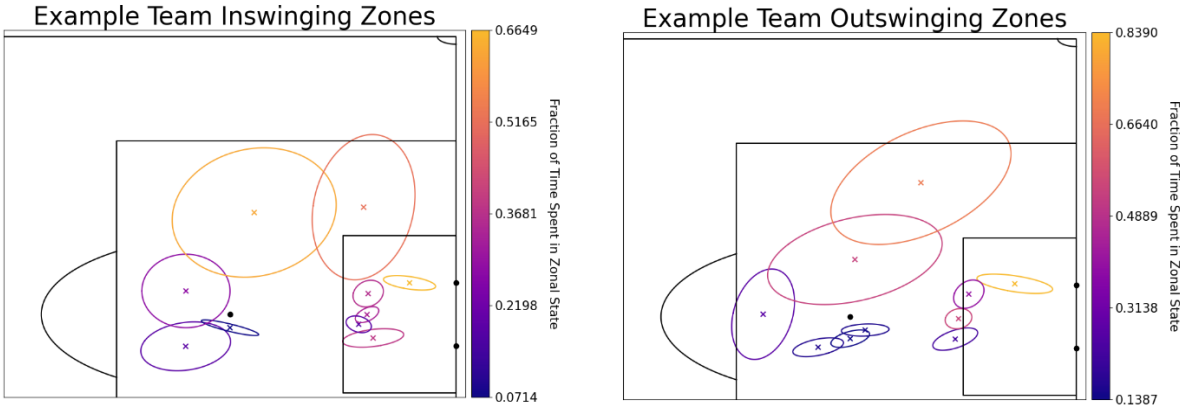

Figure 1. This figure illustrates the estimated zonal states for an example team when defending against inswinging and outswinging corner deliveries. Each sub-figure presents 10 zonal emission distributions, marked by a cross indicating the mean position and encircled by a 66% confidence interval. The colour of each zone denotes the average fraction of the corner sequence duration that a defender spends in that zonal state before transitioning to a man-marking state. Solid black lines and dots in the figure denote pitch markings.

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Code 100

Optimizing IT Strategies to Enhance Female User Engagement and Retention of Fitness Apps

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Abstract

Women engage in insufficient physical activity at higher rates than men and often encounter greater barriers to exercise. In 2016, 28% of adults worldwide were insufficiently active, with women more affected than men (WHO, 2020). This trend is especially evident in East Asia, where cultural caregiving roles often limit women's time for exercise (Mao et al., 2020). Similarly, in Western contexts, women report barriers such as childcare responsibilities and lack of time as major obstacles to physical activity (El Ansari & Lovell, 2009). Therefore, innovative strategies are needed to promote physical activity (Xu et al., 2022). Fitness apps serve as powerful tools for behavior change, fostering increased physical activity among female users. Notably, women comprise over 60% of fitness app users, yet research on the factors driving their sustained engagement remains limited. This study examines how different perceived values influence satisfaction and the continuance intention of female fitness app users. A total of 395 female fitness app users from Guangzhou, China, participated in this study. The influence satisfaction and the continuance intention constructs were evaluated using an adopted questionnaire by He (2021) and Zhang & Xu (2020) with 1– 7 scale. Findings reveal that hedonic value (β=0.190, P<0.001), utilitarian value (β=0.171, P=0.007), and health value (β=0.440, P<0.001) significantly and positively affect user satisfaction. However, only utilitarian value (β=0.135, P=0.018) and health value (β=0.436, P<0.001) have a significant positive impact on continuance intention, while hedonic value (β=0.028, P=0.547) does not. Satisfaction partially mediates the relationship between utilitarian and health values and continuance intention, while it fully mediates the relationship between hedonic value and continuance intention. These findings suggest that IT strategies for fitness apps should prioritize delivering utilitarian and health-related benefits to maximize female user engagement and retention, rather than overemphasizing entertainment-driven features.

KEYWORDS: ENGAGEMENT, SATISFACTION, CONTINUENCE INTENTION

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15th International Symposium on Computer Science in Sport

IACSS 2025

September 12 - 15, 2025

Tokyo Gakugei University
Tokyo, Japan

Theme:
Pedagogical & Environmental Study

Code 44

Research Hotspots and Trends in Physical Education Empowered by Artificial Intelligence

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Abstract

Purpose:This study aimed to clarify current research hotspots and emerging trends in the application of artificial intelligence (AI) technologies in physical education within the international academic community, providing theoretical references and methodological insights for future research in this field.

Methods: A bibliometric and visual analysis was conducted using data from the Web of Science Core Collection database. The search strategy employed the following keywords:("physical education") AND ("artificial intelligence" OR "machine learning "OR "deep learning" OR "computer vision" OR "reinforcement learning"), coveringpublications from 2000 to 2024.
A total of 279 articles were initially retrieved,with
226 meeting the inclusion criteria after screening. CiteSpace 6.4.R1 software was utilized to perform visual analyses of annual publication trends, geographical distributions, institutional collaborations,author networks, journal contributions, and keyword co-occurrence patterns.

Results: The earliest relevant publication emerged in 2003. Between 2000 and 2014, research progressed slowly, followed by accelerated growth after 2015, peaking at 69 publications in 2021. China dominated research output, with Xidian University and Shanghai University of Sport being the most productive institutions. Cao Feng was identified as the most prolific author. The journals Journal of Intelligent Fuzzy Systems and Mobile Information Systems published the highest number of articles in this domain. The most cited reference was "An artificial intelligence and machine vision based evaluation of physical education teaching" (2021).The keyword “physical education” has the highest frequency and centrality, and eight keyword clusters are generated, namely “#0 physical education”, “#1 machine learning”, “#2 motivation”, “#3 artificial intelligence”, “#4 deep learning”, “#5 built environment”, “#6 big data”, and “#7 support vector machine”.

Conclusion: Bibliometric evidence indicates China's leadership in publication volume, yet international collaboration remains limited. Research networks exhibit moderate concentration at the institutional and author levels, with insufficient interdisciplinary interaction. Emerging frontiers include "college students", "Internet applications in physical education pedagogy and assessment.

KEYWORD: ARTIFICIA INTELLIGENCE, PHYSICAL EDUCATION, CITESPACE, VISUAL ANALYSIS

Code 56

Apps for Movement Analysis in Physical Education - Investigating the Applicability and Usefulness through Selected Examples

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Abstract

Introduction

Digitalization is becoming more significant in contemporary education. In Physical Education, emerging technologies offer opportunities to enhance movement learning and improve athletic performance (Baca et al., 2024; Baca and Gröber, 2019). While digital media are theoretically important in this field, their practical application often falls short due to several challenges.

We evaluated the effectiveness of selected movement analysis apps in Physical Education, specifically regarding their influence on students' athletic performance development. The study focused on three apps– *BaM Video Delay* (BaM Video Delay, 2025), *CoachView* (CoachView, 2025), and *JumpPower* (JumpPower, 2025) – which were applied across three areas of activity (fundamentals – jumping, ball sports – throwing technique, and gymnastics – floor exercises) throughout half a term.

Methods

The interventiongroup (28 schoolgirls, 1stclass, secondary school) worked with the mentioned movement analysis apps, whereas the comparison group (23 schoolgirls, same school level) was presented with the same lesson content without digital support. The athletic performance of the school students was measured through testing at the beginning and the end of each respective teaching period and statistically evaluated.

Results

Jumping width increased by 6.1 (±13.7) cm in the intervention group using *JumpPower* and 5.8 (± 10.2) cm in the control group, jumping height by 0.99 (±4.3) cm vs 2.46 (± 3.9) cm. *BaM Video Delay*, which was used for throwing technique training and floor exercise training, proved its worth both in terms of subjective observation and assessment as well as statistical analysis of the performance results (significantly higher – $p<0.05$ – increase in the number of positively judged quality criteria in the throw as well as of number of elements accomplished in gymnastics). Due to the poor experience with *JumpPower, CoachView* was used onlyoccasionally as support for *BaM Video Delay.* Accordingly, no significant increase in performan ce was to be expected from the use of this app and could be shown.

Discussion

JumpPower was initially accepted with enthusiasm by the children. The opportunity to receive immediate feedback on the own jumping performance motivated the intervention group and the comparison group enormously. However, the weekly use of the app as part of the jumping power circle ultimately had a noticeably demotivating and counterproductive effect and hence was not suitable for improving the didactic environment. The app proved to be a mere “add-on”.

Once the challenges of fastening and positioning in the gym had been mastered, the girls accepted *BaM Video Delay* very positively throughout the entire period of use, ran to the iPad again and again in order to see their own movements in real time and, with increasing familiarity and experience, to analyze them exceptionally well, even for their age. It is therefore not surprising that a significantly greater increase in performance was demonstrated in the test group than in the comparison group during both throwing training and floor exercises.

Conclusion

The findings offer insights into how movement analysis apps impact the development of athletic performance within educational settings, and they provide recommendations for their continued use in Physical Education, along with suggestions for future research directions.

KEYWORDS: MOVEMENT ANALYSIS, PHYSICAL EDUCATION, APPS, EFFECTIVENESS

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Code 61

The Effect Of Pedagogical Model Training On The Game And Physical Performance Of Aboriginal Youth Football Student-Players (U18) In Pahang

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Abstract

Aboriginal students were found to have difficulty adapting and assimilating to training sessions that used a game-based approach. Aboriginal students are also unable to compete in football matches in terms of fitness. Therefore, this study examined the effectiveness of intervention methods using the Style-E Tactical (SET) and Skill-Based (SB) pedagogical models on decision-making (choosing the right skill and open and closed space), skill execution (passing, receiving, dribbling, scoring), and physical performance (10-m, 20-m, 30-m sprint and Yo-Yo Intermittent Recovery Test LVL 1) of youth football players among the Aboriginal people. This study made anecdotal observations of the implementation of the SET and SB models by coaches during training with Aboriginal youth football student-players. This study employs a mixed-methods approach to compare the effects of the SET and SB models on Aboriginal youth football student-players in a 5-on-5 mini-game. This study uses a quasi-experimental non-equivalent group design for pre-and post-tests with two intervention groups in football training. A total of 34 respondents from the selected school were evenly divided into the SET and SB groups. The research proxies are two coaches from the selected school. Data were analysed using one-way MANOVA with SPSS statistical software version 27.0. Meanwhile, the anecdotal report was analysed using thematic analysis with NVIVO version 14 software. The quantitative findings indicate that there is no significant difference through the multivariate test (Wilks' Lambda), $F (12, 21) = 1.55$, $p > .05$; Wilk's $\Lambda = 0.530$, partial $\eta^2 = .47$ after the intervention. The findings also indicate that the SET group is more dominant in terms of decision-making (choosing the right skill and open and closed space), skill execution (passing, receiving, dribbling, scoring), and physical endurance (Yo-Yo Intermittent Recovery Test LVL 1) at the post-test level. Qualitative findings list the following themes in the implementation of the SET model; Coach Personality (Extraversion and Humour), Fostering Cognitive (Topic explanations, Indirect task, Tactical questioning and Reflection session), Psychomotor (Adaptation, Direct instructions, Perceived exertion and Rest interval), Affective (Teamwork and enjoyment as well as Exaggeration game) Processes and SB model; Coach Personality (Extraversion and Neuroticism), Fostering Psychomotor (Direct instructions, Endurance, Perceived exertion, Rest interval and Small-sided game and drills) Cognitive (Topic explanations and Direct instructions), and Affective (Teamwork) Processes. In conclusion, the SET model is more effective in this study, and future research should continue to emphasize the aspects of norms and the culture of their society as well as the use of technology.

KEYWORD: ABORIGINAL STUDENT-PLAYERS, GAME PERFORMANCE, PHYSICAL PERFORMANCE, NURTURING PROCESSES

Code 64

Analysis on the Influencing Factors of the Number of Olympic Medals won by American Universities

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Abstract

In this paper, publicly available data is used to analyze the influencing factors of the number of Olympic medals won by American universities. The results show that: (1) The number of medals has moderate correlation (0.4-0.6) with R&D expenditures, sports science publications, student size, number of disciplines, and sports science discipline. (2) The number of medals has a low correlation (0.2-0.4) with university rankings, and number of sports teams. (3) The results of multiple linear regression analysis showed that R&D expenditures and sports science publications are powerful predictors of Olympic medals won by universities.

Introduction

Although Olympics are primarily a national endeavor, universities play a crucial role in athlete development, particularly in country with strong collegiate sports system such as the United States. NCAA shows the budget is a main factor, as Division I schools often have substantial athletic funding, producing the majority of Olympic athletes (NCAA, 2020). Also, high-quality researching and coaching are necessary, sport psychology quickly became integrated into the training and competition plans of the vast majority of Australian Olympic sports (Bond & Morris, 2018). However, few existing studies directly link the number of Olympic medals with universities, and the exploration of their influencing factors is scattered, and the evidence has not been convincing. This paper attempts to analyze the influencing factors of the number of Olympic medals won by universities.

Methods

This paper collects the number of Paris Olympic medals won by American universities and 7 independent variables data, including R&D expenditures, sports science publications, university rankings, student size, number of disciplines, number of sports teams and whether there is a sports science discipline. Then constructing the hypothesis of the influence of independent variables on the dependent variables, based on data and assumptions, perform correlation analysis and multiple linear regression analysis to discover the connections between variables and whether they had an impact on the number of Olympic medals.

Results

Correlation analysis indicates the number of medals related to all the 7 independent variables, and R&D expenditures has the strongest correlation, while number of sports teams has lowest correlation. Furthermore, multiple linear

regression analysis shows that R&D expenditures and sports science publications are powerful predictors of Olympic medals.

Discussion

The highest correlation detected by R&D expenditures may be due to the fact that well-funded universities are better able to attract top athletes, while the relationship between sports and Olympic performance still need further research to clarify. Also, R&D expenditures and publications collectively explained the percentage of variance of the 20.9% dependent variant, indicating that there were still other influential factors that had not been clarified.

Conclusion

The number of Olympic medals won by university was strongly affected by research investment and paper publication was the strongest, which shows the attractiveness of research universities to top athlete, and on the other hand, the achievement of sports performance is increasingly dependent on the progress of scientific research.

KEYWORDS: OLYMPIC MEDALS, UNIVERSITIES, INFLUENCING FACTORS

Table 1. Variables correlation analysis results

	Medal	R&D Exp.	Sports Science Publication	University Ranking	Student Size	Dicipline Number	Sports Dicipline	Sports Team
MDL	--							
RDE	0.594***	--						
SSP	0.544***	0.853***	--					
URK	0.363**	0.887***	0.652***	--				
SDS	0.526***	0.667***	0.529***	0.335**	--			
DCN	0.465***	0.928***	0.719***	0.888***	0.544***	--		
SDC	0.440***	0.375***	0.445***	0.046	0.628***	0.237	--	
STM	0.278*	0.324**	0.332**	0.503***	0.021	0.485***	0.051	--

Table 2. Linear regression analysis results

	B	SD	Beta	t	95% CI		F	Sig	R^2
C	16.691	14.299		1.167	-11.729	45.111			
RDE	4.651	2.314	0.251	2.010	0.052	9.249	11.523	<0.001	0.209
SSP	0.349	0.172	0.254	2.032	0.008	0.691			

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Code 72

Multimedia Technology to Enhance Primary School Physical Education Teacher Instructional Practices in Fundamental Movement Skills

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Abstract

The Singapore primary schools' curriculum consists primarily of different fundamental movement skills (FMS) covering a wide range of physical activities in the games and sports content area (MOE, 2024). Physical education (PE) teachers need to be proficient in teaching these movements to children. Therefore, it is imperative that pre-service PE teachers receive adequate training leveraging on multimedia tools to enhance their FMS instruction during the physical education teacher education (PETE). In this regard, digital recordings of children performing the correct form, specific to the local school context, for FMS is invaluable. These digital examples effectively break down complex movements into more manageable steps, helping teachers with their own comprehension and learning. They also help to highlight ideal movements and provide critical visual reference points to aid teachers in their own learning and performances. Furthermore, teachers can use these recordings to help them learn to observe and analyze movement skills, which is a crucial aspect of effective PE instruction. This teacher development allows them to understand how their children learn movement skills and provide the essential feedback for improvement.

Therefore, in collaboration with schools and with financial support from the Ministry of Education, a set of fundamental movement skills digital recordings were developed. These recordings reflected grade-appropriate children performing the skills specific to the different grade level syllabus. Teaching notes were also embedded into the digital recording to highlight the critical reference points, adapted from a scholarly text (Colvin, Markos, & Walker, 2023). The purpose of this presentation is to share insights into the following issues, challenges, and solutions: (a) development of the multimedia tools for use in PETE and schools, (b) implementation of the multimedia tools during PETE training, and (c) future directions to further leverage on the multimedia tools. The experiences gained from this collaborative project, coupled with feedback by preservice teachers, suggest that digital recordings, when done well, offer a popular, easy-to- use instructional resource that can assist teachers to reach higher standards in their teacher performance and are more persuasive. Therefore, multimedia technology can help make learning more meaningful and motivate teachers to participate actively in their own learning process.

KEYWORDS: MULTIMEDIA TECHNOLOGY, PHYSICAL EDUCATION TEACHER EDUCATION, BEGINNING TEACHERS, FUNDAMENTAL MOVEMENT SKILLS

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Code 75

Exploring Diversity in Global Sports Ecosystems through Squad-League Networks

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Abstract

Introduction: Social Network Analysis is a well-established method for investigating social dynamics, leadership, and interaction structures across diverse areas, including sociology, biology, computer science and sports (Lames, 2023). This study introduces the Squad-League Networks (SLN) approach as a tool to explore how national squads are embedded within international league structures. Rather than focusing solely on network properties, our aim is to highlight how differences in player mobility, domestic league attractiveness, and gender representation shape diverse organizational models in top-level team sports. By quantifying and visualizing these differences, SLN reveals how distinct sports ecosystems reflect broader socio-cultural and institutional patterns globally. **Methods:** SLN is modeled as a bipartite network connecting two distinct node sets: national squads and domestic leagues (Borgatti et al., 2024). Directed and weighted edges represent the number of players from a given squad playing in a given league. The network structure is formalized as an affiliation matrix, allowing quantitative analysis with metrics such as %Home (share of players active in their home league), density (proportion of actual to possible squad-league connections), and transitivity (tendency of squads to share league affiliations). These metrics extend the SNA toolkit to inter-organizational patterns. Micro-level metrics such as self-loops and degree centralities characterize national squads' reliance on domestic leagues and leagues' international attractiveness to top-level players. **Results:** We demonstrate SLN's analytical potential through three case studies (Fig. 1). First, we examine the historical development of women's football from 1991 to 2023 using FIFA Women's World Cup data, revealing trends in player internationalization and the diversification of domestic league engagement. Second, we compare SLN metrics across men's and women's basketball world championships (2010–2023), identifying gender-specific patterns in international player mobility and league centrality. Nations are classified into categories such as Talent Attractors, Export Specialists, Global Powerhouses, and Developing Markets, based on their SLN profiles. Third, we analyze SLNs from handball, volleyball, and water polo competitions at the 2016 Olympic Games to assess globalization levels across different sports. SLN metrics quantify differences in international talent flow, league attractiveness, and structural clustering among sports. **Conclusions:** SLN provides a comparative framework for identifying and analyzing diversity in the organization of elite team sports. By capturing how national squads interact with global league systems, SLN uncovers underlying patterns of player mobility, gender asymmetries, and league influence that define distinct sports ecosystems.

This approach facilitates cross-sport and cross-country comparisons, offering insights into how institutional and cultural contexts shape the development of elite sport. As a reproducible and flexible method, SLN supports data-driven analyses relevant for sport governance, gender equity initiatives, and strategic policy design.

KEYWORDS: SOCIAL NETWORK ANALYSIS, TEAM SPORTS, SPORTS PROFESSIONALISATION, SPORTS GENDER EQUITY, SPORTS GLOBALISATION

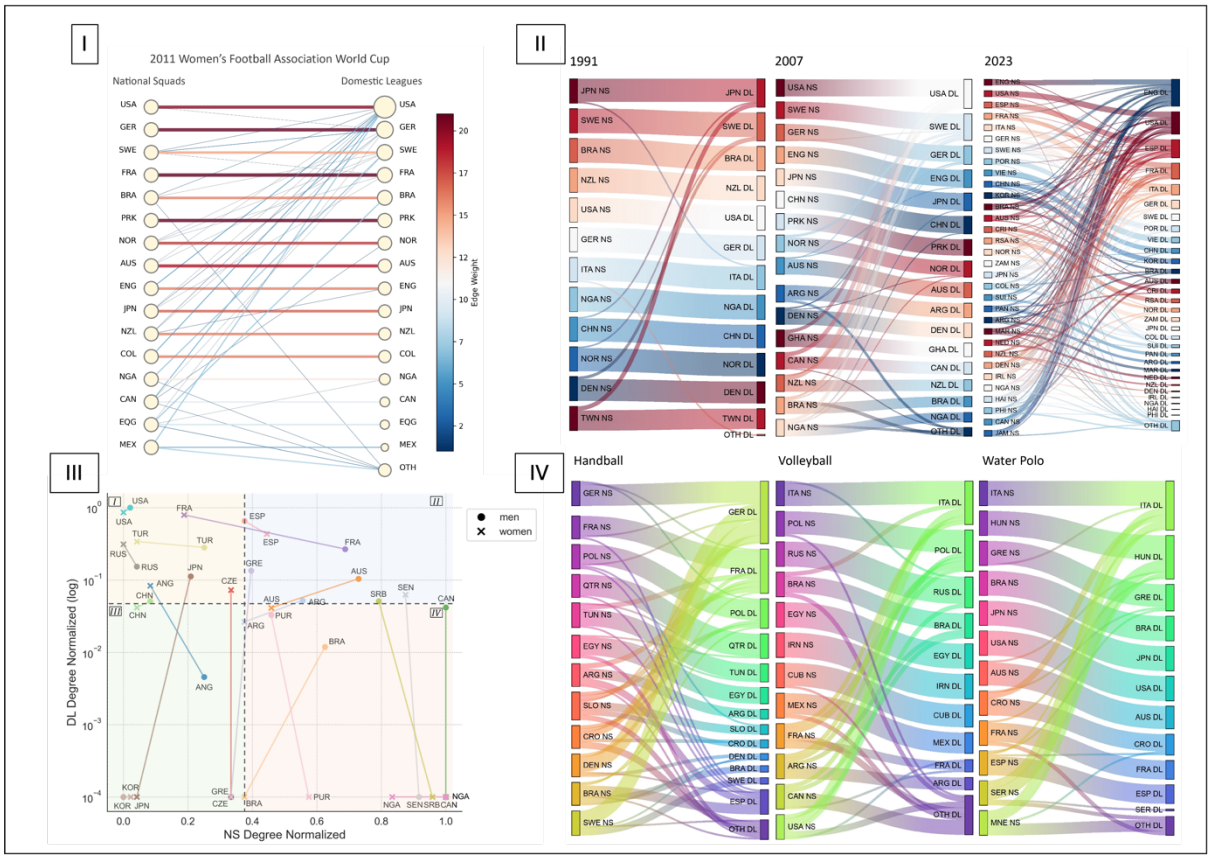

Figure 1. (I) Illustration of a bipartite network of the 2011 FIFA Women's World Cup. National squads (NS, left) are linked to domestic leagues (DL, right) based on where players are professionally active. Edge weights indicate the number of players per connection, and node sizes reflect squad size. (II) Sankey plots of SLN from 3 editions of FIFA Women's World Cups. NS are shown on the left and DL on the right. The height of the boxes on the right indicates the number of players in each country's DL. The thickness of the connecting lines are the number of players from each NS playing in a given country's DL. (III) DL and NS degrees for women's and men's basketball from 2010 to 2023 World Championships. Men's and women's squad of the same country are connected with a line. The median of the two axes leads to four quadrants: [I] Talent Attractors, [II] Global Powerhouses, [III] Developing Markets and [IV] Export Specialists. (IV) Sankey plots of SLN from 3 different men's team sports retrieved from the 2016 Summer Olympic Games.

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Code 76

Development of an Kamakura Exercise Application "KaMap" for Individualized Wellness : Expanding into "KaMap Junior" as an application for elementary school students combining school meals with exercise courses

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Kasumi Iwata[1],Rin Kawasaki[1],Rena Kuwashiro[1],Shiho Sakano[1],

Sakura Yamamoto[1], Noa Ouchi[2], Erina Shigematsu[1],Kimie Kawachi[1],

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Abstract

The Japan Sports Agency advocates a variety of physical and mental changes to improve life performance. In order to prevent the onset and severity of lifestyle diseases such as diabetes and high-LDL-cholesterolemia, it is necessary to improve lifestyle habits, especially diet and exercise habits. In the post-COVID-19 society, individual health, which encompasses nutrition and exercise, is expected to become increasingly important, and especially in school age, for prevention of lifestyle diseases in the future.

In this study, an exercise application “KaMap” was developed along with a prototype nutrition lunch for individual health in Kamakura City, which has a rugged terrain. Based on the AppSheet platform, which enables development of no-code applications, "KaMap" offers exercise courses that take advantage of the diverse landscape and nature of Kamakura, from Kita-Kamakura to Shichirigahama. In addition, the Karvonen formula(1) can be used to calculate exercise intensity from resting and exercising heart rates. Currently, a system has been started to develop that works with wearable devices to calculate exercise intensity in real time. By popularizing the application, and collecting large-scale data on users' nutritional intake and exercise status, the project aims to contribute to the design and development of a sports and health community in Kamakura City.

Moreover, regular exercise for school-aged students improves basic physical strength and leads to healthy lifestyle habits. A current initiative that is being developed for elementary school students in Kamakura City is the development of the “KaMap Junior” app. It encourages students to enjoy physical activity both during school on weekdays and on holidays -without consciously realizing they are exercising- and is also integrated with the school meal program. The app is being developed for use on tablets provided to every student in the elementary school system. On weekdays, QR codes will be placed throughout the school, allowing students to engage in a stamp rally format activity using their tablets to move around the school independently, promoting physical activity in a fun and engaging way. Furthermore, by incorporating school meal data, it is possible to calculate the amount of daily nutrition intake, and by combining it with the amount of physical activity, it can lead to the development of a system that proposes an appropriate exercise method by AI. In the future, the utilization of the “KaMap Junior” app may increase collaboration between Kamakura City and potential gaming companies that may ultimately enhance the continuity of children leading to the promotion of tourism in Kamakura City and the development of the local industry.

KEYWORDS: PREVENT OF LIFESTYLE DISEASES, AN EXERCISE APPLICATION "KAMAP", "KAMAP JUNIOR", APPSHEET PLATFORM, NO-CODE APPLICATIONS

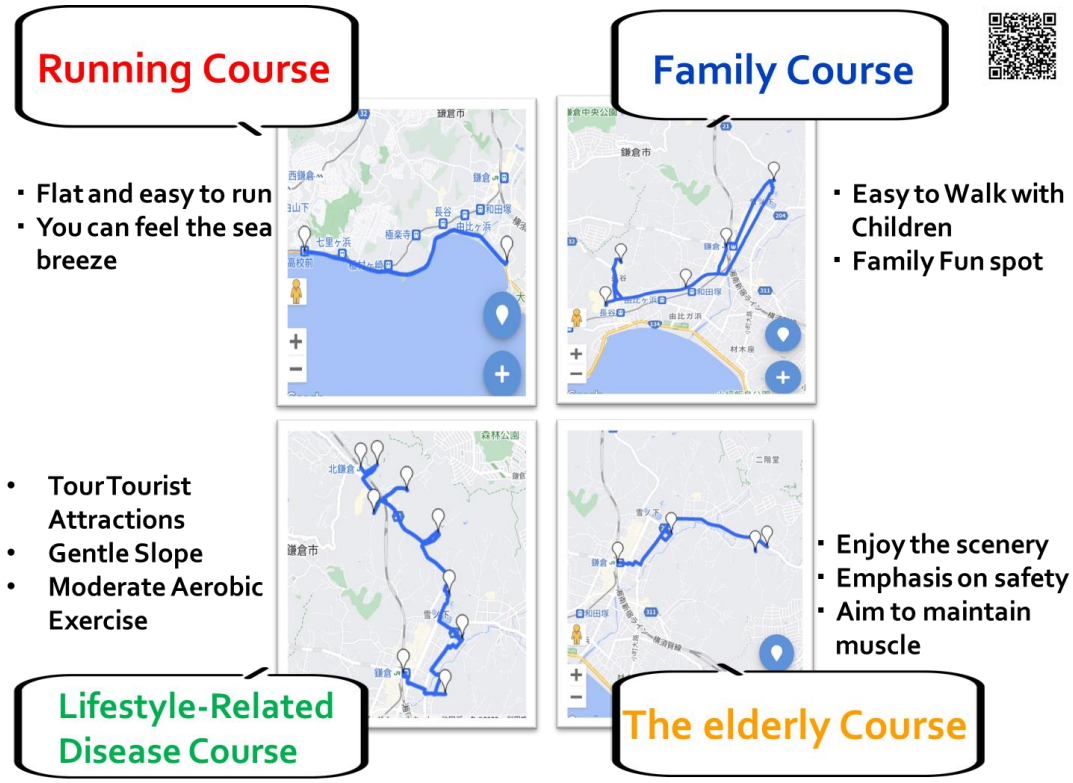

Figure 1. Four exercise courses in Kamakura City proposed in "KaMap" according to the physical fitness and needs of the subjects.

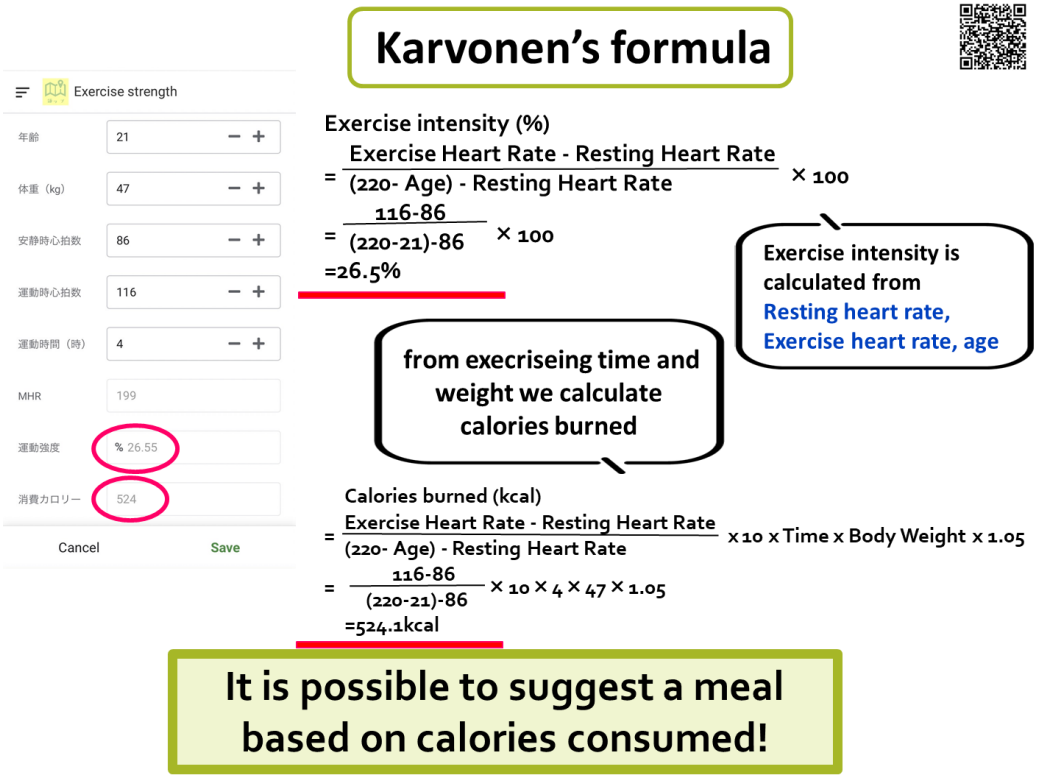

Figure 2. Exercise intensity estimation screen based on Karvonen formula used in the exercise application "KaMap".

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Code 95

Clustering Analysis of Environmental Factors in KBO, NPB, and MLB

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Abstract

Performance is influenced not only by internal factors, such as an athlete's physical abilities, but also by external factors, including climate and environmental conditions (Daniel, 2021). In fact, various environmental factors, such as temperature, humidity, wind speed, air pollution, and altitude, can significantly affect athletes' performance, with outdoor sports being particularly susceptible to performance deterioration (Segreti et al., 2024). The KBO, NPB, and MLB leagues each have distinct environmental characteristics, including differences in climate, altitude, and stadium size, and these factors can have a complex impact on both players' performance and team strategies, ultimately influencing game outcomes. Previous research has explored environmental factor differences within a single league(Huang, Chiu & Chang, 2021), but studies comparing these differences across leagues have been scarce. Therefore, this study aimed to quantitatively compare and analyze key environmental factors that may affect performance across the KBO, NPB, and MLB leagues. The research focused on teams participating in the 2024 season of the KBO, NPB, and MLB regular seasons, and data was collected on various environmental factors, including stadium locations, travel distances, altitude, stadium size, fence height, and temperature, humidity, wind speed, and precipitation over the first three hours of gameplay. All data were crawled, processed, and visualized using Python 3.13.0, utilizing official league databases, Google Maps API, national meteorological agencies' open APIs, and Open-Meteo API. Pearson correlation analysis was applied to eliminate variables with a correlation higher than 0.7, and PCA analysis was used to identify key influencing factors. Cluster analysis was then performed to group teams with similar environmental characteristics. As a result, three major clusters were identified, reflecting distinct environmental characteristics for each league. Cluster 0 predominantly consisted of MLB teams, characterized by long travel distances, high altitudes, fast wind speeds, and warm climates. Cluster 1 included all NPB teams and several MLB teams, which were located in areas with relatively low altitudes, high humidity, and significant precipitation. Finally, Cluster 2 was composed solely of KBO teams, characterized by short travel distances, low altitudes, low wind speeds, and minimal precipitation.

KEYWORDS: ENVIRONMENTAL FACTORS, BASEBALL ANALYSIS, CLUSTER ANALYSIS, PCA (PRINCIPAL COMPONENT ANALYSIS)

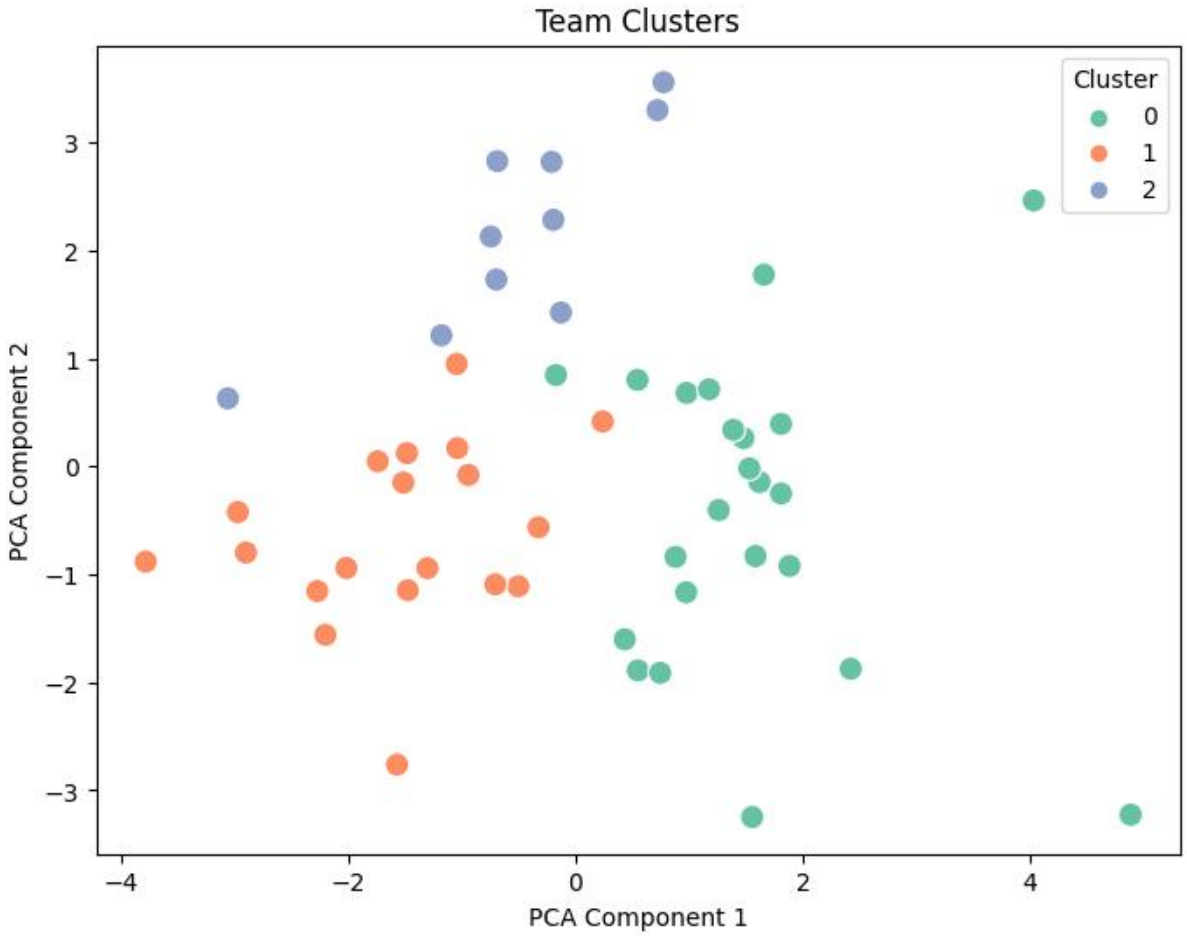

Figure 1. Cluster Analysis of Environmental Factors in KBO, NPB, and MLB Teams

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