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Biomechanical Analysis of Performance in Rugby: A Systematic Review

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ABSTRACT

Background and Study Aim. Rugby demands high-intensity physical outputs, where biomechanical factors influence performance in skills like sprinting, tackling, scrummaging, and kicking, while also informing injury prevention. This systematic review synthesizes evidence on kinetic, kinematic, and neuromuscular determinants of rugby performance. **Material and Methods.** PubMed, Scopus, and ScienceDirect were searched using terms combining "biomechanical analysis," "performance," and "rugby" up to November 28, 2025. Inclusion criteria focused on English-language empirical studies on rugby biomechanics. After screening 105 studies (PRISMA flowchart), 4 met criteria for qualitative synthesis. **Results.** Included studies (n=4) examined place-kicking kinematics, markerless 3D pose estimation in tackles, sprint acceleration strategies, and step-up kinetics for speed development. Key findings highlight technique degeneracy (multiple strategies yielding similar outcomes), technology limitations during contact/occlusion, and training specificity (e.g., jump variations for maximal speed transfer). **Conclusion:** Rugby performance optimizes through individualized kinematic strategies, force-velocity profiling, and technologies like AI/video analysis. Recommendations include personalized training, standardized post-tackle frameworks, and integrated lab/field monitoring to enhance efficacy and reduce injury risk.
Keywords: Rugby Biomechanics; Kinematic Analysis; Performance Determinants; Injury Prevention; Tackling Mechanics

Authors' Contribution: a – Study Design; b – Data Collection; c – Statistical Analysis; d – Manuscript Preparation; e – Funds Collection

INTRODUCTION

Biomechanical Analysis of Performance in Rugby aims to summarize scientific evidence related to how kinetic, kinematic, and neuromuscular factors affect rugby-specific performance such as sprints, change of direction, scrums, tackles, and lineouts (Green et al., 2019). In the past decade, rugby has evolved into a game with a very high intensity of impact and physical demands, so understanding biomechanics is crucial to integrate aspects of performance enhancement and injury prevention simultaneously (Ball et al., 2019). Biomechanical analysis allows coaches and sport scientists to link variable forces, moments, joint angles, and muscle activation patterns with match-play performance indicators, while reducing the risk of injury in repetitive contact situations typical of rugby union and rugby sevens (Lutz et al., 2020).

Technological developments such as 3D motion capture, force plates, GPS, accelerometers, and instrumented mouthguards open up opportunities for more accurate measurement of mechanical loads in the context of rugby matches and training (Dunsky et al., 2017; Mattioli & Ballerini Puviani, 2020). A study of 3D-based tackle biomechanics shows that modifications of tackle height, entry speed, and leg drive patterns can alter the style profile and potential risk of injury, while also affecting the effectiveness of tackles as a key action in the game (Edwards et al., 2021). On the other hand, head impact monitoring through sensors and mouthguards showed large variations in linear and rotational acceleration of the head, which relates to the risk of concussion and forms the basis for the development of safer safety protocols and tackling techniques without compromising the effectiveness of the game (Clark et al., 2021; Cross et al., 2019).

From a performance perspective, recent studies on rugby union and rugby sevens players have shown that strength–power quality (e.g. peak force, rate of force development, and power output) is closely related to sprint, jump, and contact ability, all of which are key determinants of match performance (Espasa et al., 2025; Gannon et al., 2016). A study of strength-power and reliability metrics measured in rugby sevens players confirms that increasing maximum strength has the potential to increase explosive ability, which is relevant for acceleration, tackle, and ruck/maul contests. At the same time, longitudinal neuromuscular analysis shows that although the team average may appear stable throughout the season, individual variation in strength–power quality is considerable and needs to be considered in load planning and performance data interpretation (Washif et al., 2024).

Biomechanics also plays an important role in analyzing rugby-specific skills such as scrum and lineout (Kneblewski et al., 2020). Studies of scrum biomechanics indicate that the success of scrummaging is greatly influenced by the optimization of joint angles, the production of horizontal forces, and the coordination of forces between players in a single scrum unit (Lallemand et al., 2020; Martin & Beckham, 2020). Research on lineout throwing shows that changes in throwing distance alter biomechanical parameters such as ground reaction force and postural control, which impact throwing accuracy and form the basis for the development of performance models and individual training programs for hookers (Lallemand et al., 2020). The integration of these findings is important for designing technical interventions and conditioning that are specific to the position and phase of the game (Vecchione et al., 2025).

Although the number of rugby biomechanics studies is increasing, the literature is still fragmented based on the phase of the game, the type of variable, and the measurement technology used (Lam et al., 2020; Vendrame et al., 2024). Some reviews highlight that many studies assess performance or load indicators in isolation, without the context of specific tactics, positions, and demands of the competition, thus limiting generalizations to elite coaching practices (Gamonales et al., 2024; López-Sierra et al., 2025; Olaizola et al., 2022). Therefore, a systematic review with a focus on "Biomechanical Analysis of Performance in Rugby" is important to synthesize the latest evidence over the past five years, identify key biomechanical determinants of performance at different phases of the game, map research gaps (e.g. integration of in-game and lab data), and provide evidence-based recommendations for coaches, strength & conditioning coaches, and researchers in designing training programs. techniques, and monitoring protocols that are more effective and safe.

METHODS

Searching Strategy

Electronic databases such as PubMed, Science Direct, and Scopus are searched extensively. The search term is created using a combination of the terms Medical Subject Title and free text, combining the following concepts: (TITLE-ABS-KEY (biomechanical analysis) AND TITLE-ABS-KEY (performance) AND TITLE-ABS-KEY (rugby)). The search includes studies published from the beginning of each database through November 28, 2025. Table 1 provides a detailed overview of the complete search strategy used.

Table 1. The detailed overview of the complete search strategy

Database	Search term
Pubmed	("biomechanical phenomena"[MeSH Terms] OR ("biomechanical"[All Fields] AND "phenomena"[All Fields]) OR "biomechanical phenomena"[All Fields] OR "biomechanic"[All Fields] OR "biomechanics"[All Fields] OR "biomechanical"[All Fields] OR "biomechanically"[All Fields]) AND ("analysis"[MeSH Subheading] OR "analysis"[All Fields]) AND ("perform"[All Fields] OR "performable"[All Fields] OR "performance"[All Fields] OR "performance s"[All Fields] OR "performances"[All Fields] OR "performative"[All Fields] OR "performatively"[All Fields] OR "performatives"[All Fields] OR "performativities"[All Fields] OR "performativity"[All Fields] OR "performed"[All Fields] OR "performer"[All Fields] OR "performer s"[All Fields] OR "performers"[All Fields] OR "performing"[All Fields] OR "performs"[All Fields]) AND ("rugby"[MeSH Terms] OR "rugby"[All Fields])]
Scopus	(TITLE-ABS-KEY (biomechanical analysis) AND TITLE-ABS-KEY (performance) AND TITLE-ABS-KEY (rugby))
Science Direct	(TITLE-ABS-KEY (biomechanical analysis) AND TITLE-ABS-KEY (performance) AND TITLE-ABS-KEY (rugby))
Database	**Search term**
Pubmed	"agility"[KEY] AND ("education"[MeSH Subheading] OR "education"[KEY] OR "training"[KEY] OR "education"[MeSH Terms] OR "train"[KEY] OR "train s"[KEY] OR "trained"[KEY] OR "training s"[KEY] OR "trainings"[KEY] OR "trains"[KEY]) AND "futsal"[KEY]
Scopus	(KEY (agility training) AND (futsal))
Science Direct	(KEY (agility training) AND (futsal))

Eligibility Criteria

The research selection was based on the following inclusion criteria: (1) research on Biomechanical Analysis of Performance in Rugby , (2) publication in English. Studies are excluded if: (1) they are non-research publications (such as conferences, book chapters, or reports), review articles, or laboratory studies involving animals; (2) they are duplicate publications; (3) they do not have complete or adequate data; or (4) are limited to abstracts or conference presentations only.

Selection of studies and extraction of data

For duplicate removal and research filtering, Mendeley Desktop version 1.19.8 (Elsevier, Mendeley Ltd.) is used. Data extraction included: Author, country, research methods, research purpose, and results.

Study identification

An initial literature search yielded 105 potential studies. After removing 33 duplicate articles, 72 articles are left for further review. At the title and abstract screening stage, 10 articles were identified, and 62 articles progressed to full-text evaluation. Furthermore, 6 articles were excluded due to conference abstracts, posters, or unavailability of full texts, leaving 56 articles for comprehensive analysis. Of the 56 articles, 52 studies were eliminated because they did not relate to the research, used languages other than English, or were closed access. Finally, 4 studies met the inclusion criteria and were included in the final analysis. The study selection process is illustrated in the PRISMA flowchart in Figure 1.

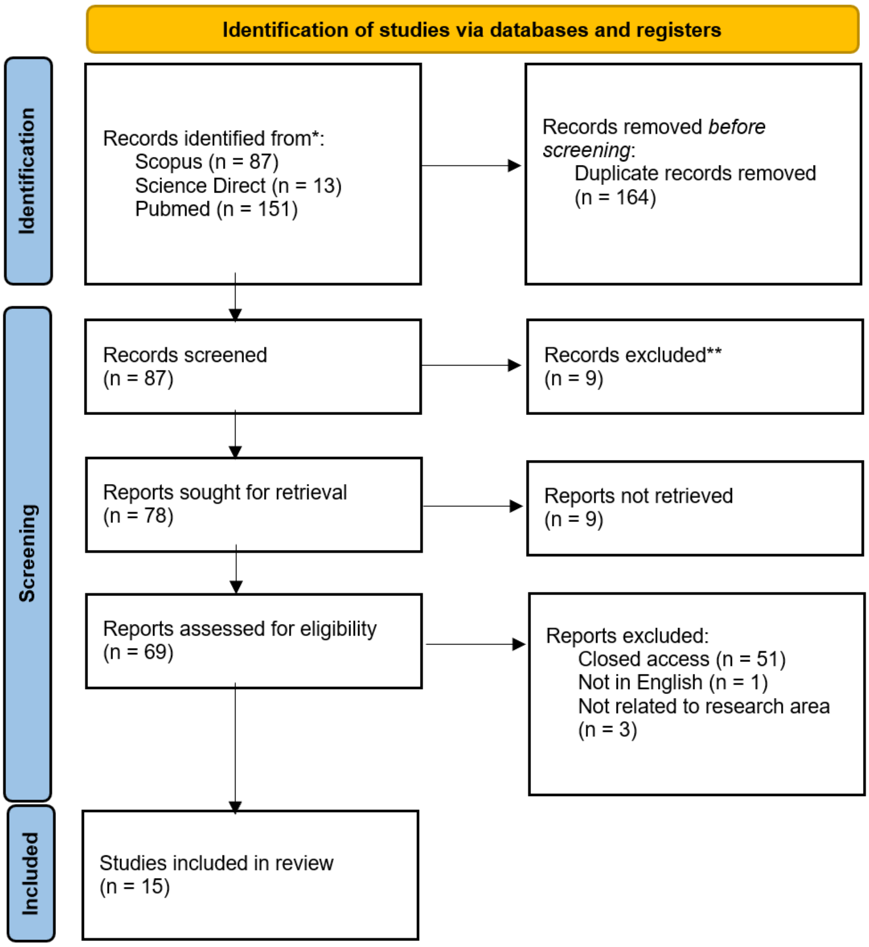

Figure 1. Selection process circuit

RESULTS

Table 2. Characteristics of the included studies

Author (Year)	Study Population	Key Methodology	Key Findings	Conclusions and Implications
Atack et al. (2019)	33 experienced rugby place kickers (amateur to senior international).	Joint kinetic analysis (inverse dynamics) and 3D kinematics during the downswing, comparing 'long' (successful) kickers with 'short' and 'wide-left' (less successful) kickers.	'Short' kickers achieved substantially slower ball velocities due to performing substantially less positive hip flexor/knee extensor joint work. 'Wide-left' kickers achieved comparable ball velocities but were less accurate due to substantially more longitudinal ball spin; they used a 'tension arc' mechanism (greater positive hip flexor joint work) resulting in greater longitudinal torso rotation. 'Long' kickers adopted a knee-dominant technique.	Understanding kicking leg and torso mechanics is crucial for successful place kicking; 'long' kickers utilized a knee-dominant technique to better control the foot trajectory.
Blythman et al. (2022)	10 staged rugby tackle movements performed by two pairs of professional rugby players.	Evaluation of a markerless deep learning (DL) model (Learnable Triangulation - LT) for 3D pose estimation against the marker-based *gold standard* (Conventional Gait Model - CGM), using 3 high-speed video cameras (sparse configuration).	The overall Mean Per Joint Position Error (MPJPE) was 47 mm. 75.6% of joint position estimates had a Mean Absolute Error (MAE) ≤25 mm. High errors occurred during challenging intervals of heavy occlusion and self-occlusion, particularly in the contact phase.	The DL model performs acceptably well for tracking kinematics before contact, but further research is required to reduce errors during the contact phase, especially with occlusion.

Wild et al. (2022)	29 professional rugby union backs.	Maximal 30m sprint (first four steps analyzed). Hierarchical agglomerative cluster analysis based on normalized spatiotemporal variables (length/rate and contact/flight ratios).	Four groups of distinct technique strategies were identified, but no significant differences in acceleration performance (NAHEP) existed between groups. Intra-individual whole-body kinematic strategies were stable. Success is achieved through degeneracy (multiple techniques yield the same outcome).	No single optimal strategy exists for initial sprint acceleration; the efficacy of technique must be considered at the individual level.
Glassbrook et al. (2024)	10 professional rugby league forwards.	Quantification of kinetic characteristics (peak force, total impulse, max RFD) at the first foot contact of four horizontally focused step-up variations: Barbell One Box (BB1), Barbell Two Box (BB2), Vest Two Box Run (VEST), and Step-Up Jump (JUMP).	The JUMP variation produced the largest relative peak force and Rate of Force Development (RFD), and equal largest total impulse, suggesting greatest transferability to maximal speed running. BB2 and VEST produced significantly greater relative peak force and RFD than BB1, suggesting better transferability to acceleration ability.	Coaches can select step-up variations that maximize specific kinetic characteristics to develop targeted running abilities (acceleration vs. maximal speed).
Petrie et al. (2025)	Interdisciplinary expert panel (18-15 individuals) from rugby union and league.	Delphi consensus method to establish a Falling and Landing Framework (FLF) to standardize falling/landing variables post-tackle/carry. Reliability assessed using Kappa (κ)	Consensus was reached on 'Additional Contextual Characteristics,' 'Falling Characteristics,' and 'Landing Characteristics' variables. FLF is crucial due to the high incidence of Head	The novel FLF provides standardized definitions to capture post-contact injury and performance markers, and should be used alongside existing rugby video

		inter-rater/intra-rater.	Acceleration Events (HAE) to the ground during the falling/landing phase (e.g., 26.1% in the Women's Super League). Reliability ranged from moderate to near perfect (κ 0.71–1.00).	analysis frameworks.
Rebelo et al. (2023)	Scoping review of 21 primary studies concerning various athletes.	Scoping review (following PRISMA) to map literature on the use of technology (GPS, accelerometers, force plates) for injury prevention.	Widespread use of triaxial accelerometer units (67%), GPS (52%), and force plates (33%). Player Load is the predominant metric (48% of studies). Force plates are critical for assessing fatigue, aiding recovery, and guiding injury rehabilitation, particularly for knee and ankle injuries.	Technology plays a pivotal role in athlete monitoring, enabling personalized adjustments to training loads based on sport demands and player positions.
Schulc et al. (2024)	91 ACL injury scenes and 38 control movements from online professional match recordings.	Development of an automated AI-based video analysis system (LSTM) to reconstruct 3D pose from a single-camera view and identify biomechanical patterns (e.g., knee abduction) associated with ACL injury.	The best AI model demonstrated good performance (F1 score = 0.63 ± 0.01, ROC AUC = 0.88 ± 0.01). The system improved the diagnostic accuracy of orthopedic surgeons (a 0.08 increase in combined F1 scores).	AI can be used to automatically detect dangerous motion patterns in-game, potentially aiding future ACL injury diagnosis and prevention.
McMahon et al. (2018)	53 professional male rugby league players.	Temporal Phase Analysis (TPA) of Countermovement Jump (CMJ) force, power, velocity, and	The high RSImod group jumped higher with a shorter Time to Take-Off (TTT). They demonstrated superior	RSImod is a valid measure of impulsive CMJ performance. Improvements

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		displacement curves, comparing athletes with high versus low Reactive Strength Index modified (RSImod) scores.	force, power, velocity, and impulse during both the eccentric and concentric phases, suggesting superior Stretch-Shortening Cycle (SSC) function.	should be achieved through long-term strength and power training, rather than technique modifications that may increase injury risk.
Hughes et al. (2021)	50 elite-level male rugby union athletes.	Development of a novel 10-point biomechanical Injury Risk Score (IRS) based on 2D video analysis of the combined *prone hip extension* (PHE) and *prone knee flexion* (PKF) movement.	A significant positive association between IRS and Posterior Chain Injury (PCI) was found ($R=0.542$, $p<0.001$). A 1-point increase in IRS was associated with a 35% increase in PCI incidence. Lumbar spine extension was the most common compensation observed.	The IRS provides preliminary support for its use as an easily applicable biomechanical injury risk assessment tool for PCI, offering guidance for intervention in compensation areas.
Simpson et al. (2021)	29 professional rugby league players.	8-week intervention comparing a Force-Velocity Optimized group (OP) vs. a General Strength-Power group (GP). Training personalized based on individual Force-Velocity imbalance (FVimb).	F-V optimized training was superior to general training in improving FVimb, maximal strength (3RM squat), Squat Jump (SJ) height, and vertical peak power. No differences were found in 10m or 20m sprint performance.	Programming targeting F-V deficits is a more efficient method for highly trained professional RL athletes to improve physical performance, especially vertical strength and power.
Bentley et al. (2021)	12 academy rugby league players.	Series of 6m sprints under uninhibited and sled towing (ST) conditions at 10%, 15%, and 20% Velocity Decrement (VDec). Trunk/lower limb kinematics and	Sled towing affected trunk, knee, and ankle joint kinematics. Peak knee flexion increased as sled loads increased, enabling greater horizontal force application. Net horizontal and propulsive impulses	A 20% VDec ST load can be used to emphasize horizontal force application. Loading should be based on % VDec rather than % BM to account for

		kinetic measures analyzed.	were significantly greater in all sled conditions and increased as loads were heavier.	individual variation.
Cazzola et al. (2016)	9 male front-row rugby union forwards.	Measured spinal muscle EMG activity (*sternocleidomastoid*, *upper trapezius*, *erector spinae* - ES) during machine scrummaging (CTS vs. CBS) and simulated live scrummaging.	CBS (*crouch-bind-set*) increased *upper trapezius* and *sternocleidomastoid* activity before and during the *engagement* compared to CTS, suggesting better cervical spine preparation (stiffening). Live scrummaging generated significantly higher ES activity during the sustained-push phase than either machine condition.	Scrummaging practice should include live situations, not just machine scrummaging, as the machine does not replicate the ES muscle demands of a live contest.
Atack et al. (2022)	17 place kickers whose maximum range was limited by distance.	PCA and stepwise regression analysis on approach kinematics (CM and GRF) and physical/strength characteristics (jump tests) to predict maximum distance.	Lower limb strength significantly predicted kicking foot velocity ($R2$=0.55) and resultant ball velocity ($R2$=0.57). However, maximum distance was ultimately determined by body position during the approach (antero-posterior position, $R2$=0.52 and CM height, $R2$=0.12).	The maximum range of accurate kickers is limited by body position and CM motion during the approach, rather than solely lower limb strength.
Appleby et al. (2019)	15 well-trained rugby union players (academy and professional).	Assessing the within-session reliability of squat kinetics (GRF, total concentric impulse) at high relative loads (70-90%	Peak and average GRF demonstrated acceptable reliability (CV% < 4.0%; ICC 0.87–0.97). The combined left and right leg average GRF	Reliable kinetic data can be confidently captured during multiple sets within one training session, increasing

		1RM) using dual force plates.	was capable of detecting the Smallest Worthwhile Change (SWC%).	the opportunity for coaches to monitor and refine training.
Weakley et al. (2020)	12 semiprofessional rugby union players.	Randomized crossover design comparing changes in barbell velocity during the back squat under 4 conditions: Control, Verbal Kinematic Feedback, Visual Kinematic Feedback, and Verbal Encouragement.	All three interventions showed almost certain improvements in barbell velocity compared to control. Differences between interventions were trivial. Verbal Encouragement showed a large inverse relationship with Conscientiousness.	Practitioners should supply kinematic feedback (verbally or visually) or verbal encouragement to enhance performance acutely. Verbal Encouragement may be most beneficial for athletes demonstrating low levels of Conscientiousness.

DISCUSSION

These studies collectively highlight advances in rugby biomechanics, from individual techniques such as place kicking and sprinting to team analysis such as tackling, scrummaging and injury prevention (Kerr et al., 2018). Key findings emphasize degeneration (multiple strategies achieve similar results), the role of AI technology and markerless tracking, and the personalization of training based on individual shortcomings (Barrera Castro et al., 2025; Tolu-Akinnawo et al., 2025).

In place kicking, Atack et al. (2019, 2022) show that success depends on knee-dominant technique and body position when approaching, not just lower leg strength. This is in line with Wild et al. (2022) on sprinting, where there is no single optimal strategy; Acceleration performance stabilizes intra-individually through degeneration, suggesting an individualized approach rather than a universal model.

Physical contact analysis uncovered challenges: Blythman et al. (2022) found the DL model to be effective pre-contact but failed at occlusion, while Petrie et al. (2025) proposed a Falling and Landing Framework (FLF) for the standardization of post-tackle analysis videos, crucial given that 26.1% of Head Acceleration Events occur during falls. Schulc et al. (2024) complemented with AI for the detection of ACL injury patterns from single-cameras, improving the accuracy of physician diagnoses.

Training and monitoring highlight efficiency: Glassbrook et al. (2024) recommend specific step-up variations for acceleration vs. maximum speed; Simpson et al. (2021) proved force-velocity optimized training to be superior for vertical strength; Bentley et al. (2021)

support 20% VDec sled towing for horizontal force. Reliability tests such as Appleby et al. (2019) and Weakley et al. (2020) feedback allow for real-time monitoring. Meanwhile, Rebelo et al. (2023) affirmed the role of GPS/accelerometers in injury prevention, and Hughes et al. (2021) and McMahon et al. (2018) identified risk scores such as IRS and RSImod for posterior chain as well as SSC function.

In scrummaging, Cazzola et al. (2016) emphasized live simulation for erector spinae activity, not just machines. Overall, the central theme is the integration of technologies (AI, DL, force plates) with individual kinematic analysis to reduce injuries and optimize performance, although challenges such as occlusion and individual variability remain.

CONCLUSION

This study concludes that rugby biomechanics is successful through individualized approaches, engineering degeneration, and advanced technologies for injury monitoring and prevention. There is no one optimal model; the trainer should prioritize the shortcomings of personal F-V, body position, and standard frameworks such as FLF.

Practical implications include: (1) using AI/video analytics for real-time risk detection (ACL, HAE); (2) adjust the exercises (step-up, sled towing, F-V optimized) based on kinetic metrics; (3) integrate kinematic feedback for acute performance; (4) Combine markerless DL with gold standard for efficiency. The future requires longitudinal validation and adaptation for the amateur/female level to reduce the burden of injury while maximizing competitive performance.

AUTHOR CONTRIBUTIONS

All authors contributed to the topic selection and drafting of the article.

DECLARATION

This manuscript was prepared by the author through a systematic review process without the use of artificial intelligence in the research design, literature search, article selection, data extraction, data analysis or interpretation of research results. Technology-based tools were used solely for language refinement and grammatical checking during the manuscript preparation process. The author bears full responsibility for the accuracy, integrity, originality and overall content of the manuscript.

TRANSPARENCY STATEMENT

Research data is available to the relevant author upon reasonable request.

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CONFLICT OF INTEREST

All authors confirm that there is no conflict of interest in this study.

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ETHICAL CONSIDERATIONS

This study did not require ethical approval as it did not involve human or animal participants, nor did it involve any direct intervention. The data used were drawn from the available scientific literature and were analysed systematically in accordance with the principles of research integrity and transparency.

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