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Article

Biomechanical insights into goalkeeper preparatory movements during defensive dives for football shots

Yuefeng Jin

Department of Sports, Nanjing University of the Arts, Nanjing 210013, China
*** Corresponding author:** Yuefeng Jin, jinyuefeng_nua@163.com

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Abstract: The kinetic demands of a football goalkeeper (GK) involve preventing opposing shots from entering the goal, which requires rapid and well-coordinated defensive actions. However, the biomechanics of these preparatory movements, particularly in response to diverse shot scenarios, remain insufficiently understood. Herein, the biomechanical characteristics intrinsic to the preparatory movements executed by GKs during defensive diving are elucidated. Three-dimensional coordinate data of the 10 GKs and 5 strikers were captured using two synchronized motion capture systems comprising cameras with an analog synchronization signal. A total of 172 trials were analyzed, during which GKs dived toward shots. GKs leaned forward, flexed their lower limbs, externally rotated and abducted the hips, and positioned their feet at 70–75% of leg length to respond quickly to shots. Preparatory takeoff occurred concurrently with the striker support leg contact, and GKs adjusted their movements after the striker-ground contact. These findings underscore the importance of effective preparatory movements for enhancing shot-stopping abilities, while also providing insights for optimizing training protocols to improve GKs adaptability and precision during matches.

Keywords: goalkeeping; biomechanics; preparatory action; dive dynamics

1. Introduction

The primary responsibility of a football goalkeeper (GK) is to prevent opposing shots from entering the goal—an act known as "shot-stopping" [1]. To protect a goal measuring 7.32 meters in width and 2.44 meters in height, GKs often perform a variety of jumps—upwards, sideways, or diagonally—executing diving actions to intercept incoming shots [2,3].

Prior research on diving actions has explored the mechanics involved in diving towards suspended balls to understand how GKs move swiftly toward a target [4–7]. Recent studies have further examined force variables and dynamic strength indices across different age groups of elite young goalkeepers, offering insights into the development of strength characteristics pertinent to shot-stopping abilities [8]. Additionally, studies have examined GK responses to shots, identifying relationships between acquiring velocity of the center of gravity and coordinated trunk and lower limb movements [9]. During football match play, GKs must react within roughly one second to intercept shots aimed at various goal areas [10,11]. Therefore, effective use of this limited time requires GKs not only to acquire significant velocity of the center of gravity in the intended direction but also to adopt a stance that facilitates swift movement toward diverse shot trajectories. Furthermore, GKs must execute preparatory actions that minimize whole-body choice reaction time [12–14].

Regarding preparatory actions, studies have indicated that counter movements and flexing of lower limb joints, thereby creating a pre-tensioned muscular state, enhance subsequent performance [15–17]. Numazu [18] defined a small vertical jump, commonly performed by GKs before executing a save, as a preparatory action. This action was frequently executed irrespective of the save success. Uzu [19] explored the split-step as a preparatory action in tennis, emphasizing its efficacy in situations where the athlete knows when, but not where, movement is required. They highlighted that the optimal timing for foot contact during preparatory action is approximately 180 ms after the directional cue—underscoring the critical role of precise timing in effective preparatory actions. It was stressed the necessity for both feet to be grounded at the moment the shot is taken. Although the exact definition of "the moment the shot is taken" remains ambiguous, it is generally interpreted as the point of contact between the ball and the striker foot ("impact"), following the concept of a directional cue [20]. Zheng [21] found that GKs initiated leg movements for diving just before the striker supporting leg made contact with the ground prior to impact during penalty kicks. However, GKs did not perform preparatory actions in that study. It is plausible that GKs time their preparatory actions to coincide with the striker supporting leg contacting the ground just before impact. Nevertheless, the exact timing of preparatory actions relative to the kicking motion remains elusive, as indicated by football match analysis of GKs.

GKs execute different diving maneuvers depending on the height and distance of incoming shots [22]. It was known that when diving towards shots aimed at greater distances, the preparatory stance and actions remained largely invariant regardless of the shot direction or height [23]. To further understand preparatory actions for diving in response to shots, it is imperative to investigate how variations in shot height and distance affect preparatory movements [24]. Moreover, elucidating the interplay between shot trajectory and preparatory action offers valuable insights for coaching—enabling precise instruction on how and when to adapt movement in response to different shot trajectories [25]. Even when a GK performs an optimally timed preparatory action and initiates movement promptly, a high-speed shot directed away from the GK remains difficult to intercept [26]. Thus, the quality of the preparatory action does not always correlate with successful shot-stopping. Consequently, while investigating preparatory actions in response to shots, analyzing actual shot scenarios remains critical; however, the biomechanical attributes of preparatory actions are unlikely to differ significantly based on the success or failure of the save attempt [27,28].

Herein, this work aims to investigate the biomechanical characteristics of preparatory actions performed by GKs during diving movements in a controlled, simulated shooting scenario, irrespective of shot-stopping success, across varied shot locations to replicate real game conditions.

2. Methods

2.1. Data collection

10 goalkeepers (GKs) from a university football team were recruited for the study (height: 181.0 ± 5.2 cm, weight: 76.0 ± 6.5 kg). 5 players also participated as kickers (height: 175.0 ± 6.1 cm, weight: 70.5 ± 5.2 kg). University-level goalkeepers were

selected due to their advanced skills, consistent training, and suitability for controlled experiments. This cohort provides a reliable model for biomechanical analysis, forming a foundation for future studies involving professional-level goalkeepers. Reflective markers were affixed to anatomical landmarks on the participants and on the ball. For the participants, markers were placed on key regions of the head, torso, arms, and legs to capture comprehensive movement data. On the ball, markers were positioned and evenly distributed across its surface to ensure accurate tracking of its trajectory. A schematic illustration of these placements is provided in **Figure 1** to facilitate replication. Two optical motion capture systems were employed to capture three-dimensional coordinates of all markers.

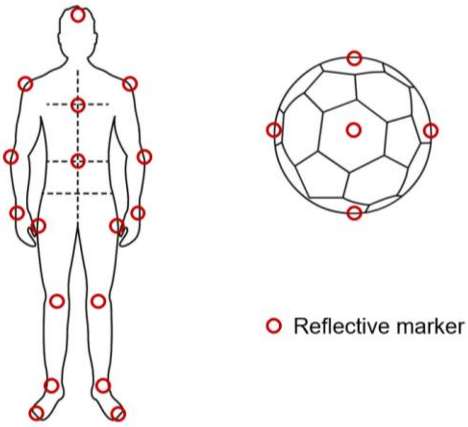

Figure 1. Placement of reflective markers on participants and the ball.

2.2. Experimental setup

Table 1 descripts the experimental setup. The trials and shooting scenarios simulated shooting situations from within the penalty area. The kicker executed shots from a distance of 16.5 m in front of the GK. A fixed shooting distance of 16.5 m was chosen to standardize experimental conditions and replicate penalty-area scenarios commonly encountered in competitive football matches. This distance ensures consistent reaction time demands for goalkeepers and facilitates the comparability of biomechanical data across trials.

Kickers were positioned 2 m of the goal center to extend the ball forward and then kick it with a run-up. The kick was to be executed before the ball crossed a shooting line set 4 meters in front of the starting position. Twelve shot locations were designated, based on direction (left or right), distance from the GK (near or far), and height (lower, middle, upper). Near shots were defined as those aimed between 1.2 and 2.4 m from the goal center, while far shots were defined as those aimed between 2.4 meters from the goal center and the goalposts. Heights were categorized as follows: lower (0.2 to 0.8 m), middle (0.8 to 1.6 m), and upper (1.6 m to the crossbar). Specifically, after completing the preparatory movement, GKs were directed to push off with the leg corresponding to the anticipated direction of the shot. The experimental setup established a fixed coordinate system (X, Y, Z), with the X-axis parallel to the goal, the Z-axis directed vertically upward, and the Y-axis derived as the cross-product of the Z- and X-axes.

Table 1. Description of experimental setup.

Area	Details
Experimental Area	Simulated real-game scenario involving GKs and kickers.
Shooting Line	The kicker was positioned 16.5 m away from the goal area. The shooting line located 4 m in front of the kicker.
Goal Area (Height Divisions)	Lower: 0–0.8 m; Middle: 0.8–1.6 m; Upper: 1.6–2.4 m
Goal Area (Width Divisions)	Near: 1.2–2.4 m; Far: 2.4–3.6 m

2.3. Data processing

2.3.1. Selection of trials for analysis

172 trials were meticulously selected for analysis. Each trial involved a shot that remained within the designated shot course and a successful diving save by the goalkeeper (GK). The shot courses were classified using footage captured from behind the kicker, resulting in the following categories, as shown in **Table 2**. The leg on the same side as the diving direction was designated as the Ball Side leg (BS leg), while the leg on the opposite side was referred to as the Contralateral Side leg (CS leg). All trials were standardized by assuming the GK dived to the right. Consequently, the right leg was considered the BS leg, and the left leg was considered the CS leg for all data calculations.

Table 2. Description of trials.

Shot Course	Number of Trials
Near Upper (NU)	28
Near Middle (NM)	32
Near Lower (NL)	14
Far Upper (FU)	26
Far Middle (FM)	36
Far Lower (FL)	36

2.3.2. Definitions of actions

The moment at which the kicker kicking foot made contact with the ball was defined as Impact (Imp). The moment just preceding Impact, when the support leg (Support Leg) made contact with the ground, was defined as Support Leg on the ground (SLon). The instant prior to SLon, when the kicking leg (Kicking Leg) left the ground, was termed Toe off of the Kicking Leg (KLoff). The moment when either leg left the ground during the preparatory action was defined as Toe off of the Preparation Jump (PJoff). The subsequent moment when the Contralateral Side leg (CS leg) made ground contact was designated as Contralateral Side leg on the ground (CSon). The moment both feet left the ground, marked by the Ball Side leg (BS leg) leaving the ground, was termed Toe off of the Ball Side leg (BSoff). In this study, the GK posture at KLoff was designated as the preparatory posture, and the preparatory action was defined, as the movement from KLoff to CSon. Across all analyzed trials, GKs performed a small upward jump akin to a split-step as part of the preparatory action.

2.3.3. Smoothing

The three-dimensional coordinate data of each body segment were smoothed using a Butterworth digital filter. The optimal cutoff frequencies, ranging from 2.5 Hz to 25 Hz, were determined using the residual analysis method described by Wells [29]. This method systematically evaluates the residual error between filtered and raw data to identify a cutoff frequency that minimizes noise while preserving the fidelity of the biomechanical signal. The chosen range was verified to ensure that the filtering process retained all relevant motion data while effectively eliminating noise artifacts inherent to the data acquisition process.

2.3.4. Rigid link model construction and body segment coordinate systems

The lower body of participants was modeled using a seven-segment rigid link representation, which included the right foot, right shank, right thigh, left foot, left shank, left thigh, and lower trunk. The ankle and knee joints were represented by the midpoint between two markers placed on the medial and lateral sides of the joint. The hip joint center was estimated using the previous method [30].

2.3.5. Body segment coordinate systems

To represent the posture of each body segment, a right-handed orthogonal local coordinate system was established for the foot, shank, thigh, and lower trunk segments using direction cosine matrices. The relative orientation between the global coordinate system and each local coordinate system was subsequently calculated.

2.4. Calculated variables

2.4.1. Movement time

The time from KLoff to CSon was calculated as the preparatory movement time, while the airborne time of the preparatory movement was defined as the time from PJoff to CSon. Additionally, to evaluate the timing differences between the GK preparatory movements and the kicker actions, the time intervals from Imp and SLon to PJoff, as well as from Imp to CSon, were calculated. These time values were obtained by subtracting the kicker action time point (Imp or SLon) from the GK action time point (PJoff or CSon). A positive value indicated that the GK action occurred prior to the kicker action, whereas a negative value signified that the GK action followed the kicker action.

2.4.2. Stance width relative to leg length

The length of each leg was determined by calculating the vector length from the heel to the ankle joint center, from the ankle joint center to the knee joint center, and from the knee joint center to the greater trochanter, summing these values. The average of the left and right leg lengths was used as the leg length for each participant. The stance width at KLoff was determined by dividing the distance between the centers of mass of the left and right feet by the average leg length.

2.4.3. Preparatory jump height

The center of mass for each segment and for the whole body was computed using the reported method [31]. The preparatory jump height was determined by subtracting the vertical position of the center of mass at KLoff from the peak vertical position of the center of mass during the preparatory jump.

2.4.4. Velocity of center of mass at BSoff

The velocity of the center of mass at BSoff was obtained by differentiating the position of the center of mass with respect to time at the moment when both feet left the ground.

2.4.5. Trunk angle in the sagittal plane

The trunk forward or backward inclination angle was defined as the angle between the trunk midline and the global *Z*-axis. A posture in which the midline aligned with the positive direction of the *Z*-axis was defined as 0 degrees, with backward inclination represented by positive values and forward inclination by negative values.

2.4.6. Lower limb joint angles

The proximal segment planes (flexion/extension and dorsiflexion/plantarflexion in the *yz* plane, abduction/adduction in the *zx* plane, and internal/external rotation in the *xy* plane) were used to project the distal segment axes (flexion/extension and dorsiflexion/plantarflexion along the *y*-axis, abduction/adduction along the *z*-axis, and internal/external rotation along the *x*-axis), and the angles between these axes were defined as joint angles.

2.4.7. 3D coordinates and speed of the ball

The three-dimensional coordinates of the ball center and the speed of the kicked ball (referred to as shot speed) were calculated using the method outlined by Murata [32]. Shot speed was specifically determined following the method used by Numazu [33].

3. Results

3.1. Shot speed and movement timing analysis

Figure 2 shows the mean shot speed and standard deviations for all participants across each shot course. The shot speed was consistently around 23.8 m/s, with minimal variation across near and far distances or upper, middle, and lower positions. The shot speed ranged from 23.6 ± 1.1 m/s to 24.0 ± 1.4 m/s, indicating a uniform effort by participants across all conditions.

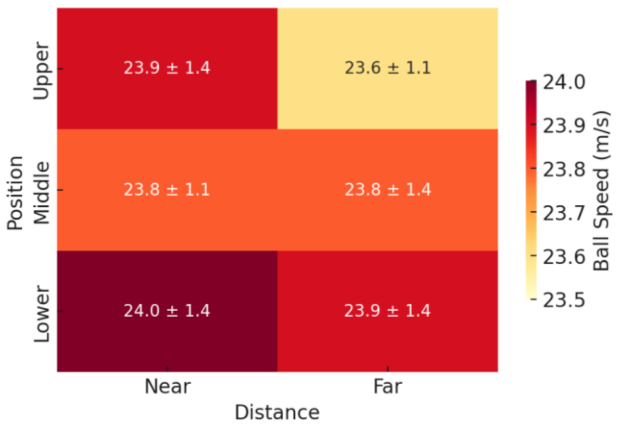

Figure 2. Ball speed heatmap at different positions and distances.

Figure 3 presents the mean values and standard deviations of the preparatory movement time and the airborne time of the preparatory movement for all participants across each shot course. As shown in **Figure 3a**, the elapsed time from KLoff to CSon was relatively consistent across upper, middle, and lower shot positions, with near and far conditions both averaging around 0.4 seconds. Similarly, **Figure 3b** illustrates that the elapsed time from PJoff to CSon was also consistent, with values ranging between 0.2 to 0.3 seconds for both near and far shots. These results suggest that goalkeepers maintained a similar temporal pattern in their preparatory movements regardless of the shot distance or position, indicating uniformity in their response timing under different conditions.

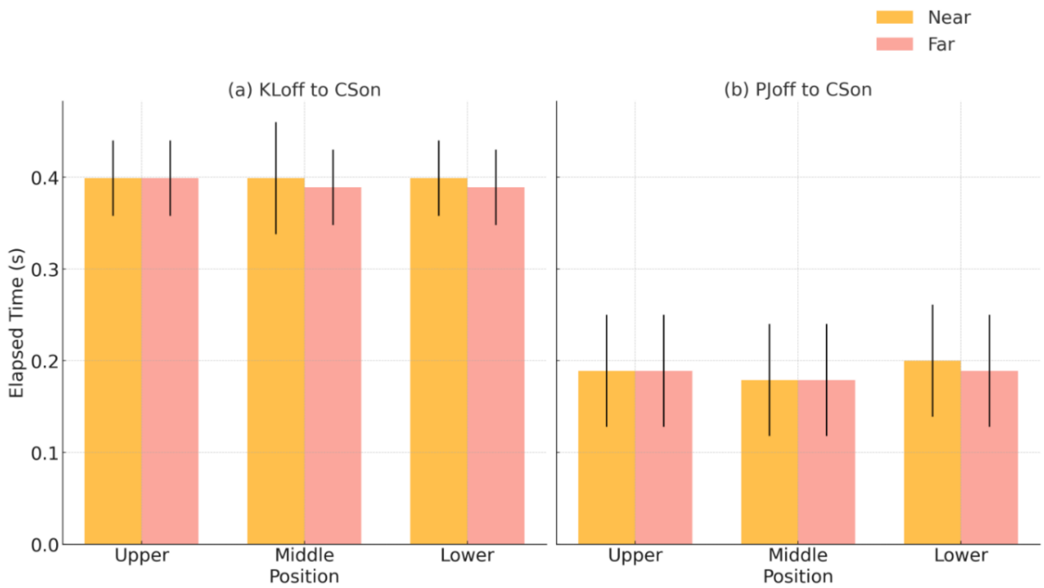

Figure 3. Elapsed times of preparatory motion: **(a)** KLoff to CSon and; **(b)** PJoff to CSon at different positions.

Figure 4 shows the mean values and standard deviations of the differences in timing for PJoff and SLon, PJoff and Imp, and CSon and Imp for all participants across each shot course. The timing differences from PJoff to SLon and PJoff to Imp were relatively small, ranging from -0.09 ± 0.05 to 0.04 ± 0.06 seconds, with no significant main effects or interactions across shot courses. However, the time difference from CSon to Imp showed consistent values around −0.15 seconds for all shot positions, indicating that goalkeepers were reaching CSon shortly after the ball impact, regardless of shot distance or position. This suggests a uniform response in preparation timing for dives, allowing goalkeepers to initiate movement promptly after the ball was struck.

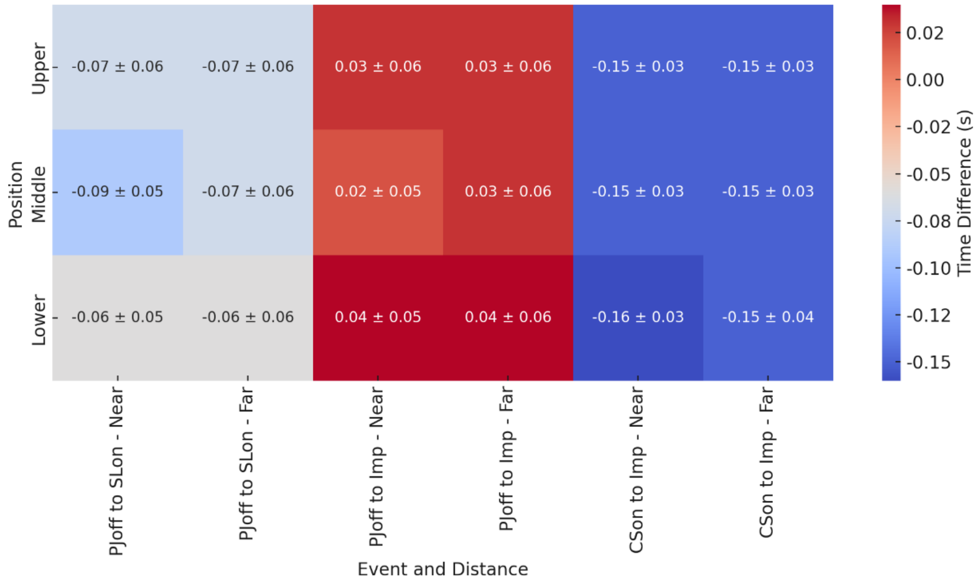

Figure 4. Time differences between actions of PJoff and SLon, PJoff and Imp, and CSon and Imp at different positions.

3.2. Center of gravity velocity and stance width

Figure 5 presents the mean vertical and horizontal components of center of gravity (CG) velocity for all participants across each shot course. The horizontal CG velocity consistently exceeded the vertical CG velocity across all positions, suggesting a predominant emphasis on lateral movement during goalkeeping dives. For example, at the near upper position, horizontal velocity reached approximately 3.5 m/s, while vertical velocity was around 1.8 m/s. This trend indicates that goalkeepers prioritized lateral movement to effectively respond to shots, regardless of height or distance.

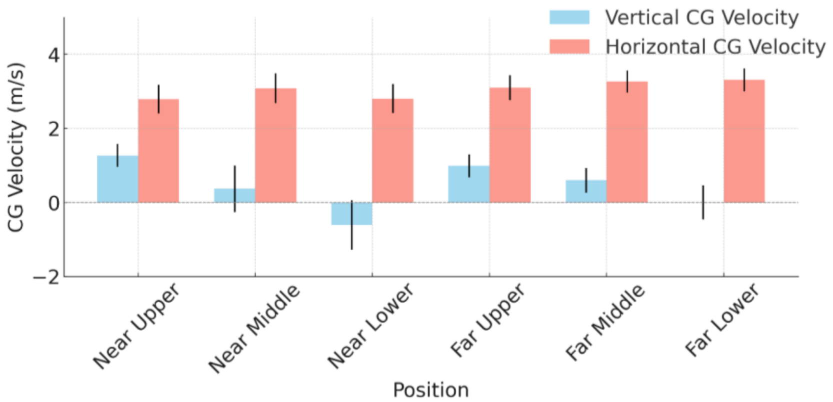

Figure 5. Vertical and horizontal CG velocity at different positions.

Notably, the Near Lower position displayed a negative vertical CG velocity of approximately −0.5 m/s, suggesting a downward adjustment before executing lateral movement. In contrast, the Far Upper position demonstrated the highest horizontal velocity, approximately 4.2 m/s, emphasizing the need for rapid lateral adjustment in response to distant high shots. The differences in CG velocity components between near and far conditions further highlight the distinct movement strategies employed by goalkeepers to adapt to shot height and distance.

Figure 6 presents the mean stance width relative to leg length for all participants across each shot course. The stance width remained consistent across upper, middle, and lower shot positions, with near and far conditions showing values of approximately 70% to 75% of leg length. The consistency in stance width across different positions suggests that goalkeepers adopted a similar base stance regardless of shot distance or height, ensuring stability and readiness for diving movements. This uniformity in stance width highlights the importance of a stable preparatory posture that facilitates effective movement execution in response to incoming shots.

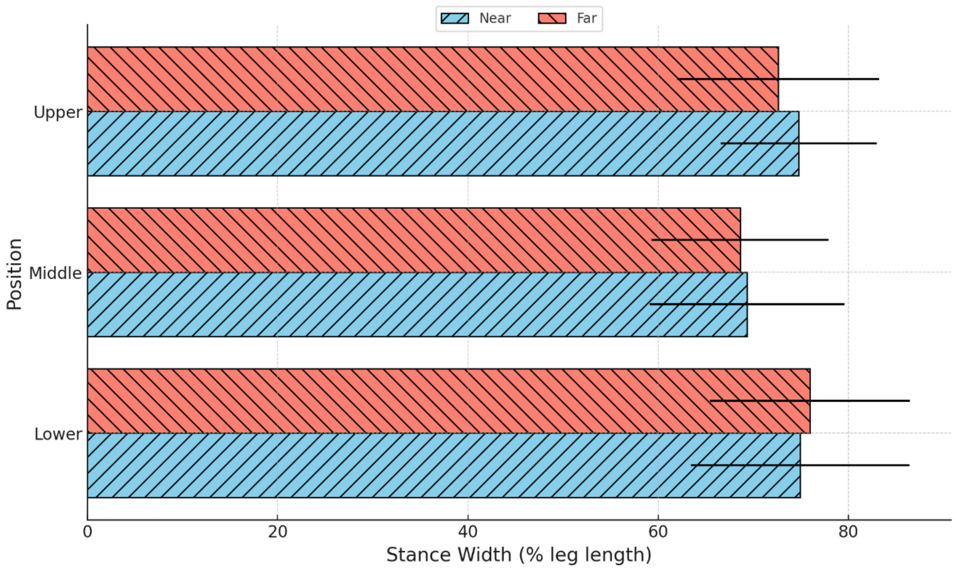

Figure 6. Stance width relative to leg length for all participants across each shot course.

3.3. Preparatory jump height

Figure 7 presents the mean values and standard deviations of preparatory jump height for all participants across each shot course. The results indicate that the jump height was consistent across upper, middle, and lower positions, with near and far shots showing similar values ranging from approximately 0.08 m to 0.13 m. This consistency suggests that goalkeepers used a comparable preparatory jump height regardless of the shot distance or position, which may contribute to maintaining balance and readiness for subsequent diving actions. The standard deviations reflect some variability among participants, but overall, the preparatory jump height remained within a similar range, highlighting a uniform approach to preparatory movement.

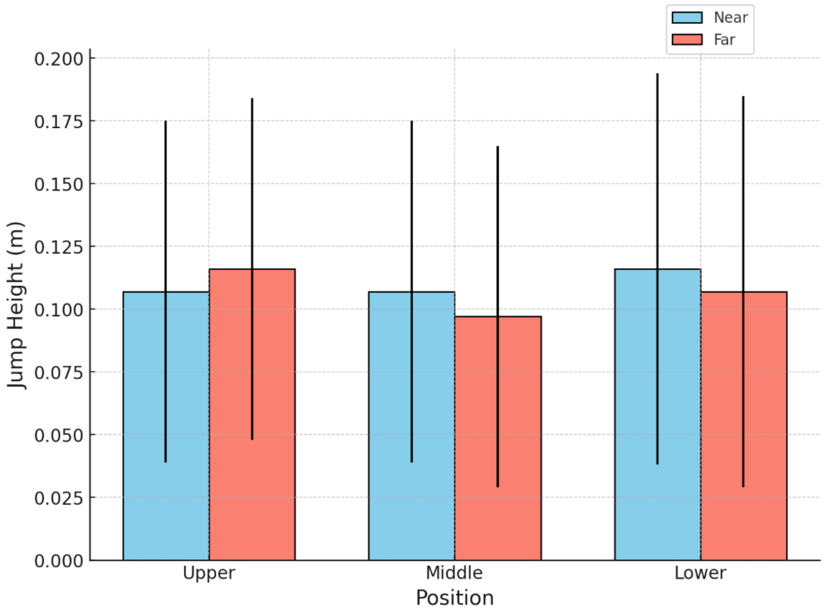

Figure 7. Preparatory jump height for all participants across each shot.

3.4. Trunk inclination angle and lower limb joint angles

Figure 8a provides the mean values and standard deviations of trunk inclination angle and lower limb joint angles at KLoff for all participants across each shot course. At KLoff, goalkeepers exhibited a similar trunk inclination across all shot positions, with the CS leg showing significantly greater external rotation in Near shots compared to Far shots. This trend was also observed in the BS leg, emphasizing that goalkeepers used increased external rotation during the early stages of movement preparation to handle closer shots effectively.

Figure 8b shows the joint angles at PJoff, indicating more differentiation, particularly in the CS leg. For Near shots, the CS leg demonstrated greater hip external rotation and ankle plantarflexion compared to Far shots, suggesting that goalkeepers adjusted their posture to optimize positioning for rapid lateral dives. This increased external rotation and plantarflexion for Near shots is indicative of a strategy to enhance lateral movement capacity when facing closer threats.

Figure 8c presents joint angles at CSon, where further adjustments were observed. The CS leg showed increased knee flexion and ankle dorsiflexion for far shots compared to near shots, along with greater hip external rotation for near shots. This reflects a shift toward a more grounded and flexed posture for distant shots, potentially providing greater control during dives. The BS leg consistently showed increased external rotation for near shots, reinforcing its role in stabilizing and preparing for lateral movement during closer shot scenarios. Collectively, these adjustments across KLoff, PJoff, and CSon phases indicate a nuanced strategy by goalkeepers to adapt their biomechanics to the shot distance and position, balancing mobility and stability for optimal performance.

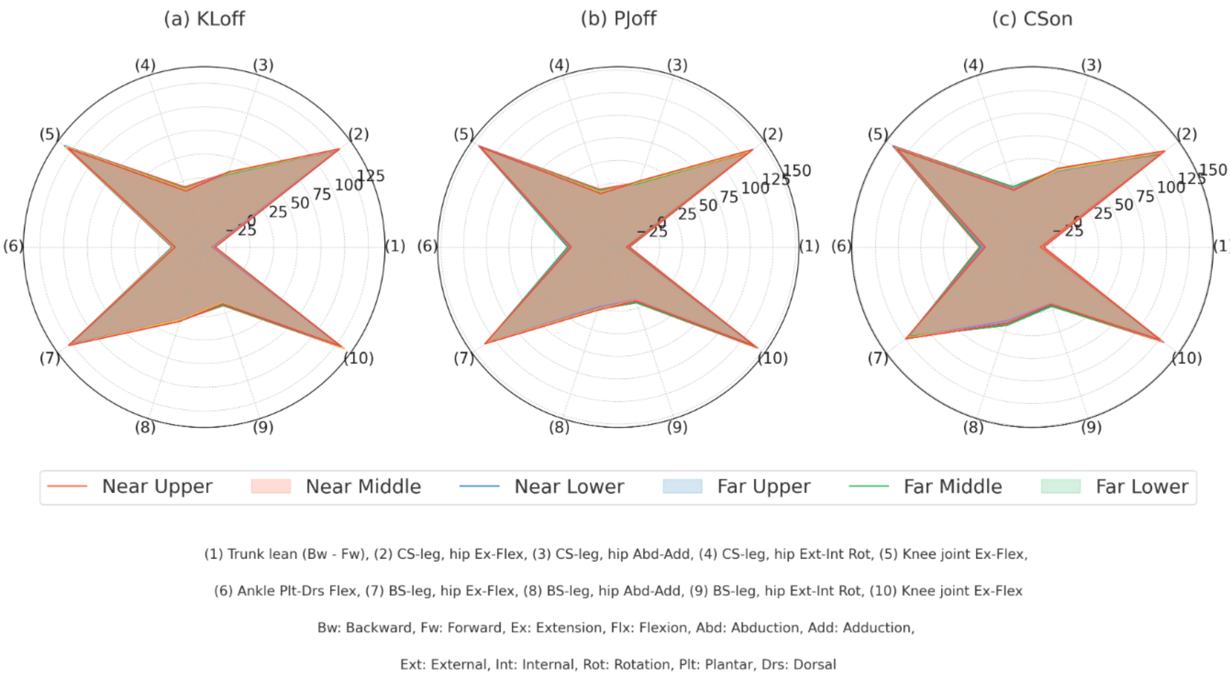

Figure 8. Trunk inclination angle and lower limb joint angles. **(a)** KLoff; **(b)** PJoff; **(c)** CSon.

Analysis of trunk inclination and lower limb joint angles at key phases of preparatory movements (KLoff, PJoff, CSon) did not yield direct statistical correlations with save success in this study. However, goalkeepers demonstrating greater external rotation of the contralateral hip and increased knee flexion during preparatory phases appeared to execute more efficient and stable lateral dives. These adjustments likely contribute to enhanced responsiveness and movement precision, suggesting their potential importance in optimizing shot-stopping performance. Although no direct correlations between trunk inclination and lower limb joint angles with save success were identified, the angular measurements provide critical insights into the biomechanics underlying effective preparatory movements. Specifically, increased external hip rotation and knee flexion during the preparatory phase may enhance stability and facilitate rapid lateral propulsion, enabling goalkeepers to respond more effectively to shots. These findings underscore the value of incorporating targeted flexibility, strength, and coordination training into goalkeeper development programs to refine movement efficiency and overall performance.

4. Discussion

The studies above delved into the preparatory movements of GKs during diving actions in response to shots of varying distances and heights. The results revealed that GKs maintained consistent preparatory postures across all shot trajectories, characterized by approximately 40 degrees of forward trunk inclination, 125 degrees of hip flexion, 130 degrees of knee flexion, and 15 to 20 degrees of external hip rotation. The timing of pivotal movements, such as PJoff and CSon, was closely synchronized with the kicker actions, with CSon occurring roughly 0.14 seconds post-impact (Imp), thereby facilitating an efficient response immediately following the shot. These findings suggest that GKs prioritize a stable preparatory stance, adjusting their timing to align with the kicker cues rather than making extensive modifications based on shot trajectory.

Although no significant differences in preparatory movements were observed across different shot courses, GKs exhibited subtle adjustments in their center of mass velocity to accommodate specific shot distances and heights during the diving phase. For instance, significant variations were noted in the lateral component of center of mass velocity between NU and FU, NM and FM, as well as NL and FL shot courses, with effect sizes ranging from small to large. This suggests that while GKs initially maintain a consistent preparatory posture, intricate adaptations to the specific shot characteristics emerge during the latter stages of the movement sequence. The study provides valuable insights into how GKs can enhance their preparedness for unpredictable shot scenarios, underscoring the critical balance between stability and adaptability in their preparatory actions.

However, several limitations in this work should be noted. The controlled experimental environment may not fully account for the influence of real-world variability. Environmental factors, such as field surface (e.g., natural grass, artificial turf), weather conditions (e.g., rain, wind), and lighting, could potentially affect movement patterns and performance. For instance, wet or uneven surfaces might compromise stance stability or preparatory jump execution, while wind could alter shot trajectories, necessitating different anticipatory strategies. Future research should explore these factors to improve the ecological validity of the findings. Furthermore, the fixed shooting distance of 16.5 meters, while ensuring consistency, may not fully reflect the variability of real-game scenarios where shooting distances can differ. Shorter distances may require faster and more reactive movements, while longer distances could allow for greater anticipatory adjustments. Future studies should investigate how varying shooting distances influence goalkeeper biomechanics to enhance the generalizability of these findings.

Another potential limitation of the study is the exclusive use of university-level goalkeepers, which may constrain the generalizability of the findings to other populations, such as professional or amateur goalkeepers. Professional goalkeepers, for instance, may exhibit greater precision, faster reaction times, and different biomechanical adaptations due to their advanced training and match experience. Conversely, amateur goalkeepers may lack the consistency or technical execution observed in the current cohort. Despite these potential differences, the foundational biomechanical principles observed in this study are likely applicable across skill levels. Future research should aim to compare goalkeepers across various levels of expertise to identify skill-specific biomechanical adaptations.

The conclusions of this study highlight the potential to refine goalkeeper training by providing evidence-based insights into the biomechanics of preparatory movements. The findings underscore the importance of optimizing hip external rotation, knee flexion, and stance width stability to enhance movement efficiency and responsiveness during dives. Coaches can design drills, such as split-step exercises and lateral push-offs, that replicate game scenarios and align with these biomechanical principles. Additionally, incorporating visual cue-based training, focusing on the striker's support-leg placement and ball contact, can further improve timing and anticipatory skills. These recommendations bridge the gap between biomechanical research and practical implementation, offering a framework for advancing goalkeeper preparation techniques.

5. Conclusions

The biomechanical characteristics of GK preparatory movements during diving actions in response to simulated real-game shots from different locations were investigated. The findings revealed that GKs consistently adopted specific postural adjustments—including forward trunk inclination, hip flexion, knee flexion, ankle dorsiflexion, hip abduction, and external rotation—enabling efficient responses. Preparatory movements were executed in coordination with the kicker actions, allowing GKs to swiftly initiate dives following shot impact. The results highlight the importance of an anticipatory posture for effective shot response, with adjustments based on shot trajectory becoming apparent during the diving phase. These insights provide a foundation for future research to explore optimal preparatory movements and GK-specific strategies for shot-stopping under various match conditions.

Ethical approval: Not applicable.

Conflict of interest: The author declares no conflict of interest.

References

1. White, S.P. Hills, C.B. Cooke, T. Batten, L.P. Kilduff, C.J. Cook, C. Roberts, M. Russell, Match-play and performance test responses of soccer goalkeepers: A review of current literature, Sports Medicine, 48 (2018) 2497-2516.
2. T.C. Valkanidis, C.M. Craig, A. Cummins, J.C. Dessing, A goalkeeper's performance in stopping free kicks reduces when the defensive wall blocks their initial view of the ball, Plos one, 15 (2020) e0243287.
3. F. Otte, T. Dittmer, J. West, Goalkeeping in modern football: Current positional demands and research insights, International Sport Coaching Journal, 10 (2022) 112-120.
4. K. Matsukura, T. Asai, K. Sakamoto, Characteristics of movement and force exerted by soccer goalkeepers during diving motion, Procedia Engineering, 72 (2014) 44-49.
5. R.L.M. Monteiro, B.L.S. Bedo, P.H.M. Monteiro, F.d.S.P. de Andrade, F.A. Moura, S.A. Cunha, R.d.S. Torres, D. Memmert, et al., Penalty feet positioning rule modification and laterality effect on soccer goalkeepers' diving kinematics, Scientific reports, 12 (2022) 18493.
6. K. Matsukura, T. Asai, Characteristics of lower limb force exertion during diving motions by collegiate male soccer goalkeepers, Science and Medicine in Football, 4 (2020) 127-134.
7. F. Esatbeyoğlu, İ. Kırkaya, S. Şenaysoy, S. Bicici-Ulusahin, The Need for the Evaluation of Sport-Specific Skills in Paralympic Goalball with a 3-D Kinematic Analysis: Research Note, Palaestra, 38 (2024).
8. D.L. Portella, P. Jatene, A.O. Da Silva, G.S. dos Santos, D. Monteiro, J.E. Teixeira, L. Branquinho, R. Ferraz, et al., Comparison of force variables and dynamic strength index between age groups in elite young Brazilian football goalkeepers, Frontiers in Sports and Active Living, 6 (2024).
9. X. Zhang, G. Shan, F. Liu, S. Yang, M. Meng, Diversity of scoring, ingenuity of striking, art of flying-conceptual and systematical identification of soccer scoring techniques, Physical Activity Review, 1 (2021) 79-92.
10. M. Jamil, A. Phatak, S. Mehta, M. Beato, D. Memmert, M. Connor, Using multiple machine learning algorithms to classify elite and sub-elite goalkeepers in professional men's football, Scientific reports, 11 (2021) 22703.
11. G. Gelade, Evaluating the ability of goalkeepers in English Premier League football, Journal of quantitative analysis in sports, 10 (2014) 279-286.
12. R. Lidor, G. Ziv, T. Gershon, Psychological preparation of goalkeepers for the 11-m penalty kick in soccer—A review, The Sport Psychologist, 26 (2012) 375-389.
13. R.L.M. Monteiro, C.C.A. Dos Santos, P. Blauberger, D. Link, T.G. Russomanno, A.K. Tahara, A.G. Chinaglia, P.R.P.

Santiago, Enhancing soccer goalkeepers penalty dive kinematics with instructional video and laterality insights in field conditions, Scientific Reports, 14 (2024) 10225.
14. K. Gramage Medina, F. Delvaux, C. Schwartz, G. Berwart, T. Barnerat, J.-L. Croisier, J.-F. Kaux, Coaches' perceptions on the Spread: A 1 vs 1 goalkeeper technique. International survey on 400+ goalkeeper coaches, International Journal of Sports Science & Coaching, (2024) 17479541241289419.
15. P.V. Komi, C. Bosco, Utilization of stored elastic energy in leg extensor muscles by men and women, Medicine and science in sports, 10 (1978) 261-265.
16. Van Hooren, J. Zolotarjova, The difference between countermovement and squat jump performances: a review of underlying mechanisms with practical applications, The Journal of Strength & Conditioning Research, 31 (2017) 2011-2020.
17. A.M. Williams, J.L. Thomas, G. Jordet, P.R. Ford, Anticipation and decision-making, in: Science and Soccer, Routledge, 2023, pp. 124-140.
18. N. Numazu, N. Fujii, M. Nakayama, M. Koido, Game performance analysis in the university male soccer goalkeepers, Coaching research, 31 (2017) 43-52.
19. R. Uzu, M. Shinya, S. Oda, A split-step shortens the time to perform a choice reaction step-and-reach movement in a simulated tennis task, Journal of Sports Sciences, 27 (2009) 1233-1240.
20. S.W. Peterson, M.R. Bruton, A review of the interaction between the striker and the goalkeeper at the individual tactical level in football, International Journal of Sports Science & Coaching, 15 (2020) 452-464.
21. R. Zheng, C. de Reus, J. van der Kamp, Goalkeeping in the soccer penalty kick: The dive is coordinated to the kicker's non-kicking leg placement, irrespective of time constraints, Human Movement Science, 76 (2021) 102763.
22. P. Graham-Smith, A. Lees, D. Richardson, Analysis of technique of goalkeepers during the penalty kick, Journal of Sports Sciences, 17 (1999) 905-929.
23. R. Ibrahim, I. Kingma, V. de Boode, G.S. Faber, J.H. van Dieën, The Effect of Preparatory Posture on Goalkeeper's Diving Save Performance in Football, Frontiers in Sports and Active Living, 1 (2019).
24. R. Ibrahim, I. Kingma, V. de Boode, G.S. Faber, J.H. van Dieën, Angular Velocity, Moment, and Power Analysis of the Ankle, Knee, and Hip Joints in the Goalkeeper's Diving Save in Football, Frontiers in Sports and Active Living, 2 (2020).
25. M. Fujimoto, M. Sato, A. Nagano, M.W. Rogers, T. Isaka, Preparatory knee flexion movement facilitates faster sideways jumping execution in male collegiate soccer goalkeepers, Sports Biomechanics, 1-15.
26. K. Piechota, E. Majorczyk, Decision-Making Time and Neuromuscular Coordination in Youth and Senior Soccer Goalkeepers, Sensors, 23 (2023) 4483.
27. Q. Ji, C. Zhou, Y. Wang, Influence of conflicting prior information on action anticipation in soccer players: an ERP study, Frontiers in Behavioral Neuroscience, 17 (2023).
28. Jara, E. Ortega-Toro, M.-Á. Gómez-Ruano, F.J. García-Angulo, P. Sainz de Baranda, Multivariate analysis of goalkeeper actions in youth football, International Journal of Sports Science & Coaching, 19 (2024) 745-756.
29. R.P. Wells, Assessment of signal and noise in the kinematics of normal, pathological and sporting gaits, in: Proc. Special Conf. Can. Soc. Biomech., 1980, pp. 92-93.
30. R. Hayashi, Y. Kariyama, K. Zushi, Comparison of loads and characteristics of lower extremity joint kinetics during clean exercises, Japanese Journal of Physical Fitness and Sports Medicine, 65 (2016) 243-254.
31. Y. Manabe, T. Yokozawa, M. Ogata, Effect of movement variation on lower limb muscle activity and joint torque during squat, Japanese Journal of Physical Fitness and Sports Medicine, 53 (2004) 321-336.
32. M. Murata, N. Fujii, Differential rotation in tennis serve focusing on upper limbs and upper torso, Physical Education Research, 59 (2014) 413-430.
33. N. Numazu, N. Fujii, M. Koido, A kinematic study of the diving motion for a shot ball in soccer goalkeepers: Focusing on shots that fly far from the goalkeeper, Physical Education Research, 64 (2019) 647-664.