Journal of Science in Sport and Exercise
https://doi.org/10.1007/s42978-024-00276-x

REVIEW ARTICLE

The Role of Upper Body Motions in Stationary Ball-Kicking Motion: A Systematic Review

Junze Chen[1,2] · Kerry Peek[1] · Ross Howard Sanders[3] · Jack Lee[3,4] · Johnson Chun Yiu Pang[5] · Kanchana Ekanayake[6] · Allan Chak Lun Fu[1]

Received: 26 August 2023 / Accepted: 4 January 2024

Abstract

A ball-kicking motion requires a coordinated sequencing of all body segments for maximum ball release speed. Evidence of the role of upper body rotations and motor coordination during a ball-kicking motion is inconsistent among existing evidence. This study aimed to systematically review the role of upper body rotations on all modes of ball kicking and performance metrics. A comprehensive search of seven electronic databases from the inception was conducted. Studies reporting on the relationships between upper body rotation, and ball-kicking performance were included. From 1486 potentially relevant studies, we analysed 27 studies involving 457 participants. These studies encompassed instep soccer kicks ($n=21$), inside-of-the-foot soccer kicks ($n=1$), rugby place kicks ($n=4$) with a stationary ball, and a volley kick ($n=1$). Methodological quality assessment was performed using Standard Quality Assessment Criteria. Our results provide moderate evidence that increasing thoracolumbar rotations along the longitudinal axis and the transverse plane can enhance ball-releasing velocity through a "whip-like effect" based on the kinetic link principle. However, to gain a comprehensive understanding, further research is needed to explore the effects of timing and the ranges of motion of all relevant upper and lower body segments on ball release velocity and its potential influence on ball release accuracy. The current coaching manuals do not emphasise the significance of upper body rotation, indicating a pressing requirement for revisions in training guidelines to enhance ball-kicking performance.

Keywords Biomechanics · Kinetics · Performance · Training · Kicking · Coaching

Introduction

Kicking is a fundamental movement skill and is highly prevalent and essential in many sports, including soccer, rugby, American Football and Australian Rules Football [15]. Kicking motion in all types of sports is a skill used to score goals or points, which necessitates the generation of a high ball-releasing velocity [32]. Kicking performance is evaluated by ball release velocity [39] and accuracy [18]. Previous research has focused predominantly on the kinematics of the lower body [29, 35, 38], and the recommended instruction for coaching the upper-body motion is limited [15]. With the increasing number of recent kicking biomechanics studies, it is worth reviewing the necessity of adding an upper body rotation technique.

From a biomechanics perspective, generating high ball release velocities can be explained in terms of the kinetic link principle, where angular momentum is sequentially transferred from proximal to distal body segments.

✉ Allan Chak Lun Fu
allan.fu@sydney.edu.au

1 Discipline of Physiotherapy, School of Health Sciences, Faculty of Medicine and Health, The University of Sydney, Level 7, Susan Wakil Health Building D18, Sydney, NSW 2006, Australia

2 RECOVER Injury Research Centre, The University of Queensland, Brisbane, QLD, Australia

3 Discipline of Exercise and Sport Science, School of Health Sciences, Faculty of Medicine and Health, The University of Sydney, Sydney, NSW, Australia

4 School of Allied Health, Human Services & Sport, La Trobe University, Melbourne, Australia

5 School of Health Sciences, Caritas Institute of Higher Education, Hong Kong SAR, China

6 The University of Sydney Library, Sydney, NSW, Australia

Although kicking performance includes accuracy [18] consistently, the kinetic link principle cannot account for this definition of kicking performance; instead, it explains a coordinated sequencing of body segments to produce a high ball release velocity. From a sports coaching perspective, descriptions of the kicking skill [15] typically indicate that torque at the hip joint initiates the motion [35], followed by the peak extension of the ipsilateral knee joint [38], rather than from rotational motions of the upper body. These lower limb motions are explained by mathematical equations [2, 38] that indicate the transfer of angular velocities from the thigh to the shank (or lower leg) to generate a high foot velocity at ball impact. Foot velocity is further noted as the most significant predictor of ball release velocity [2, 9, 17]. However, the origin of the angular velocity of the hip action remains unclear. Thus, upper body segment motions should be considered (in addition to other body motions such as the action of supporting leg) to ascertain their contribution to prestrike foot velocity and, thus, ball release velocity in this review.

The kicking motion has already been defined as a 'whip-like' motion. The application of the kinetic link principle in biomechanics analysis is evident in studies examining other 'whip-like' motions, such as overarm throws [16, 19]. The angular momentum from upper torso rotation is sequentially transferred to the upper chest, upper arm, lower arm and hand to generate a maximum ball release velocity [19]. The possibility and its impact of an angular velocity transferred from the upper to the lower body segments in kicking warrants investigation.

The role of the upper body transferring angular momentum to the hip and knee joints during the kicking motion has been explored in previous studies [18, 32]. However, due to a variety of variables and differing definitions of the body segments involved, the contributions of the upper body segments remain unexplored in the current guideline [15, 21]. Thus, this systematic review aimed to synthesise findings in the extant literature from seven major sports science research databases to explore the role of upper body rotations in optimising kicking skills.

Methods

A predefined systematic review protocol was registered with the PROSPERO International Prospective Register of Systematic Reviews (registration ID: CRD42020176108). The review was conducted and reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [31].

Literature Identification

An initial systematic search of existing literature was conducted using the combined keywords 'All ball kicking sports AND Kick AND Upper body' (Appendix 1). These keywords were generated in consultation with a specialist librarian to locate literature that explored the role of upper body rotations in kicking performance outcomes. Comprehensive searches were conducted on MEDLINE, CINAHL, SPORTDiscus, Web of Science, PUBMED, SCOPUS and EMBASE from the first record to 30th October 2023. Additional studies that met the inclusion criteria were identified from the reference lists of the included studies from the database search.

Inclusion Criteria

We included original research reporting on the relationship between upper body kinematics (segments above the hip) and ball kicking performance. We also included participants' characteristics, including the type of sport, sex, age, health status, playing status of participant and languages. Studies reporting on the coordination patterns of the upper body during ball kicking, coaching and/or training applications, as well as adverse effects were included.

Exclusion Criteria

We excluded research reporting outcomes not related to the application of upper body rotation training on athletes such as robotic prototypes, muscle strength, or cross-sectional area, the lower extremity (segments including only the hip or below the hip). We also excluded editorials, conference papers, systematic reviews or unpublished studies without a peer-review process.

The title, abstract and full-text screening of the retrieved papers was independently conducted by three authors (AF, JL and JC) based on the inclusion and exclusion criteria. The final review of all included studies was then conducted by all authors. Any discrepancies were addressed through discussion with all authors.

Methodological Quality Assessment

The quality of each included study was assessed independently by three authors (AF, JL and JC) using an assessment checklist specifically designed for this review (Table 1 and Appendix 2). This checklist was modified based on the Standard Quality Assessment Criteria [26]. Items 1, 2, 4, 5, 6, 7, 9, 10, 12 and 13 were included from the existing list. Subsections were created within items 4, 5 and 6 and items 3, 8 and 11 were added to make this checklist specifically relevant towards biomechanical analysis in ball kicking motions. A score of 0 was given for each item when the corresponding criterion was not met, and a score of 2 when the criterion of the item was met fully. A score of 1 was given for each item when the information was reported partially and required interpretation or prior understanding. A total score of 80% or higher in a study indicated a high-quality study, as the methods used were considered reproducible to answer the intended research question. Any discrepancies in scoring were resolved through discussion by all authors.

Data Extraction

Data extraction was undertaken by AF, JL and JC, with all authors checking for accuracy. Data extracted were the year of publication, the purpose of the study, mode of kicking, participant characteristics (age, sex, skill level), study design and methods, alongside the main finding (Table 2).

Data synthesis and Analysis

Due to the heterogeneity of included studies in terms of study methodology and analysis of joints and segments, a meta-analysis would be potentially misleading. Thus a narrative synthesis of the results was presented. The findings of the kicking motion in differing sports were discussed separately due to variances in ball size, mass and shape, as well as differences in kicking technique. Where reported, for each study, results were considered significant if the reported p-value was less than their stated critical p-value.

Results

Of the initial 1486 papers, 27 papers were deemed eligible for inclusion (Fig. 1) [3, 5, 7, 10, 12, 13, 20, 22–25, 27, 28, 32, 33, 36, 41–49, 51, 52] and a total of 457 participants included. The included papers involved the motion of the instep soccer kick ($n=21$), the inside-of-the-foot soccer kick ($n=1$), the rugby place kick ($n=4$) with a stationary ball, and volley kick ($n=1$). These papers analysed head ($n=2$), upper torso ($n=3$), thoracolumbar spine ($n=19$), pelvic ($n=19$), shoulder ($n=7$) and elbow ($n=6$) (Table 2). No eligible studies involving other sports including Australian Rules Football, and American Football were located. Participants in the included papers ranged from having no experience to professional athletes, allowing for a demonstration of a wide scope that distinguishes skill differences. None of the included studies studied the use of upper body rotation in coaching applications. A detailed summary of the results from each study is presented in Table 2.

Methodological Quality Assessment

The quality assessment of the papers is reported in Table 1. All studies were included in the review regardless of methodological quality, acknowledging their research contributions. Seven studies, with high-quality scores, directly referred to the kinetic link principle using appropriate biomechanical definitions [3, 5, 7, 9, 10, 13, 32, 41]. All included studies except three used three-dimensional data capture and analysis techniques. In the four studies [13, 27, 36, 42], two digital cameras with orthogonal views were used to investigate the planar motions of participants from the front and side views.

Relationship Between Upper Body and Lower Body Rotations

The transfer of angular momentum from proximal to distal body segments is presented based on the kinetic link principle. Nine studies of the instep soccer kick [10, 13, 23, 25, 24, 32, 33, 41, 48] indicated that thoracolumbar rotation due to muscle moments about the longitudinal [13, 25, 28, 32, 33, 41] or transverse [10, 13, 23, 24, 28, 33, 48] axes resulted in a transfer of angular motion to the thigh and shank segments, with their respective segmental velocity magnitudes positively correlated. Langhout et al. [24] reported that during the leg-cocking phase, increasing the maximal range of thoracolumbar extension combined with non-kick side shoulder overhead extension motion produces a powerful tension arc which assists in the acceleration of hip flexion by the transference of angular momentum. This finding is supported by Langhout et al. [25], Smith et al. [48] and Carvalho et al. [13] that as the magnitude of the thoracolumbar rotation on the transverse axis increased, an increase in the range of motion of leg back swing accelerates hip flexion, which produces a maximum “whip-like effect”. This, in turn, resulted in an increased acceleration in knee extension [24, 32] in the leg-acceleration phase. Further, Augustus and colleagues [5, 7] concluded that the pelvis plays a pivotal role in generating transverse momentum to the kicking leg, and a strong relationship was demonstrated between change in pelvis transverse angular velocity and thigh-knee angular velocity upon ball contact. In contrast, the study conducted by Orloff et al. [36] revealed no significant impact of thoracolumbar angle on hip and knee joint angles. When the soccer ball was elevated for a volley kick, notable changes were observed for both the pelvis and the leg segments: there was an increase in pelvis clockwise rotation, a decrease in left hip linear velocity, a reduction in hip/knee flexion, and an increase in hip internal rotation [49].

For rugby place kicks, Bezodis et al. [12] reported that an increase in non-kick-side arm angular momentum about

Table 1 Methodological quality assessment checklist for included studies

	Assessment checklist	Atack et al., 2019 [3]	Augustus et al., 2017 [5]	Augustus et al., 2022 [7]	Bertozzi et al., 2022 [10]	Bezodis et al., 2007 [12]	Carvalho et al., 2021 [13]	Fullenkamp et al., 2015 [20]	Green et al., 2016 [22]	Juarez et al., 2011 [23]	Langhout et al., 2016 [24]	Langhout et al., 2017 [25]	Lees and Nolan., 2002 [27]	Lees et al., 2005 [28]
1	Is the question/objective sufficiently described?	2	2	2	2	1	2	2	2	2	1	1	2	2
2	Study design evident and appropriate	2	2	2	2	1	2	2	1	1	2	1	1	1
3	Connection to a theoretical framework/wider body of knowledge	2	2	2	1	2	2	2	2	1	2	1	2	2
4	Are subject characteristics sufficiently described?													
4.1	Age	2	2	2	2	2	2	2	2	2	2	1	0	2
4.2	Gender	2	2	2	2	2	2	2	0	0	2	0	0	2
4.3	Sport specific experience	1	2	2	2	2	2	2	2	2	2	2	2	2
5	Are data collection methods appropriate and clearly described?													
5.1	Type of motion capture	2	2	2	2	2	2	2	2	2	2	2	0	2
5.2	Location of body markers (upper body included)	2	2	2	2	1	2	2	1	2	2	2	2	2
5.3	Research protocol (including warm-up)	2	2	2	1	1	2	1	1	1	2	2	2	1

Table 1 (continued)

	Assessment checklist	Atack et al., 2019 [3]	Augustus et al., 2017 [5]	Augustus et al., 2022 [7]	Bertozzi et al., 2022 [10]	Bezodis et al., 2007 [12]	Carvalho et al., 2021 [13]	Fullenkamp et al., 2015 [20]	Green et al., 2016 [22]	Juarez et al., 2011 [23]	Langhout et al., 2016 [24]	Langhout et al., 2017 [25]	Lees and Nolan., 2002 [27]	Lees et al., 2005 [28]
5.4	Were subjects blinded and is it reported?	0	0	0	0	0	0	0	0	0	0	0	0	0
6	Data analysis method is clearly described and appropriate													
6.1	Use of correct biomechanical definitions	2	2	2	1	1	2	1	1	1	1	1	1	1
6.2	Axes of rotation/planes of motion defined	2	1	2	2	1	2	1	1	1	1	1	2	2
6.3	Analysis of upper body	2	1	1	2	1	1	1	1	1	1	1	2	1
7	Are confounders identified and controlled?	1	1	1	1	1	1	1	1	1	1	0	1	1
8	Is the data processing protocol described and applicable?	2	2	2	2	2	2	1	1	1	2	1	1	1
9	Some estimate of variance is reported for the main results	2	2	2	2	2	1	1	2	2	2	2	2	2

Table 1 (continued)

	Assessment checklist	Atack et al., 2019 [3]	Augustus et al., 2017 [5]	Augustus et al., 2022 [7]	Bertozzi et al., 2022 [10]	Bezodis et al., 2007 [12]	Carvalho et al., 2021 [13]	Ful-lenkamp et al., 2015 [20]	Green et al., 2016 [22]	Juarez et al., 2011 [23]	Langhout et al., 2016 [24]	Langhout et al., 2017 [25]	Lees and Nolan., 2002 [27]	Lees et al., 2005 [28]
10	Number of participants sufficient to draw conclusions	1	1	1	1	1	1	1	1	1	1	1	0	1
11	Statistical analysis is described, appropriate and sufficiently powered	1	2	2	2	1	1	1	1	2	1	1	2	1
12	Results reported in sufficient detail?	2	1	2	2	2	2	2	2	2	2	1	2	1
13	Conclusions supported by data	2	2	2	2	1	2	2	1	2	2	1	1	1
	Total (*n*) Total (%)	34 85%	33 83%	36 90%	33 83%	27 68%	35 88%	29 73%	25 63%	27 68%	31 78%	22 55%	25 63%	28 70%

		Naito et al., 2010 [32]	Naito et al., 2012 [33]	Orloff et al., 2008 [36]	Scurr and Hall, 2009 [42]	Sakuma et al., 2020 [41]	Shan et al., 2005 [45]	Shan and Westerhoff, 2005 [44]	Shan, 2009 [43]	Shan et al., 2012 [46]	Smith et al., 2006 [48]	Smith and Gilleard, 2016 [47]	Sugi et al., 2022 [49]	Zago et al., 2014 [51]	Zhang et al., 2012 [52]
1	Is the question/objective sufficiently described?	2	2	1	2	2	2	2	2	2	2	2	2	1	2
2	Study design evident and appropriate	1	1	1	2	2	2	1	2	1	1	2	2	2	1
3	Connection to a theoretical framework/wider body of knowledge	2	2	2	1	2	1	2	1	1	2	1	2	2	1
4	Are subject characteristics sufficiently described?														

Table 1 (continued)

		Naito et al., 2010 [32]	Naito et al., 2012 [33]	Orloff et al., 2008 [36]	Scurr and Hall, 2009 [42]	Sakuma et al., 2020 [41]	Shan et al., 2005 [45]	Shan and Westerhoff, 2005 [44]	Shan, 2009 [43]	Shan et al., 2012 [46]	Smith et al., 2006 [48]	Smith and Gilleard, 2016 [47]	Sugi et al., 2022 [49]	Zago et al., 2014 [51]	Zhang et al., 2012 [52]
4.1	Age	2	2	2	2	2	2	2	2	2	2	2	2	2	0
4.2	Gender	0	0	2	2	2	2	2	2	2	2	2	2	2	0
4.	Sport specific experience	2	2	2	2	2	2	1	2	2	2	2	2	1	0
5	Are data collection methods appropriate and clearly described?														
5.1	Type of motion capture	2	2	0	0	2	2	2	2	2	2	1	2	2	2
5.2	Location of body markers (upper body included)	2	2	1	2	2	2	2	2	2	1	2	2	1	2
5.	Research protocol (including warm-up)	2	1	1	2	2	1	1	2	2	1	1	1	2	1
54	Were subjects blinded and is it reported?	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	Data analysis method is clearly described and appropriate														
6.1	Use of correct biomechanical definitions	2	2	1	1	2	1	1	1	2	1	2	1	2	2
6.2	Axes of rotation/planes of motion defined	2	2	1	1	1	0	1	1	1	1	1	2	2	1
6.3	Analysis of upper body	2	1	1	1	2	1	1	1	1	1	1	1	1	1

Table 1 (continued)

		Naito et al., 2010 [32]	Naito et al., 2012 [33]	Orloff et al., 2008 [36]	Scurr and Hall, 2009 [42]	Sakuma et al., 2020 [41]	Shan et al., 2005 [45]	Shan and Westerhoff, 2005 [44]	Shan, 2009 [43]	Shan et al., 2012 [46]	Smith et al., 2006 [48]	Smith and Gilleard, 2016 [47]	Sugi et al., 2022 [49]	Zago et al., 2014 [51]	Zhang et al., 2012 [52]
7	Are confounders identified and controlled?	1	1	1	0	1	0	1	1	1	2	2	1	1	1
8	Is the data processing protocol described and applicable?	2	2	1	1	2	1	1	2	2	1	2	1	2	2
9	Some estimate of variance is reported for the main results	2	2	1	2	2	1	1	1	2	2	1	2	1	1
10	Number of participants sufficient to draw conclusions	1	1	1	1	1	1	1	1	1	1	1	1	1	1
11	Statistical analysis is described, appropriate and sufficiently powered	1	1	1	1	2	1	1	1	1	1	1	1	1	1
12	Results reported in sufficient detail?	2	2	2	1	1	1	1	1	1	2	2	1	2	1
13	Conclusions supported by data	2	2	1	2	1	1	1	2	2	1	1	2	1	1
	Total (*n*)	32	30	23	26	33	24	25	29	30	28	29	30	29	21
	Total (%)	80%	75%	58%	65%	81%	60%	63%	73%	75%	70%	73%	75%	73%	53%

Listed by alphabetically by mode of kicking

Maximum total = 40

the transverse and longitudinal axes increased maximal kicking leg angular velocity later in the kicking cycle in support of the kinetic link principle. Green et al. [22] investigated rotations about the longitudinal axis, reporting that with an increase in the magnitude between the thorax and pelvic rotations (when viewed from above the head), thorax rotation and head rotation, the ball kicking distance increased. Although this finding implies that the kinetic link principle applied to the transference of angular momentum to the lower body, this was not directly examined. Atack et al. [3] found that kickers boasting a maximum placement kick distance beyond the international average (i.e., > 32 m) exhibited lower accuracy, attributed to a tension arc across their torso. This phenomenon resulted in heightened positive hip flexor joint exertion during the downward swing compared to their more accurate counterparts. Additionally, Zhang et al. [52] reported in the rugby place kick that lateral pelvic tilt towards the standing leg (1.2 m/s) and posterior rotation (0.3 m/s) played a significant role in the speed of foot movement during hip extension to hip flexion (1.6 m/s) and during knee flexion to knee extension (9.1 m/s). This observation highlights the transference of angular momentum from proximal to distal body segments.

Relationship Between Upper Body Rotations and Ball Release Velocity

Thoracolumbar rotations about the longitudinal axis were reported to have had a direct correlation with ball release velocity from an instep soccer kick following the kinetic link principle [20, 27, 41–47]. Fullenkamp et al. [20] found that individuals with a background in organised soccer experience, on average, have 53% more thoracolumbar ROM and 62% higher peak thoracolumbar rotation velocity than those with no soccer experience, which has a moderate, positive correlation with the ball velocity ($r = 0.57$, $P < 0.01$). On the other hand, although Lees et al. [28] reported that thoracolumbar rotations on the longitudinal and transverse axes followed classical proximal-to-distal temporal sequencing by transferring its angular velocity to the hip, knee and foot joints sequentially, there was no direct correlation with ball release velocity. Thus, there was no clear evidence that shoulder rotations or hip rotations on the longitudinal axis were related to ball release velocity or accuracy. Additionally, Scurr and Hall [42] reported that despite the magnitude of pelvic rotations about the longitudinal axis being greater in the 45° and the 60° approach angle conditions than in the self-selected approach angle ($P < 0.05$), there was no significant difference in ball release velocity ($P = 0.59$) between approach angles. When examining the transverse axis, thoracolumbar flexion and extension accounted for variances in ball release velocity [27, 41, 43–45]. A more recent study by Atack et al. [4] found that the width of the approach and a more forward body position can result in higher foot and ball velocities.

Participants performing the instep soccer kick with faster ball velocity exhibited an increase in the magnitude of thoracolumbar rotations about the longitudinal and transverse axes [20, 27, 43–46], leading to a greater ball release velocity when compared to novice participants. The selection of the preferred leg also plays a significant role. According to Shan and colleagues [45], greater ball release velocity was associated with the dominant foot, primarily due to an amplified magnitude of thoracolumbar rotations around both the longitudinal and transverse axes.

Discussion

This systematic review synthesised evidence on the role of upper body rotations in relation to the lower body and optimising kicking skills. Our findings revealed a clear relationship between upper body rotations and the lower body with kicking motion following the kinetic link principle. Most of the evidence was provided by studies of the instep soccer kick [5, 7, 10, 13, 20, 23–25, 28, 27, 32, 33, 36, 41–49], with additional supporting insights provided by studies of the rugby place kick [3, 12, 22, 52]. The thoracolumbar rotations along both the longitudinal and transverse axes amplify the magnitude of hip extension and enhance ball-release velocity.

Extant coaching literature indicates that the kicking motion is initiated at the hip joint [15], with angular momentum sequentially transferred to the thigh, shank and foot [38]. This review provides evidence that upper body motions should also be considered in the transfer of motion from proximal to distal body segments. Established definitions that indicate that hip extension initiates the kicking motion should now be expanded to indicate that the magnitude of hip extension is a consequence of the transfer of motion from thoracolumbar rotations about both the longitudinal [3, 12, 20, 22, 25, 27, 32, 33, 41–47, 52] and transverse axes [12, 13, 24, 27, 33, 43–45, 48]. This finding expands the application of the kinetic link principle applied to the kicking motion and thus has implications for coaching to improve kicking performance. However, an examination of segmental sequencing by evaluating the time of the maximum angular velocity or energy-flow analysis of all involved joints and body segments is required to fully establish a whole-body model of instep kicking performance [6, 13].

Lees and colleagues [29]underscored the significance of integrating temporal sequencing with fundamental biomechanical principles, encompassing factors like range of motion, the stretch–shortening cycle, end-point velocity, and the dynamics of action and reaction. A comprehensive understanding of these concepts not only allows for a

Table 2 Abridged summary of records screened in the systematic search. Listed by alphabetically by mode of kicking

Author, year	Purpose of study relevant to aim	Mode of kicking	Upper body joints and segments analysed	Performance (outcomes) discussed	Instrumentation	Sample	Main finding (relating to the upper body)
Atack et al., 2019 [3]	To identify differences in thoracolumbar mechanics alongside skill levels	Rugby place kick	• Thoracolumbar • Rotation • Pelvic • Rotation	Kinematics kinetics	• Vicon MX3 system (measurement accuracy of 0.0009 m) (240 Hz) • 80 markers to define a 14-segment human-body model • Kistler 9287BA force platform (960 Hz) to measure ground reaction force (GRF)	• $n = 33$ • Gender: Male • Age: 22 ± 4 years • Height: 1.82 ± 0.06 m • Mass: 86.2 ± 8.8 kg • Experience: Amateur-international	Increasing pelvis-thorax separation angle (the difference in angles of the pelvis and thorax about the longitudinal axis) during the downswing phase increased foot and ball release velocities, but negatively affected the ability of the hip to control the direction of the foot trajectory and thus reduced accuracy
Augustus et al., 2017 [5]	Assess if a Technique Refinement Intervention that increases vertical hip displacement in the kicking stride enhances maximal instep kick performance	Instep soccer kick	• Pelvic • Rotation • Tilt	Kinematics kinetics	• The ball was placed so that the planted foot landed on a Kistler 9821B force platform (Kistler Instruments, Hook, UK), which collected ground reaction forces at 1000 Hz. • The force platform was synchronised electronically with a 10-camera optoelectronic motion analysis system (250 Hz) (Vicon T40S, Vicon Motion Systems, Oxford, UK). A Casio Exilim EX-FH20 (Casio Ltd, Tokyo, Japan) digital camera (210 Hz) was used • 24 passive reflective markers (12.6 mm diameter) were attached to selected lower limb landmarks	• $n = 9$ • Gender: Male • Age: 23.7 ± 3.8 years • Height: 1.82 ± 0.06 m • Mass: 78.5 ± 6.1 kg • Experience: senior amateur or semi-professional level (experience 14.7 ± 3.8 years)	Greater active contraction and extension of the planted leg musculature during the kicking stride may facilitate power flow across the pelvis and passive acceleration of the lower leg to maximise foot linear and angular velocities at ball impact

Table 2 (continued)

Author, year	Purpose of study relevant to aim	Mode of kicking	Upper body joints and segments analysed	Performance (outcomes) discussed	Instrumentation	Sample	Main finding (relating to the upper body)
Augustus et al., 2022 [7]	To examine relationships between pelvis and kick leg rotations in male players performing soccer instep kicks and to classify different 'types' of kickers based on the observed movement strategies	Instep soccer kick	• Pelvic • Rotation	Kinematics	• A 10-camera, opto-electronic 3D motion analysis (Vicon T40S, Oxford, UK) at 1000 Hz • Reflective markers defined the position and orientation of seven segments (bilateral feet, shanks, thighs and pelvis) using a direct kinematic (six degrees of freedom at each joint) approach	• $n = 20$ • Gender: Male • Age: 23.8 ± 4.0 years • Height: 1.80 ± 0.10 m • Mass: 79.0 ± 7.5 kg • Experience: Semi-professional (least 10 years of experience)	A strong relationship was found between change in pelvis transverse angular velocity and thigh-knee angular velocity ratio upon ball contact ($r = 0.76$, $P < 0.001$)
Bertozzi et al., 2022 [10]	To analyse the effects of the ball approach angle and the foot used on the whole-body kinematics of soccer players performing an instep kick	Instep soccer kick	• Pelvic • Anteversion/ retroversion • Thoracolumbar • Flexion/Extension • Shoulder • Flexion/Extension • Adduction /abduction • Elbow • Flexion/Extension	Kinematics	• Forty-five spherical (diameter: 15 mm) reflective markers were positioned • Six markers were placed equally spaced on the ball • three-dimensional position was collected during the protocol with a 9-camera opto-electronic system at 60 Hz (BTS Bioengineering, Milan, Italy)	• $n = 24$ • Gender: 6 female; 18 male • Age: 20.7 ± 1.7 years • Height: 1.74 ± 0.075 m • Mass: 66.7 ± 8.5 kg • Experience: experienced non-professional level (13.8 ± 2.3 years; practice sessions per week: 2.7 ± 0.8)	A significant effect was revealed in some parts of the kicking action for body CoM vertical position and velocity, trunk flexion/extension angle, and support side shoulder adduction/ abduction angle CoM vertical position and pelvis anteversion values were higher when kicking with the dominant foot. In contrast, the support side elbow was more flexed, and the shoulder was more adducted in some segments when kicking with the non-dominant foot

Table 2 (continued)

Author, year	Purpose of study relevant to aim	Mode of kicking	Upper body joints and segments analysed	Performance (outcomes) discussed	Instrumentation	Sample	Main finding (relating to the upper body)
Bezodis et al., 2007 [12]	To investigate non-kick side arm motion during kicking with an accuracy and distance requirement	Rugby place kick	• Arm • Rotation • Flexion/Extension • Abduction/Adduction	Kinematics kinetics	• 8-camera ViconTM 612 motion analysis system (Oxford Metrics Ltd., Oxford, UK) (120 Hz) • 39 spherical markers (diameter = 12.5 mm) attached to specific anatomical landmarks • 2 further 50 Hz digital video cameras (Sony, DCR TRV-900E) were placed in front of the kicker	• $n = 5$ • Gender: Male • Age: 20.6 ± 2.7 years • Height: 1.81 ± 0.09 m • Mass: 80.2 ± 7.7 kg • Experience: First-team university with 5 years kicking experience	All kickers possessed minimal non-kick-side arm angular momentum about the global medio-lateral axis. The more accurate kickers exhibited greater non-kick-side arm angular momentum about the global antero-posterior and longitudinal axes. With an additional distance requirement, all kickers exhibited greater non-kick-side arm angular momentum about the global longitudinal axis
Carvalho et al., 2021 [13]	To investigate the angular kinetic energy transfers and expenditure among the trunk (bisegmented), the pelvis and the kick limb during maximal soccer instep kicking, and to characterize kicking kinetics and kinematics	Instep soccer kick	• Thoracolumbar • Flexion/Extension • lumbo-pelvic • Tilt	Kinematics kinetics	• 4 camera three-dimensional motion analysis system Codamotion (Charnwood Dynamics, Rothley, England) • 33 active tracking markers attached to body landmarks + 1 active tracking marker was attached to the ground and below the ball • OR6-6 force platform (Advanced Mechanical Technology Inc.—AMTI, Watertown, USA)	• $n = 18$ • Gender: Male • Age: 24.0 ± 4.1 years • Height: 1.73 ± 0.07 m • Mass: 69.57 ± 10.5 kg • Experience: amateur level (least eight years of experience)	There was a concentric extension moment at the lumbo-pelvic joint, with an input of energy to the lower trunk, which was partly transferred to the upper trunk by the eccentric moment at the extending thoraco-lumbar joint

Table 2 (continued)

Author, year	Purpose of study relevant to aim	Mode of kicking	Upper body joints and segments analysed	Performance (outcomes) discussed	Instrumentation	Sample	Main finding (relating to the upper body)
Fullenkamp et al., 2015 [20]	To establish the relationship of thoracolumbar rotation to ball release velocity	Instep soccer kick	• Thoracolumbar • Rotation	Kinematics	• 10-camera passive, optical high-resolution 3D motion analysis system (Motion Analysis Corporation, Santa Rosa, CA) (120fps) • 60 retro-reflective markers (diameter = 1.25 cm)	• $n = 20$ • Gender: Male • Age: 21.8 ± 2.7 years • Height: 1.793 ± 0.057 m • Mass: Not specified • Experience: Novice, skilled	Skilled participants used 53% greater thoracolumbar range of motion (ROM) and 62% greater peak thoracolumbar rotation velocity compared to the novice participant, accounting for increased ball release velocities ($P < 0.01$)
Green et al., 2016 [22]	To determine the relationship between kicking accuracy and rotational kinematics	Rugby place kick	• Thoracic • Rotation • Thoracolumbar junction • Flexion/Extension • Lateral Bend • Pelvic • Rotation • Elbow • Flexion/Extension • Arm • Abduction/Adduction • Head • Rotation • Flexion/Extension	Kinematics	• 18-camera system Optitrack flex: V100r2 (Natural Point Inc., Corvallis, Oregon, USA) (100 Hz)	• $n = 12$ • Gender: Not specified • Age: 22 ± 3 years • Height: 1.79 ± 0.06 m • Mass: 89 ± 2 kg • Experience: First-team university	The current study showed a positive correlation between torso ($r = 0.76$) and pelvis ($r = 0.66$) rotation with kick distance. Place kick distance ($r = 0.24$) or accuracy ($r = 0.54$) were not correlated to playing experience. Negative correlations between stance elbow flexion ($r = -0.78$), torso rotation ($r = -0.74$) and X-factor ($r = -0.79$) with kick accuracy were noted
Juarez et al., 2011 [23]	To describe the kinematic pattern of the kicking movement by examining linear velocities and angular positions of the kick leg	Instep soccer kick	• Thoracolumbar • Flexion/Extension • Lateral Bend	Kinematics	• 6 camera three-dimensional motion-capture system (VICON Motion Systems, Oxford Metrics Ltd., Oxford, England) (250 Hz) • 31 reflective markers (diameter = 14 mm) attached to body landmarks	• $n = 21$ • Gender: Not specified • Age: 16.1 ± 0.2 years • Height: 1.77 ± 0.06 m • Mass: 67.7 ± 6.3 kg • Experience: Junior international	Significant ($P < 0.01$) differences were detected (at various critical timepoints) in the angular positions of the thoracolumbar region about the transverse axis as well as the non-kick-side arm between participants. No significant differences in the angular position of the thoracolumbar region were observed about the longitudinal axis

Table 2 (continued)

Author, year	Purpose of study relevant to aim	Mode of kicking	Upper body joints and segments analysed	Performance (outcomes) discussed	Instrumentation	Sample	Main finding (relating to the upper body)
Langhout et al., 2016 [24]	To describe duration and relative timing of the phases of kicking with respect to maximal ROM, angular acceleration and velocity of body segments	Instep soccer kick	• Thoracolumbar • Flexion/Extension • Shoulder • Flexion/Extension • Pelvic • Rotation • Tilt	Kinematics	• 3D motion-capture system with 8 infrared (IR) cameras (VICON Motion Systems, Oxford Metrics Ltd., Oxford, England) (200 Hz) and 2 high-speed digital video (DV) cameras (Basler AG, Ahrensburg, Germany) (100 Hz) • 31 reflective markers (diameter = 14 mm) attached to body landmarks according to VICON's full body model	• $n = 20$ • Gender: Male • Age: 22.1 ± 5 years • Height 1.81 ± 0.09 m • Mass: 80.8 ± 8.42 kg • Experience: Semi-professional, professional	Increased maximal ROM of thoracolumbar extension and non-kick side shoulder extension assists in the acceleration of hip flexion during the leg-cocking phase and a deceleration of hip flexion and acceleration of knee flexion during the leg-acceleration phase
Langhout et al., 2017 [25]	To examine ROM of body segments during the phases of maximal and sub-maximal kicking	Instep soccer kick	• Thoracolumbar • Rotation • Flexion/Extension • Pelvic • Rotation • Tilt	Kinematics	• 3D motion-capture system with 8 infrared (IR) cameras (VICON Motion Systems, Oxford Metrics Ltd., Oxford, England) (200 Hz) and 2 high-speed digital video (DV) cameras (Basler AG, Ahrensburg, Germany) (100 Hz) • 31 reflective markers (diameter = 14 mm) attached to body landmarks according to VICON's full body model	• $n = 15$ • Gender: Not specified • Age: 22.1 ± 5 years • Height 1.81 ± 0.09 m • Mass: 80.8 ± 8.42 kg • Experience: Professional	Increased thoracolumbar rotation increased hip extension and knee flexion velocity

Table 2 (continued)

Author, year	Purpose of study relevant to aim	Mode of kicking	Upper body joints and segments analysed	Performance (outcomes) discussed	Instrumentation	Sample	Main finding (relating to the upper body)
Lees and Nolan, 2002 [27]	To investigate changes in kinematic characteristic of the stationary instep soccer kick under a speed-accuracy paradigm	Instep soccer kick	• Thoracolumbar • Flexion/Extension • Lateral Bend • Pelvic • Rotation	Kinematics kinetics	• 2 cine cameras (100 Hz) placed with their optical axes at approximately 90° to each other • 18 body landmarks used to reconstruct 3D motion using standard DLT procedures	• $n=2$ • Gender: Not specified • Age: Not specified • Height: Not specified • Mass: Not specified • Experience: Professional	Increasing range of rotation between the pelvis and shoulder lines generated a greater ball release velocity. A reduction in ball release velocity of 6 m/s was seen alongside a reduction in all peak linear and angular joint velocities when an accuracy requirement was introduced
Lees et al., 2005 [28]	To quantify the 3D kinematic characteristics of the kicking leg, trunk and upper body during the maximal instep soccer kick	Instep soccer kick	• Thoracolumbar • Flexion/Extension • Lateral Bend • Shoulder • Tilt • Pelvic • Rotation • Tilt	Kinematics	• 6-camera Pro Reflex automatic motion analysis system (Qualysis, Savedalen, Sweden) located in an indoor laboratory (240 Hz) • 16 reflective markers placed on the player's joints that defined a 12-segment biomechanical model	• $n=8$ • Gender: Male • Age: 20.6 years • Height: 1.799 m • Mass: 72.8 kg • Experience: Specified as 'experienced'	All joints showed temporal patterning of velocity peaks in a classical proximal-to-distal sequencing. Thoracolumbar lean and flexion/extension remained upright throughout the kicking motion. However, ball release velocity did not correlate with the angular ROM of the hips or the shoulders. Thus, there is no clear evidence that hip and shoulder rotation or pelvic retraction are related to performance
Naito et al., 2010 [32]	To quantify the contributions of the causal dynamical factors to the production of maximum angular velocity during knee extension	Instep soccer kick	• Thoracolumbar • Rotation	kinetics	• 3D motion capture system (Mac 3-D system, Motion analysis Inc., Santa Rosa, USA) • T10 cameras were used to track 24 reflective body markers (250 Hz)	• $n=9$ • Gender: Not specified • Age: 21.6 ± 1.9 years • Height 1.733 ± 0.049 m • Mass: 63.4 ± 8.2 kg • Experience: Collegiate	Thoracolumbar rotation muscular moment contributed 57.9% to maximum kicking knee extension angular velocity

Table 2 (continued)

Author, year	Purpose of study relevant to aim	Mode of kicking	Upper body joints and segments analysed	Performance (outcomes) discussed	Instrumentation	Sample	Main finding (relating to the upper body)
Naito et al., 2012 [33]	To develop a model to analyse energy redistribution and examine the mechanisms underlying the production of mechanical energy of the system during instep soccer kicking	Instep soccer kick	• Thoracolumbar • Rotation • Flexion/Extension • Lateral bend • Pelvic • Rotation	Kinematics kinetics	• 10 camera three-dimensional motion capture system (Mac 3D system, Motion Analysis Inc., Santa Rosa, USA) (250 Hz) • 24 reflective markers attached at the right and left lateral tips of the acromion processes of trunk, greater trochanter, the lateral epicondyle of the femur, the lateral malleolus and toe of both legs	• $n = 11$ • Gender: Not specified • Age: 21.5 ± 1.9 years • Height: 1.75 ± 0.049 m • Mass: 65.7 ± 7.5 kg • Experience: Collegiate (at least 8 years playing experience)	The instant of the peak values among the thoracolumbar region (about all axes), kicking thigh, shank and foot exhibited a proximal to distal sequential pattern. The kinetic energy of the thoracolumbar region was greatest at toe-off and decreased after toe-off until ball contact
Orloff et al., 2008 [36]	To compare kinetics and kinematics between male and female players during instep soccer kicking	Instep soccer kick	• Thoracolumbar • Flexion/Extension • Lateral bend	Kinematics	• 2 video cameras (60 Hz) • Markers placed on the shoulder, hip, and knee markers were placed over the estimated axis of rotation. From the posterior view, markers were placed on the upper (T1) and lower (L4) spine, shank, and on the heel	• $n = 23$ • Gender: Male (11) and female (12) • Age: 20.2 ± 1.2 years • Height: Not specified • Mass: Not specified • Experience: Amateur NCAA Division III collegiate (at least 10 years playing experience)	Males exhibited a thoracolumbar flexion/extension of 3° (± 8°) compared to the 13° (± 10°) flexion/extension of females which did not significantly impact the angle created by the plant leg

Table 2 (continued)

Author, year	Purpose of study relevant to aim	Mode of kicking	Upper body joints and segments analysed	Performance (outcomes) discussed	Instrumentation	Sample	Main finding (relating to the upper body)
Sakuma et al., 2020 [41]	To identify critical technical points that lead to increased ball speed in a maximal toe kick with no run-up (a 'static kick') in blind football	Instep soccer kick	• Head • Upper torso • Lower limb • Bilateral limb (arm, forearm, and hand)	Kinematics kinetics	• 6 Bonita motion capture cameras (Vicon Motion Systems Ltd., Oxford, UK) • 47 reflective spherical markers attached to body landmarks + 3 additional markers were attached to the surface of the ball	• $n = 6$ with visual impairment • Gender: Male • Age: 24.5 ± 9.1 years • Height: 1.70 ± 0.03 m • Mass: 69.0 ± 7.1 kg • Experience: 4.8 ± 5.2 years • $n = 8$ normal sighted individuals • Gender: Male • Age: 20.4 ± 1.4 years • Height: 1.73 ± 0.05 m • Mass: 67.9.0 ± 2.5 kg • Experience: 13.9 ± 2.3 years	increased kicking-side foot velocity during the static kick with fully removed visual information was the backwards- rotating movement of the torso to adequately extend the kicking-side hip joint during the back-swing phase. In addition, a stable posture of the lower torso on the frontal plane during the forward-swing phase was also important to increase the precision of the foot contact position on the ball
Scurr and Hall, 2009 [42]	To examine the effects of 3D kinematics and approach angle on kicking accuracy	Instep soccer kick	• Pelvic • Rotation • Tilt	Kinematics kinetics	• 2 digital cameras (Sony, TRV 900E) (50 Hz) at a shutter speed of 10 kHz for video recording • Markers attached to 6 anatomical landmarks on both sides of the body	• $n = 7$ • Gender: Male • Age: 26 ± 3 years • Height: 1.74 ± 0.06 m • Mass: 74.0 ± 6.8 kg • Experience: Amateur	No evidence to suggest that an increase in pelvic rotation or tilt was beneficial/detrimental towards ball release velocity ($P = 0.59$) or kicking accuracy ($P = 0.27$)
Shan et al., 2005 [45]	To reveal the effects of long-term training	Instep soccer kick	• Thoracolumbar • Rotation • Flexion/Extension • Shoulder • Rotation • Flexion/Extension • Abduction/Adduction • Elbow • Flexion/Extension	Kinematics kinetics	• 9-camera VICON V8i motion capture system (VICON Motion Systems: Oxford Metrics Ltd. Oxford, England) (120frames/second) • 45 reflective markers (diameter = 9 mm) to track EMG data (markers defined a 15-segment linked system representing the body and the ball	• $n = 20$ • Gender: Female • Age: 19–24 years • Height: Not specified • Mass: Not specified • Experience: Novice, skilled	Increasing non-kick side shoulder flexion/extension and abduction/adduction, thoracolumbar flexion/extension and twist ROM alongside lower body factors accounted for 36.1% and 23.5% difference between ball release velocities in skilled and novice participants for the dominant and non-dominant kicks respectively

Table 2 (continued)

Author, year	Purpose of study relevant to aim	Mode of kicking	Upper body joints and segments analysed	Performance (outcomes) discussed	Instrumentation	Sample	Main finding (relating to the upper body)
Shan and Westerhoff, 2005 [44]	To define a full-body model capable of revealing more detailed characteristics of kicking	Instep soccer kick	• Thoracolumbar • Rotation • Flexion/Extension • Shoulder • Rotation • Flexion/Extension • Abduction/Adduction • Elbow • Flexion/Extension	Kinematics kinetics	• 9-camera VICON v8i motion capture system (VICON Motion Systems, Oxford Metrics Ltd. Oxford. England) to track markers (120 Hz) • 42 reflective markers (diameter = 9 mm) to build a 15-segment biomechanical model	• $n = 15$ • Gender: Male • Age: 20–26 years • Height: Not specified • Mass: Not specified • Experience: Novice, skilled	Increased distance between the non-kick side shoulder and the kick-side hip and increased thoracolumbar flexion and twist towards the kick-side, non-kick side arm flexion and adduction accounted for a 43.2% increase in ball release velocity
Shan, 2009 [43]	To examine the influence of gender and experience on kicking	Instep soccer kick	• Thoracolumbar • Rotation • Flexion/Extension	Kinematics kinetics	• VICONTM 3D motion capture (9 high-speed cameras, 120 Hz) • NORAXON wireless electromyography • 42 reflective markers (diameter = 9 mm) fixed to clothing	• $n = 44$ • Gender: Male (22) and female (22) • Age: 21.7 ± 2.2 years • Height: Not specified • Mass: Not specified • Experience: Novice, skilled	Increased thoracolumbar flexion and quality of the 'tension arc' (the distance between the non-kick side shoulder and the kick-side hip) increased muscle pre-lengthening (quadriceps, rectus abdominis, pectoralis major, obliquus externus abdominis and obliquus internus abdominis) to increase ball release velocity
Shan et al., 2012 [46]	To establish user-friendly regression equations to evaluate kick quality	Instep soccer kick	• Thoracolumbar • Rotation • Shoulder • Flexion/Extension	kinetics	• 9-camera VICON motion capture system (Oxford Metrics Ltd., Oxford, England) (120 Hz) • 15-segment body model with 42 body markers and 3 ball markers	• $n = 50$ • Gender: Male (24) and female (26) • Age: 21.7 ± 2.2 years • Height: Not specified • Mass: Not specified • Experience: Novice, skilled	Ball release velocity and flexion/extension of the shoulder can be used as a predictor of 'kick quality' ($r = 0.755–0.986$)

Table 2 (continued)

Author, year	Purpose of study relevant to aim	Mode of kicking	Upper body joints and segments analysed	Performance (outcomes) discussed	Instrumentation	Sample	Main finding (relating to the upper body)
Smith et al., 2006 [48]	To investigate the inter-relationships among 3D kinematic variables during performance	Instep soccer kick	• Thoracolumbar • Rotation • Flexion/Extension • Abduction/Adduction • Pelvic • Tilt	Kinematics	• 4-camera (50 Hz) motion analysis system • 12 retro reflective markers • Peak Motus version 7.0 for digitising and processing	• $n = 13$ • Gender: Male and Female • Age: 23.9 ± 6.1 years • Height: 1.73 ± 0.10 m • Mass: 74.7 ± 12.0 kg • Experience: Amateur (experienced)	A decrease in thoracolumbar extension prior to leg-cocking, at the point of maximum and at non-kick side heel-strike is associated with an increase in hip extension at the respective timepoints
Smith and Gilleard, 2016 [47]	To investigate the differences in motion patterns between sexes	Instep soccer kick	• Thoracolumbar • Rotation • Flexion/Extension • Abduction/Adduction	Kinematics kinetics	• Gen-locked 4 camera (Panasonic WV-CL830/G) Peak Motus motion analysis system (50 Hz) and Peak Motus v7.0 software (Englewood, CO, USA)	• $n = 13$ • Gender: Male (6) and female (7) • Age (male): 22.3 ± 3.4 years • Age (female): 25.3 ± 7.6 years • Height (male): 1.82 ± 0.04 m • Height (female): 1.648 ± 0.048 m • Mass (male): 81.9 ± 10.8 kg • Mass (female): 68.5 ± 9.7 kg • Experience: Amateur (experienced)	Increased thoracolumbar anticlockwise rotation during leg-cocking was associated with a reduction in hip abduction and an increase in hip internal rotation between heel-strike and impact, resulting in increased ball release velocities

Table 2 (continued)

Author, year	Purpose of study relevant to aim	Mode of kicking	Upper body joints and segments analysed	Performance (outcomes) discussed	Instrumentation	Sample	Main finding (relating to the upper body)
Sugi et al., 2022 [49]	To quantify the contribution of lower body segment rotations in producing foot velocity during the soccer volley kick	volley kicking at (25 cm, 50 cm and 75 cm) and instep soccer kick	• Pelvic • Rotation • Tilt	Kinematics	• an eight-camera optoelectronic motion capture system (Vicon Motion Systems, Oxford, U.K.) at 500 Hz • Twenty-three reflective markers were placed on both sides of participant's lower body • Eight hemispherical reflective markers were also attached on the forward half of the ball to which the kicking foot would not have contact	• $n = 15$ • Gender: Male • Age: 21.5 ± 0.9 years • Height: 1.727 ± 0.016 m • Mass: 66.7 ± 3.2 kg • Experience: university soccer players; 14.7 ± 1.4 years	Pelvis counterclockwise rotation in the horizontal plane increased gradually as ball height increased Pelvis clockwise rotation was decreased systematically as the ball height increased In the case of place kicking, among the non-sagittal plane motions, the motions which showed more than 10% contribution were pelvis clockwise rotation within the frontal plane Left hip linear velocity, knee extension and pelvis posterior tilt in the sagittal plane showed substantial contributions in producing forward foot velocity in all the heights (0, 25, 50 and 75 cm) place kicking
Zago et al., 2014 [51]	To investigate skill kinematics	Inside-of-foot soccer kick	• Thoracolumbar • Rotation • Elbow • Flexion/Extension	Kinematics kinetics	• Optoelectronic motion analyser (BTS S.p.A, Garb agnate Milanese, Italy) with 9 infrared cameras (120 Hz) • 20 anatomical landmarks identified by passive markers	• $n = 9$ • Gender: Male • Age: 23.0 ± 2.1 years • BMI: 22.2 ± 2.6 kg/m^2 • Experience: Not specified	Preferred-leg kicks had a 45% success rate attributed to higher foot and shank velocities (5% increase) ($P < 0.01$), where forearm velocity was lower and the shoulders more rotated and less inclined towards the target than when kicking with the non-preferred leg (33% success rate)

Table 2 (continued)

Author, year	Purpose of study relevant to aim	Mode of kicking	Upper body joints and segments analysed	Performance (outcomes) discussed	Instrumentation	Sample	Main finding (relating to the upper body)
Zhang et al., 2012y [52]	To examine movement sequencing on the contributions of the motions of body segments to foot velocity during rugby place kicking	Rugby place kick	• Pelvic • Rotation • Tilt	Kinematics kinetics	• 8-camera Vicon TM motion analysis system (250 Hz) • Spherical markers attached to specific anatomical landmarks on the lower extremities of participants for use with a plug-in-gait model	• $n = 7$ • Gender: Male • Age: Not specified • Height: Not specified • Mass: Not specified • Experience: Skilled university team	At ball contact, knee flexion/extension (9.1 m/s), hip flexion/extension (1.6 m/s), pelvic tilt (1.2 m/s) and pelvic rotation (0.3 m/s) were all contributors to foot speed. During the backswing phase, flexion at the hip and knee are the most important contributors while the linear velocities of the pelvis cause a negative contribution to the total speed. During the first half forward swing phase, the linear velocities of the pelvis are the most important contributors

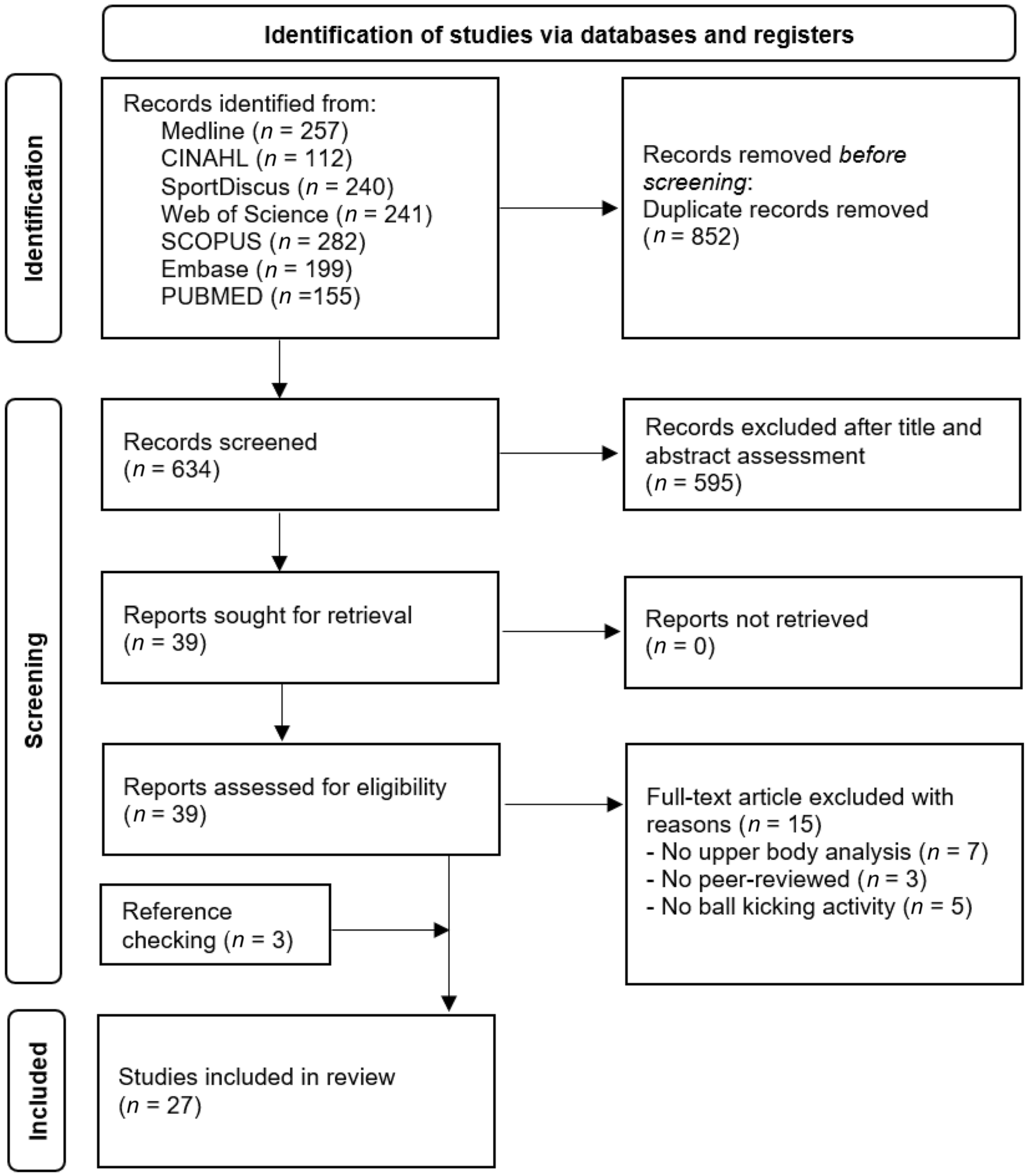

Fig. 1 Flowchart of the systematic literature search ($n=27$)

mechanical insight into skill execution but also streamlines the process of conducting qualitative performance assessments. This concept can be universally applied across various kicking modes. Further, given the noteworthy evidence in our study, which links greater upper body rotations to increased ball release velocity via enhanced segmental sequencing across the body, we advocate for the inclusion of a whole-body analysis (encompassing both upper and lower body movements) to conduct a more thorough examination of a soccer kick. However, the upper body and pelvis rotation was not listed as the key skill criteria in the coaching manual for the development of kicking skills in children and adolescents [15]. Despite being updated in 2017 [21], it does not include any description related to the upper trunk and the pelvis, nor the sequencing of the rotations. Consequently, the valuable insights from research have not been effectively applied in youth coaching, resulting in limited improvement in practical training. This underscores the need for a holistic approach to skill analysis and for effectively translating experimental research into real-world coaching practices.

Performance of the instep soccer kick with the dominant foot produced highly coordinated, skilful movements as a result of long-term motor learning and practice in skilled participants [45, 51]. This in turn produced a greater ball release velocity than kicking with the non-dominant foot. This was attributed to a greater magnitude of upper body rotations during kicking with the dominant foot, further supporting the importance of upper body rotations in skilled performance. Although the better performance of the instep soccer kick with the dominant foot was attributed to a greater magnitude of upper body rotations than when kicking with the non-dominant foot, further research is required to understand the variations in coordination patterns and segmental sequencing during the performance with the non-dominant foot. Thus, the development of instructions that help improve the general kinematics during motor learning of the non-dominant foot would enhance coaching practices.

The association between upper body rotations and ball release velocity was best described, where thoracolumbar rotations increased resultant foot velocity to increase ball release velocity, including a discussion of the interactions of the hip, thigh and shank segments [44, 47]. The findings of these studies indicate that established equations representing the transfer of momentum [2, 38] can be expanded and re-established by incorporating the upper body. Atack et al. [2] analysed the sequencing and magnitude of a multi-segment model involving thorax, pelvis, hip, knee and foot rotations, which in turn increased ball release velocity in the rugby place kick. Results were discussed alongside a graphical representation to demonstrate the concurrence of the relative peak timing of each body segment. Thus, this approach must be applied to other modes of kicking to create a true understanding of kicking performance. Also, to educate coaches about the role of upper body rotations in increasing ball release velocity, future studies must identify the applications of the findings to coaching practice.

The examination of the kicking motion using a stationary ball was prevalent across all reviewed papers. However, this applies only in certain instances of sports involving the kick motion, such as free kicks, corner kicks or goal kicks in soccer and rugby place kicks. Enhancing the practicality and real-world applicability of kick motion analysis necessitates the inclusion of more dynamic scenarios, such as varying approaches to the ball and the choice of kicking foot. These factors have been shown to exert a significant influence on the overall kinematic patterns of the body [10]. Therefore, it is highly recommended that further research be conducted focusing on analysing the role of the upper limb in kicking motions while using a moving ball. A recent study [11] suggested that the difference between using a moving ball and a stationary ball may significantly impact whole-body kinematics and ball velocity during an instep kick in soccer. The study proposed that the ball approach angle influences various limb variables and upper body variables while kicking with the dominant foot results in higher linear and angular velocities of the swinging limb and a higher vertical position of the centre of mass. Furthermore, to improve our understanding of the relationship between upper body rotations and kicking accuracy, further research is necessary. Two studies [3, 22] investigated whether increased upper body rotations contribute to kicking accuracy. However, the sample size might be inadequate. It is recommended to provide formal priori sample size estimations for sports research. Otherwise it is still being determined what changes could be considered as a meaningful effect [1]. Hence, it is imperative for future research endeavours to address the sample size estimation to allow robust outcomes in soccer research.

Leg muscle mass is positively correlated with the ability to generate joint torques [40]. This, in turn, will influence prestrike foot velocity and hence ball release velocity, as prestrike foot velocity is the most significant predictor of ball release velocity [2, 8, 17]. Thus, when assessing movement patterns with skill level, it is essential to normalise the effects of muscle mass to counter the confounding effects of muscle mass. Limb length or height is another contributing factor. For example, Atack et al. [3] normalised the joint kinetics using height. It is suggested that ball release velocity may be normalised by dividing each participant's stature to minimise the effect of longer limb length and associated mechanical advantage. However, none of the included studies checked the statistical assumption for using the scaling variables in normalisation [50]. The readers should interpret the results with caution. Further, anatomical and biological differences between sexes necessitate the need for separate analyses. By analysing male and female participants independently, comparisons between sex and skill levels can be made within and between studies [36, 46, 47]. It is recommended that future research include separate analyses of male and female participants, as suggested by Nimphius [34].

No studies investigated the feasibility of adding upper body rotation in kicking training for less-skilled athletes, particularly children or adolescent athletes. This is a gap in the literature as most athletes start developing skills acquisition during their younger years. Performance indicators and injury predictors also surface in the early stage of a career. The correlations between kinematic changes in the upper body and common soccer injuries, such as groin and hamstring injuries, need to be better understood. The current guidelines for improving kicking performance primarily focus on lower-body coordination training [15]. This raises the question of whether the movement pattern or the energy transfer from the upper body could complement these guidelines, reducing the risk of injuries or contributing to the occurrence of these injuries. Previous studies demonstrated that when the whip-effect is greatly increased, the chance of injury may also be increased [14, 37]. DeLang et al. indicated that he probability of injury of the inertial leg is 1.6 times that of the non-inertial leg in soccer. At the same time, while among youth athletes, the rate has increased by another 1.5 times [14]. Hamstring strain injuries have already been proven to be highly prevalent in sports [30]; risk of such injury may be increased by an excessive strain during eccentric contraction in the late kicking phase. Further studies could investigate the impact of energy flow between the trunk and the extremities and their contribution to injuries.

Currently, there is no standardised protocol to quantify the strength of evidence in biomechanics studies with different study designs. However, given that 10 of the 12 included studies demonstrated a positive relationship between upper body rotation and ball release speed. This review appears to provide at least moderate evidence that increased upper body rotations promote ball release velocity following the kinetic link principle. The impact of the upper body rotation is not highlighted in current coaching manuals, which should be updated to improve the kicking skill acquisition.

Perspective

This review provides moderate evidence that increased upper body rotations play a crucial role in promoting ball release velocity, aligning with the kinetic link principle. Specifically, developing thoracic and pelvic rotations has been found to have a positive impact on ball release velocity during the in-step kicking motion. However, an important gap emerged in the current coaching guidelines, as they do not emphasise the critical significance of upper body rotation, underscoring the urgent need for updates to enhance kicking skill acquisition. By gaining a deeper understanding of how the upper trunk and upper limb segments interact with the pelvis and lower limb segments, coaches can effectively prescribe techniques, and athletes can acquire the necessary skills for improved performance. To comprehensively optimise ball-kicking motion, thereby updating the coaching manual, further research is warranted to explore the effects of timing and the ranges of motion of all relevant upper and lower body segments on maximum ball release velocity.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s42978-024-00276-x.

Funding Open Access funding enabled and organized by CAUL and its Member Institutions.

Declarations

Competing interests The authors declare that there are no competing interest.

References

1. Abt G, Boreham C, Davison G, Jackson R, Nevill A, Wallace E, Williams M. Power, precision, and sample size estimation in sport and exercise science research. J Sports Sci. 2020;38(17):1933–5. https://doi.org/10.1080/02640414.2020.1776002.
2. Andersen TB, Dörge and Thomsen. Collisions in soccer kicking. Sports Eng. 1999;2:121–5. https://doi.org/10.1046/j.1460-2687.1999.00015.x.
3. Atack AC, Trewartha G, Bezodis NE. A joint kinetic analysis of rugby place kicking technique to understand why kickers achieve different performance outcomes. J Biomech. 2019;87:114–9. https://doi.org/10.1016/j.jbiomech.2019.02.020.
4. Atack AC, Trewartha G, Bezodis NE. The approach towards the ball, rather than the physical characteristics of the kicker, limits accurate rugby place kicking range. J Sports Sci. 2022;40(1):104–15. https://doi.org/10.1080/02640414.2021.1976494.
5. Augustus S, Mundy P, Smith N. Support leg action can contribute to maximal instep soccer kick performance: an intervention study. J Sports Sci. 2017;35(1):89–98. https://doi.org/10.1080/02640414.2016.1156728.
6. Augustus S, Hudson PE, Harvey N, Smith N. Whole-body energy transfer strategies during football instep kicking: implications for training practices. Sports Biomech. 2021;27:1–16. https://doi.org/10.1080/14763141.2021.1951827.
7. Augustus S, Hudson PE, Smith N. Defining movement strategies in soccer instep kicking using the relationship between pelvis and kick leg rotations. Sports Biomech. 2022;29:1–12. https://doi.org/10.1080/14763141.2022.2106297.
8. Ball K. Biomechanical considerations of distance kicking in Australian Rules football. Sports Biomech. 2008;7(1):10–23. https://doi.org/10.1080/14763140701683015.
9. Ball K. Kinematic comparison of the preferred and non-preferred foot punt kick. J Sports Sci. 2011;29(14):1545–52.
10. Bertozzi F, Rabello R, Zago M, Esposito F, Sforza C. Foot dominance and ball approach angle affect whole-body instep kick kinematics in soccer players. Sports Biomech. 2022;22:1–21. https://doi.org/10.1080/14763141.2022.2110514.
11. Bertozzi F, Rabello R, Zago M, Esposito F, Sforza C. Foot dominance and ball approach angle affect whole-body instep kick kinematics in soccer players. Sport Biomech. 2022;22:1–21. https://doi.org/10.1080/14763141.2022.2110514.
12. Bezodis N, Trewartha G, Wilson C, Irwin G. Contributions of the non-kicking-side arm to rugby place-kicking technique. Sports Biomech. 2007;6(2):171–86. https://doi.org/10.1080/14763140701324487.
13. Carvalho DDS, Ocarino JM, Cruz AC, Barsante LD, Teixeira BG, Resende RA, Fonseca ST, Souza TR. The trunk is exploited for energy transfers of maximal instep soccer kick: a power

flow study. J Biomech. 2021;121:20210409. https://doi.org/10.1016/j.jbiomech.2021.110425.
14. DeLang MD, Salamh PA, Farooq A, Tabben M, Whiteley R, an Dyk N, Chamari K. The dominant leg is more likely to get injured in soccer players: systematic review and meta-analysis. Biol Sport. 2021;38(3):397–435. https://doi.org/10.5114/biolsport.2021.100265.
15. Department of Education Western Australia. Fundamental movement skills: Book 2—The tools for learning, teaching and assessment. 2013. https://myresources.education.wa.edu.au/docs/default-source/resources/first-steps-fundamental-movement-skills/first022.pdf?sfvrsn=e84dd527_3.
16. Dillman CJ, Fleisig GS, Andrews JR. Biomechanics of pitching with emphasis upon shoulder kinematics. J Orthop Sports Phys Ther. 1993;18(2):402–8. https://doi.org/10.2519/jospt.1993.18.2.402.
17. Dorge HC, Anderson TB, Sorensen H, Simonsen EB. Biomechanical differences in soccer kicking with the preferred and the non-preferred leg. J Sports Sci. 2002;20(4):293–9. https://doi.org/10.1080/026404102753576062.
18. Finnoff JT, Newcomer K, Laskowski ER. A valid and reliable method for measuring the kicking accuracy of soccer players. J Sci Med Sport. 2002;5(4):348–53. https://doi.org/10.1016/S1440-2440(02)80023-8.
19. Fu ACL, Cobley SP, Sanders RH. Segmental sequencing of the upper body segments in unconstrained maximum overarm throws: an implication for coaching. Scand J Med Sci Sports. 2022;32(12):1747–56. https://doi.org/10.1111/sms.14233.
20. Fullenkamp AM, Campbell BM, Laurent CM, Lane AP. The contribution of trunk axial kinematics to poststrike ball velocity during maximal instep soccer kicking. J Appl Biomech. 2015;31(5):370–6. https://doi.org/10.1123/jab.2014-0188.
21. Government of Western Australia. Physical education fundamental movement skills performance assessment support material overarm throw. 2017. https://k10outline.scsa.wa.edu.au/__data/assets/pdf_file/0006/348702/Fundamental-Movement-Skills-Performance-Assessment-Support-Material-Overarm-Throw.PDF.
22. Green A, Kerr S, Olivier B, Dafkin C, McKinon W. The trade-off between distance and accuracy in the rugby union place kick: a cross-sectional, descriptive study. Kinesiology. 2016;48(2):251–7.
23. Juarez D, Mallo J, De Subijana C, Navarro E. Kinematic analysis of kicking in young top-class soccer players. J Sports Med Phys Fitness. 2011;51(3):366–73.
24. Langhout R, Weber M, Tak I, Lenssen T. Timing characteristics of body segments during the maximal instep kick in experienced football players. J Sports Med Phys Fit. 2016;56(7–8):849–56.
25. Langhout R, Tak I, Van der Westen R, Lenssen T. Range of motion of body segments is larger during the maximal instep kick than during the submaximal kick in experienced football players. J Sports Med Phys Fit. 2017;57(4):388–95. https://doi.org/10.23736/S0022-4707.16.06107-7.
26. Leanne M, Kmet RCL, Linda SC. Standard quality assessment criteria for evaluating primary research papers from a variety of fields. 2004. https://doi.org/10.7939/R37M04F16. Accessed 26 July 2023.
27. Lees A, Lee N. Three-dimensional kinematic analysis of the instep kick under speed and accuracy conditions. Science and football IV. Lundon: Routledge; 2013. pp. 16–21.
28. Lees A, Kershaw L, Moura F. The three-dimensional nature of the maximal instep kick in soccer. J Sports Sci. 2004;22(6):65–70.
29. Lees A, Asai T, Andersen TB, Nunome H, Sterzing T. The biomechanics of kicking in soccer: a review. J Sports Sci. 2010;28(8):805–17. https://doi.org/10.1080/02640414.2010.481305.
30. Liu H, Garrett WE, Moorman CT, Yu B. Injury rate, mechanism, and risk factors of hamstring strain injuries in sports: a review of the literature. J Sport Health Sci. 2012;1:92–101. https://doi.org/10.1016/j.jshs.2012.07.003.
31. Moher D, Liberati A, Tetzlaff J, Altman DG; the PRISMA group. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. PLoS Med. 2009;6(7):20090721. https://doi.org/10.1371/journal.pmed.1000097.
32. Naito K, Fukui Y, Maruyama T. Multijoint kinetic chain analysis of knee extension during the soccer instep kick. Hum Mov Sci. 2010;29(2):259–76. https://doi.org/10.1016/j.humov.2009.04.008.
33. Naito K, Fukui Y, Maruyama T. Energy redistribution analysis of dynamic mechanisms of multi-body, multi-joint kinetic chain movement during soccer instep kicks. Hum Mov Sci. 2012;31(161–181):20111007. https://doi.org/10.1016/j.humov.2010.09.006.
34. Nimphius S. Exercise and sport science failing by design in understanding female athletes. Int J Sports Physiol Perform. 2019;14(9):1157–8. https://doi.org/10.1123/ijspp.2019-0703.
35. Nunome H, Asai T, Ikegami Y, Sakurai S. Three-dimensional kinetic analysis of side-foot and instep soccer kicks. Med Sci Sports Exerc. 2002;34(12):2028–36. https://doi.org/10.1097/00005768-200212000-00025.
36. Orloff H, Sumida B, Chow J, Habibi L, Fujino A, Kramer B. Ground reaction forces and kinematics of plant leg position during instep kicking in male and female collegiate soccer players. Sport Biomech. 2008;7(2):238–47. https://doi.org/10.1080/14763140701841704.
37. Pryhoda MK, Sabick MB. Lower body energy generation, absorption, and transfer in youth baseball pitchers. Front Sports Act Living. 2022;4:975107. https://doi.org/10.3389/fspor.2022.975107.
38. Putnam CA. A segment interaction analysis of proximal-to-distal sequential segment motion patterns / Analyse de l ' interaction entre segments lors de mouvements segmentaires dont la sequence est de type rapproche a eloigne. Med Sci Sports Exerc. 1991;23(1):130–44.
39. Rada A, Kuvacic G, De Giorgio A, Sellami M, Ardigò LP, Bragazzi NL, Padulo J. The ball kicking speed: a new, efficient performance indicator in youth soccer. PLoS ONE. 2019;14(5):20190517. https://doi.org/10.1371/journal.pone.0217101.
40. Raymond-Pope CJ, Dengel DR, Fitzgerald JS, Bosch TA. Association of compartmental leg lean mass measured by dual X-ray absorptiometry with force production. J Strength Cond Res. 2020;34(6):1690–9. https://doi.org/10.1519/JSC.0000000000002688.
41. Sakuma T, Kobayashi M, Kinoshita H, Matsui Y, Kobayashi Y, Watanabe M. Three-dimensional kinematics analysis of blind football kicking. Sports Biomech. 2023;22(9):1136–52. https://doi.org/10.1080/14763141.2020.1787499.
42. Scurr J, Hall B. The effects of approach angle on penalty kicking accuracy and kick kinematics with recreational soccer players. J Sports Sci Med. 2009;8(2):230–4.
43. Shan GB. Influence of gender and experience on the maximal instep soccer kick. Eur J Sport Sci. 2009;9:107–14. https://doi.org/10.1080/17461390802594250.
44. Shan G, Westerhoff P. Full-body kinematic characteristics of the maximal instep soccer kick by male soccer players and parameters related to kick quality. Sports Biomech. 2005;4(1):59–72. https://doi.org/10.1080/14763140508522852.
45. Shan G, Daniels D, Wang C, Wutzke C, Lemire G. Biomechanical analysis of maximal instep kick by female soccer players. J Hum Mov Stud. 2005;49(3):149–68.

46. Shan G, Yuan J, Hao W, Gu M, Zhang X. Regression equations for estimating the quality of maximal instep kick by males and females in soccer. Kinesiology. 2012;44(2):139–47.
47. Smith T, Gilleard W. Three-dimensional analysis of a lofted instep kick by male and female footballers. Eur J Sport Sci. 2016;16(1):57–64. https://doi.org/10.1080/17461391.2014.992477.
48. Smith C, Gilleard W, Hammond J, Brooks L. The application of an exploratory factor analysis to investigate the inter-relationships amongst joint movement during performance of a football skill. J Sports Sci Med. 2006;5(4):417–524.
49. Sugi S, Nunome H, Tamura Y, Iga T, Lake MJ. Contribution of lower body segment rotations in various height soccer volley kicking. Sports Biomech. 2022;21(6):669–84. https://doi.org/10.1080/14763141.2019.1667422.
50. Van Hooren B, Hirsch SM, Meijer K. A comparison of five methods to normalize joint moments during running. Gait Posture. 2023;105:81–6. https://doi.org/10.1016/j.gaitpost.2023.07.278.
51. Zago M, Francesco Motta A, Mapelli A, Annoni I, Galvani C, Sforza C. Effect of leg dominance on the center-of-mass kinematics during an inside-of-the-foot kick in amateur soccer players. J Hum Kinet. 2014;42:51–61.
52. Zhang Y, Liu G, Xie SQ. Movement sequences during instep rugby kick: a 3 D biomechanical analysis. Int J Sports Sci Eng. 2012;6:089–95.