

Revista Andaluza de Medicina del Deporte

Volumen 19. Número 3

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RAMD

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- Patrones de lesiones y factores asociados en jugadores portugueses federados de hockey sobre patines: un estudio transversal
- Minería de datos de las variables antropométricas clave en luchadores de élite y no élite mediante análisis de componentes principales
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- Potencial del ácido ascórbico durante el ejercicio físico para reducir el estrés oxidativo: revisión sistemática



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Originals

Sagittal-plane lower-limb kinematics during single-leg landing in athletes: implications for knee injury risk

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ABSTRACT

Objective: To characterize sagittal-plane lower-limb kinematics during a standardized single-leg landing task and to compare landing mechanics between male and female athletes. **Methods:** One hundred and sixty-two athletes performed three single-leg landings from a 30-cm platform. Two-dimensional photogrammetric analysis was used to evaluate trunk, hip, knee and ankle kinematics at initial ground contact and at maximum knee flexion. Variables included knee flexion at initial contact and maximum knee flexion, hip flexion, trunk inclination, ankle position and ankle dorsiflexion range of motion. Independent t-tests were used to examine sex-related differences. **Results:** Athletes landed with a mean knee angle of $145.89 \pm 6.24^\circ$ at initial contact and reached a maximum knee flexion angle of $116.72 \pm 9.71^\circ$. Mean hip flexion increased from $10.02 \pm 1.82^\circ$ to $20.98 \pm 1.38^\circ$, while trunk position changed from $102.94 \pm 3.23^\circ$ at initial contact to $59.33 \pm 2.60^\circ$ at maximum knee flexion. Ankle dorsiflexion range of motion during landing was $41.54 \pm 4.32^\circ$. No significant differences were observed between males and females for any of the kinematic variables analysed ($p > 0.05$). **Conclusions:** Single-leg landing is characterized by coordinated sagittal-plane motion of the trunk, hip, knee and ankle. The absence of sex-related differences suggests that male and female athletes adopt similar landing strategies under standardized conditions. These findings support the use of an integrated biomechanical approach when assessing landing mechanics and may provide reference values for injury prevention, movement screening and rehabilitation programmes.

Keywords: Anterior cruciate ligament; Knee biomechanics; Motion analysis; Lower-limb kinematics; Landing.

Cinemática del miembro inferior en el plano sagital durante el aterrizaje unipodal en deportistas: implicaciones para el riesgo de lesión de rodilla

RESUMEN

Objetivo: Caracterizar la cinemática del miembro inferior en el plano sagital durante una tarea estandarizada de aterrizaje unipodal y comparar la mecánica de aterrizaje entre deportistas hombres y mujeres. **Métodos:** Ciento sesenta y dos deportistas realizaron tres aterrizajes unipodales desde una plataforma de 30 cm. Se utilizó un análisis fotogramétrico bidimensional para evaluar la cinemática del tronco, la cadera, la rodilla y el tobillo en el contacto inicial con el suelo y en la máxima flexión de rodilla. Las variables incluyeron la flexión de rodilla en el contacto inicial y en la máxima flexión de rodilla, la flexión de cadera, la inclinación del tronco, la posición del tobillo y el rango de movimiento de dorsiflexión del tobillo. Se utilizaron pruebas t independientes para examinar las diferencias relacionadas con el sexo. **Resultados:** Los deportistas aterrizaron con un ángulo medio de rodilla de $145,89 \pm 6,24^\circ$ en el contacto inicial y alcanzaron un ángulo máximo de flexión de rodilla de $116,72 \pm 9,71^\circ$. La flexión media de cadera aumentó de $10,02 \pm 1,82^\circ$ a $20,98 \pm 1,38^\circ$, mientras que la posición del tronco cambió de $102,94 \pm 3,23^\circ$ en el contacto inicial a $59,33 \pm 2,60^\circ$ en la máxima flexión de rodilla. El rango de movimiento de la dorsiflexión del tobillo durante el aterrizaje fue de $41,54 \pm 4,32^\circ$. No se observaron diferencias significativas entre hombres y mujeres para ninguna de las variables cinemáticas analizadas ($p > 0,05$). **Conclusiones:** El aterrizaje unipodal se caracteriza por un movimiento coordinado en el plano sagital del tronco, la cadera, la rodilla y el tobillo. La ausencia de diferencias relacionadas con el sexo sugiere que los deportistas hombres y mujeres adoptan estrategias de aterrizaje similares bajo condiciones estandarizadas. Estos hallazgos respaldan el uso de un enfoque biomecánico integrado al evaluar la mecánica del aterrizaje y pueden proporcionar valores de referencia para programas de prevención de lesiones, valoración funcional del movimiento y rehabilitación.

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Palabras clave: Ligamento cruzado anterior; Biomecánica de la rodilla; Análisis de movimiento; Cinemática del miembro inferior; Aterrizaje.

Cinemática dos membros inferiores no plano sagital durante a aterragem unipodal em atletas: implicações para o risco de lesão do joelho

RESUMO

Objetivo: Caracterizar a cinemática dos membros inferiores no plano sagital durante uma tarefa padronizada de aterragem unipodal e comparar a mecânica de aterragem entre atletas masculinos e femininos. **Métodos:** Cento e sessenta e dois atletas realizaram três aterragens unipodais a partir de uma plataforma de 30 cm. Foi utilizada a análise fotogramétrica bidimensional para avaliar a cinemática do tronco, quadril, joelho e tornozelo no contacto inicial com o solo e na flexão máxima do joelho. As variáveis incluíram a flexão do joelho no contacto inicial e na flexão máxima do joelho, a flexão do quadril, a inclinação do tronco, a posição do tornozelo e a amplitude de movimento de dorsiflexão do tornozelo. Foram utilizados testes t independentes para examinar as diferenças relacionadas com o sexo. **Resultados:** Os atletas aterraram com um ângulo médio do joelho de $145,89 \pm 6,24^\circ$ no contacto inicial e atingiram um ângulo máximo de flexão do joelho de $116,72 \pm 9,71^\circ$. A flexão média do quadril aumentou de $10,02 \pm 1,82^\circ$ para $20,98 \pm 1,38^\circ$, enquanto a posição do tronco mudou de $102,94 \pm 3,23^\circ$ no contacto inicial para $59,33 \pm 2,60^\circ$ na flexão máxima do joelho. A amplitude de movimento de dorsiflexão do tornozelo durante a aterragem foi de $41,54 \pm 4,32^\circ$. Não foram observadas diferenças significativas entre homens e mulheres para nenhuma das variáveis cinemáticas analisadas ($p > 0,05$). **Conclusões:** A aterragem unipodal caracteriza-se pelo movimento coordenado no plano sagital do tronco, quadril, joelho e tornozelo. A ausência de diferenças relacionadas com o sexo sugere que atletas masculinos e femininos adotam estratégias de aterragem semelhantes sob condições padronizadas. Estes achados apoiam a utilização de uma abordagem biomecânica integrada ao avaliar a mecânica de aterragem e podem fornecer valores de referência para programas de prevenção de lesões, triagem de movimento e reabilitação.

Palavras-chave: Ligamento cruzado anterior; Biomecânica do joelho; Análise de movimento; Cinemática dos membros inferiores; Aterragem.

INTRODUCTION

Landing is a fundamental component of many sporting actions, particularly those involving repetitive jumping, sprinting, and rapid changes of direction^{1,2}. From a biomechanical perspective, landing is a demanding motor task in which the lower extremity must rapidly dissipate impact forces while maintaining dynamic stability and preparing for subsequent movement^{3,4}. Efficient impact attenuation relies on the coordinated interaction of the trunk and lower-limb segments, allowing mechanical energy to be progressively absorbed through controlled joint motion rather than transferred to passive musculoskeletal structures^{1,5}. Consequently, landing has become one of the most widely used experimental tasks for investigating lower-limb biomechanics, as it provides a reproducible and functionally relevant model for evaluating movement strategies under conditions that closely resemble sporting performance^{6,3}. Altered landing mechanics have been associated with changes in impact absorption capacity, joint loading and neuromuscular control, highlighting the importance of understanding the kinematic characteristics that determine movement quality during this functional task^{7,2}.

Among the biomechanical determinants of landing performance, sagittal-plane kinematics play a fundamental role because they largely determine the capacity of the lower extremity to attenuate impact forces during the deceleration phase^{5,4}. In particular, knee flexion has been consistently recognised as one of the primary mechanisms responsible for shock absorption, facilitating eccentric muscle action and reducing the transmission of mechanical loads across the knee joint^{1,8}. However, the mechanical behaviour of the knee cannot be interpreted independently, since its motion is intrinsically linked to the coordinated contribution of adjacent segments^{1,5}. Hip flexion contributes to proximal control and regulates lower-limb alignment, trunk inclination influences the position of the centre of mass and external joint moments, while ankle motion, especially dorsiflexion during weight acceptance, facilitates the progressive transfer and dissipation of impact forces throughout the kinetic chain^{9,5}. Therefore, efficient landing mechanics should be

understood as the result of coordinated intersegmental motion rather than the isolated behaviour of a single joint, emphasising the need for comprehensive biomechanical analyses that simultaneously evaluate the kinematics of the trunk, hip, knee and ankle^{3,2}.

Previous investigations have demonstrated that modifications in sagittal-plane kinematics alter the mechanical demands experienced by the lower extremity during landing^{5,10}. Reduced knee flexion has been associated with stiffer landing strategies and diminished impact attenuation, while inadequate hip flexion, altered trunk positioning, and restricted ankle dorsiflexion may compromise load distribution across the lower limb^{5,11}. Nevertheless, recent evidence suggests that these variables should not be considered independent biomechanical factors but rather components of an integrated movement strategy in which the interaction between body segments determines overall landing performance^{1,4}. Consequently, analysing only a single joint may provide an incomplete representation of movement quality^{12,6}. A comprehensive evaluation including trunk, hip, knee and ankle kinematics at critical phases of landing, such as initial ground contact and maximum knee flexion, may therefore provide a more accurate characterisation of lower-limb movement patterns and improve our understanding of the biomechanical mechanisms underlying efficient impact absorption^{5,3}. Furthermore, these movement patterns have attracted considerable attention because they are considered relevant biomechanical mechanisms associated with non-contact anterior cruciate ligament injury, reinforcing the clinical relevance of studying landing kinematics within a functional and integrated framework^{1,7}.

Despite the growing body of research on landing biomechanics, several methodological limitations remain^{6,3}. Previous studies have predominantly focused on isolated biomechanical variables, kinetic measurements or injury prediction models, making direct comparisons difficult because of differences in landing protocols, participant characteristics and outcome measures^{6,2}. Moreover, although sagittal-plane kinematics are routinely assessed, relatively few investigations have simultaneously characterised trunk, hip, knee and ankle motion during the key phases of a standardized single-leg landing task¹². Assessing these segments at initial ground

contact and during impact absorption may provide a more comprehensive understanding of landing mechanics and identify movement strategies associated with effective impact attenuation^{13,10}. Furthermore, two-dimensional motion analysis provides a practical and clinically applicable approach to sagittal-plane assessment, with acceptable validity and reliability for several lower-limb kinematic variables^{14,3}.

Therefore, this study aimed to comprehensively characterise sagittal-plane kinematics during a standardized single-leg landing task by simultaneously assessing trunk, hip, knee, and ankle motion at initial ground contact and maximum knee flexion using two-dimensional photogrammetric analysis. It was hypothesised that landing would be characterised by coordinated, segment-specific kinematic patterns across these key phases, supporting a multisegmental approach to the assessment of landing mechanics.

Methods

Study design

This cross-sectional observational study aimed to characterize sagittal-plane lower-limb kinematics during a standardized single-leg

landing task using two-dimensional photogrammetric analysis. All experimental procedures were conducted in accordance with the ethical standards of the Declaration of Helsinki and were approved by the Ethics Committee of the University of Sevilla. Prior to participation, all athletes received verbal and written information regarding the study procedures and potential risks before providing written informed consent.

Subjects

A total of 200 athletes were initially recruited to participate in this study. Following the eligibility screening, 38 volunteers withdrew before testing, resulting in a final sample of 162 participants. Participants were eligible if they engaged in physical activity for at least 30 minutes per day on three or more days per week and had not sustained any knee or ankle injury during the previous 12 months. Before testing, all participants completed a questionnaire regarding their weekly physical activity levels and provided anthropometric information, including age, height and body mass (Table 1).

Table 1. Anthropometric characteristics of the study participants.

Variables	Total	Men	Women
N	162	122	40
Age (years)	24 ± 3	25 ± 2	22 ± 1
Weight (N)	714.56 ± 125.18	754.59 ± 79.66	641.18 ± 44.34
Height (cm)	174 ± 7	180 ± 9	163 ± 6

Experimental procedure

Before testing, participants completed a standardized 5-minute warm-up followed by 15 familiarization trials to minimize potential learning effects. Each participant then performed three successful single-leg landings from a 30-cm platform, with one minute of recovery between trials. Participants were instructed to keep their hands on their iliac crests, gaze forward, and land naturally on their dominant limb, without specific instructions regarding landing technique. All trials were performed under identical experimental conditions.

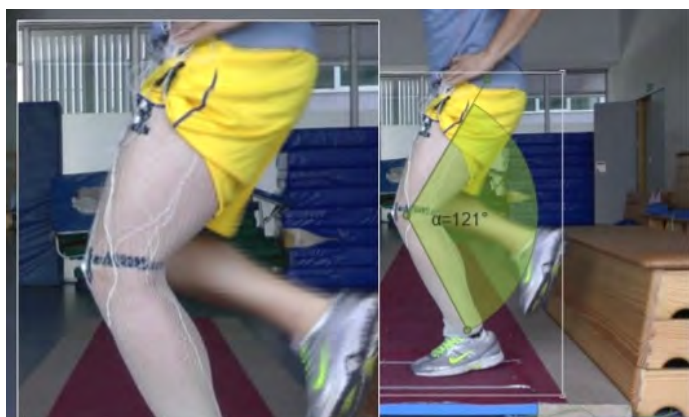


Figure 1. Experimental setup of the standardized single-leg landing task.

Kinematic Assessment

Sagittal-plane lower-limb kinematics were assessed using two-dimensional photogrammetric analysis. Four reflective markers were placed on standardized anatomical landmarks of the dominant

lower limb: the greater trochanter, the lateral femoral condyle, the lateral malleolus, and the midpoint of the ipsilateral shoulder. These landmarks were used to determine trunk, hip, knee and ankle joint angles throughout the landing task.

A digital video camera was positioned perpendicular to the sagittal plane at knee height, 2 m from the landing area to minimize perspective error. Joint kinematics were analysed at initial ground contact and maximum knee flexion, representing the onset and peak of the impact-absorption phase, respectively.

Sagittal-plane trunk, hip, knee, and ankle angles were assessed at both events, together with ankle dorsiflexion range of motion. Joint angles were defined according to standardized anatomical references: trunk angles were referenced to the ground (90° = upright, with lower values indicating greater forward flexion); hip angles to the horizontal plane (90° = horizontal thigh; 0° = vertically aligned femur); knee angles to full extension (180°, with lower values indicating greater flexion); and ankle angles ranged from 180° at maximum plantarflexion to 0° at maximum dorsiflexion. Angle definitions are illustrated in Figure 2.

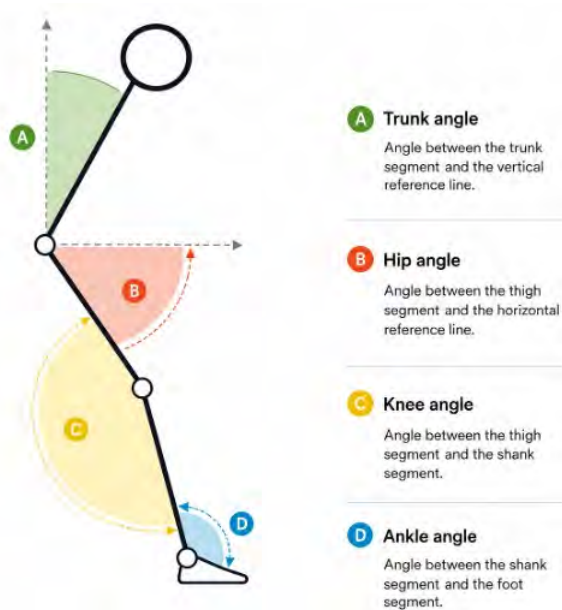


Figure 2. Definition of sagittal-plane joint angles obtained using two-dimensional photogrammetric analysis.

Statistical analysis

Table 2. Sagittal-plane kinematics during the single-leg landing task.

Variables	Mean $\pm$ SD
Initial knee flexion angle	145.89 $\pm$ 6.24
Maximum knee flexion angle	116.72 $\pm$ 9.71
Initial hip flexion angle	10.02 $\pm$ 1.82
Maximum hip flexion angle	20.98 $\pm$ 1.38
Initial trunk flexion angle	102.94 $\pm$ 3.23
Maximum trunk flexion angle	59.33 $\pm$ 2.60
Initial ankle angle	93.80 $\pm$ 2.61
Maximum ankle angle	52.26 $\pm$ 3.84
Ankle dorsiflexion ROM	41.54 $\pm$ 4.32

Data are presented as mean $\pm$ SD. All angular variables are expressed in degrees ($^{\circ}$). Initial angle refers to the first ground contact, whereas maximum angle corresponds to the instant of maximum knee flexion during landing. ROM = range of motion.

No statistically significant differences were observed between male and female athletes for any of the kinematic variables analysed during the landing task ($p > 0.05$; Table 3). Knee flexion at initial contact was $145.57 \pm 6.32^{\circ}$ in males and $147.13 \pm 5.87^{\circ}$ in females ($p = 0.184$), whereas maximum knee flexion reached $115.99 \pm 9.81^{\circ}$ and $118.83 \pm 9.15^{\circ}$, respectively ($p = 0.120$). Likewise, hip flexion,

Statistical analyses were performed using R statistical software (version 4.2.2; R Foundation for Statistical Computing, Vienna, Austria). Data normality was assessed using the Kolmogorov-Smirnov test, and descriptive statistics are presented as mean $\pm$ standard deviation (SD). Sex-related differences were analysed using independent-samples t-tests, while a two-way repeated-measures analysis of variance (ANOVA) was performed when appropriate to evaluate group and measurement-phase effects. Statistical significance was set at $p \leq 0.05$, with Bonferroni-adjusted p-values additionally calculated for multiple sex-related comparisons. Intraclass correlation coefficients (ICC) were calculated to assess the reliability of kinematic measurements. Effect sizes (Cohen's d) with corresponding confidence intervals were calculated to quantify the magnitude of observed differences.

Results

The sagittal-plane kinematic characteristics recorded during the standardized single-leg landing task are presented in Table 2. At initial ground contact, the mean knee flexion angle was $145.89 \pm 6.24^{\circ}$, decreasing to $116.72 \pm 9.71^{\circ}$ at maximum knee flexion during the impact absorption phase. Hip flexion increased from $10.02 \pm 1.82^{\circ}$ at initial contact to $20.98 \pm 1.38^{\circ}$ at maximum knee flexion. Similarly, trunk flexion changed from $102.94 \pm 3.23^{\circ}$ to $59.33 \pm 2.60^{\circ}$, while the ankle angle decreased from $93.80 \pm 2.61^{\circ}$ to $52.26 \pm 3.84^{\circ}$. The mean ankle dorsiflexion range of motion during landing was $41.54 \pm 4.32^{\circ}$.

trunk flexion, ankle angle, and ankle dorsiflexion range of motion did not differ significantly between male and female athletes (all $p > 0.05$). Cohen's d values indicated trivial to small effect sizes for all comparisons, supporting the absence of meaningful between-group differences. These findings remained unchanged after Bonferroni correction.

Table 3. Comparison of sagittal-plane kinematics between male and female athletes.

Variables	Men	Women	p-value	Cohen's d (95% CI)
Initial knee flexion angle	145.57 $\pm$ 6.32	147.13 $\pm$ 5.87	.184	0.251 (-0.05 - 0.552)
Maximum knee flexion angle	115.99 $\pm$ 9.81	118.83 $\pm$ 9.15	.120	0.294 (-0.007 - 0.595)
Initial hip flexion angle	10.14 $\pm$ 1.68	9.67 $\pm$ 2.22	.177	-0.257 (-0.558 - 0.043)
Maximum hip flexion angle	21.09 $\pm$ 1.29	20.67 $\pm$ 1.63	.111	-0.304 (-0.605 - -0.003)
Initial trunk flexion angle	102.93 $\pm$ 3.25	103.08 $\pm$ 3.20	.809	0.046 (-0.253 - 0.346)
Maximum trunk flexion angle	59.26 $\pm$ 2.68	59.59 $\pm$ 2.38	.498	0.126 (-0.174 - 0.426)
Initial ankle angle	93.62 $\pm$ 2.50	94.40 $\pm$ 2.91	.112	0.299 (-0.002 - 0.6)
Maximum ankle angle	51.95 $\pm$ 3.83	53.13 $\pm$ 3.80	.105	0.309 (0.008 - 0.61)

Variables	Men	Women	p-value	Cohen's d (95% CI)
Ankle dorsiflexion ROM	41.66 ± 4.30	41.27 ± 4.42	.630	-0.09 (-0.39 - 0.21)

Data are presented as mean ± SD. All angular variables are expressed in degrees (°). CI= confidence interval. Bonferroni-adjusted p-values are performed.

Discussion

The present study aimed to characterize sagittal-plane lower-limb kinematics during a standardized single-leg landing task and to determine whether sex-related differences exist in the movement strategy adopted by athletes. The main findings indicate that the landing task was characterized by a coordinated increase in knee and hip flexion together with ankle dorsiflexion during the impact absorption phase, while trunk motion remained within a range considered compatible with efficient load attenuation^{12,5,4}. Furthermore, no significant differences were observed between male and female athletes for any of the analysed kinematic variables^{15,16,11}. Collectively, these findings reinforce the concept that landing biomechanics should be interpreted as the result of coordinated intersegmental motion rather than the behaviour of an isolated joint, supporting current evidence that efficient impact attenuation depends on the interaction between the trunk, hip, knee and ankle throughout the landing manoeuvre^{17,12,11,18,3,7,4,2}.

Knee flexion has consistently been identified as one of the primary determinants of impact absorption during landing because it directly influences the distribution of mechanical loads across the lower extremity^{17,12,11,8,10}. In the present study, athletes landed with a mean knee flexion angle of approximately 34° at initial contact and progressively increased flexion to approximately 63° during the impact absorption phase. This movement pattern suggests that participants adopted an effective strategy to dissipate landing forces through progressive joint excursion rather than maintaining a relatively extended knee throughout ground contact^{13,11}. Previous biomechanical investigations have demonstrated that limited knee flexion during landing increases quadriceps dominance, anterior tibial shear forces and anterior cruciate ligament loading, whereas greater knee flexion facilitates mechanical energy dissipation and reduces the loads transmitted to passive joint structures^{1,5,19,20,10}. Although the present study did not quantify ligament loading directly, the observed kinematic profile appears consistent with a movement strategy that promotes impact attenuation through controlled sagittal-plane motion^{12,5}.

Our findings are generally consistent with previous investigations evaluating landing biomechanics under similar experimental conditions^{12,8,11}. Kristianslund and Krosshaug reported comparable knee flexion angles at initial contact during landing tasks, although participants in their study exhibited greater peak knee flexion than observed in the present investigation²¹. Differences in landing technique probably explain these discrepancies, as their protocol involved bilateral landings whereas the current study evaluated a single-leg landing task, which imposes greater stability demands and generally limits the available range of motion during impact absorption^{3,11}. Rather than considering these differences contradictory, they reinforce the notion that landing kinematics are highly task-dependent and should always be interpreted within the context of the specific motor demand being evaluated^{6,21,3}. Consequently, knee flexion should not be interpreted in isolation but as one component of an integrated neuromuscular strategy that continuously adapts to changes in task constraints^{12,4}.

However, contemporary evidence suggests that analysing knee motion alone provides only a partial understanding of landing biomechanics^{17,12,5}. During dynamic tasks, proximal segments substantially influence lower-limb alignment, and alterations in hip or trunk motion may modify knee loading despite similar sagittal-plane knee angles^{17,1,5,18,2}. This concept has gained increasing attention in recent years, shifting the focus from isolated joint

mechanics towards coordinated movement patterns involving the entire kinetic chain^{3,7,2}. Therefore, the interpretation of knee kinematics should always be accompanied by an evaluation of adjacent segments, particularly the hip and trunk, which play a fundamental role in controlling the position of the body's centre of mass throughout landing^{12,22,1,2}.

Consistent with this integrated perspective, the present study demonstrated a progressive increase in hip flexion throughout the landing manoeuvre^{12,4,23}. Athletes increased hip flexion from approximately 10° at initial contact to approximately 21° at maximum knee flexion, indicating active participation of the hip during impact absorption. Previous studies have similarly reported that greater hip flexion contributes to reducing knee loading by increasing the contribution of the hip extensors to energy absorption and improving control of lower-limb alignment^{24,3,25,26}. Likewise, van der Harst et al. described comparable hip flexion patterns during single-leg landing tasks, supporting the reproducibility of these movement characteristics across different populations²³. Although the magnitude of hip flexion observed in our study was slightly lower than previously reported, these differences are likely attributable to variations in landing protocols and participant characteristics rather than fundamentally different movement strategies^{6,23}.

The influence of trunk motion on landing biomechanics has also received increasing attention because trunk position directly affects whole-body balance and the mechanical demands imposed on the lower extremities^{1,5,2}. In the present study, trunk posture remained close to an upright position at initial contact before progressing towards greater flexion during the impact absorption phase^{12,5}. This behaviour agrees with previous investigations demonstrating that controlled forward trunk inclination facilitates hip recruitment, reduces knee extensor demand and contributes to a more favourable distribution of landing loads^{5,25}. Conversely, excessively upright trunk positions have been associated with increased knee extensor moments, greater anterior tibial loading and potentially less favourable landing mechanics^{8,27,28}. Importantly, trunk motion should not be interpreted as an isolated risk factor but rather as one element within the coordinated neuromuscular strategy that regulates lower-limb alignment during dynamic tasks^{1,3}.

The ankle also plays a fundamental role in landing biomechanics by regulating the transmission of forces from the foot to the proximal joints^{12,9,4}. In the present study, athletes exhibited a mean ankle dorsiflexion range of motion of approximately 41.5°, reflecting substantial sagittal-plane excursion during the impact absorption phase. Adequate dorsiflexion has been associated with a greater capacity to dissipate landing forces through progressive ankle motion, thereby reducing the mechanical demand transferred to the knee^{12,9,4}. Conversely, restricted ankle dorsiflexion has been linked to stiffer landing strategies, increased vertical ground reaction forces, reduced knee flexion and greater dynamic knee loading during high-impact tasks^{9,1,26}. Although the present investigation did not evaluate ankle mobility as an isolated predictor of injury, the dorsiflexion values observed suggest that participants adopted an ankle strategy compatible with effective impact attenuation during landing^{12,4}.

Taken together, the findings of the present study reinforce the concept that landing biomechanics should not be interpreted through isolated joint behaviour^{12,3,4}. Instead, efficient impact absorption emerges from the coordinated interaction between the trunk, hip, knee and ankle, each contributing to the progressive dissipation of mechanical energy throughout the landing manoeuvre^{12,5,2}. Recent biomechanical research increasingly supports this systems-based perspective, demonstrating that alterations in one segment inevitably

influence movement patterns in adjacent joints^{1,5,3}. Consequently, focusing exclusively on knee flexion provides an incomplete representation of landing mechanics and may oversimplify the mechanisms underlying both performance and injury risk^{3,7,2}. From this perspective, the kinematic profile observed in the present study appears to represent an integrated movement strategy in which coordinated sagittal-plane motion across multiple segments facilitates efficient load distribution while maintaining dynamic stability during landing.

Contrary to the commonly reported higher incidence of knee injuries in female athletes, no statistically significant sex-related differences were identified in any of the analysed kinematic variables^{16,4,11}. These findings suggest that, under standardized landing conditions, male and female athletes adopted remarkably similar sagittal-plane movement strategies^{16,4}. Previous investigations have frequently described females as landing with reduced knee and hip flexion and a more upright trunk posture, characteristics that have traditionally been associated with increased anterior cruciate ligament loading^{8,27,10}. However, more recent evidence indicates that sex alone does not consistently explain biomechanical variability and that individual neuromuscular control, physical capacity, task characteristics and training background may exert a greater influence on landing mechanics than biological sex itself^{9,7}. Therefore, the absence of sex differences observed in the present study supports the growing consensus that movement quality should be evaluated individually rather than assuming stereotypical biomechanical patterns based exclusively on sex^{3,7}.

These findings have several practical implications for clinicians, strength and conditioning coaches, and rehabilitation professionals^{1,6,2}. Since landing biomechanics depend on coordinated intersegmental motion rather than isolated knee behaviour, assessment protocols should incorporate the simultaneous evaluation of trunk, hip, knee and ankle kinematics^{12,18,3,2}. Likewise, neuromuscular training programmes designed to optimise landing technique should prioritise movement quality and whole-body coordination instead of focusing exclusively on increasing knee flexion^{1,5,3,2}. This integrated approach may improve impact absorption efficiency, optimise lower-limb mechanics and potentially contribute to reducing excessive mechanical loading during sport-specific tasks^{1,13,2}. Although the present study was not designed to establish causal relationships with injury occurrence, the kinematic profile described here may provide useful reference values for functional assessment, movement screening and return-to-sport decision-making following lower-limb injuries^{1,3,7}.

Overall, the present findings demonstrate that single-leg landing is characterised by a coordinated sagittal-plane movement strategy involving the trunk, hip, knee and ankle^{12,5}. Rather than identifying isolated joint positions associated with injury risk, the results support the concept that effective landing performance depends on the integration of multiple segments acting together to attenuate impact forces^{12,3,4}. Consequently, the evaluation of landing biomechanics should adopt a comprehensive approach that considers the interaction between lower-limb joints and the trunk, providing a more complete understanding of movement quality and its potential implications for injury prevention and athletic performance^{12,1,6,2}.

Limitations

Despite the strengths of the present study, several limitations should be acknowledged. First, joint kinematics were assessed using two-dimensional photogrammetric analysis, which only allows the evaluation of movement in the sagittal plane and does not capture three-dimensional joint mechanics, particularly frontal and transverse plane motions that may also contribute to knee injury mechanisms. Second, kinetic variables, including ground reaction forces and joint moments, were not recorded, preventing a comprehensive interpretation of the mechanical demands experienced during landing. Third, muscle activation patterns were

not evaluated, making it impossible to determine the neuromuscular strategies underlying the observed kinematic behaviour. Finally, although the sample included a large number of athletes, participants were not stratified according to sport discipline or competitive level, factors that may influence landing mechanics. Future studies should integrate three-dimensional motion analysis, kinetic assessments and electromyographic measurements to provide a more comprehensive understanding of lower-limb biomechanics during landing tasks.

Conclusions

The present study provides a comprehensive characterization of sagittal-plane lower-limb kinematics during a standardized single-leg landing task in athletes. The findings demonstrate that landing performance is characterized by coordinated motion of the trunk, hip, knee and ankle, supporting the concept that impact attenuation depends on the integrated contribution of multiple segments rather than the behaviour of an isolated joint. Furthermore, no significant sex-related differences were identified under the standardized testing conditions employed in this study. These findings reinforce the importance of adopting a whole-body biomechanical approach when evaluating landing mechanics and may provide useful reference values for movement assessment, injury prevention strategies and rehabilitation programmes aimed at optimizing lower-limb function.

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CONFLICT OF INTEREST

The authors declare no conflicts of interest.

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Originales

Injury patterns and associated factors among Portuguese federated rink hockey players: a cross-sectional study



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ABSTRACT

Objective: To describe injury patterns and identify factors associated with the number of reported injuries among Portuguese senior first-division rink hockey players during the 2024–2025 competitive season.

Methods: This cross-sectional observational study included Portuguese senior first-division rink hockey players who completed an anonymous electronic questionnaire regarding injuries sustained during the 2024–2025 season. Demographic and sport-related characteristics, injury location, type, mechanism, severity, supervised strength training, and physiotherapy availability were collected. Descriptive statistics and independent-samples t-tests were used to compare reported injury numbers between participant groups.

Results: 124 athletes participated (mean age 23.8 ± 5.3 years; mean federated practice 16.9 ± 5.6 years), of whom 115 (92.7%) reported at least one injury. Lower limb injuries were most frequent (143; 36%), followed by head and neck injuries (119; 30%). Facial injuries accounted for 94 (79%) head and neck injuries. Trauma from stick or ball contact was the most frequent mechanism (105; 26.4%). Overall, 119 (30%) injuries were severe and 25 (6.4%) required surgery. Playing position was associated with reported injury numbers, with goalkeepers sustaining approximately 52% fewer injuries than field players ($p = 0.00066$). No significant associations were observed with sex, training frequency, years of federated practice, supervised strength training, or physiotherapy availability.

Conclusions: Lower limb and facial injuries were the most frequently reported patterns. Playing position was the only participant characteristic significantly associated with reported injury numbers. These findings highlight potential targets for injury prevention, particularly lower limb prevention and facial protection, and support future prospective research.

Keywords: Athletic injuries; Hockey; Athletes; Epidemiology.

Patrones de lesiones y factores asociados en jugadores portugueses federados de hockey sobre patines: un estudio transversal

RESUMEN

Objetivo: Describir los patrones de lesión e identificar factores asociados con el número de lesiones notificadas en jugadores portugueses de hockey sobre patines de primera división durante la temporada 2024–2025.

Método: Estudio observacional transversal mediante un cuestionario electrónico anónimo sobre las lesiones sufridas durante la temporada 2024–2025. Se recogieron datos demográficos y deportivos, características de las lesiones, entrenamiento de fuerza y fisioterapia. Se utilizaron estadísticos descriptivos y pruebas t de muestras independientes.

Resultados: Participaron 124 atletas (edad media $23,8 \pm 5,3$ años; práctica federada media $16,9 \pm 5,6$ años); 115 (92,7%) notificaron al menos una lesión. Las lesiones de las extremidades inferiores fueron las más frecuentes (143; 36%), seguidas de las de cabeza y cuello (119; 30%). Las lesiones faciales representaron 94 (79%) lesiones de cabeza y cuello. El traumatismo por contacto con stick o pelota fue el mecanismo más frecuente (105; 26,4%). En total, 119 (30%) lesiones fueron graves y 25 (6,4%) requirieron cirugía. La posición de juego se asoció con el número de lesiones, con aproximadamente un 52% menos en los porteros que en los jugadores de campo ($p = 0,00066$). No hubo asociaciones significativas con sexo, frecuencia de entrenamiento, años de práctica, entrenamiento de fuerza o fisioterapia.

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Conclusiones: Las lesiones de las extremidades inferiores y faciales fueron las más frecuentes. La posición de juego fue la única característica asociada significativamente con el número de lesiones. Estos hallazgos señalan objetivos preventivos y respaldan estudios prospectivos futuros.

Palabras clave: Lesiones deportivas; Hockey; Deportistas; Epidemiología.

Padrões de lesão e fatores associados em jogadores portugueses federados de hóquei em patins: um estudo transversal

RESUMO

Objetivo: Descrever os padrões de lesão e identificar fatores associados ao número de lesões reportadas em jogadores portugueses de hóquei em patins da primeira divisão durante a época 2024–2025.

Método: Estudo observacional transversal através de um questionário eletrónico anónimo sobre as lesões sofridas durante a época 2024–2025. Foram recolhidos dados demográficos e desportivos, características das lesões, treino de força e fisioterapia. Foram utilizadas estatísticas descritivas e testes t para amostras independentes.

Resultados: Participaram 124 atletas (idade média $23,8 \pm 5,3$ anos; prática federada média $16,9 \pm 5,6$ anos); 115 (92,7%) reportaram pelo menos uma lesão. As lesões dos membros inferiores foram as mais frequentes (143; 36%), seguidas das lesões da cabeça e pescoço (119; 30%). As lesões faciais corresponderam a 94 (79%) das lesões da cabeça e pescoço. O traumatismo por contacto com stick ou bola foi o mecanismo mais frequente (105; 26,4%). No total, 119 (30%) lesões foram graves e 25 (6,4%) necessitaram de cirurgia. A posição de jogo associou-se ao número de lesões, com aproximadamente 52% menos lesões nos guarda-redes do que nos jogadores de campo ($p = 0,00066$). Não houve associações significativas com sexo, frequência de treino, anos de prática, treino de força ou fisioterapia.

Conclusões: As lesões dos membros inferiores e faciais foram as mais frequentes. A posição de jogo foi a única característica associada significativamente ao número de lesões. Estes resultados destacam potenciais alvos preventivos e apoiam estudos prospetivos futuros.

Palavras-chave: Lesões desportivas; Hóquei; Atletas; Epidemiologia.

BACKGROUND

Rink hockey is a fast-paced team sport characterized by repetitive skating, rapid directional changes, and frequent interactions involving sticks, ball, and player contact. These sport-specific demands expose athletes to a wide spectrum of injuries, including both acute traumatic events and overuse syndromes.

In recent years, the epidemiology of injuries in rink hockey has been increasingly investigated, revealing consistent injury patterns across different competitive levels and populations. Previous studies have reported injury incidence rates ranging from approximately 4.5 to 5.9 injuries per 1000 hours of exposure, highlighting the substantial injury burden associated with the sport^{1,2}. Lower limb injuries are consistently reported as the most common injuries, particularly involving the hip/groin and thigh. This pattern reflects the substantial biomechanical demands imposed by skating, rapid accelerations, and repetitive mechanical loading^{1,3,4}. In addition to lower limb injuries, head and facial injuries represent a significant proportion of traumatic events, often resulting from direct impacts with the stick or ball³. Musculotendinous injuries, contusions, and fractures have also been commonly reported, reflecting the multifactorial injury mechanisms present in rink hockey, including both contact and non-contact mechanisms^{1,3}.

Previous studies have also explored factors associated with injury occurrence. Sex-specific analyses have demonstrated similar overall injury incidence between male and female players, although match exposure has been associated with higher injury risk compared to training⁵. Furthermore, positional differences in injury patterns have been observed in hockey-related sports, with variations in exposure, movement demands, and protective equipment contributing to differences in injury risk².

Comparisons with ice hockey, a related high-intensity sport with greater body contact and more extensive protective equipment, provide additional insight into injury mechanisms and risk factors. Both sports demonstrate a predominance of lower limb injuries and

positional variation in injury risk; however, rink hockey appears to present a higher relative frequency of head and facial injuries, likely related to greater exposure to stick and ball impacts and less extensive facial protection^{2,3}.

Collectively, these findings provide valuable insights into injury patterns and factors associated with injury occurrence in rink hockey. However, limited data are available regarding injury patterns among Portuguese federated rink hockey players. A better understanding of injury patterns and associated factors in this population is essential to inform targeted injury prevention strategies and optimize athlete safety and performance.

Therefore, the aim of this study was to describe injury patterns and identify factors associated with self-reported injuries among Portuguese federated rink hockey players using a cross-sectional survey.

MATERIALS AND METHODS

Study Design and Participants

This cross-sectional observational study investigated self-reported injuries among Portuguese federated male and female senior first-division rink hockey players during the 2024–2025 competitive season. Eligible participants were athletes competing in the Portuguese first division during the study period. Data were collected using a structured anonymous electronic questionnaire distributed to first-division clubs through coaching staff and team representatives between July and September 2025. Incomplete questionnaires were excluded from the analysis. A total of 124 athletes met the inclusion criteria and were included in the study.

This study was conducted in accordance with the principles of the Declaration of Helsinki. Participation was voluntary, and electronic informed consent was obtained before questionnaire completion. The study involved an anonymous questionnaire administered to adult athletes and did not involve patients, clinical

records, or experimental procedures. All data were anonymized to ensure confidentiality.

Data Collection

Data were collected using a structured questionnaire that included demographic and sport-specific information such as age, sex, years of federated practice, playing position, dominant hand, and weekly training frequency. The questionnaire was originally developed in Portuguese; an English translation is provided in [Appendix 1](#).

Injury data included the number of injuries sustained, anatomical location, injury type, injury mechanism, severity, and requirement for surgical intervention. Injuries were defined as any physical complaint sustained in training or competition during the 2024-2025 season that resulted in interruption of sport participation for at least one day. Severe injuries were defined as time-loss injuries resulting in more than 28 days of absence from sport participation.

Additional variables included participation in supervised strength training and the availability of physiotherapy support during training or competition.

Injury Classification

Injuries were classified according to anatomical region as head and neck, trunk, upper limb, or lower limb.

Mechanisms of injury were categorized as trauma resulting from stick or ball contact, overload, fall, collision with another player, and other mechanisms.

Injury types were categorized as fracture, muscle injury/contracture, haematoma/contusion, wound/laceration, and tendon injury/inflammation. Less frequent injuries that did not fit these predefined categories were grouped under the category "Other".

Statistical Analysis

Descriptive statistics were used to summarize demographic characteristics and injury distribution. Continuous variables were expressed as mean $\pm$ standard deviation, whereas categorical variables were expressed as frequencies and percentages. Comparative analyses were performed to evaluate differences in the number of reported injuries according to participant characteristics, including sex, playing position, years of federated practice, weekly training frequency, participation in supervised strength training, and physiotherapy availability. Group comparisons were performed using independent-samples t-tests. Statistical significance was set at $p < 0.05$. Statistical analyses were performed using IBM SPSS Statistics version 24 (IBM Corp., Armonk, NY, USA).

RESULTS

Participant Characteristics

A total of 124 federated rink hockey players participated in the study, including both male and female athletes. Participant demographic and training characteristics, including comparisons by sex, are presented in [Table 1](#). Male players were older, had more years of federated practice, and reported a higher weekly training frequency than female players. Right-hand dominance was most common, although the proportion of left-handed players was higher than the approximately 10% reported in the general population⁶. The distribution of playing positions reflected standard rink hockey team composition, with a predominance of field players compared with goalkeepers (4:1).

Table 1. Participant demographic and training characteristics

Variable	Overall(n = 124)	Female	Male	p value
Age, mean $\pm$ SD (years)	23.8 $\pm$ 5.3	22.4 $\pm$ 4.9	25.1 $\pm$ 4.7	0.0016
Years of federated practice, mean $\pm$ SD	16.9 $\pm$ 5.6	15.0 $\pm$ 5.4	18.8 $\pm$ 5.0	<0.001
Training sessions per week, mean $\pm$ SD	3.9 $\pm$ 1.1	3.25 $\pm$ 0.5	4.71 $\pm$ 1.2	<0.001
Dominant hand, right, n (%)	90 (72.6%)	—	—	—
Field players, n (%)	99 (79.8%)	—	—	—
Players with strength training supervision, n (%)	78 (63.4%)	—	—	—
Players with physiotherapist access, n (%)	71 (57.7%)	—	—	—
Abbreviations: SD, standard deviation.				
Continuous variables are presented as mean $\pm$ SD. Categorical variables are presented as n (%).				
P values for continuous variables compare female and male athletes using independent-samples t-tests.				

Injury Occurrence and Severity

Most athletes reported at least one injury during the season. The mean number of reported injuries per athlete was 3.19 $\pm$ 4.06. Overall, 119 (30%) reported injuries were classified as severe,

resulting in more than 28 days of time loss, while 25 (6.4%) required surgical intervention. Injury occurrence and severity are presented in [Table 2](#).

Table 2. Injury characteristics among Portuguese federated rink hockey players

Variable	Value
Injury Occurrence	
Athletes reporting ≥ 1 injury	115 (92.7%)
Mean number of reported injuries per player, mean $\pm$ SD	3.19 $\pm$ 4.06

Variable	Value
Anatomical Region	
Lower limb	143 (36.0%)
Head and neck	119 (30.0%)
Upper limb	75 (19.0%)
Trunk	59 (15.0%)
Injury Type	
Fracture	42 (10.5%)
Haematoma/contusion	41 (10.4%)
Tendon injury/inflammation	35 (8.9%)
Muscle injury/contracture	34 (8.6%)
Wound/laceration	33 (8.3%)
Other	185 (46.7%)
Mechanism	
Stick or ball trauma	105 (26.4%)
Overload	71 (18.0%)
Falls	64 (16.1%)
Player collisions	51 (13.0%)
Other mechanisms	105 (26.4%)
Injury severity	
Severe injuries (>28 days of time loss), n (% of injuries)	119 (30.0%)
Injuries requiring surgical treatment, n (% of injuries)	25 (6.4%)
Abbreviations: SD, standard deviation	

Anatomical Distribution of Injuries

Lower limb injuries were the most frequently reported, followed by injuries affecting the head and neck region, while upper limb and trunk injuries were less common (Table 2). Within the head and neck category, facial injuries accounted for 79% of cases and represented the most frequent individual anatomical location overall. Lower limb injuries were distributed across multiple anatomical regions without a single dominant location.

Injury Types and Mechanisms

The distribution of injuries by type and mechanism is presented in Table 2. Fractures and soft tissue injuries were among the most frequently reported injury types, while trauma resulting from stick or ball contact was the predominant injury mechanism.

Factors Associated with the Number of Reported Injuries

Playing position was significantly associated with the number of reported injuries. Goalkeepers sustained approximately 52% fewer injuries than field players ($p = 0.00066$), with this difference being particularly pronounced for head and neck injuries, for which goalkeepers sustained approximately 83% fewer injuries (Supplementary Table S1).

Most athletes reported participation in supervised strength training (63.4%) and access to physiotherapy during training or competition (57.7%). However, no statistically significant associations were observed between number of reported injuries and either supervised strength training or physiotherapy availability. Similarly, no statistically significant associations were found between number of reported injuries and sex, weekly training frequency, or years of federated practice. Additional analyses exploring injury occurrence across these variables are provided in the Supplementary Material (Supplementary Tables S2-6).

DISCUSSION

This study provides a detailed overview of injury patterns among Portuguese senior first-division rink hockey players and identifies factors associated with injury occurrence that may inform injury prevention strategies.

The principal finding was the predominance of lower limb injuries, which accounted for more than one-third of all injuries. This finding is consistent with previous literature^{1,3} and may reflect the substantial biomechanical demands associated with skating, including repetitive propulsion, rapid accelerations and decelerations, and repetitive mechanical loading. These demands may contribute to both acute injuries and overuse conditions affecting the lower extremities. The consistency of this finding with previous epidemiological studies supports the relevance of lower limb injuries as an important target for injury prevention in rink hockey, despite differences in study populations and methodologies.

Head and neck injuries, particularly facial injuries, represented the second most common anatomical category and the most frequent individual injury location. The high frequency of facial injuries may be related to repeated exposure to stick and ball impacts^{3,4}, consistent with trauma being the predominant reported injury mechanism and with previous studies reporting a substantial proportion of head and facial injuries in rink hockey^{3,4}. Differences in injury definitions, competitive level, and protective equipment between studies may contribute to variations in the reported frequency of these injuries.

Playing position was the only participant characteristic significantly associated with the number of reported injuries, consistent with previous literature highlighting positional differences in exposure, biomechanics, and injury patterns^{2,5}. Goalkeepers reported substantially fewer injuries overall than field players, particularly in the head and neck region. This difference may reflect lower exposure to high-speed skating and differences in protective equipment between positions. The marked reduction in head and neck injuries among goalkeepers is compatible with a potential protective effect of specialized equipment, although causality cannot be established in the present study.

No significant associations were observed between the number of reported injuries and sex, weekly training frequency, years of federated practice, strength training participation, or physiotherapy availability. These findings should be interpreted cautiously, as the absence of statistically significant associations does not necessarily indicate an absence of effect. Previous studies have also reported differences in injury patterns according to sex and exposure characteristics, although findings have not been consistent across populations^{2,5}. Differences in study design, sample characteristics, injury definitions, and exposure assessment may partly explain these discrepancies. In the present population, these findings suggest that playing position may be more relevant to injury occurrence than the general training and support characteristics assessed.

Approximately 30% of reported injuries were classified as severe, highlighting the potential clinical impact of injuries in rink hockey athletes. Severe injuries may result in prolonged absence from sport, functional limitations, and increased risk of subsequent injury. This finding reinforces the importance of prevention strategies addressing both the high frequency of lower limb injuries and the potentially greater consequences associated with severe injuries.

From a clinical perspective, these findings highlight several important implications for injury prevention. First, the predominance of lower limb injuries supports consideration of targeted prevention programmes incorporating strength development, neuromuscular control, proprioception, and structured load management. Exercise-based injury prevention programmes have been shown to significantly reduce overall sports injury incidence, with systematic reviews reporting reductions of up to 37% across multiple sports disciplines⁷. Given the high proportion of lower limb injuries observed in this population, structured neuromuscular prevention strategies may be particularly relevant for rink hockey athletes. Second, the high frequency of facial injuries supports consideration of greater use of facial protective equipment, particularly among field players. Evidence from contact sports suggests that protective equipment, particularly full facial protection, may reduce the severity of head injuries in ice hockey⁸. Given the positional differences observed in this study, reinforcement of appropriate protective equipment policies may represent a potentially simple and practical preventive strategy.

This study has several limitations. First, the self-reported design may have introduced recall bias and potentially resulted in underreporting of injuries, particularly minor injuries. In addition, injuries were self-reported and were not independently verified through medical records, which may have introduced misclassification bias. For example, some participants may have classified minor procedures, such as wound suturing, as surgical interventions, potentially leading to an overestimation of surgical treatment in this dataset. Second, the absence of exposure data prevented calculation of injury incidence rates per 1000 hours, which are commonly used in sports injury epidemiology to account for differences in exposure. Third, the cross-sectional design precludes assessment of temporal associations and does not allow causal inference. Nevertheless, the consistency of the main injury distribution findings with previous epidemiological studies supports the relevance of the observed patterns despite these methodological limitations. Future prospective studies should incorporate standardized injury definitions, medical verification of diagnoses, exposure tracking, and position-specific injury surveillance to allow calculation of injury incidence rates and better characterize factors associated with injury occurrence.

Despite these limitations, this study provides novel data on injury patterns among Portuguese federated rink hockey players, a population for which published evidence remains limited. The

findings identify clinically relevant targets for injury prevention and may support the development of future sport-specific prevention strategies and prospective injury surveillance studies.

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SUPPLEMENTARY MATERIAL

Appendix 1. Questionnaire used for data collection

This questionnaire was developed by the authors for the purpose of this study and was originally administered in Portuguese.

Credits: Alice Vicente, João Rosa Silva, Joana Alves de Campos, Isabel Crespo, Diogo Rodrigues da Silva, José Maria Moreira

The following questionnaire refers to injuries sustained during the 2024–2025 competitive season.

An injury was defined as any physical complaint sustained during training or competition that resulted in interruption of sport participation for at least one day. Severe injuries were defined as time-loss injuries resulting in more than 28 days of absence from sport participation.

Section	Question	Response Options
Demographics	Age (years)	_____
	Sex	☐ Male ☐ Female

Section	Question	Response Options
	Years of federated practice	_____
	Playing position	☐ Goalkeeper ☐ Field player
	Dominant hand	☐ Right ☐ Left
	Training sessions/week	_____
Injury history	Number of injuries	_____
	Severe injuries (>28 days)	_____
	Injuries requiring surgery	_____
Injury characteristics	Anatomical region	☐ Head/neck ☐ Trunk ☐ Upper limb ☐ Lower limb
	Specific location	_____
	Type of injury	☐ Fracture ☐ Muscle ☐ Contusion ☐ Laceration ☐ Tendon ☐ Other: _____
	Mechanism	☐ Overload ☐ Fall ☐ Stick/ball ☐ Collision ☐ Other: _____
Additional info	Supervised strength training	☐ Yes ☐ No
	Physiotherapy support	☐ Yes ☐ No

Supplementary Material

Table S1. Association between playing position and the number of reported injuries

Variable	Field players	Goalkeepers	t value	p value
Total injuries, mean $\pm$ SD	3.57 $\pm$ 4.44	1.72 $\pm$ 1.40	4.49	0.00066
Head and neck injuries, mean $\pm$ SD	1.16 $\pm$ 1.88	0.2 $\pm$ 0.50	4.05	1.67e-5
Trunk injuries, mean $\pm$ SD	0.34 $\pm$ 0.86	0.08 $\pm$ 0.28	-2.49	0.014
Upper limb injuries, mean $\pm$ SD	0.86 $\pm$ 1.29	0.52 $\pm$ 0.65	-1.83	0.072
Lower limb injuries, mean $\pm$ SD	1.21 $\pm$ 1.57	0.92 $\pm$ 1.00	-1.16	0.25
Abbreviations: SD, standard deviation				
Statistical test: Independent-samples t-test.				

Table S2. Comparison of demographic and training characteristics by playing position

Variable	Field players	Goalkeepers	t value	p value
Age (years), mean $\pm$ SD	23.9 $\pm$ 4.8	22.4 $\pm$ 5.4	-1.30	0.20
Years of practice, mean $\pm$ SD	17.1 $\pm$ 5.1	15.5 $\pm$ 6.9	-1.09	0.28
Training sessions/week, mean $\pm$ SD	3.9 $\pm$ 1.2	3.8 $\pm$ 0.7	-0.54	0.59
Abbreviations: SD, standard deviation				
Statistical test: Independent-samples t-test.				

Table S3. Comparison of demographic and training characteristics by dominant hand

Variable	Right hand	Left hand	t value	p value
Age (years), mean $\pm$ SD	23.5 $\pm$ 5.0	24.0 $\pm$ 5.0	-0.52	0.60
Years of practice, mean $\pm$ SD	16.6 $\pm$ 5.5	17.1 $\pm$ 5.5	-0.38	0.71
Training sessions/week, mean $\pm$ SD	3.9 $\pm$ 1.2	3.8 $\pm$ 1.0	0.41	0.68
Abbreviations: SD, standard deviation				
Statistical test: Independent-samples t-test.				

Table S4. Comparison of injury counts by sex

Variable	Female	Male	t value	p value
Total injuries, mean $\pm$ SD	3.5 $\pm$ 4.0	2.9 $\pm$ 4.2	-0.79	0.43
Head and neck injuries, mean $\pm$ SD	1.1 $\pm$ 1.9	0.8 $\pm$ 1.6	-1.08	0.28
Trunk injuries, mean $\pm$ SD	0.30 $\pm$ 0.84	0.27 $\pm$ 0.73	-0.22	0.83
Upper limb injuries, mean $\pm$ SD	0.82 $\pm$ 1.21	0.75 $\pm$ 1.19	-0.33	0.74
Lower limb injuries, mean $\pm$ SD	1.2 $\pm$ 1.5	1.1 $\pm$ 1.5	-0.57	0.57
Abbreviations: SD, standard deviation				
Statistical test: Independent-samples t-test.				

Table S5. Comparison of injury counts by physiotherapy availability

Variable	PT	No PT	t value	p value
Total injuries, mean $\pm$ SD	2.86 $\pm$ 2.99	3.65 $\pm$ 5.21	-0.99	0.33
Head and neck injuries, mean $\pm$ SD	0.91 $\pm$ 1.65	1.04 $\pm$ 1.86	-0.38	0.70
Trunk injuries, mean $\pm$ SD	0.28 $\pm$ 0.68	0.28 $\pm$ 0.91	-0.05	0.96
Upper limb injuries, mean $\pm$ SD	0.75 $\pm$ 1.12	0.85 $\pm$ 1.30	-0.44	0.66
Lower limb injuries, mean $\pm$ SD	0.92 $\pm$ 0.92	1.48 $\pm$ 1.96	-1.93	0.057
Abbreviations: PT, physiotherapy; SD, standard deviation				
Statistical test: Independent-samples t-test.				

Table S6. Comparison of injury counts by strength training participation

Variable	ST	No ST	t value	p value
Total injuries, mean $\pm$ SD	2.9 $\pm$ 4.0	3.8 $\pm$ 4.3	-1.14	0.26
Head and neck injuries, mean $\pm$ SD	0.96 $\pm$ 1.88	0.98 $\pm$ 1.48	-0.05	0.96
Trunk injuries, mean $\pm$ SD	0.26 $\pm$ 0.71	0.33 $\pm$ 0.90	-0.49	0.63
Upper limb injuries, mean $\pm$ SD	0.68 $\pm$ 1.00	0.98 $\pm$ 1.47	-1.21	0.23
Lower limb injuries, mean $\pm$ SD	0.97 $\pm$ 1.40	1.47 $\pm$ 1.55	-1.76	0.08
Abbreviations: SD, standard deviation; ST, strength training				



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Originales

Data mining of key anthropometric variables in elite and non-elite wrestlers using principal component analysis



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ABSTRACT

Objective. To identify the key anthropometric variables that characterise elite and non-elite wrestlers by means of principal component analysis, and to compare the anthropometric profile of both competitive levels.

Method. Sixty male Iranian wrestlers (30 elite, 30 non-elite) underwent an anthropometric assessment including height, body mass, body mass index, eight skinfolds, two bicondylar breadths, eleven girths, body fat percentage, body fat mass, skeletal muscle index and total-body skeletal muscle mass. Principal component analysis was applied to the 27 variables in order to identify the most representative ones. Independent t-tests compared both groups and Cohen's d was calculated as effect size.

Results. Anthropometric features were reduced to two principal components explaining 76.3% of the total variance. The first component (50.7%) showed high loadings for girth measurements and muscular properties, whereas the second (25.5%) was associated with skinfold thicknesses and body fat properties. Elite wrestlers were taller, showed larger girths (shoulders, chest, biceps, forearm, thigh, knee and wrist), thinner skinfolds (triceps, calf, chest and front thigh), lower body fat percentage, lower skeletal muscle index and greater total-body skeletal muscle mass ($p < .05$). No differences were found for body mass index, bicondylar breadths or body fat mass.

Conclusions. Principal component analysis is a useful tool to detect representative anthropometric variables in wrestlers. Girth measurements and muscular properties emerged as the most informative dimension, which may support a more efficient variable selection process for talent identification and strength and conditioning programming in wrestling clubs.

Keywords: Body composition; Muscle; Big data; Sport science; Data mining.

Minería de datos de las variables antropométricas clave en luchadores de élite y no élite mediante análisis de componentes principales

RESUMEN

Objetivo. Identificar las variables antropométricas clave que caracterizan a los luchadores de élite y no élite mediante el análisis de componentes principales, y comparar el perfil antropométrico de ambos niveles competitivos.

Método. Sesenta luchadores iraníes varones (30 de élite y 30 no élite) fueron evaluados antropométricamente: talla, masa corporal, índice de masa corporal, ocho pliegues cutáneos, dos diámetros bicondíleos, once perímetros, porcentaje de grasa corporal, masa grasa, índice de masa muscular esquelética y masa muscular esquelética total. Se aplicó un análisis de componentes principales a las 27 variables para identificar las más representativas. Se emplearon pruebas t para muestras independientes y se calculó la d de Cohen como tamaño del efecto.

Resultados. Las características antropométricas se redujeron a dos componentes principales que explicaron el 76.3% de la varianza total. El primer componente (50.7%) presentó cargas elevadas en los perímetros y las propiedades musculares, mientras que el segundo (25.5%) se asoció a los pliegues cutáneos y a las propiedades de la grasa corporal. Los luchadores de élite fueron más altos, presentaron mayores perímetros (hombros, tórax, bíceps, antebrazo, muslo, rodilla y muñeca), menores pliegues cutáneos (triceps, pantorrilla, tórax y muslo anterior), menor porcentaje de grasa corporal, menor índice de masa muscular esquelética y mayor masa muscular esquelética total ($p < .05$). No se hallaron diferencias en el índice de masa corporal, los diámetros bicondíleos ni la masa grasa.

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Conclusiones. El análisis de componentes principales resulta útil para detectar variables antropométricas representativas en luchadores. Los perímetros y las propiedades musculares emergieron como la dimensión más informativa, lo que puede favorecer una selección de variables más eficiente en los procesos de detección de talentos y en la programación del entrenamiento de fuerza en los clubes de lucha.

Palabras clave: Composición corporal; Músculo; Macrodatos; Ciencias del deporte; Minería de datos.

Mineração de dados das variáveis antropométricas-chave em lutadores de elite e não elite por meio da análise de componentes principais

RESUMO

Objetivo. Identificar as variáveis antropométricas-chave que caracterizam lutadores de elite e não elite por meio da análise de componentes principais e comparar o perfil antropométrico de ambos os níveis competitivos.

Método. Sessenta lutadores iranianos do sexo masculino (30 de elite e 30 não elite) foram avaliados antropometricamente: estatura, massa corporal, índice de massa corporal, oito dobras cutâneas, dois diâmetros bicondilares, onze perímetros, percentual de gordura corporal, massa gorda, índice de massa muscular esquelética e massa muscular esquelética total. Aplicou-se a análise de componentes principais às 27 variáveis para identificar as mais representativas. Foram utilizados testes t para amostras independentes e calculou-se o d de Cohen como tamanho de efeito.

Resultados. As características antropométricas foram reduzidas a dois componentes principais que explicaram 76.3% da variância total. O primeiro componente (50.7%) apresentou cargas elevadas nos perímetros e nas propriedades musculares, enquanto o segundo (25.5%) associou-se às dobras cutâneas e às propriedades da gordura corporal. Os lutadores de elite foram mais altos, apresentaram maiores perímetros (ombros, tórax, bíceps, antebraço, coxa, joelho e punho), menores dobras cutâneas (tríceps, panturrilha, tórax e coxa anterior), menor percentual de gordura corporal, menor índice de massa muscular esquelética e maior massa muscular esquelética total ($p < .05$). Não foram encontradas diferenças no índice de massa corporal, nos diâmetros bicondilares nem na massa gorda.

Conclusões. A análise de componentes principais é uma ferramenta útil para detectar variáveis antropométricas representativas em lutadores. Os perímetros e as propriedades musculares emergiram como a dimensão mais informativa, o que pode favorecer uma seleção de variáveis mais eficiente nos processos de detecção de talentos e na programação do treinamento de força em clubes de luta.

Palavras-chave: Composição corporal; Músculo; Big data; Ciências do esporte; Mineração de dados.

INTRODUCTION

Multiple factors may contribute to predicting the future success of wrestlers, yet most of them are difficult to control. Kaynar reported that coaches ($n = 165$) based talent identification mainly on competition observation and technical characteristics (27.9%), the physical structure and wrestling tendencies of the athletes (24.9%), basic motor features (20%), previous success (15.8%) and intelligence (11.5%).¹ In the literature there is consistent evidence of a connection between anthropometric and body composition factors and the attainment of high-level wrestling performance.^{2,3} Pallarés et al. showed that elite female wrestlers were older (8-10%) and had more fat-free mass (3%) than amateur wrestlers.⁴ As such, measuring physical factors is imperative for those working within talent identification systems in order to evaluate and monitor athletes and to establish short- and long-term goals.⁵ Therefore, identifying which variables provide the most relevant information about the physical features of wrestlers can be considered a critical component of future success.

In order to reduce large sets of variables into key features, several statistical methods, such as principal component analysis (PCA), single value decomposition and factor analysis, have been developed within sports performance research.⁶⁻⁸ Previous studies on talent identification⁹ and athlete monitoring¹⁰ revealed that PCA can reduce the dimensionality of a dataset and identify its most relevant variables. PCA is an unsupervised technique used for the reduction of high-dimensional data that transforms many correlated variables into a smaller number of new variables, or principal components (PC), while minimising information loss.¹¹ Thus, as a data reduction technique, PCA can distinguish the most significant variables and highlight performance indicators in various sports.

Physical and anthropometric variables have been explored using PCA in sports such as rugby,¹⁰ hockey¹² and basketball.¹³ For example, McCormack et al. examined the physical qualities of academy and international youth rugby league players using PCA, and their findings suggested that this technique can help identify overall differences between playing levels.¹⁴ PCA has also been used to explore an anthropometric, growth and maturity index in soccer and its relationship with players' physical attributes, fitness, motivation and skills.¹⁵ Given the several applications of PCA in performance analysis as a data reduction method, identifying key body-related differences between wrestlers of different competitive levels can be expected; however, this hypothesis has not been assessed in wrestling yet.

Considering the importance of talent identification in wrestling, determining the optimum physical features at an early stage might play a relevant role in planning, performance analysis and coaching. Therefore, the main goal of this study was to identify the key anthropometric variables that predict wrestlers' future success using PCA. Secondarily, the overall differences in anthropometric features between elite and non-elite wrestlers were examined.

METHODS

Participants

Sixty male Iranian wrestlers took part in this cross-sectional study: 30 elite (age 18.73 ± 4.48 years; body mass 69.56 ± 15.50 kg; height 171.67 ± 8.74 cm) and 30 non-elite (age 14.27 ± 3.43 years; body mass 57.32 ± 16.88 kg; height 161.25 ± 15.91 cm). The elite group trained at least six days a week, involving considerable skill and fitness sessions (up to 10 per week, 60-90 minutes per session), and

competed in one to two tournaments every six months. The non-elite group trained up to three days per week, mainly in educational-type exercise workouts (three sessions weekly, 45-60 minutes each), and none of them were professional or full-time athletes. None of the wrestlers was under medical treatment when participating in the study or reported neuromuscular functional or structural issues. All participants, and the legal guardians of those under 18 years of age, gave their written informed consent to a protocol approved by the university institutional review board, in accordance with the Declaration of Helsinki.

Instruments and procedures

Body mass (kg) and height (cm) were measured using a scale (Seca, Hamburg, Germany) and a stadiometer (Harpender, Burgess Hill, United Kingdom). Wrestlers were weighed and measured while wearing underwear and barefoot. Body mass index (BMI) was computed as body mass divided by height squared (kg/m^2). Eight skinfold thicknesses (triceps, subscapular, supraspinal, calf, chest, abdominal, front thigh and axilla) were measured with a Holtain skinfold calliper (precision of 0.2 mm). Girth measurements were taken using a calibrated cloth tape (accuracy of ± 0.1 cm) and included six muscular (shoulders, chest, biceps, forearm, thigh and calf) and five non-muscular (abdomen, hips, knee, ankle and wrist) segments.¹⁶ All girth measurements were taken by the same experienced researcher. Two bicondylar breadths (humerus and femur) were measured using a Holtain bone breadth calliper (precision of 0.1 cm; Holtain Ltd., Crymch, United Kingdom). Body fat percentage was calculated with the Jackson and Pollock estimation formulae.¹⁷ Total-body skeletal muscle mass (kg) was determined using the body weight and height model of Lee et al.¹⁸ Finally, the skeletal muscle index (%) was obtained as total body lean mass divided by body mass and multiplied by 100. All variables were measured on the dominant side of the body twice, and the mean value was recorded.

Statistical analysis

PCA was applied to the anthropometric variables following published guidelines.^{9,19} The procedure was performed on 27 variables for a total sample of 60 wrestlers. Before completing the PCA, the observed data were centred (subtraction of the mean), normalised (division by the standard deviation) and then stored in an $n \times m$ matrix, where n was the observations (wrestlers) and m the variables (anthropometry). The number of PC equals the number of inputted variables: the first PC explains the most variance and the last PC the least, each PC being a linear combination of the 27 original measured variables.

The first and second PCs were extracted for further analysis, as they explained the most variance in the dataset and had eigenvalues > 1 , a typical threshold for determining which PCs to extract. Using these PC, a scatter plot of the first two components was created for each group (MATLAB PCA toolbox). To assist in visualising the groups, convex hulls were plotted around each group. The scree plot of the explained variance of each PC and the contribution of the anthropometric variables to PC1 and PC2 were also depicted.

Descriptive data are presented as mean and standard deviation. Independent t-tests were used to compare anthropometric data between elite and non-elite wrestlers, with the level of significance set at $p \leq .05$. To evaluate the magnitude of the differences, Cohen's effect size (d) was calculated and interpreted as very small ($0.00 < 0.20$), small ($0.20 < 0.50$), medium ($0.50 < 0.80$) and large (≥ 0.80).²⁰

RESULTS

The mean and standard deviation values of the anthropometric measurements and the differences between elite and non-elite wrestlers are presented in Table 1. Elite wrestlers were significantly taller than non-elite wrestlers, whereas no differences were found for BMI. The triceps, calf, chest and front thigh skinfold thicknesses were significantly higher in non-elite wrestlers, while most girth measurements (shoulders, chest, biceps, forearm, thigh, knee and wrist) were significantly higher ($p < .05$) in elite wrestlers. No significant differences were detected between the two groups for humerus and femur breadths.

Elite wrestlers showed a significantly lower body fat percentage and a significantly lower skeletal muscle index than non-elite wrestlers, whereas no difference was found between groups in body fat mass. Total-body skeletal muscle mass was significantly higher in elite than in non-elite wrestlers.

Figure 1A displays the scree plot of the PCA, depicting the variance explained by each PC. PC1 (50.7%) and PC2 (25.5%) accounted for 76.3% of the variance in the dataset, whereas PC3 to PC27 only added 23.7%. The contribution of the physical features to PC1 and PC2 is shown in Figures 1B and 1C, respectively. Table 2 displays the component loadings of each variable for PC1 and PC2, which demonstrate the contribution of each physical feature to each of the PC.

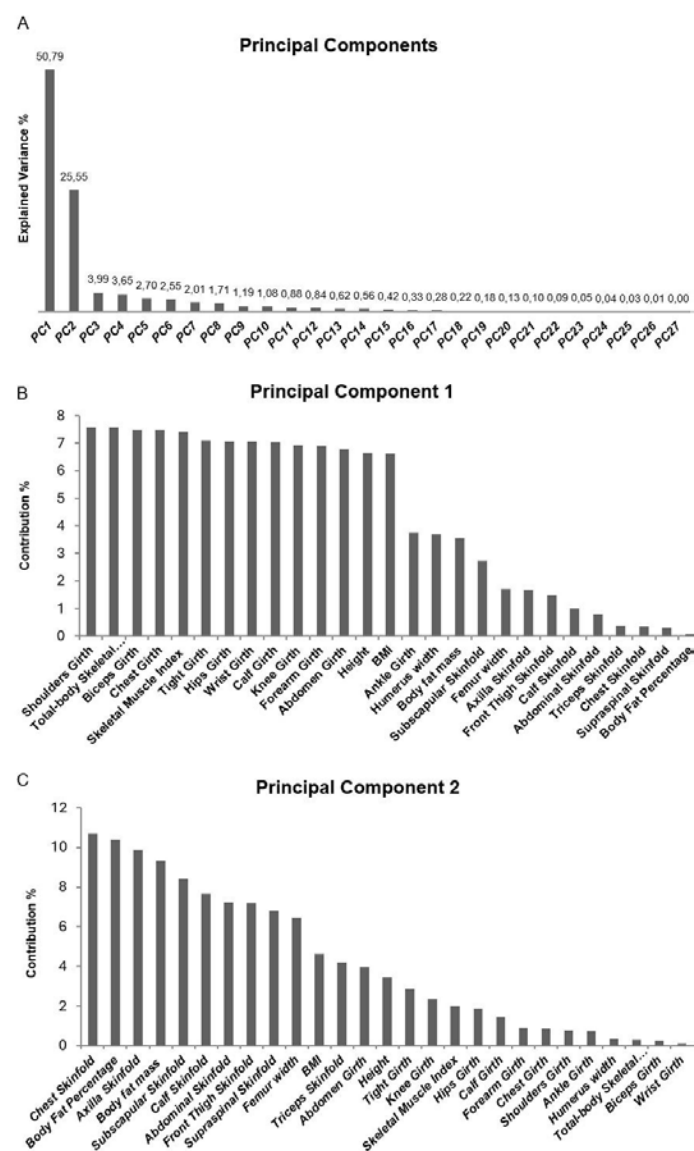


Figure 1. (A) Scree plot for the principal component analysis and the fractional variance attributed to each principal component. (B) Contribution

Table 1. Mean and standard deviation values of the anthropometric measurements and differences between elite and non-elite wrestlers.

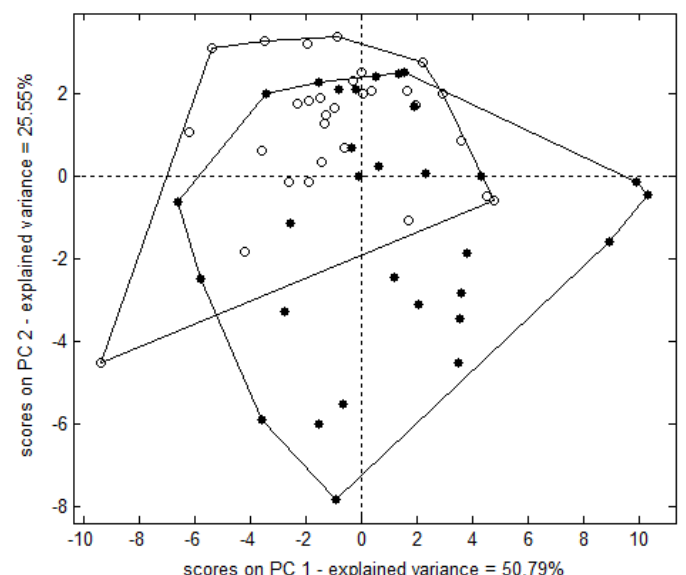
Variable	Elite (n = 30)	Non-elite (n = 30)	p	95% CI	Cohen's d
Height (cm)	171.67 ± 8.74	161.25 ± 15.91	0.003*	3.70 / 17.50	0.81 (large)
Body mass index (kg/m ²)	23.38 ± 3.86	21.53 ± 3.72	0.064	-0.11 / 3.80	0.48 (small)
Triceps skinfold (mm)	8.13 ± 2.64	10.80 ± 5.15	0.015*	-4.77 / -0.54	0.65 (medium)
Subscapular skinfold (mm)	9.24 ± 2.64	9.93 ± 3.47	0.415	-2.35 / 0.98	0.22 (small)
Supraspinal skinfold (mm)	6.71 ± 2.67	8.28 ± 4.13	0.086	-3.36 / 0.22	0.45 (small)
Calf skinfold (mm)	7.49 ± 3.55	10.34 ± 4.90	0.013*	-5.06 / -0.63	0.66 (medium)
Chest skinfold (mm)	6.15 ± 2.30	8.95 ± 4.61	0.004*	-4.67 / 0.91	0.76 (medium)
Abdominal skinfold (mm)	10.81 ± 4.80	13.48 ± 6.20	0.067	-5.53 / 0.19	0.48 (small)
Front thigh skinfold (mm)	10.86 ± 3.77	14.52 ± 6.44	0.009*	-6.38 / -0.92	0.69 (medium)
Axilla skinfold (mm)	8.42 ± 3.37	9.71 ± 4.55	0.217	-3.36 / 0.78	0.32 (small)
Shoulders girth (cm)	109.58 ± 11.22	98.48 ± 13.08	0.001*	4.80 / 17.39	0.91 (large)
Chest girth (cm)	94.32 ± 11.42	85.35 ± 11.97	0.004*	2.92 / 15.01	0.76 (medium)
Biceps girth (cm)	32.87 ± 3.86	29.00 ± 4.77	0.001*	1.62 / 6.10	0.89 (large)
Forearm girth (cm)	27.40 ± 3.04	24.36 ± 3.57	0.001*	1.32 / 4.75	0.91 (large)
Thigh girth (cm)	54.00 ± 5.30	49.90 ± 6.75	0.011*	0.96 / 7.23	0.67 (medium)
Calf girth (cm)	35.12 ± 3.32	33.63 ± 3.98	0.122	-0.41 / 3.37	0.40 (small)
Abdomen girth (cm)	76.97 ± 8.67	73.58 ± 8.97	0.143	-1.17 / 7.94	0.38 (small)
Hips girth (cm)	86.42 ± 8.73	82.00 ± 10.22	0.077	-0.49 / 9.32	0.46 (small)
Knee girth (cm)	36.63 ± 2.64	34.95 ± 3.62	0.044*	0.45 / 3.32	0.53 (medium)
Ankle girth (cm)	26.18 ± 2.57	25.38 ± 3.06	0.278	-0.66 / 2.26	0.28 (small)
Wrist girth (cm)	16.88 ± 0.93	16.09 ± 1.54	0.019*	0.13 / 1.45	0.62 (medium)
Humerus breadth (cm)	7.16 ± 0.86	6.63 ± 1.18	0.054	-0.01 / 1.05	0.51 (medium)
Femur breadth (cm)	8.77 ± 0.49	8.91 ± 1.01	0.486	-0.55 / 0.26	0.17 (very small)
Body fat (%)	7.11 ± 2.77	10.14 ± 5.44	0.009*	-5.26 / -0.79	0.70 (medium)
Skeletal muscle index (%)	44.06 ± 4.07	47.49 ± 5.89	0.011*	-6.04 / -0.80	0.67 (medium)
Body fat mass (kg)	5.15 ± 3.12	5.87 ± 3.49	0.407	-2.42 / 0.99	0.21 (small)
Total-body skeletal muscle mass (kg)	30.07 ± 4.20	26.35 ± 5.46	0.004*	1.20 / 6.24	0.76 (medium)

CI: confidence interval.

* Statistically significant difference between elite and non-elite wrestlers (p < .05).

of the variables to the first principal component. (C) Contribution of the variables to the second principal component.

Figure 2 shows the scatter diagram of the component scores for the first and second principal components, which together explain 76.3% of the total amount of information. Elite wrestlers are marked with white circles and non-elite wrestlers with black circles. Despite evident overlap between the two groups, which is common in anthropometric features due to experimental variability, the plot highlights a potential trend toward separation and a systematic distribution of samples with respect to anthropometric values.

**Figure 2.** Scatter plot of the first two principal component scores. Elite wrestlers are marked with white circles and non-elite wrestlers with black circles.

DISCUSSION

To our knowledge, this is the first report identifying key anthropometric variables that contribute to successful wrestling. The main results of the present study were that (1) anthropometric measures were reduced to two PC explaining 76.3% of the variance,

Table 2. Component loadings of each variable for the first and second principal components.

Variable	PC1	PC2
Height	.845	-.311
Body mass index	.844	.419
Triceps skinfold	-.048	.379
Subscapular skinfold	.349	.759
Supraspinal skinfold	.037	.613
Calf skinfold	-.126	.693
Chest skinfold	-.043	.964
Abdominal skinfold	.102	.653
Front thigh skinfold	-.188	.650
Axilla skinfold	.214	.891
Shoulders girth	.965	-.068
Chest girth	.955	.076
Biceps girth	.956	.024
Forearm girth	.878	-.079
Thigh girth	.903	.256
Calf girth	.898	.130
Abdomen girth	.866	.357
Hips girth	.901	.170
Knee girth	.882	.213
Ankle girth	.479	.065
Wrist girth	.901	-.011
Humerus breadth	.469	.030
Femur breadth	.217	.582
Body fat percentage	.007	.939
Skeletal muscle index	-.943	-.181
Body fat mass	.454	.842
Total-body skeletal muscle mass	.964	-.029

PC: principal component. Loadings ≥ |.75| are shown in bold.

with PC1 (50.7%) influenced by girth measurements and muscular properties (shoulders, biceps, chest, thigh, hips, wrist, calf, knee, forearm, abdomen, skeletal muscle index and total-body skeletal muscle mass) and PC2 (25.5%) influenced by skinfold thicknesses and body fat properties (subscapular, supraspinal, calf, chest, abdominal, front thigh and axilla skinfolds, body fat percentage and body fat mass); and (2) independent t-tests indicated significant differences ($p \leq .05$) between elite and non-elite wrestlers in height, several skinfold thicknesses (triceps, calf, chest and front thigh), most girth measurements (shoulders, chest, biceps, forearm, thigh, knee and wrist), skeletal muscle index, body fat percentage and total-body skeletal muscle mass.

Within PC1, girth measurements (except for ankle girth) and muscular properties (total-body skeletal muscle mass and skeletal muscle index) had higher contributions than the remaining variables. These findings suggest that girth measurements and muscular properties should be monitored, as they appear to be associated with wrestlers' performance. It is accepted that strength is related to muscle size, and previous studies have reported that isometric strength is one of the most important factors of wrestling success.²¹ Therefore, developing girth measurements and muscular properties may be an important factor in achieving success in wrestling.

One of the major findings of the present study was that girth measurements, both muscular and non-muscular components, were higher in elite than in non-elite wrestlers (Table 1). Few researchers have examined girth measurements separated into muscular and non-muscular components in wrestlers of different skill levels. The chest, hip, biceps, forearm, thigh and calf girths of the non-elite wrestlers in the present study were lower than those previously reported for Colombian elite male wrestlers,²² which could be related to the fact that our participants were younger. However, these results

were higher than those reported for wrestlers between 7 and 18 years old.²³ Consequently, it is likely that the differences observed in girth measurements may be partly explained by differences in the strength and conditioning programmes used by elite and non-elite wrestlers.

Concerning muscular properties, and as expected, elite wrestlers demonstrated greater total-body skeletal muscle mass than non-elite wrestlers. This information may be useful for creating optimal strength training programmes for wrestlers with varying levels of strength. However, a distinctive finding of the present study was that non-elite wrestlers had higher skeletal muscle indices than elite wrestlers. Because this variable is directly dependent on total body mass and the magnitude of total-body skeletal muscle mass, this result may be due to various factors, including the contribution of non-skeletal muscle tissues.

Basic measurements such as height and BMI may be relevant factors for achieving success in wrestling. In both PC1 and PC2, BMI and height contributed moderately compared with other variables. Considering that these variables do not account for differences in body composition, they might not be accurate indicators of long-term future success. In agreement with previous research, no significant differences in BMI were detected between elite and non-elite groups.²⁴ However, the wrestlers in our study showed lower mean BMI values than Olympic wrestlers²⁵ and than the values reported by other studies.^{24,26} In contrast, height values were significantly higher in elite than in non-elite wrestlers, and the mean height of our elite wrestlers was rather similar to that of Olympic wrestlers.²⁵ These results suggest that height may be a better indicator than BMI to identify differences between elite and non-elite wrestlers and to predict future success.

Regarding skinfold thicknesses and body fat percentage, our PCA showed that these variables had lower contributions to PC1 and

higher contributions to PC2 than other variables. Consistent with our results, Horswill found no relationship between body fat percentage and competitive success.²⁷ Body fat percentage is influenced by genetics, age, nutritional strategy, prior training history and physical exercise level, so these variables may not be predictive of longer-term functional outcomes.

When comparing elite and non-elite wrestlers, our results indicated that elite wrestlers had lower mean values in the sum of skinfolds. Our elite wrestlers' skinfold values are lower than those reported by Ramírez-Vélez et al.²² Compared with Olympic wrestlers under 18 years of age, the elite wrestlers of the present study had lower values for all skinfold thicknesses except calf and axilla.²⁵ In contrast, Olympic wrestlers over 18 years old had lower values for all skinfold thicknesses, except calf and subscapular, than our elite wrestlers.²⁵

In line with the skinfold results, body fat percentage was significantly lower in elite than in non-elite wrestlers. Yoon suggested that a wrestler's ideal body fat percentage should be between 7% and 10%,²⁸ and our findings are relatively similar to those described by Zaccagni, who determined the body fat percentage of Italian national team elite wrestlers by weight category as 7.1% (55 kg), 8.6% (60 kg), 10.5% (66 kg), 9.5% (74 kg), 9.4% (84 kg) and 15.5% (96 kg).² However, the mean body fat percentage values of the wrestlers in the present study are slightly lower than those previously described by other studies,^{22,29} a discrepancy that may be explained by differences in the training programs.

Lastly, femur and humerus breadths contributed relatively little to both PC1 and PC2, so these variables may not be important factors in predicting future success in wrestlers. In agreement with this finding, no significant differences were found for humerus and femur breadths between groups. Yaşar and Sağır evaluated the humerus and femur breadths of 21 elite Turkish wrestlers and reported higher values in all three weight categories, except for humerus breadth in lightweight wrestlers, compared with our study.³⁰ These differences may be due to the measurement method and to age differences.

The two-dimensional scatter plot of the PC1-PC2 scores (Figure 2) indicated that the clustering trends of elite and non-elite wrestlers were not fully satisfactory and that a partial overlap existed between both groups, possibly because of the lower variance contribution rate. Nevertheless, it shows a systematic distribution of elite and non-elite wrestlers with respect to anthropometric values, with greater dispersion among non-elite wrestlers.

Limitations

This study did not consider physiological factors related to success in wrestling, such as maximal dynamic strength, isometric strength, explosive strength and strength endurance. As this was the first approach to identify key anthropometric variables in wrestling through PCA, several limitations should be mentioned. The most important is the sample size, which means that the data are specific to the study population and cannot be generalised to all wrestlers. In addition, the key anthropometric variables were not calculated separately for elite and non-elite wrestlers. Accordingly, we suggest that future research focuses on the sample sizes required for coaches to confidently identify talented athletes, and compares the key anthropometric variables between elite and non-elite wrestlers.

CONCLUSIONS

PCA proved a useful data-reduction technique for identifying key anthropometric variables in elite and non-elite wrestlers. Anthropometric measures were reduced to two PC explaining 76.3% of the variance: girth measurements and muscular properties influenced PC1 (50.7%), whereas skinfold thicknesses and body fat variables contributed to PC2 (25.5%). These findings emphasise

the importance of girth measurements and muscular properties within the talent identification process in wrestling. Elite wrestlers were taller, had larger girth measurements and greater total-body skeletal muscle mass, and had lower skinfold thicknesses, body fat percentage, and skeletal muscle index than non-elite wrestlers, with similar BMI, bicondylar breadths, and body fat mass. Consequently, these findings may support a more efficient variable selection process in wrestling clubs.

AUTHOR CONTRIBUTIONS

Conceptualisation: M.A., M.E. and D.R.-V.; methodology: M.A., M.E. and D.R.-V.; investigation and data collection: M.A. and M.E.; formal analysis and data curation: M.A., B.A.B.-P. and D.R.-V.; visualisation: M.A. and D.R.-V.; writing, original draft: M.A. and B.A.B.-P.; writing, review and editing: all authors.

CONFLICT OF INTEREST

The authors declare that they have no competing interests.

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Originales

Comparison of centre-of-pressure movement variability between elite and non-elite wrestlers during a wrestling stance task



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ABSTRACT

This study compared the variability of centre of pressure (CoP) movement between elite and non-elite wrestlers during a repetitive wrestling stance task. Sixty male wrestlers (30 elite, 30 non-elite) performed a simulated 30 s protocol involving short-cycle repetitive wrestling stance tasks under two conditions: dominant and non-dominant leg. Non-linear Poincaré analysis was applied to the medial-lateral (ML) and anterior-posterior (AP) directions and to total (T) CoP displacement, computing short-term (SD1) and long-term (SD2) variability indicators. A mixed-model ANOVA with Bonferroni correction was used. Non-elite wrestlers showed significantly higher SD1 ($p = .018$) and SD2 ($p = .008$) in the ML direction of the dominant leg, whereas no differences appeared in the AP direction or in T displacement. Between legs, elite wrestlers differed significantly in SD1 ($p = .008$) and SD2 ($p = .014$) in the AP direction and in SD1 ($p = .025$) and SD2 ($p = .039$) of T displacement. No differences were found between the beginning and the end of the task. Poincaré analysis is a useful procedure for monitoring CoP movement variability during back-and-forth movements in wrestling.

Keywords: Dynamic postural control; Poincaré plot analysis; Back-and-forth movements; Performance evaluation; Wrestling.

Comparación de la variabilidad del desplazamiento del centro de presiones entre luchadores de élite y no élite durante una tarea de posición de guardia

RESUMEN

El objetivo de este estudio fue comparar la variabilidad del desplazamiento del centro de presiones (CdP) entre luchadores de élite y no élite durante una tarea repetitiva de posición de guardia. Sesenta luchadores varones (30 de élite y 30 no élite) realizaron un protocolo simulado de 30 s de ciclos cortos repetitivos en posición de guardia bajo dos condiciones: pierna dominante y no dominante. Se aplicó el análisis no lineal de Poincaré a las direcciones medio-lateral (ML) y anteroposterior (AP) y al desplazamiento total (T) del CdP, calculando los indicadores de variabilidad a corto plazo (SD1) y a largo plazo (SD2). Se empleó un ANOVA de modelo mixto con corrección de Bonferroni. Los luchadores no élite mostraron valores significativamente mayores de SD1 ($p = .018$) y SD2 ($p = .008$) en la dirección ML de la pierna dominante, sin diferencias en la dirección AP ni en el desplazamiento T. Entre piernas, los luchadores de élite difirieron en SD1 ($p = .008$) y SD2 ($p = .014$) en la dirección AP y en SD1 ($p = .025$) y SD2 ($p = .039$) del desplazamiento T. No se hallaron diferencias entre el inicio y el final de la tarea. El análisis de Poincaré resulta un procedimiento útil para monitorizar la variabilidad del CdP durante los movimientos de vaivén en lucha.

Palabras clave: Control postural dinámico; Análisis del diagrama de Poincaré; Movimientos de vaivén; Evaluación del rendimiento; Lucha.

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Comparação da variabilidade do deslocamento do centro de pressão entre lutadores de elite e não elite durante uma tarefa de posição de guarda

RESUMO

Este estudo comparou a variabilidade do deslocamento do centro de pressão (CoP) entre lutadores de elite e não elite durante uma tarefa repetitiva de posição de guarda. Sessenta lutadores (30 de elite e 30 não elite) realizaram um protocolo simulado de 30 s com ciclos curtos repetitivos sob duas condições: perna dominante e não dominante. A análise não linear de Poincaré foi aplicada às direções médio-lateral e anteroposterior e ao deslocamento total do CoP, calculando-se os indicadores de variabilidade de curto prazo (SD1) e longo prazo (SD2). Foi utilizada ANOVA de modelo misto com correção de Bonferroni. Os lutadores não elite apresentaram SD1 e SD2 significativamente maiores na direção médio-lateral da perna dominante, sem diferenças na direção anteroposterior ou no deslocamento total. Entre as pernas, os lutadores de elite apresentaram diferenças em SD1 e SD2 na direção anteroposterior e no deslocamento total. A análise de Poincaré é útil para monitorar a variabilidade do CoP durante movimentos de vaivém na luta.

Palavras-chave: Controle postural dinâmico; Análise do gráfico de Poincaré; Movimentos de vaivém; Avaliação do desempenho; Luta.

Introduction

Wrestling is a high-intensity, short-interval combat sport in which repetitive back-and-forth movements for explosive attacks and counterattacks are performed¹. Wrestler must have a stable stance throughout a match to perform these repetitive back-and-forth movements. A stable wrestling stance must be both offensive and defensive in nature². Hence, an elite wrestler is expected to demonstrate high levels of static and dynamic balance during wrestling stances³. Studies examining postural control in specific motor skills showed that postural function reflects the sport performance level of athletes (elite, sub-elite, and non-elite)^{4,5}. However, it has not been established that there is a close relationship between sports competition and postural skill level within repetitive tasks in dynamic conditions.

In wrestling, there is a tendency to use a specific leg during repetitive back-and-forth movements. This tendency may lead to asymmetries and trends of lateralisation during the match. It has been shown that the dominant and non-dominant leg asymmetries can exhibit differences in consequence of sporting activity^{6,7,8}. For example, Bailey⁶ reported negative correlations between the peak force symmetry index and all jump variables (e.g., jump height and peak power), indicating that as asymmetry increases jump performance decreases. To our knowledge, only one study has assessed biomechanical differences between the dominant and non-dominant legs during back-and-forth movements while participants performed repetitive lower-limb tasks⁹. Results revealed no significant difference between the dominant and non-dominant leg in all joint angle variables during both steps forward lunge and jump forward lunge. Accordingly, it is necessary to gain more insight into the biomechanical differences between the dominant and non-dominant legs and into postural control during repetitive back-and-forth movements.

One of the most used methods for assessing body postural control and fall risks in sports skills is the centre of pressure (CoP) movement variability. Although the existing literature provides information that helps us better understand the relationship between the CoP movement variability and the postural control system, few studies have examined the CoP movement variability in repetitive back-and-forth tasks^{10,11,12,13}. For example, a recent investigation by Cantù¹⁰ examined the effect of additional load placed on the trunk on the posture and movement adaptations to fatigue induced by performing a repetitive arm movement (pointing) task. Their findings suggested that fatigue significantly increased reach-to-reach variability in the CoP displacement. In contrast, in performing a repetitive reaching task, Fuller¹² reported that the reach-to-reach

variability of the CoP position was not affected by fatigue. These studies investigated the effect of fatigue induced by repetitive arm tasks on CoP displacement in both ML and AP directions. In contrast, it is unknown to what extent the repetitive leg tasks would develop strategies that jeopardise postural body control in back-and-forth movements.

In studies examining postural control based on the CoP displacement trajectories, linear measures of variability (e.g., statistics of range, standard deviation, and coefficient of variation) are often used. Linear measures provide information about a signal's amplitude and dispersion, but they do not tell us about the time-evolving nature of the signal¹⁴. In contrast, non-linear measures described temporal variations in motor behaviour over time. In the literature, multiple methods exist for exploring non-linear time series analysis (e.g., Lyapunov exponent, fractal, symbolic dynamics measures, Poincaré plot, and approximate entropy). Nonlinear Poincaré analyses (also called return maps) are applied to assess the short-term and long-term spatial-temporal variability during each trial¹⁵. In this method, each measurement result in data points is plotted as a function of a previous one¹⁶. Generally, Poincaré analyses have been most commonly used in heart rate research^{17,18} and their application as a measure of kinematic and kinetic time-series patterns is limited^{19,15,20}.

Therefore, the primary purpose of this study was to examine the CoP movement variability via non-linear Poincaré analyses between elite and non-elite wrestlers during short-cycle repetitive wrestling stance tasks. Accordingly, we hypothesised that non-elite wrestlers would have an increased variability in CoP displacement compared to elite wrestlers during wrestling stance tasks. Moreover, we aimed to compare the CoP movement variability between the dominant and non-dominant leg during the wrestling stance task. Hence, it was hypothesised that no significant difference occurred in the CoP movement variability between both legs.

Methodology

Participants

We recruited 30 elite (age: 18.73 ± 4.48 years, body mass: 69.56 ± 15.50 kg, height: 171.67 ± 8.74 cm, body mass index: 23.38 ± 3.86 kg/m²) and 30 non-elite (age: 14.27 ± 3.43 years, body mass: 57.32 ± 16.88 kg, height: 161.25 ± 15.91 cm, body mass index: 21.53 ± 3.72 kg/m²) male wrestlers for this study. The elite group trained six days a week involving considerable skill and fitness sessions (up to 10 per week, 60-90 minutes per session), and they played in one-two competitive games per six months. The non-elite

group trained up to three days a week, mainly in educational-type exercise workouts (3 sessions weekly, 45-60 minutes per session), but none were professional or full-time athletes. Wrestlers reporting any abnormalities (e.g., due to orthopaedic injury) that may impact balance control were excluded from participation. All participants gave their written informed consent before beginning the trials.

Procedure

A schematic representation of the protocol is shown in Figure 1. In this study, two groups of wrestlers (elite and non-elite) performed a simulated 30s protocol that involved a short-cycle, repetitive wrestling-stance task. This task was utilized to measure physical performance capacities related to balance control and change of direction ability.

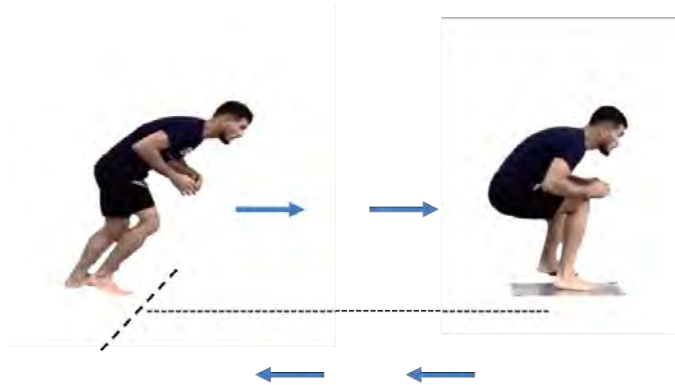


Figure 1. Schematic diagram of a wrestling stance position from the starting position (left) to the ending position (right).

Each wrestler had a practice session of two minutes or until the participant felt familiar with the task. Then, they performed the repetitive tasks of wrestling stance with five-minute breaks in between. Wrestlers began the task in the start line with the wrestling stance position; then, upon an auditory signal, they moved to a force plate, touched the force plate with their leg in the wrestling stance position and returned to the start line, touching down on the start line with their leg again. They then moved to the force plate and back to the start line until 30 s of the task had been completed. Wrestlers were required to move back and forth on a 130cm course (from the centre point of the force plate to the start line) under two conditions: dominant and non-dominant leg (without shoes). The dominant leg was defined by asking a wrestler to kick a ball²¹. Three trials were performed on the dominant leg; the wrestlers changed leg position and repeated the task on the non-dominant leg. The average of the three trials on each leg was used for subsequent analyses.

An expert observed wrestlers to ensure that appropriate pace and trunk posture were maintained during the task. None showed or expressed difficulty keeping the required pace, and all wrestlers completed the 30 s task. Wrestlers were instructed to ignore any errors and proceed to the next one.

Data analysis

The CoP position was calculated using the ground reaction forces by a Kistler force plate (Kistler Instrument AG, Winterthur, Switzerland) at a sampling frequency of 1000 Hz. The raw data were digitally filtered using a fourth-order Butterworth filter with a low-pass cutoff frequency of 15 Hz. Wrestling stance events of the foot-strike and foot-off were identified using a threshold of 10 N on the vertical ground reaction force. Then, each cycle was interpolated to 100 data points using the spline method. The number of cycles

for each trial varied depending on a sports performance level but averaged 17 cycles.

The equations used to calculate the medial-lateral (ML) and anterior-posterior (AP) CoP coordinates in the force plate were considered for further analysis. For each subject, instantaneous displacement (D_i) in the ML and AP directions and the total (T) displacement of CoP movement was calculated as follows (Bizovska et al., 2014):

$$D_{iML} = |ML_i - ML_{i-1}| \quad (1)$$

$$D_{iAP} = |AP_i - AP_{i-1}| \quad (2)$$

$$D_{iT} = \sqrt{D_{iML}^2 + D_{iAP}^2} \quad (3)$$

Where, AP_i and ML_i are i -th sample-time of the CoP one dimensional time series in the anterior-posterior and medial-lateral directions, respectively. Then, to evaluate the nature of the variability present in the D_{iML} , D_{iAP} and D_{iT} (Figure 2), Poincaré plot analysis (a nonlinear method) was used to calculate short- and long-term variability during each trial as follows¹⁶:

$$SD1 = \frac{\sqrt{2}}{2} SD(x_n - x_{n+1}) \quad (4)$$

$$SD2 = \sqrt{2SD(x_n)^2 - \frac{1}{2}SD(x_n - x_{n-1})^2} \quad (5)$$

SD is the time series' standard deviation, SD1 represents short-term, and SD2 indicates long-term variability. The SD1 and SD2 were determined within each cycle and considered variables describing CoP movement variability.

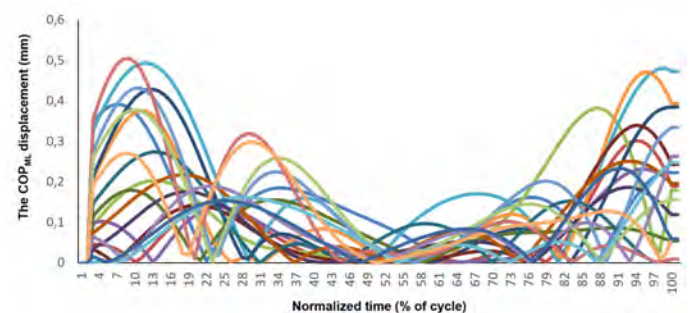


Figure 2. Example of the evaluation of inter-cycle variability from the normalised cycle.

To measure the effect of activity duration on CoP oscillations, each trial performed by subjects was split into three equal time intervals based on the execution order (beginning, middle and end). The mean of three successive cycles calculates each time interval. Finally, the mean value of the ML and AP directions and T displacement of CoP movement into three-time intervals were determined.

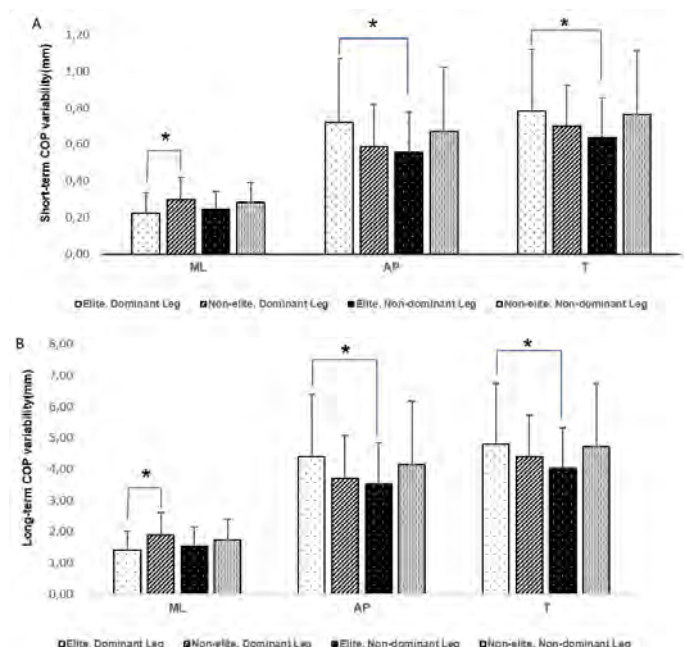
Generally, our study variables were calculated separately for the dominant and non-dominant leg. All calculations were performed using custom-written Matlab programs (MATLAB R2014b, Mathworks, Inc., Natick, MA, USA).

Statistical analysis

The mean values of SD1 and SD2 in the ML and AP directions and T displacement of CoP movement were examined using a mixed-model ANOVA (2 groups $\times$ 2 legs $\times$ 3-time intervals) to determine if significant differences occurred in three-time intervals. A pairwise comparison with a Bonferroni correction was used if any significant main effects were found for group, leg, or time interval. A mixed-model ANOVA (2 groups $\times$ 2 legs) was also used to determine differences between groups and legs for each dependent variable based on the overall average obtained by each trail for all cycles. Differences were considered significant at $p < .05$.

Results

Figure 3 shows the mean values of SD1 and SD2 of CoP movement under the dominant and non-dominant leg conditions between elite and non-elite wrestlers. A comparison of the groups revealed significant differences in mean values of SD1 ($p = .018$) and SD2 ($p = .008$) in the ML direction of CoP movement in the dominant leg. However, no significant difference was found between the two groups in the AP direction and T displacement of CoP movement. In comparison between the dominant and non-dominant leg, no significant difference was found in the mean values of SD1 and SD2 variables in the ML and AP directions and T displacement of CoP movement in non-elite wrestlers. In contrast, elite wrestlers showed a significant difference in mean values of SD1 ($p = .008$) and SD2 ($p = .014$) in AP direction and SD1 ($p = .025$) and SD2 ($p = .039$) in T displacement of CoP movement.



Abbreviations: ML (AP) – COP displacement in the mediolateral (anterior-posterior) direction, T: total COP displacement

Figure 3. The mean values and standard deviations of short-term, A, and long-term, B, variabilities of COP movement in two groups: elite and non-elite wrestlers, under two conditions: dominant and non-dominant legs. * = significant difference between groups ($p < .05$).

Finally, comparing the beginning and end times of the wrestling stance task, the result showed no significant difference in mean

values of ML and AP directions and T displacement of CoP movement in the two groups (Figure 4).

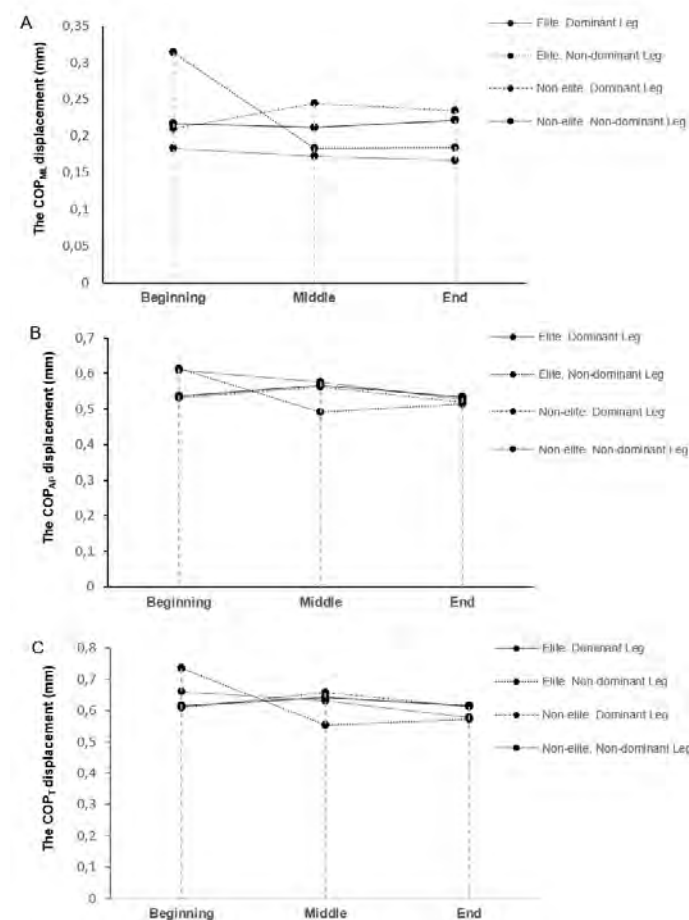


Figure 4. The mean values of mediolateral (ML), A, and anterior-posterior (AP), B, directions and the total (T), C, of displacement COP movement in two groups: elite and non-elite wrestlers under two conditions: dominant and non-dominant legs for the three-time intervals (beginning, middle, and end). * = significant difference between groups ($p < .05$).

Discussion

To our knowledge, no study has examined the variability of CoP movement during wrestling stance. Thus, we conducted this study to investigate the variability of CoP movement between elite and non-elite wrestlers during wrestling stance tasks. In this experiment, we define variability as SD1 and SD2 changes in the ML and AP directions and T displacement CoP movement. SD1 reflects the cycle-to-cycle variability in CoP movement, whereas SD2 is the continuous variability over the trial when cycle-to-cycle variability is removed²². Nestico¹⁵ reported that SD1 might reflect reactive balance control, whereas SD2 might be more indicative of an anticipatory balance control strategy. However, although the role of intra-individual variability has been analysed^{23,24}, previous studies have reported that a low variability in many sports situations is considered an indicator of improved performance²⁵ and desirable postural performance^{26,27}. Based on these observations, we defined increased movement variability as an indicator of poor postural control and increased fall risk²⁸. Consequently, we hypothesised that non-elite wrestlers would have an increased variability in CoP displacement compared to elite wrestlers during the wrestling stance task.

In support of our hypothesis, non-elite wrestlers displayed significantly higher mean values of SD1 and SD2 of CoP movement in the ML direction compared to the elite group in the dominant leg. Our results agree with a previous study by Hopper²⁹ that demonstrated

the CoP displacements of elite dancers were smaller than those of amateur dancers and control subjects. Also, Paillard³⁰ showed that professional soccer players than amateur soccer players have smaller CoP displacements during the test of bipedal standing posture. However, no significant difference between the two groups was observed in the AP direction and T displacement of CoP movement. These results indicate that when postural control is the primary focus in back-and-forth movements, measures of AP direction and T displacement of CoP movement cannot identify differences between skill levels in the wrestling stance task³⁰. Therefore, this result suggested that the changes in the magnitude of the SD1 and SD2 of CoP movement in the ML direction can be used as a good index for assessing postural control in wrestlers of different competitive levels.

In line with our findings, studies have indicated a relationship between performance level and body balance-controlling ability. They displayed that professional athletes show better postural control than their less proficient counterparts^{23,5}. As an example, Musa³¹ attributed that the elite and medalist archers had better postural performance compared to the non-medalist and novice archers. Hence, due to continuous body position changes during a wrestling match, elite wrestlers would be expected to maintain their balance in static and dynamic conditions to not only resist falling but also to act efficiently in wrestling techniques³².

Back-and-forth movements and balance are intimately linked and inseparable in many wrestling situations. Hence, both legs' symmetrical behaviour has been assumed in evaluating these movements. In line with this assumption, our results revealed no significant difference between the dominant and non-dominant leg in the mean values of SD1 and SD2 in the ML and AP directions and T displacement of CoP movement in non-elite wrestlers. Our findings are consistent with previous research^{33,34}. In contrast, elite wrestlers showed significantly higher mean values of SD1 and SD2 in the AP direction and T displacement of CoP movement in the dominant leg than in the non-dominant leg. This increased variability in the dominant leg may reflect the flexibility in adapting to perturbations³⁵. This finding is consistent with previous reports showing greater AP and vertical oscillations of pistol tremor with no difference in ML direction^{36,37}. As a result, understanding both variability and symmetry in the dominant and non-dominant leg during the back-and-forth movements can assist coaches in developing movement strategies and maintaining postural balance.

Researchers have long debated whether performance in sports skills changes over time. Accordingly, there are two basic approaches to measures of within-person performance variability over time³⁸. The first is short-timeframe variability relevant to the variation in performance in short periods (e.g., seconds, minutes, hours, or days)^{39,40}. The second is long-timeframe variability, which attempts to answer whether performance is static or variable over long periods (e.g., months, years, or decades)^{41,42}. Considering the importance of critical moments in wrestling, evaluating a wrestler's performance from occasion to occasion over short periods could improve our understanding of the factors involved in body postural control. Hence, we assessed the effect of execution duration (beginning, middle, and end) on the variability of CoP movement during the wrestling stance task. Our results showed that execution duration did not affect the variability of any ML and AP directions and T displacement of CoP movement analysed parameters. This is consistent with the previous finding by Roberts⁴³, who reported no change in the variability of CoP displacement in the ML direction during quiet stance trials. However, they reported that the AP CoP displacement was greater during the 5% and 10% compared to the 0% load. Generally, the outcomes of our research showed that the mean value of ML and AP directions and T displacement of CoP movement remained relatively stable over time in non-elite wrestlers than in elite wrestlers (Figure 4), which contradicts our hypothesis.

Limitations and future directions

This study, which aims to understand postural control, has some limitations. First, it analyzed only the role of center of pressure (CoP) variability in postural control. Future studies should examine the role of center of mass (COM) variability during postural tasks in wrestling. A second limitation is that we analyzed time-series data using a nonlinear method that requires mathematical programming techniques to assess performance variability, which is primarily calculated in a research setting¹⁴. Therefore, it is necessary to design devices with integrated software to assess postural control using nonlinear methods in natural training and competition settings. Finally, there is a lack of any analysis of postural control during repetitive forward and backward leg movements over short periods (e.g., seconds, minutes).

Conclusions

In the present study, the non-linear Poincaré analysis method was used to determine the CoP movement variability between elite and non-elite wrestlers during the wrestling stance task. The results suggested that the Poincaré analysis can provide a useful method for measuring CoP movement variability during back-and-forth movements when the wrestlers are being monitored. Moreover, the findings above demonstrate that quantifying performance variability in repetitive wrestling-stance tasks can provide insights into wrestlers' ability to maintain postural control during training and competition.

Conflict of interest

The authors declare that they have no conflict of interest, financial or otherwise, regarding the material discussed in this manuscript.

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Ethical considerations

The study was conducted in accordance with the Declaration of Helsinki. All participants, and the legal guardians of participants under 18 years of age, gave written informed consent before the trials.

Author contributions

Conceptualisation: M.A., M.E.; methodology: M.A., M.E.; formal analysis: M.A., J.P.; investigation: M.A.; data curation: J.P., D.R.-V.; writing – original draft: M.A., J.P.; writing – review and editing: M.E., D.R.-V.; supervision: M.E., D.R.-V. All authors have read and approved the final version of the manuscript.

Data availability

The datasets generated and analysed during the current study are available from the corresponding author on reasonable request.

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Originales

Organización y prestación de servicios médicos durante la World Rowing Cup Seville 2026: experiencia de un evento internacional de remo



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Objetivo: Describir la organización, planificación y prestación de los servicios médicos y de rescate durante la World Rowing Cup Seville 2026, así como caracterizar la actividad asistencial y las intervenciones de rescate acuático desarrolladas durante el evento.

Método: Estudio observacional, descriptivo y retrospectivo realizado en el Centro Especializado de Alto Rendimiento La Cartuja (Sevilla) durante las sesiones oficiales de entrenamiento y las jornadas de competición, del 27 al 31 de mayo de 2026. Se incluyeron todos los registros asistenciales y de rescate generados por el dispositivo sanitario, independientemente del perfil de la persona atendida. Se realizó un análisis descriptivo mediante frecuencias absolutas y porcentajes, sin análisis inferencial por el reducido número de eventos.

Resultados: El dispositivo integró rescate acuático, asistencia sanitaria, transporte sanitario, comunicaciones y coordinación de emergencias. Durante la competición se dispusieron siete embarcaciones de rescate, además de recursos terrestres de soporte vital avanzado, soporte vital básico y un vehículo de intervención rápida. Se registraron 17 personas atendidas: cuatro deportistas, un miembro del personal del evento, dos personas del público y diez voluntarios. La mayoría de las asistencias fueron de carácter leve. Se produjeron dos rescates acuáticos; uno correspondió a una deportista tras un vuelco y otro a una persona no participante localizada inconsciente y en apnea, que requirió reanimación cardiopulmonar, soporte vital avanzado y evacuación hospitalaria, con retorno de la circulación espontánea.

Conclusiones: La organización integrada de los recursos médicos y de rescate permitió responder a incidencias de diferente naturaleza y gravedad. La planificación previa, los simulacros, la proximidad de los recursos al agua y la coordinación entre los equipos de rescate y asistencia sanitaria constituyen elementos relevantes para la preparación de futuras competiciones internacionales de remo.

Palabras clave: Medicina deportiva; Servicios médicos de urgencia; Remo; Rescate; Reuniones masivas.

Keywords: Sports medicine; Emergency medical services; Rowing; Rescue work; Mass gatherings.

Palavras-chave: Medicina desportiva; Serviços médicos de emergência; Remo; Resgate; Reuniões em massa.

Organization and provision of medical services during the 2026 World Rowing Cup in Seville: experience of an international rowing event

ABSTRACT

Objective: To describe the organization, planning, and provision of medical and rescue services during the 2026 World Rowing Cup in Seville, and to characterize the medical activity and aquatic rescue interventions performed during the event.

Methods: An observational, descriptive, retrospective study was conducted at the La Cartuja High-Performance Sports Centre (Seville) during the official training sessions and competition days from 27 to 31 May 2026. All medical and rescue records generated by the healthcare system were included, regardless of the profile of the person attended. Descriptive analyses were performed using absolute frequencies and percentages. No inferential analysis was conducted because of the small number of medical events.

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Results: The system integrated aquatic rescue, medical care, medical transport, communications, and emergency coordination. During the competition, seven rescue boats were deployed, together with advanced life support, basic life support, and rapid intervention ground resources. A total of 17 people received medical care: four athletes, one event staff member, two members of the public, and ten volunteers. Most medical encounters were minor. Two aquatic rescue interventions occurred. One involved an athlete following a capsized, while the other involved a non-participant found unconscious and apneic who required cardiopulmonary resuscitation, advanced life support, and hospital evacuation, with return of spontaneous circulation.

Conclusions: The integrated organization of medical and rescue resources enabled a response to incidents of different types and severity. Advance planning, simulation exercises, proximity of resources to the water, and coordination between rescue and medical teams are relevant elements for the preparation of future international rowing competitions.

Keywords: Sports medicine; Emergency medical services; Rowing; Rescue work; Mass gatherings.

Organização e prestação de serviços médicos durante a World Rowing Cup Seville 2026: experiência de um evento internacional de remo

RESUMO

Objetivo: Descrever a organização, o planeamento e a prestação dos serviços médicos e de resgate durante a World Rowing Cup Seville 2026, bem como caracterizar a atividade assistencial e as intervenções de resgate aquático realizadas durante o evento.

Método: Foi realizado um estudo observacional, descritivo e retrospectivo no Centro Especializado de Alto Rendimento La Cartuja (Sevilha), durante as sessões oficiais de treino e os dias de competição, de 27 a 31 de maio de 2026. Foram incluídos todos os registos de assistência médica e de resgate gerados pelo dispositivo de saúde, independentemente do perfil da pessoa atendida. Foi realizada uma análise descritiva através de frequências absolutas e percentagens. Não foi realizada análise inferencial devido ao reduzido número de eventos assistenciais.

Resultados: O dispositivo integrou resgate aquático, assistência médica, transporte sanitário, comunicações e coordenação de emergências. Durante a competição foram utilizadas sete embarcações de resgate, além de recursos terrestres de suporte avançado de vida, suporte básico de vida e intervenção rápida. Foram atendidas 17 pessoas: quatro atletas, um membro da equipa do evento, duas pessoas do público e dez voluntários. A maioria das assistências foi de caráter ligeiro. Foram realizadas duas intervenções de resgate aquático. Uma envolveu uma atleta após um capotamento e outra uma pessoa não participante encontrada inconsciente e em apneia, que necessitou de reanimação cardiopulmonar, suporte avançado de vida e evacuação hospitalar, com recuperação da circulação espontânea.

Conclusões: A organização integrada dos recursos médicos e de resgate permitiu responder a ocorrências de diferente natureza e gravidade. O planeamento prévio, os exercícios de simulação, a proximidade dos recursos à água e a coordenação entre as equipas de resgate e assistência médica constituem elementos relevantes para a preparação de futuras competições internacionais de remo.

Palavras-chave: Medicina desportiva; Serviços médicos de emergência; Remo; Resgate; Reuniões em massa.

Introducción

Los grandes eventos deportivos internacionales constituyen escenarios complejos desde el punto de vista de la protección de la salud, debido a la concentración de deportistas, personal técnico, oficiales, voluntarios y espectadores, así como a la posibilidad de aparición simultánea de lesiones, enfermedades agudas y situaciones de emergencia que requieren una respuesta coordinada. La planificación de los servicios sanitarios debe integrarse desde las fases iniciales de organización mediante una evaluación específica de los riesgos, la definición de los recursos asistenciales, el establecimiento de planes de actuación ante emergencias y la disponibilidad de medios adecuados para la asistencia y evacuación. Las recomendaciones internacionales para grandes eventos deportivos señalan la necesidad de adaptar estos componentes a las características específicas de cada disciplina y sede.¹

La experiencia de grandes acontecimientos deportivos demuestra, además, que la asistencia médica durante una competición comprende un amplio espectro de situaciones clínicas. En los Juegos Olímpicos de Tokio 2020 se registraron atenciones tanto en deportistas como en personas no deportistas, incluyendo diferentes tipos de lesiones y enfermedades, lo que pone de manifiesto la necesidad de disponer de estructuras asistenciales capaces de responder a necesidades clínicas diversas y de establecer criterios adecuados para la atención y el transporte sanitario.²

En este contexto, la planificación de la respuesta ante emergencias constituye un componente esencial del dispositivo sanitario. Los planes de actuación ante emergencias deportivas deben establecer de forma anticipada las funciones y responsabilidades de los profesionales implicados, los recursos humanos y materiales disponibles, los sistemas de comunicación, el transporte sanitario, la localización del recinto y de los puntos de asistencia y los centros de referencia, así como los procedimientos de activación y coordinación.^{3,4}

Las competiciones de remo presentan, además, particularidades que condicionan de forma importante la planificación de la asistencia sanitaria. A diferencia de otros deportes desarrollados íntegramente en tierra, los entrenamientos y las competiciones tienen lugar sobre una lámina de agua, lo que introduce riesgos específicos relacionados con vuelcos, inmersión y, especialmente, la posibilidad de ahogamiento tras una pérdida de conciencia o un accidente durante la práctica deportiva. El FISA (Fédération Internationale des Sociétés d'Aviron) Basic Events Manual establece la necesidad de integrar los servicios médicos, de rescate y de seguridad en las regatas, teniendo en cuenta las características específicas del campo de competición y del entorno acuático.⁵

La actividad asistencial generada durante los eventos deportivos debe, asimismo, registrarse de forma sistemática. Los consensos internacionales han propuesto definiciones y métodos estandarizados para la identificación, clasificación y registro de los encuentros médicos relacionados con lesiones y enfermedades, con el objetivo

de facilitar la comparación entre eventos y mejorar la planificación de los servicios sanitarios.^{6,7}

En el ámbito específico del remo, World Rowing, a través de su Sports Medicine Commission, tiene entre sus responsabilidades la supervisión de los aspectos médicos relacionados con este deporte, la monitorización de los servicios médicos en las regatas y la elaboración y difusión de recomendaciones para su prestación.⁸ Sin embargo, la experiencia publicada sobre la organización y actividad de dispositivos médicos integrados específicamente en competiciones internacionales de remo es todavía limitada, particularmente en relación con la integración de la asistencia médica, el rescate acuático, el transporte sanitario y la coordinación con los servicios de emergencia.

La World Rowing Cup Seville 2026, celebrada del 29 al 31 de mayo en el Centro Especializado de Alto Rendimiento de La Cartuja (Sevilla), constituyó un escenario internacional que requirió la planificación y puesta en funcionamiento de un dispositivo integrado de asistencia médica, rescate acuático, transporte sanitario y coordinación con los servicios de emergencia. La actividad desarrollada permitió registrar tanto las asistencias médicas producidas durante el evento como dos intervenciones de rescate acuático, una de ellas asociada a una emergencia vital que requirió reanimación cardiopulmonar y posterior evacuación sanitaria.

El objetivo de este trabajo fue describir la organización, planificación y prestación de los servicios médicos y de rescate durante la World Rowing Cup Seville 2026, así como caracterizar la actividad asistencial desarrollada y las intervenciones de rescate acuático realizadas durante el evento.

Material y métodos

Diseño y ámbito del estudio

Se realizó un estudio observacional, descriptivo y retrospectivo de la actividad médico-asistencial y de rescate desarrollada durante la World Rowing Cup Seville 2026. El estudio se llevó a cabo en el Centro Especializado de Alto Rendimiento (CEAR) La Cartuja, Sevilla, sede de la competición, que dispone de un campo de regatas de 2.000 metros y diferentes áreas de salida, recorrido, meta, calentamiento, embarque y desembarque y zonas destinadas a deportistas, organización y público. El periodo de cobertura sanitaria comprendió las sesiones oficiales de entrenamiento de los días 27 y 28 de mayo de 2026 y las jornadas de competición del 29 al 31 de mayo de 2026. El dispositivo fue diseñado para proporcionar cobertura a deportistas, entrenadores, oficiales, personal técnico, voluntarios, miembros de la organización y público asistente.^{1,2}

Organización del dispositivo médico y de rescate

La planificación del dispositivo se realizó de acuerdo con las recomendaciones internacionales para la organización de servicios médicos en grandes eventos deportivos y con las directrices específicas de World Rowing para la cobertura médica y de rescate en regatas.³⁻⁵ El dispositivo se estructuró como un sistema integrado de asistencia sanitaria, rescate acuático, transporte sanitario, comunicaciones y coordinación de emergencias.

Durante las sesiones oficiales de entrenamiento se estableció un dispositivo de rescate acuático compuesto por cuatro embarcaciones, cada una con patrón y socorrista, distribuidas para cubrir la zona de salida, el recorrido intermedio, la zona de meta y las áreas de calentamiento y retorno. Durante las jornadas de competición se dispusieron siete embarcaciones de rescate: seis embarcaciones neumáticas con patrón y socorrista y una embarcación de intervención reforzada con patrón y tres socorristas militares. Las

embarcaciones disponían de material de rescate, elementos de flotación, mantas térmicas, botiquín básico y radiocomunicación permanente. Como apoyo al dispositivo acuático se contó además con embarcaciones institucionales del Servicio Marítimo de la Guardia Civil y de la Policía Nacional.⁵

La cobertura sanitaria estuvo operativa durante los entrenamientos y la competición. Se dispuso de una ambulancia de soporte vital avanzado (A1), con médico, técnico de emergencias sanitarias y conductor, ubicada junto a la rampa de varada y próxima al campo de regatas; una ambulancia de soporte vital básico (A2), destinada principalmente a la cobertura del área de público, acreditaciones y zonas operativas; y un vehículo ligero de intervención rápida (A3) para proporcionar una primera respuesta en diferentes puntos del recinto. Se estableció asimismo un Puesto Sanitario Avanzado próximo al área de deportistas, equipado con material de soporte vital, desfibrilación, inmovilización, oxigenoterapia, material de atención al trauma, curas y medicación de urgencia. El puesto estuvo atendido por el personal médico y de enfermería del Centro Andaluz de Medicina del Deporte (CAMD), que asumió además la coordinación médica del evento y la supervisión de los recursos sanitarios y de la coordinación asistencial con los dispositivos de rescate, transporte sanitario y asistencia hospitalaria.⁵

La coordinación operativa se realizó mediante un sistema unificado de comunicaciones por radio, con un canal específico para emergencias médicas y rescates acuáticos. El dispositivo mantuvo comunicación con los responsables médicos, de rescate, seguridad y organización de la competición. Ante una emergencia grave se contemplaba la activación inmediata del soporte vital avanzado, del equipo médico y de la coordinación hospitalaria, estableciéndose como hospital de referencia el Hospital Universitario Virgen Macarena.⁵

En los incidentes acuáticos, el procedimiento operativo establecía la intervención inmediata de la embarcación de rescate más próxima, seguida de la valoración inicial, prevención de la hipotermia y traslado al punto sanitario o recurso de transporte correspondiente según la gravedad. En situaciones de emergencia vital se activaba simultáneamente la asistencia sanitaria avanzada y el procedimiento de evacuación hospitalaria.⁵

Como parte de la preparación del dispositivo, y a requerimiento de World Rowing, el 26 de mayo de 2026, en la víspera del inicio de los entrenamientos oficiales, se realizaron dos simulacros de rescate acuático. Para su ejecución se dispuso de una embarcación de rescate y una ambulancia de soporte vital avanzado. Se simulon dos escenarios: rescate de una persona consciente y colaboradora tras una situación de emergencia en el agua, y rescate de una persona inconsciente y en apnea. Los ejercicios pretendieron comprobar la activación de la respuesta, la coordinación entre los equipos de rescate y asistencia sanitaria, la comunicación por radio y los procedimientos de recuperación, transferencia y atención inicial.

Población y criterios de selección

La población de estudio estuvo constituida por todas las personas que recibieron atención sanitaria por parte del dispositivo médico durante el periodo de cobertura establecido, independientemente de su condición de deportista, personal de organización, voluntario, oficial o público, así como por las personas implicadas en las intervenciones de rescate acuático registradas durante el evento.

Se incluyeron todos los registros asistenciales y de rescate generados por el dispositivo durante los días de entrenamiento y competición. No se establecieron criterios de exclusión clínicos. Los registros que correspondían a una misma persona y episodio asistencial fueron considerados como un único encuentro médico,

evitando la duplicación de casos cuando la asistencia estuvo vinculada a una intervención de rescate.

Recogida y definición de variables

La información se obtuvo retrospectivamente a partir de los registros asistenciales cumplimentados durante el evento, los informes específicos de rescate acuático y la documentación operativa del dispositivo médico y de seguridad.

Para cada encuentro médico se recogieron, cuando estaban disponibles, las siguientes variables: fecha de asistencia, condición de la persona atendida, tipo de incidente, localización, motivo de consulta o problema de salud, diagnóstico o categoría clínica registrada, intervención o tratamiento realizado, utilización de recursos asistenciales, derivación y destino posterior (elegibilidad del deportista para continuar en la competición, en su caso).

La actividad asistencial se clasificó de acuerdo con las categorías disponibles en los registros del evento. Se diferenciaron las asistencias médicas individuales de las actuaciones de rescate acuático. En estas últimas se registraron, además, las características del incidente, tiempo de activación y respuesta cuando constaban en el informe, actuación realizada durante el rescate, necesidad de reanimación cardiopulmonar, utilización de recursos sanitarios y destino final.

El registro de los encuentros médicos se estructuró siguiendo los principios de los consensos internacionales sobre definición y recogida de datos de asistencia médica en eventos deportivos, que recomiendan documentar de forma sistemática los episodios de lesión y enfermedad para facilitar la descripción y comparación de la actividad sanitaria.^{6,7}

Análisis de los datos

Se realizó un análisis descriptivo de la actividad asistencial. Las variables cualitativas se expresaron mediante frecuencias absolutas y porcentajes, mientras que las variables cuantitativas se describieron mediante medidas de tendencia central y dispersión cuando correspondía.

Se calcularon el número total de encuentros médicos, su distribución por jornada, tipo de persona atendida, motivo de asistencia, localización, tipo de lesión o enfermedad, intervención realizada y derivación. Las intervenciones de rescate acuático se analizaron de forma específica y se describieron individualmente debido a su relevancia clínica y a las particularidades de la respuesta asistencial.

No se realizaron análisis inferenciales, debido al carácter descriptivo del estudio y al reducido número de eventos asistenciales.

Consideraciones éticas

El estudio se realizó mediante el análisis retrospectivo de los registros operativos generados durante la prestación de los servicios médicos y de rescate. Para el análisis se utilizaron datos anonimizados y no se incorporaron al manuscrito datos personales que permitieran identificar individualmente a las personas atendidas.

El estudio no modificó la asistencia recibida ni implicó ninguna intervención adicional sobre los participantes. La presentación de los resultados se realizó de forma agregada y anonimizada, preservando la confidencialidad de las personas atendidas.

Resultados

Simulacros previos de rescate

Los dos escenarios planificados en la víspera de los entrenamientos oficiales se desarrollaron satisfactoriamente y permitieron validar la activación y coordinación de la respuesta de emergencia. Durante los ejercicios se introdujeron algunas mejoras operativas, entre ellas la utilización de la consigna “Rescue, Rescue, Rescue!” como mensaje de activación por radio, la preparación de medios específicos para la transferencia de las personas rescatadas —silla de ruedas para el escenario de persona consciente y camilla para el escenario de persona inconsciente— y la disponibilidad de biombos para preservar la privacidad de las personas atendidas y limitar su exposición a fotografías o grabaciones realizadas por espectadores.

Dispositivo médico y de rescate

Durante las jornadas oficiales de entrenamiento se desplegó un dispositivo de rescate acuático compuesto por cuatro embarcaciones (R1–R4), distribuidas a lo largo del campo de regatas para cubrir las zonas de salida, recorrido intermedio, meta y calentamiento/retorno. El dispositivo terrestre estuvo constituido por una ambulancia de soporte vital avanzado (A1), una ambulancia de soporte vital básico (A2), un vehículo ligero de intervención rápida (A3) y un puesto de primeros auxilios. La distribución espacial de los recursos durante los entrenamientos se muestra en la [Figura 1](#).



Figura 1. Distribución de los recursos sanitarios durante los entrenamientos oficiales

Durante las jornadas de competición se incrementó la capacidad de respuesta acuática hasta siete embarcaciones de rescate (R1–R7), seis de ellas con patrón y socorrista y una séptima, R7, dotada de patrón y tres socorristas militares para intervenciones reforzadas. El dispositivo se complementó con embarcaciones de apoyo de la Guardia Civil y la Policía Nacional. Se mantuvieron los tres recursos terrestres de asistencia y el puesto sanitario, con la ambulancia de soporte vital avanzado situada junto a la rampa de varada, en el punto de acceso más próximo al agua. La distribución espacial del dispositivo durante la competición se muestra en la [Figura 2](#).

Tabla 1. Actividad asistencial registrada durante la World Rowing Cup Seville 2026.

Fecha	Perfil	Sexo	Equipo/ país	Motivo de consulta	Diagnóstico	Actuación
28/05/2026	Deportista	F	Uruguay	Herida superficial	Herida superficial	Limpieza, desinfección y apósito
28/05/2026	Personal del evento	M	España	Pérdida de tejido en dedo anular	Herida con pérdida de sustancia	Limpieza, desinfección y apósito
28/05/2026	Deportista	F	Venezuela	Dolor de cabeza tras contusión en el cráneo zona parietal	Traumatismo craneoencefálico menor	Analgésico y observación 24 h
29/05/2026	Deportista	F	Países Bajos	Vuelco en el río de su embarcación y crisis de ansiedad	Estado de ansiedad aguda	Rescate, manta térmica y apoyo psicológico
31/05/2026	Deportista	M	Portugal	Cefalea, mareo y dolor torácico	Golpe de calor con crisis ansiedad y crisis respiratoria	Oxígeno a bajo flujo; apoyo psicológico
31/05/2026	Público	M	España	Dolor e inflamación en tobillo tras caída.	Esguince de tobillo	Reposo, Hielo, Compresión y Elevación
31/05/2026	Público	F	España	Síntomas de ahogamiento tras intento de autolisis por precipitación al medio acuático	Parada cardiorrespiratoria	Rescate y Soporte Vital
31/05/2026	10 voluntarios/as	No consta	España	Ansiedad	Crisis de ansiedad en 10 voluntarios/as por presenciar rescate de persona inconsciente en el río	Apoyo psicológico



Figura 2. Distribución de los recursos sanitarios durante la competición

El dispositivo permitió establecer una cobertura diferenciada del campo de regatas y de las áreas terrestres del recinto, con dos puntos principales de evacuación sanitaria y acceso directo de los vehículos de emergencia al perímetro técnico. El Hospital Universitario Virgen Macarena, establecido como centro hospitalario de referencia, se encontraba aproximadamente a 1,4 km del campo de regatas.

Actividad asistencial

Durante el periodo analizado se registraron 17 personas atendidas por el dispositivo sanitario. De ellas, cuatro fueron deportistas, una correspondió a personal del evento, dos a público y diez a personal voluntario. Las atenciones se distribuyeron entre los días de entrenamiento y competición, con tres asistencias el 28 de mayo, una el 29 de mayo y trece el 31 de mayo. Entre los deportistas atendidos se registraron una herida superficial, una herida con pérdida de sustancia, un traumatismo

craneoencefálico menor, un episodio de ansiedad aguda tras un vuelco y un cuadro compatible con golpe de calor asociado a crisis de ansiedad y síntomas respiratorios. Entre el público se registraron un esguince de tobillo y una parada cardiorrespiratoria en una persona localizada inconsciente en el medio acuático. La asistencia al personal del evento correspondió a una herida con pérdida de sustancia en un dedo. Asimismo, se registraron episodios de ansiedad entre el personal voluntario tras presenciar una emergencia acuática. La distribución de las asistencias según perfil, motivo de consulta, diagnóstico y actuación se recoge en la Tabla 1.

La mayoría de las atenciones correspondieron a procesos de carácter leve que fueron resueltos mediante medidas terapéuticas básicas, observación o apoyo psicológico. Entre las intervenciones realizadas se incluyeron limpieza y cura de heridas, analgesia, medidas físicas para un esguince, oxigenoterapia a bajo flujo y apoyo psicológico. Una deportista que sufrió un vuelco rechazó posteriormente la exploración médica después de ser rescatada y trasladada al puesto sanitario.

Rescates acuáticos

Se produjeron dos intervenciones de rescate acuático durante la competición. La primera tuvo lugar el 29 de mayo, aproximadamente a las 09:15 h, tras el vuelco de una embarcación cerca del punto de 600 m. La embarcación de rescate R2, situada en torno al punto de 500 m, acudió al incidente y recuperó a la deportista del agua en aproximadamente 40 segundos. La deportista se encontraba consciente y no presentaba traumatismo físico descrito, aunque mostraba afectación psicológica. Tras la recuperación se realizó una valoración inicial, se aplicó protección térmica y fue trasladada al puesto sanitario, donde rechazó la exploración médica posterior y abandonó el dispositivo sin tratamiento específico.

La segunda intervención se produjo el 31 de mayo a las 08:22 h, cuando una persona no participante en la regata fue localizada inconsciente y en apnea en las proximidades de la zona de salida. La embarcación R4 realizó la recuperación inmediata y se iniciaron maniobras de reanimación cardiopulmonar durante el

Tabla 2. Características de las intervenciones de rescate acuático durante la competición.

Fecha	Persona	Sexo	Situación	Recurso	Estado inicial	Intervención	Resultado
29/05/2026	Deportista	F	Vuelco y entrada al agua cerca de 600 m	Embarcación R2 (punto 500 m)	Consciente. Afectación psicológica. Sin traumatismo físico descrito	Recuperación del agua. Valoración inicial. Manta térmica. Traslado al puesto sanitario. Rechazó exploración médica	Sin tratamiento. Abandonó el puesto sanitario
31/05/2026	No participante en la regata	F	Persona localizada en el agua. Inconsciente y en apnea	Embarcación R4 (Zona de la salida)	Inconsciente. No respiraba	RCP inmediata en embarcación. Traslado continuo con RCP a rampa. Equipo médico del evento A1. Control de vía aérea. Ventilación con balón-válvula-mascarilla. Desfibrilador/monitorización. Dos vías IV. Activación del 112	Llegada del 061 a las 08:45. Retorno de circulación espontánea. Estabilización. Evacuación hospitalaria a las 09:25

traslado hacia la rampa. Una vez en tierra, el equipo de soporte vital avanzado continuó la asistencia, incluyendo control de la vía aérea, ventilación con balón-válvula-mascarilla, desfibrilación/monitorización y canalización de dos vías venosas periféricas. Se activaron los servicios de emergencias extrahospitalarias, con llegada del 061 a las 08:45 h. Se obtuvo retorno de la circulación espontánea, seguido de estabilización y evacuación hospitalaria a las 09:25 h. Las características y actuaciones de ambas intervenciones se resumen en la [Tabla 2](#).

Discusión

La experiencia de la World Rowing Cup Seville 2026 pone de manifiesto que la organización sanitaria de una competición internacional de remo debe plantearse como un sistema integrado de prevención, rescate, asistencia y evacuación. Esta consideración adquiere especial relevancia en acontecimientos deportivos que reúnen simultáneamente a deportistas, personal técnico, oficiales, voluntarios y espectadores, ya que la demanda asistencial puede proceder de diferentes grupos y presentar características clínicas heterogéneas. Las revisiones sobre asistencia sanitaria en reuniones masivas señalan precisamente la necesidad de adaptar la planificación al tipo de evento, al perfil de los asistentes y a los recursos disponibles.^{9,10}

En nuestro caso, la actividad asistencial fue mayoritariamente de carácter leve, aunque se produjeron situaciones de diferente naturaleza y gravedad, incluida una emergencia cardiopulmonar. La presencia de lesiones traumáticas, problemas médicos agudos y episodios de ansiedad entre distintos colectivos refuerza la necesidad de que el dispositivo no se limite a las lesiones deportivas previsibles. La experiencia de otros grandes acontecimientos deportivos internacionales muestra igualmente que la demanda sanitaria puede afectar a diferentes grupos presentes en el recinto, por lo que la planificación debe contemplar un espectro clínico amplio.^{11,12}

La planificación previa y la definición de procedimientos de actuación constituyeron elementos esenciales del dispositivo. Las recomendaciones sobre emergencias médicas en el deporte destacan la importancia de establecer anticipadamente las funciones de los profesionales, la localización de los recursos, los sistemas de comunicación, los procedimientos de activación y las vías de evacuación.^{3,4,13-15} En eventos acuáticos, estos elementos adquieren una dimensión adicional, puesto que la asistencia puede comenzar en el agua y requerir una transición coordinada hacia los recursos sanitarios terrestres.⁵

Un aspecto especialmente relevante fue la realización de simulacros antes del inicio de la actividad oficial. Estos ejercicios permitieron comprobar la aplicabilidad del procedimiento en las condiciones concretas del evento e introducir modificaciones

operativas antes de afrontar situaciones reales. La utilidad de la simulación resulta particularmente pertinente en el rescate acuático, donde la respuesta integra diferentes fases y la ejecución de la aproximación, el remolque y la extracción puede condicionar el rendimiento global del rescate. En socorristas profesionales, las fases de remolque y extracción han mostrado capacidad para discriminar el nivel de competencia durante rescates simulados.¹⁶ Estos resultados apoyan la incorporación de ejercicios prácticos como parte de la preparación de dispositivos de rescate en competiciones acuáticas.

La adaptación de los recursos a las diferentes fases de la actividad constituyó asimismo un elemento relevante. El incremento de los medios de rescate durante la competición respecto a los entrenamientos permitió ajustar la cobertura a las condiciones operativas de cada periodo. Esta planificación dinámica es coherente con los principios de organización sanitaria de grandes eventos, en los que la distribución espacial de los recursos y la accesibilidad para la evacuación deben adaptarse a las características del recinto y a la actividad desarrollada.^{11,13} La disponibilidad de distintos niveles de asistencia y transporte sanitario permitió, además, responder a incidentes de diferente complejidad.

Los dos rescates acuáticos registrados durante la competición ilustran, desde perspectivas diferentes, la importancia de esta integración. El primero correspondió a una emergencia deportiva sin consecuencias clínicas relevantes, mientras que el segundo requirió una respuesta de soporte vital avanzado y posterior evacuación hospitalaria. Sin reproducir los detalles ya expuestos en los Resultados, ambos episodios muestran que el rescate acuático no debe considerarse una actuación aislada, sino el primer componente de una cadena asistencial que debe garantizar la continuidad entre recuperación del agua, valoración, tratamiento y evacuación cuando sea necesaria.^{5,13,16}

La experiencia también pone de relieve la importancia del registro sistemático de la actividad asistencial. Los sistemas de vigilancia de lesiones y enfermedades desarrollados para grandes competiciones deportivas permiten caracterizar la carga sanitaria y mejorar la planificación de recursos. Una revisión del sistema de vigilancia del Comité Olímpico Internacional señaló su utilidad para el seguimiento de las incidencias sanitarias durante los juegos multideportivos.⁹ En nuestro caso, aunque el carácter descriptivo y el reducido número de eventos impiden establecer tasas epidemiológicas comparables, el registro individualizado permitió identificar los perfiles de las personas atendidas, los motivos de consulta y las intervenciones realizadas. La incorporación futura de sistemas de vigilancia estandarizados facilitaría la comparación entre competiciones y permitiría analizar con mayor precisión la demanda asistencial y los tiempos de respuesta.

La coordinación interinstitucional constituye finalmente un elemento transversal de la respuesta sanitaria. La interacción entre asistencia médica, rescate, seguridad, organización y servicios

externos de emergencia resulta necesaria para garantizar la continuidad de la atención desde el lugar del incidente hasta la evacuación hospitalaria. Esta coordinación debe quedar definida previamente y ser posteriormente comprobada mediante ejercicios prácticos, de acuerdo con los principios establecidos para los planes de actuación ante emergencias deportivas.^{3,4,14,15}

Este estudio presenta las limitaciones propias de una experiencia descriptiva de un único evento. El número reducido de asistencias y de emergencias graves no permite establecer tasas generalizables ni valorar estadísticamente la efectividad de los diferentes componentes del dispositivo. Asimismo, la utilización de registros asistenciales y operativos generados durante la actividad puede limitar la disponibilidad y homogeneidad de algunas variables. Futuros eventos deberían incorporar sistemas estandarizados de vigilancia sanitaria y registro de tiempos de respuesta que permitan realizar comparaciones entre competiciones y mejorar progresivamente la planificación.⁹

En conjunto, la experiencia sugiere que la preparación sanitaria de una competición internacional de remo requiere integrar planificación previa, simulación, rescate acuático, asistencia médica, evacuación y vigilancia de la actividad asistencial. La combinación de estos elementos puede favorecer una respuesta coordinada y adaptable a las características específicas de cada competición y proporcionar una base para la mejora continua de futuros dispositivos sanitarios en entornos acuáticos.

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Revisiones

Potential of ascorbic acid during physical exercise to reduce oxidative stress: a systematic review



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ABSTRACT

Background: The increase in ROS during exercise is widely studied and reportedly appears to be interrelated with the pathology of several illnesses, including Alzheimer's disease, atherosclerosis, and metabolic syndrome.

Objectives: This study aims to determine whether supplementing ascorbic acid during exercise has an effect in reducing malondialdehyde levels as one of the markers of oxidative stress during exercise.

Material & Methods. For this study, a number of journal databases were searched, such as Pubmed, Science Direct, Web of Science, and Scopus. The research considered a number of factors, such as studies on physical exercise, ascorbic acid and malondialdehyde published in the last five years. Papers published in non-reputable journals were excluded from the analysis. A total of 127 papers were found using Pubmed, Science Direct, Web of Science, and Scopus databases. About 8 carefully selected, peer-reviewed papers addressed the need for this systematic review.

Results. Findings from the systemic analysis showed that ascorbic acid supplementing while working out has been demonstrated to lower malondialdehyde levels.

Conclusion. Ascorbic acid supplementation has been shown to reduce malondialdehyde levels after exercise in both humans and animals. However, further testing with specific human subjects and experimental studies are needed to confirm the potential effect of ascorbic acid in reducing MDA levels, a marker of oxidative stress.

Keywords: Physical exercise; Ascorbic acid; Malondialdehyde; Oxidative stress; Healthy lifestyle.

Potencial del ácido ascórbico durante el ejercicio físico para reducir el estrés oxidativo: revisión sistemática

RESUMEN

Antecedentes: El aumento de especies reactivas de oxígeno durante el ejercicio se ha relacionado con diversas enfermedades. El objetivo fue determinar si la suplementación con ácido ascórbico asociada al ejercicio reduce el malondialdehído, marcador de estrés oxidativo.

Material y métodos: Se realizó una búsqueda en PubMed, ScienceDirect, Web of Science y Scopus de estudios sobre ejercicio físico, ácido ascórbico y malondialdehído. De 127 registros identificados, ocho artículos revisados por pares cumplieron los criterios establecidos.

Resultados: La síntesis sistemática mostró que la suplementación con ácido ascórbico asociada al ejercicio redujo las concentraciones de malondialdehído.

Conclusión: La suplementación con ácido ascórbico puede reducir el malondialdehído después del ejercicio en humanos y animales; se requieren más estudios experimentales en humanos.

Palabras clave: Ejercicio físico; Ácido ascórbico; Malondialdehído; Estrés oxidativo; Estilo de vida saludable.

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Potencial do ácido ascórbico durante o exercício físico para reduzir o estresse oxidativo: revisão sistemática

RESUMO

Contexto: O aumento de espécies reativas de oxigênio durante o exercício tem sido relacionado a diversas doenças. O objetivo foi determinar se a suplementação com ácido ascórbico associada ao exercício reduz o malondialdeído, marcador de estresse oxidativo.

Material e métodos: Foi realizada uma busca no PubMed, ScienceDirect, Web of Science e Scopus por estudos sobre exercício físico, ácido ascórbico e malondialdeído. Dos 127 registros identificados, oito artigos revisados por pares atenderam aos critérios estabelecidos.

Resultados: A síntese sistemática mostrou que a suplementação com ácido ascórbico associada ao exercício reduziu as concentrações de malondialdeído.

Conclusão: A suplementação com ácido ascórbico pode reduzir o malondialdeído após o exercício em humanos e animais; são necessários mais estudos experimentais em humanos.

Palavras-chave: Exercício físico; Ácido ascórbico; Malondialdeído; Estresse oxidativo; Estilo de vida saudável.

Introduction

Regular physical exercise is proven to increase endurance. Adequate nutrition accompanied by an optimal recovery phase can keep the body healthy and avoid sustained physical injury¹. Physical exercise has been shown to closely manage oxidative stress, a process that involves an rise in reactive nitrogen species (RNS) and reactive oxygen species (ROS)². Exercise intensity, duration, and state of health of these individuals influence the level of oxidative stress induced by exercise, and can even have a positive or negative impact on human survival³. The increase of ROS during exercise is widely studied and reportedly appears to be interrelated with the pathology of several illnesses, including alzheimer's disease, atherosclerosis, and metabolic syndrome⁴. Furthermore, oxidative stress levels have the ability to precipitate a number of chronic illnesses, including infections, cancer, neurological illnesses, and cardiovascular illnesses⁵. Overproduction of ROS can result in changes in cell structure and function causing chronic degenerative diseases and aging disease pathology⁶.

We already know from research reports that antioxidants can help reduce oxidative stress and can improve health, especially in the heart⁷. Increasing antioxidants has demonstrated the ability to lessen the negative consequences of oxidative stress⁸. During aerobic exercise, increased contractile activity raises oxygen consumption. This can lead to electron leakage from mitochondria, which in turn increases ROS production⁹. In this case, if free radical production outpaces the body's antioxidant capacity, it can be detrimental, leading to cellular damage and muscle dysfunction¹⁰. Although ROS are known to be bad and can damage cells, the presence of ROS also contributes significantly to the improvement of other cellular defense processes including the antioxidant defense system¹¹.

Vitamin C, sometimes referred to as ascorbic acid, is a popular and powerful antioxidant that scavenges free radicals¹². In addition, ascorbic acid can also protect cell membranes and DNA from oxidative stress damage¹³. Ascorbic acid has protective characteristics

that allow it to interact with free oxygen ions, superoxide ions, and hydroxyl ions while inhibiting inflammation¹². The results of the research report prove that antioxidant levels in the body have increased after 1000 mg ascorbic acid supplementation and cycling physical exercise intervention, in addition to preventing and reducing muscle damage triggered by sports training¹⁴. Likewise, other studies have shown a decrease in malondialdehyde levels in research subjects given 1000 mg ascorbic acid intervention and aerobic physical exercise intervention¹⁵.

However, there is very little discussion about ascorbic acid during physical exercise, and a detailed explanation of how ascorbic acid reduces malondialdehyde levels is still confusing among researchers. There is other evidence that ascorbic acid can not only reduce MDA levels during exercise, but can also boost the immune system in healthy individuals¹⁶. Therefore, the objective of this review is to discuss how the effect of ascorbic acid in lowering malondialdehyde levels, one of the oxidative stress biomarkers, during physical activity.

Materials and methods

Study Design

A systematic review, which evaluates scientific papers according to criteria set by the researchers, was the strategy employed in this investigation. To choose articles about how ascorbic acid lowers MDA levels following physical activity, the scientific literature was examined. The search engines Web of Science, Pubmed, Science Direct, and Scopus were used to locate the scientific literature. MDA levels, physical activity, and ascorbic acid were the search phrases used. Publications were chosen based on the following inclusion criteria: year of publication, experimental investigations, and human and animal-related literature.

Table 1. Inclusion criteria

Web search engines	Pubmed, Science Direct, Scopus, and Web of Science
Publishing period	2015 – 2025
Keyword	Ascorbic acid, physical exercise, and MDA levels
Language	English
Type of article	Original research article
Full Text	Articles matched the purpose and/or topic of the research

Eligibility criteria

Study inclusion criteria were established by examining current databases for information released between 2015 and 2025. An experimental research of the impact of ascorbic acid supplementation following physical activity on MDA levels was part of this study. MDA levels, physical activity, and ascorbic acid were among the search phrases used. Additionally, papers that did not fit the criteria for scientific validity or that were not listed in reputable search engines such as Scopus, Web of Science, PubMed, or Science Direct were not included in our analysis. As a result, we used our predetermined inclusion criteria to screen the chosen papers.

Procedure

Each publication's complete text, abstract, and title were added to the Mendeley database following review and verification. Using Scopus, Science Direct, Pubmed, and Web of Science, 127 papers were found during the initial screening stage. 76 appropriate papers were chosen for the second screening stage after duplicate articles were found and the reasons behind title mismatches were addressed. 43 papers were selected for the next stage based on the concordance of the title, abstract, and keywords analyzed. After going over each paper, we come to the following conclusions: the study had to be experimental, the parameter had to be the MDA biomarker, the intervention had to be physical exercise, and both human and animal samples had to be used. This was the last phase of the process. We carried out a screening procedure to find papers that satisfied our predefined inclusion criteria. Following a rigorous review and

scrutiny procedure, eight papers that satisfied the inclusion criteria were chosen for study. Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) criteria were adhered to in this study. This study looked at earlier studies that met bioethical and ethical standards.

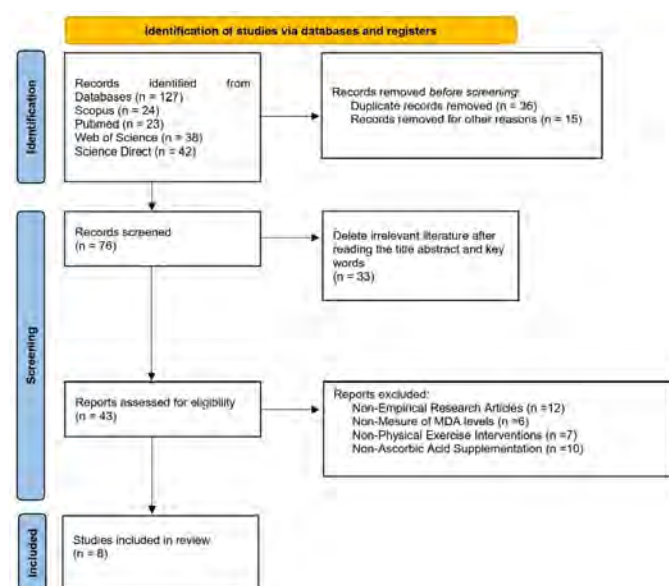


Figure 1. PRISMA flowchart of the article selection process

Results

Table 2. Results of Ascorbic Acid Supplementation During Physical Exercise in Reducing Malondialdehyde Levels as a Marker of Oxidative Stress

Author	Sample Characteristics	Study Design	Ascorbic Acid Dosage	Intervention	Results
(Bunpo et al., 2021) [17]	19 healthy women took part in the research and were split up into two groups: physical exercise + ascorbic acid supplementation intervention group and placebo + physical exercise + ascorbic acid supplementation intervention group. ascorbic acid supplementation and physical exercise + placebo intervention group.	Experimental	1000 mg	Moderate intensity exercise by cycling for 30 minutes.	The group's MDA levels have significantly dropped with physical exercise intervention + 1000 mg ascorbic acid supplementation.
(Bunpo et al., 2024) [18]	20 sedentary women took part in the research and were split up into two groups: a group with physical exercise intervention + 1000 mg ascorbic acid supplementation, and a group with physical exercise intervention + placebo.	Experimental	1000 mg	Moderate intensity exercise by cycling for 30 minutes.	The group's MDA levels have significantly dropped with physical exercise intervention + 1000 mg ascorbic acid supplementation.
(Wibawa et al., 2021) [15]	28 healthy In this study, males were split up into four groups: control group without physical exercise, control with physical exercise, physical exercise + ascorbic acid 500 mg, physical exercise + ascorbic acid 1000 mg.	Experimental	500 mg and 1000 mg	Moderate intensity physical exercise with 2400 meters of running for 12 minutes.	MDA levels in the blood significantly dropped in the ascorbic acid 1000 mg supplementation + physical exercise group.
(Boonthongkaew et al., 2021) [19]	This research included 24 participants with type 2 diabetes mellitus and were divided into 2 groups: physical exercise +	Experimental	1000 mg	Physical exercise test with moderate intensity on an ergometer for 20 minutes.	There was a significant decrease in MDA levels in the group with 1000 mg physical exercise intervention.

Author	Sample Characteristics	Study Design	Ascorbic Acid Dosage	Intervention	Results
	ascorbic acid 1000 mg group, and physical exercise + placebo group.				
(Chaoqun et al., 2021) [20]	81 male Sprague-dawley rats took part in the research and were split up into three treatment groups consisting of exercise only, exercise + 4% H ₂ , exercise + ascorbic acid 500 mg.	Experimental	500 mg	Aerobic physical training of rats for 60 minutes on a treadmill.	There was a significant decrease in MDA levels in the group with physical exercise intervention + 500 mg ascorbic acid supplementation.
(Eatemadyboroujeni et al., 2021) [21]	50 male rats participated in this study and were divided into 5 groups: exercise group, exercise + ascorbic acid, exercise + polluted air, exercise in polluted air + ascorbic acid, and control group.	Experimental	Aerobic physical training on a treadmill 30 minutes per day, 5 days a week for 12 weeks.	20 mg per kg of body weight.	There was a decrease in MDA levels in the physical exercise group in polluted air + ascorbic acid.
(Alves et al., 2021) [22]	84 male athletes participated in the pre-test and post-test research.	Experimental	Test run to exhaustion on the treadmill.	87 mg per day	There was a decrease in MDA levels after the exercise intervention post test.
(de Oliveira et al., 2019) [23]	21 soccer athletes took part in the research and were split up into two groups: placebo and ascorbic acid and vitamin e supplementation groups.	Experimental	Plyometric jump test, strength and endurance training until exhaustion.	Ascorbic acid 500 mg and Vitamin E 500 UI.	There was a decrease in the lowest MDA levels after 72 hours after the intervention of ascorbic acid and vitamin E supplementation.

Discussion

Physical exercise increases ROS (reactive oxygen species)

Cell damage is triggered by an increase in ROS levels in the body. ROS increases one of which is caused by exercise²⁴. It is evident that the pathophysiology of diabetes mellitus, cancer, cardiovascular disease, hypertension, and a number of neurological illnesses is linked to persistent oxidative damage²⁵. Other reports suggest that regular exercise provides significant health benefits through blood sugar regulation and cardiovascular health in the general population. It is evident that regular physical exercise proves to have a lower risk of cardiovascular disease²⁶. ROS during exercise is a physiological response caused by exercise. However, if high ROS exceeds the antioxidant capacity, it will also adversely affect health. The adverse effects of high ROS include alterations to lipids, proteins, and nucleic acids²⁷.

When the level of oxidative stress surpasses the protective capacity in the body, it will result in cell damage and lipid peroxidation. Additionally, redox imbalance has a strong correlation with a number of illnesses, including aging and cancer²⁸. There is an increase in oxygen during activity demand by active muscles due to acute exercise causing an increase in oxygen consumption concentration and mitochondrial activity, which consequently increases the synthesis of reactive oxygen species (ROS), including superoxide radicals (O₂⁻), which causes oxidative stress²⁹. Recent research reports have shown that low- or moderate-intensity exercise can cause oxidative stress, the failure of the antioxidant defense system is the main mediator of exercise-induced oxidative stress³⁰. The findings of 25 Wistar rats were studied who were given a high-intensity physical exercise intervention with swimming 1 hour per day, 5x a week for 8 weeks said that MDA levels increased after physical exercise³¹. The results of other studies also prove that there is an increase in MDA levels when subjects are given a physical

exercise intervention of 2400 m for 12 minutes¹⁵. It is evident that MDA increases during physical exercise.

Ascorbic Acid During Physical Training Lowers Malondialdehyde Levels

The results prove that ascorbic acid 1000 mg supplementation supplied to 19 women with moderate level of intensity physical exercise intervention for 30 minutes is proven to reduce MDA levels as one of the markers of oxidative damage¹⁷. The outcomes of further studies are also the same that 1000 mg ascorbic acid supplementation is proven to reduce MDA levels after physical exercise using an ergocycle¹⁸. The results of another study comparing supplementing with 1000 mg of ascorbic acid and a dose of 500 mg during physical exercise showed that a dose of 1000 mg lowered MDA levels than 500 mg¹⁵. The results of various studies prove that by exercising it will make the body healthier by improving physical fitness, cardiorespiratory, heart health, muscle and bone strength, cardiometabolic health³². Furthermore, a research revealed that ascorbic acid administration effectively decreased exercise-induced lipid peroxidation and that MDA levels increased considerably immediately following physical activity. These outcomes also support earlier research showing ascorbic acid may be used as a treatment to reduce ROS production and boost the body's antioxidant capacity¹⁸.

Increasing the antioxidant capacity in the body is essential for protection against lipid damage. It is known that lipid damage can lead to serious health problems related to increased chronic inflammation and cardiovascular disease³³. If the body's antioxidant reserves aren't enough to combat free radicals, exogenous antioxidants are needed in an effort to reduce the adverse effects of free radicals. Ascorbic acid is an important cellular antioxidant that is responsible for detoxifying free radicals and scavenging ROS³⁴. The results of various studies show that ascorbic acid contains antioxidants and provides a protective impact against oxidative stress-related diseases³³. When the human body performs heavy

physical exercise, it will also have an adverse effect on the body and will also increase physical fatigue if not balanced with a good recovery process. Research has shown that supplementation with ascorbic acid protects the body and alleviates fatigue²⁰. Furthermore, ascorbic acid is listed as an effective and essential medicine published by the World Health Organization. Its main function is to protect cellular cells from oxidative stress triggered by ROS.

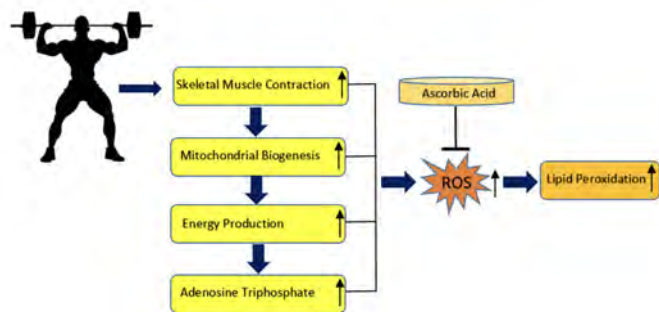


Figure 2. The Mechanisms of Ascorbic Acid Supplementation During Physical Exercise in Reducing Malondialdehyde Levels as a Marker of Oxidative Stress

The results of the study in rats given 500 mg ascorbic acid intervention and given physical exercise for 60 minutes on a treadmill demonstrated that there a significant reduction in MDA concentrations²⁰. The results of other studies in rats given ascorbic acid intervention and physical exercise also prove the same thing, namely a decrease in MDA levels after physical exercise²¹. So, it can be proven that ascorbic acid supplementation during physical exercise has a protective effort and can reduce MDA levels as one of the signs of oxidative stress brought on by physical activity. A significant reduction in MDA levels also occurred in athletes who had been given ascorbic acid intervention and physical exercise until they experienced fatigue³⁵. There is confusion and it is still unclear how protective ascorbic acid is in reducing MDA levels during exercise and what the underlying theory is. For future research, the topic of ascorbic acid is an interesting one to discuss as it has been shown to have strong antioxidant properties. This could be a recommendation especially for athletes to consume ascorbic acid supplements for muscle recovery³⁶.

Results Other studies also support the data that supplementation of ascorbic acid supplementation of 1,000 mg/day consistently for several weeks proved to be able to result in rehabilitation of muscular strength and a decrease in discomfort in males who are not trained who performed 90 minutes of running physical exercise³⁷. Ascorbic acid in its efforts to counteract free radicals is by donating electrons, so that ROS become more neutral and unreactive which can trigger lipid peroxidation and cell damage³⁸. But, of course in this systematic review there are still limitations in the analysis, namely only looking at how ascorbic acid as an endogenous antioxidant has a remarkable effect in reducing MDA levels during exercise. During physical exercise, it is known that ROS increases and this can have an impact on lipid peroxidation. However, it should also be noted that the increase in MDA levels during physical exercise is also a physiological response caused by physical training. For further research, it is necessary to study in depth how the molecular response of ascorbic acid in reducing MDA after physical exercise so that it can provide understanding to the public and academics related to the importance of ascorbic acid supplementation as an effort to protect cells from oxidative stress during exercise.

Conclusions

Ascorbic acid supplementation has been shown to reduce malondialdehyde levels after exercise in both humans and animals.

However, further testing with specific human subjects and experimental studies are needed to confirm the potential effect of ascorbic acid in reducing MDA levels, a marker of oxidative stress.

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Potential conflict of interest

The authors declare no conflict of interest.

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