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Content

Foreword

Message from Editor-in-Chief

Greetings to all readers, authors, editors, and supporting parties. As we present the second issue of the first volume of the Sports Therapy Journal, we extend our heartfelt gratitude to all stakeholders for their continued support. This issue marks the introduction of new members to our Editorial Board: Mr Anthony Bosson, Dr Anthony Weldon, and Dr Kate William, listed in alphabetical order. With their extensive experience and professional backgrounds in both sports therapy practice and scholarly pursuits, we are confident that they will contribute significantly to the journal, enhancing its role as an international platform for connection and information sharing.

In addition to our usual articles and sections, this issue features a new segment dedicated to the research proposal abstracts submitted by sports therapy students. This initiative aims to showcase their involvement in generating new knowledge within the realms of sports therapy and sports science.

Finally, we are excited to announce that the Sports Therapists Association of Hong Kong (STAoHK) will organise the 2nd Student Conference at the Technological and Higher Education Institute of Hong Kong (THEi) in June 2026. We look forward to meeting all of you there, as we strengthen our bonds and learn from one another.

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VOLUME 1, ISSUE 2

Testimonial

A Rising Star in Sports Therapy Jeremy Leung from Hong Kong

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Five years ago, I never imagined my life would be filled with such a passion for learning and growth. At that time, I could not have foreseen that sports therapy would become my professional calling. If I could meet my younger self now, I would tell him: "You will be amazed by what you can achieve. Trust in your abilities, embrace challenges, and remain open to pursuing what truly excites you." It is perfectly acceptable to feel lost at times, as you will eventually find your way.

> Today, I am proud to say I have discovered my passion and commitment to a career in Sports Therapy.

The journey to becoming a sports therapist has been both challenging and rewarding. Four years ago, I made the life-changing decision to leave my full-time career as a personal trainer and return to school as a full-time student. Balancing work and study were not easy, but I embraced the challenge knowing it was a commitment to my future.

During my two and a half years of studying sports therapy at the Technological and Higher Education Institute of Hong Kong (THEi), I faced long hours of research, late nights preparing for exams, and moments of stress. Yet, I refused to give up. Instead, I developed stronger time management skills and learned to prioritise tasks effectively, ensuring that my time was spent productively. These experiences taught me the value of discipline, perseverance, and focus on my goals, shaping myself into a more resilient and determined individual, ready to face the demands of this field.

One of the most rewarding experiences in my academic journey was presenting my research at professional conferences. In June 2025, I had the honour of sharing my thesis at the inaugural Sports Therapy Conference in Hong Kong, hosted by the Sports Therapist Association of Hong Kong (STAoHK). This was followed by a presentation the same study in October 2025 at the International Conference (ICPM), organised by AIBPM and THEi. These opportunities deepened my understanding of evidence-based practice and strengthened my commitment to advancing the field of sports therapy.

On the practical side, I was privileged to intern at Vegvísir Sports Therapy, one of Hong Kong's leading clinics. This transformative experience allowed me to work with elite athletes, including members of Hong Kong's national teams in track and field, fencing, rugby, and long-distance running. These experiences taught me how to tailor treatment plans for high-performance cases, combining clinical knowledge with adaptability in dynamic and demanding environments.

As a sports therapy student with a background as a personal trainer, I believe that sports therapy extends far beyond treating injuries. It is about using knowledge and compassion to improve patients' quality of life, empowering them to regain their strength, confidence, and passion. A sports therapist's mission is to bridge the gap between science and practice, building relationships founded on trust, empathy, and a shared vision of recovery. What distinguishes an exceptional sports therapist is the ability to integrate knowledge, apply evidence-based techniques, and demonstrate empathy in treatment, ensuring that every patient receives care that is both effective and meaningful.

Looking ahead, I aspire to integrate cutting-edge research into practical applications, strengthening the connection between sports therapy and evidence-based science. My vision is to create a space where athletes and individuals alike can not only recover but thrive, physically, mentally, and emotionally. I aim to expand my expertise by exploring related fields like strength and conditioning and exercise science, combining these with rehabilitation techniques to provide holistic care.

I also want to raise awareness about the versatility of sports therapy, demonstrating that it is not solely for athletes, but for anyone from active individuals to everyday people, and even those with special conditions. By showcasing the value of sports therapy, I hope to inspire the next generation of students to explore this field, fostering a stronger community of passionate and skilled professionals dedicated to improving lives through movement and recovery.

I am deeply grateful to my mentors, professors, and peers who have guided and supported me throughout this journey. I would like to specially thank Dr. Jim Luk, Mr. Indy Ho, and Mr. Stone Shek for providing me with invaluable opportunities to grow as a future sports therapist. Being recognised as a “rising star” is not only an honour but also a reminder of the responsibility I carry to contribute to this field. I look forward to continuing my journey with passion, purpose, and an unwavering belief in the transformative power of sports therapy to improve lives.

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VOLUME 1, ISSUE 2

Research Article

Functional Leg Length Discrepancy and Its Impact across Different Drop Landing Biomechanics: A Clinical Perspective of Motor Control and Kinematics Carry-over on ACL Injury Prevention and Rehabilitation

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Abstract

Background

Functional Leg Length Discrepancy (FLLD) disrupts symmetrical lower limb mechanics and contributes to kinematic carryover, where compensatory movement patterns developed during low-impact activities (e.g., walking) persist in high-impact tasks such as landing. This study explores how FLLD influences landing mechanics, affecting hip and ankle kinematics, and highlights its role in increasing anterior cruciate ligament (ACL) injury risk.

Method

This experimental, within-subject repeated-measures study analysed 23 healthy adults from 18 to 40 of age with mild FLLD. Participants performed four landing variations: 1) double-leg (DL); 2) single-leg (SL); 3) anterior-lateral (SLAL); and 4) anterior-medial (SLAM) in which joint kinematics and vertical ground reaction forces (vGRF) were measured by inertial measurement units and force plates.

Result

Findings revealed significant hip abduction (5.6° ± 5.44° vs. 1.54° ± 6.11°) and ankle adduction (-4.12° ± 3.8° vs. -6.61° ± 3.04°) asymmetries in the shorter leg during DL. SLAM elicited the highest hip flexion (36.6° ± 9.11°), reflecting greater biomechanical demands. Despite kinematic changes, vGRF remained consistent across variations, suggesting effective compensatory mechanisms.

Discussion

The findings underscore FLLD's impact on lower limb kinematics and its implications for ACL injury prevention. Rehabilitation programs should address kinematic asymmetries through neuromuscular training and motor learning interventions to refine joint stability, improve performance, and mitigate injury risks during high-impact activities.

Keywords: *leg length discrepancy, functional leg length discrepancy, kinematic carryover, drop landing, joint kinematics, biomechanics, ACL injury, lower limb asymmetry, vertical ground reaction force.*

Introduction

Leg length discrepancy (LLD) has been a topic of debate among researchers and clinicians for decades (Mattatia et al., 2024). LLD can be caused by structural differences, which refer to anatomical deformities between two legs, such as variations in the length from the proximal femoral head to the distal edge of the tibia (Walsh et al., 2000). However, LLD can also result from functional deformities caused by abnormal foot, ankle, knee, and hip movements across various planes of motion (Khamis et al., 2018). This phenomenon, known as "Functional Leg Length Discrepancy" (FLLD), represents a biomechanical adaptation rather than a fixed structural abnormality (Khamis et al., 2017a).

FLLD has been widely recognised as a compensatory mechanism that affects lower limb kinematics and contributes to numerous musculoskeletal conditions (Khamis & Carmeli, 2017b). Unlike anatomical LLD, which is caused by structural bone length differences, FLLD arises from functional abnormalities such as joint malalignment, muscle weakness, or altered gait mechanics (Knutson, 2005). Even minor discrepancies of 5–10 mm can lead to significant biomechanical compensations, including pelvic obliquity, gait asymmetry, and altered joint mechanics of the lower limb (Young et al., 2000; Khamis & Carmeli, 2017b). These compensations often result in asymmetrical movement patterns, increasing the risk of injury during dynamic activities.

The compensatory mechanisms underlying FLLD can be explained through motor control theory, which focuses on how individuals adapt and develop movement patterns in response to biomechanical and neuromuscular stimuli (Mulla & Keir, 2023). LLD disrupts symmetrical movement patterns, forcing individuals to alter joint kinematics and neuromuscular control during functional tasks, particularly gait (Azizan et al., 2018). These compensations are regulated by motor control processes, which integrate sensory and proprioceptive feedback to maintain dynamic balance (Young et al., 2000; Khamis & Carmeli, 2017b). However, asymmetrical loading in individuals with FLLD can disrupt normal feedback loops, leading to inefficient motor strategies and altered gait mechanics (Khamis & Carmeli, 2017b; Resende et al., 2016).

These gait-related asymmetries often result in a phenomenon known as kinematic carryover, where movement patterns established during walking influence other dynamic tasks, such as landing (Chiddarwar et al., 2025). During gait, individuals with FLLD adapt by increasing pelvic obliquity, hip abduction, and ankle adduction on the shorter limb to maintain balance and forward progression (Yong & Park, 2019; Resende et al., 2016). These adaptations, while it is effective for low-impact movements such as walking but become problematic during high-impact movements like landing, where greater motor coordination and joint alignment are required to absorb forces (Chiddarwar et al., 2025). For instance, the lateral pelvic tilt and reduced hip stability observed during walking often carry over to landing, resulting in suboptimal joint positioning, such as decreased hip and knee flexion angles (Khamis & Carmeli, 2017b). This lack of proper alignment limits the body's ability to distribute impact forces effectively, increasing the risk of excessive knee valgus, anterior tibial translation, and rotational instability (Pollard et al., 2009).

On the other hand, the ACL plays a vital role in stabilising the knee joint by preventing excessive anterior tibial translation and rotational instability, but it is highly susceptible to injury during dynamic movements (Yu & Garrett, 2007). Approximately 70% of ACL injuries occur through non-contact mechanisms, such as landing with reduced hip flexion or increased knee valgus (Hewett et al., 2006; Boden & Sheehan, 2021). Dynamic knee valgus, which combines hip adduction, internal rotation, and decreased knee flexion, is a major risk factor for ACL injuries (Boden et al., 2009; Schmitz et al., 2008). While studies have explored the relationship between FLLD and gait, the effects of FLLD on landing kinematics across different directions, and its implications for ACL injury risk, remain poorly defined. Understanding these compensatory mechanisms highlights the importance of targeting motor learning interventions in injury prevention and rehabilitation programs for individuals with FLLD.

Method

This study utilised an experimental, cross-over, within-subject repeated-measures design to investigate the effects of functional leg length discrepancy (FLLD) on lower limb joint kinematics and vertical ground reaction forces (vGRF) during different landing tasks. A single two-hour session was conducted for each participant, comprising screening tests, instructional training, and data collection using inertial measurement units (IMUs) and force plates. The landing tasks included double-leg landing (DL), single-leg landing (SL), single-leg anterior-lateral landing (SLAL), and single-leg anterior-medial landing (SLAM). These tasks were performed in randomised order to minimise order effects and fatigue. Data from IMUs and force plates were synchronised to ensure accurate measurements of joint angles and vGRF.

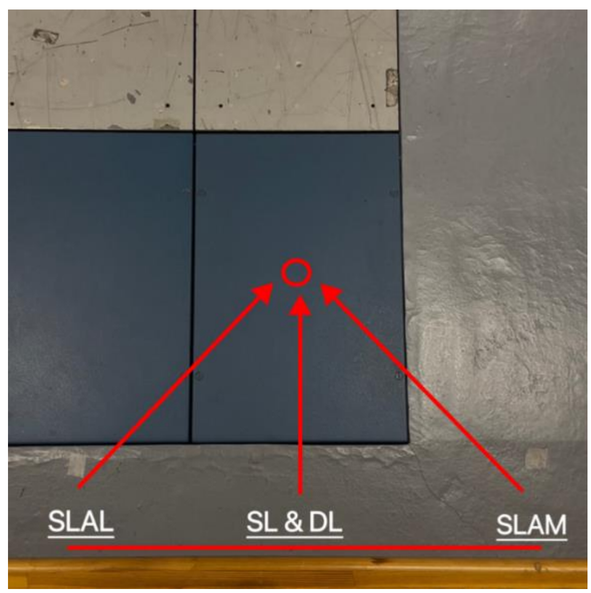

Figure 1. Landing Directions

Note.
SL = Single-Leg
SLAL = Single-Leg Anterior-Lateral
SLAM = Single-Leg Anterior-Medial
DL = Double-Leg

Participants

According to the study by Thomas and Kollock (2022), which investigated the reliability of inertial measurement units (IMUs) in capturing lower limb joint kinematics during single-leg drop landing tasks, IMUs demonstrated excellent reliability. Their study included 19 participants, which informed the determination of our minimum sample size. Accordingly, we recruited a total of 24 participants for our study to ensure robust data collection and analysis.

The participants consisted of 24 healthy adults aged 18–40 years, each with at least two years of consistent sports experience. Inclusion criteria required participants to be free from musculoskeletal injuries, non-specific lower extremity pain, or recent surgeries within the past 12 months. Individuals taking prescribed medications or those who did not meet the criteria for functional leg length discrepancy (FLLD) during screening were excluded. FLLD was identified using the validated supine long sitting test (SLS), a method for detecting sacroiliac dysfunction (Cooperstein & Lucente, 2017; Bemis & Daniel, 1987).

Participants were instructed to refrain from resistance training or high-intensity activities for 48 hours before the session to ensure consistent performance (Cheung et al., 2003). Ethical approval for the study was obtained from the Human Subjects Ethics Sub-committee of the Technological and Higher Education Institute of Hong Kong. All participants provided informed consent and completed a physical activity readiness questionnaire (PAR-Q) prior to participation.

Warm-up and Screening

The session was divided into four phases: warm-up, screening, instructional training, and landing task performance. The warm-up consisted of a 10-minute protocol following the RAMP (Raise, Activate, Mobilise, and Potentiate) principle, which included dynamic stretches and light aerobic exercises to prepare participants for testing.

The screening phase involved two tests. The first was the **Supine Long Sitting Test (SLS)**, used to confirm the presence of functional leg length discrepancy (FLLD). Participants lay supine on a plinth while the examiner compared the positions of the medial malleolus. The test was then repeated in a long sitting position to identify discrepancies in leg length (Bemis & Daniel, 1987). The second screening test was a landing test, where participants performed a forward drop landing from a 30-cm box, landing on both feet. This assessed whether participants could execute proper landing mechanics safely.

Participants were also instructed to identify their dominant take-off leg, which was reported to the examiner for use in comparisons across different landing variations. In addition to investigating differences between landing variations, comparisons between the shorter and longer leg were conducted, as this was a primary focus of the study.

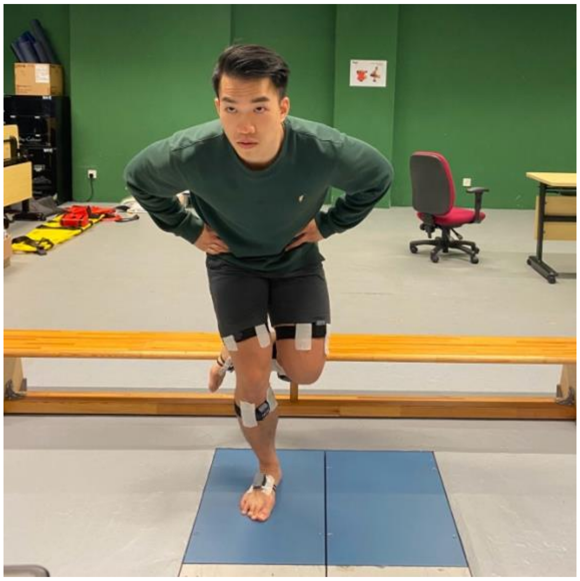

Figure 2 Single-Leg landing position

Following the screening phase, participants received detailed instructions and demonstrations for the four landing variations. The research team ensured participants understood the correct techniques and provided supervised practice trials until participants were comfortable performing the tasks. The landing tasks were conducted barefoot to ensure consistent force distribution. Participants performed one set of three repetitions for each landing variation in randomised order, with a two-minute rest between tasks to minimise fatigue. The four landing variations were: **Double-Leg Landing (DL)**, in which participants stood on a 30-cm box with knees and hips slightly flexed and hands on hips, then jumped forward to land on a force plate using both legs. Participants were required to stabilise their position for 10 seconds after landing (Taylor et al., 2016). **Single-Leg Landing (SL)** followed the same procedure as DL, but participants landed on one leg, alternating legs between repetitions (DiCesare et al., 2019). **Single-Leg Anterior-Lateral (SLAL)** required participants to jump forward and diagonally toward the lateral force plate before stabilising, while **Single-Leg Anterior-Medial (SLAM)** landing involved a diagonal forward jump toward the medial target. These directional variations were included to assess the biomechanical demands of multidirectional landings.

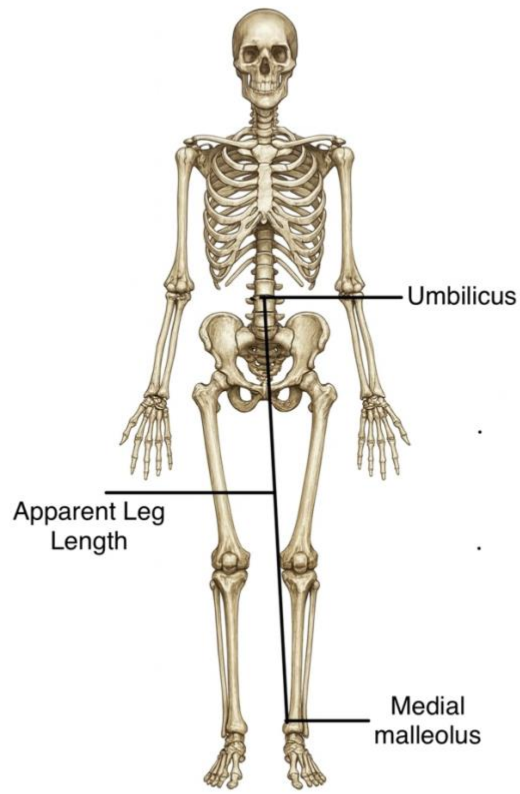

Figure 3

Tape Measurement Bony Method (TMM)

Note. Photo were generated with GPT-4 by OpenAI, Version: GPT-4.0

Prompt used: "A highly detailed and anatomically accurate illustration of a human skeleton, front view. The skeleton is perfectly symmetrical and proportional, with all bones accurately represented, including the skull, ribcage, spine, pelvis, arms, hands, legs, and feet. Special attention is given to the correct proportions of the lower limbs (femur, tibia, fibula, and feet), ensuring they match the average proportions of an adult human skeleton. The overall height and *proportions are consistent with standard anatomical references. The bones are illustrated in a realistic beige tone with subtle shading to enhance depth and detail. The background is plain white, with no additional elements, resembling a clean and professional medical textbook illustration. The focus is on precision and clarity, ensuring the skeleton's height, bone structure, and alignment are anatomically correct and proportional."*

To measure FLLD, the Tape Measurement Method (TMM) was used, which is a validated technique comparable to radiographic assessments (Neelly et al., 2013). Participants lay supine on a mat while the examiner measured the distance between the anterior superior iliac spine and the medial malleolus on both legs (Sabharwal & Kumar, 2008). For joint kinematics and vGRF, IMUs and force plates were employed. Kinematic motion data during landing was measured with an IMU system MyoMotion (Noraxon U.S.A. Inc., Scottsdale, USA). The smapling rate of IMUs was 400Hz as maximum. The IMUs were then placed on the dorsal foot, anterior tibia, above the patellofemoral tendon, and sacrum with tape for fixation and stability by following the placement guidelines described by Fain et al. (2024). These devices provided reliable data on joint angles for the ankle, knee, and hip during landing tasks despite the decreased accuracy in the frontal and transverse plane (Chia et al., 2021). Force plates were used to measure vGRF during each landing with 1000Hz sampling rate and low-pass filter with 50Hz cut off frequency to remove high frequency noise from the ground reaction force (Tomescu et al., 2018). The data synchronised and recorded on a laptop computer for subsequent analysis.

Data Collection and Statistical Analyses

Data collection focused on IMU signals and force plate readings from all three repetitions of each landing variation. Data were recorded as mean values with standard deviations (SD) for analysis. The IMUs captured joint angles at the ankle, knee, and hip during the maximum vGRF time. The force plates are used to measure peak vGRF during the landing. These data were used to identify biomechanical differences across landing variations and between the longer and shorter legs.

Statistical analyses were conducted using SPSS Version 27.0 (IBM: Armonk, NY). All data were first assessed for normality using the Shapiro-Wilk test. The reliability of the IMU and force plate measurements across trials was evaluated using the intraclass correlation coefficient (ICC), with classifications as poor (<0.5), moderate (0.5–0.75), good (0.75–0.9), or excellent (>0.9) (Koo & Li, 2016). To compare joint kinematics and vGRF across the four landing variations within the same leg, a one-way repeated measures ANOVA was performed, with the Greenhouse-Geisser correction applied to account for violations of sphericity where necessary. Pairwise differences were analysed to further explore significant findings. An independent samples t-test was used to assess differences in joint kinematics and vGRF between the longer and shorter legs. Effect sizes were reported using Cohen's d, which classifies values as small (0.2), medium (0.5), or large (0.8) (Cohen, 1989). Comparison between FLLD and landing kinematics were visualised using tables and bar graphs to ensure clarity.

Results

A total of 24 subjects participated in the experiment, there were 1 subject was excluded due to the predeterminate exclusion criteria (Failed with the long sitting test and no apparent leg length difference).

The intraclass correlation coefficient (Cronbach's Alpha) ensures the reliability and consistency of the results from all trials. The consistency of vertical ground reaction force from the force plate and joint angles from the IMU data of three times of landing variations are presented in Table 2 for each joint. The closer value to 0.9 indicates the more reliable the data is when the trails are repeated. The Cronbach's Alpha score for the ankle dorsi flexion in double-leg landing was lower (0.37) when compared to the average range of another joint movement (0.78-0.99).

Table 1

Descriptive Statistics (Mean ± SD) for Subject Demographics and Physical Characteristics

	Age	Height (cm)	Weight (kg)	Landing Distance (cm)	Longer Leg Length (cm)	Shorter Leg Length (cm)
Mean ± SD	24.85 ± 3.57	170.1 ± 8.62	51.03 ± 2.58	51.03 ± 2.58	96.71 ± 5.43	95.87 ± 5.3

Table 1 above describes the measurements collected to ensure the subjects were suitable for the experimental procedure as apparent leg length differences. Subjects (N=23) were collected with means and standard deviation of age (years), height (cm), weight (kg), landing distance (cm), and both longer and shorter leg length (cm).

Table 2

Intraclass Correlation Coefficient (Cronbach's Alpha) Across Three Trials for Kinematic Analysis of Take-off leg in Different Landing Styles

ICC Values	vGRF	Hip_Flex	Hip_Abd	Knee_Abd	Knee_Flex	Ankle_DF	Ankle_Abd
SL	0.88	0.96	0.92	0.99	0.86	0.80	0.78
SLAL	0.9	0.97	0.94	0.99	0.96	0.96	0.86
SLAM	0.94	0.98	0.96	0.98	0.94	0.92	0.93
DL	0.78	0.91	0.97	0.99	0.9	0.89	0.37

Note. ICC values for reliability: poor (<0.5), moderate (0.5-0.75), good (0.75-0.9), and excellent (>0.9) (Koo & Li, 2016).

Table 3

Kinematics results comparing the different types of single leg landing styles of take-off leg. Values are given as mean ± SD.

	SL (N=23)	SLAL (N=23)	SLAM (N=23)	*F*	*P*
vGRF (N)	2505.62±701.24	2600.57± 736.65	2491.73± 635.61	1.22	0.3
Hip_Flex (deg)	34.46± 9.75	32.35± 8.67	36.6± 9.11	8.84	<0.05*
Hip_Abd (deg)	3.56± 4.7	8.56± 4.67	1.76± 5.5	91.01	<0.05*
Knee_Abd (deg)	2.73± 5.24	3.15± 5.34	2.53± 5.23	1.35	0.26
Knee_Flex (deg)	32.86± 7.08	32.26± 7.54	32.87± 7.16	0.48	0.61
Ankle_DF (deg)	0.32± 4.94	1.03± 6.08	-0.1± 6.09	1.08	0.33
Ankle_Abd (deg)	-4.14± 2.52	-5.03± 2.22	-1.05± 2.79	45.58	<0.05*

Note. One-way repeated measure ANOVA. Greenhouse-Geisser Test. Indicate a significant difference between the landing styles (p<0.05). SL = Single Leg Landing; SLAL = Single Leg Anterior Lateral Landing; SLAM = Single Leg Anterior Medial Landing; DL = Double Leg Landing; Flex = Flexion; Abd = Abduction; DR = Dorsi Flexion; *= P<0.05

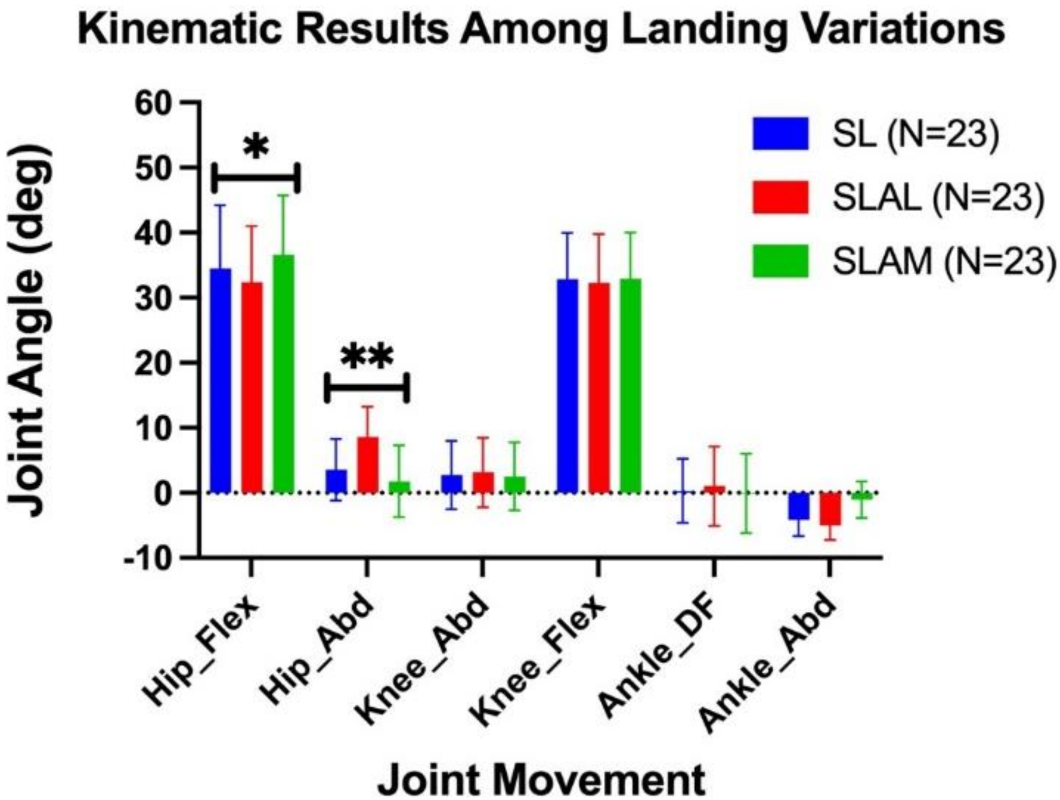

Figure 5

Bar graph representing the mean and standard deviation of joint kinematic in take-off leg across landing variation.

Note. SL = Single Leg Landing; SLAL = Single Leg Anterior Lateral Landing; SLAM = Single Leg Anterior Medial Landing; DL = Double Leg Landing; Flex = Flexion; Abd = Abduction; DR = Dorsi Flexion. *= P<0.05, **=P<0.01.

Table 4

Mean and Standard Deviations of Joint Kinematics and vertical ground reaction force for Longer and Shorter Legs Across Four Landing Variations (N=23) with mean ± SD

	SL_L	SL_S	SLAL_L	SLAL_S	SLAM_L	SLAM_S	DL_L	DL_S
vGRF	2476.79 ± 631.17	2407.09 ± 731.87	2598.84 ± 674.08	2617.83 ± 716.72	2429.9 ±611.08	2435.68 ±586.72	1349.76 ± 765.49	1454.91 ± 822.4
Hip_Flex	34.03 ±9.05	33.67 ±9.93	32.39 ±8.11	31.64 ±9.27	36.28 ±9.75	35.59 ±8.72	48.56 ±12.02	48.15 ±11.55
Hip_Abd	4.15 ±6.4	3.59 ±4.94	8.25 ±6.46	8.83 ±4.71	2.79 ±7.56	1.43 ±5.25	1.54 ±6.11	5.6 ±5.44
Knee Abd	2.92 ±6.83	2.24 ±4.21	3.31 ±6.67	2.45 ±4.34	2.44 ±6.7	1.72 ±4.06	2.82 ±8.44	1.82 ±7.35
Knee_Flex	32.56 ±7.31	32.62 ±8.19	32.2 ±7.24	31.98 ±8.08	32.32 ±7.66	32.1 ±7.78	48.99 ±12.87	49.12 ±12.94
Ankle_DF	0.57 ±4.26	0.87 ±5.1	0.47 ±4.16	1.31 ±6.04	-0.74 ±5.21	-0.14 ±5.85	5.95 ±7.09	6.1 ±7.24
Ankle_Abd	-5.02 ±2.8	-3.5 ±2.93	-5.03 ±3.09	-4.68 ±2.14	-1.88 ±2.63	-0.51 ±3.16	-6.61 ±3.04	-4.12 ±3.8

Note. Independent sample t-tests were used to compare the kinematics of the longer and shorter legs. Significant differences are indicated ($p < 0.05$).

Table 5

Statistical Analysis of Kinematics and Ground Reaction Forces Between Apparent Longer and Shorter Legs Across Landing Styles

	SL (N=23)		SLAL (N=23)		SLAM (N=23)		DL (N=23)	
	P	*Effect Size*	*P*	*Effect Size*	*P*	*Effect Size*	*P*	*Effect Size*
vGRF	0.3	0.1	0.92	-0.02	0.97	-0.01	0.65	-0.13
Hip_Flex	0.9	0.03	0.77	0.08	0.8	0.07	0.9	0.03
Hip_Abd	0.74	0.09	0.73	-0.1	0.48	0.2	0.02	-0.7
Knee_Abd	0.68	0.12	0.6	0.15	0.66	0.12	0.67	0.12
Knee_Flex	0.98	0	0.92	0.03	0.92	0.02	0.97	-0.01
Ankle_DF	0.83	-0.06	0.58	-0.16	0.71	-0.1	0.94	-0.02
Ankle_Abd	0.07	-0.53	0.65	-0.13	0.11	-0.47	0.01	-0.72

Note. $p<.05$ = statistical significance. Cohen's d effect size values indicate effect size as small=0.2, medium=0.5, or large=0.8 Cohen (1988).

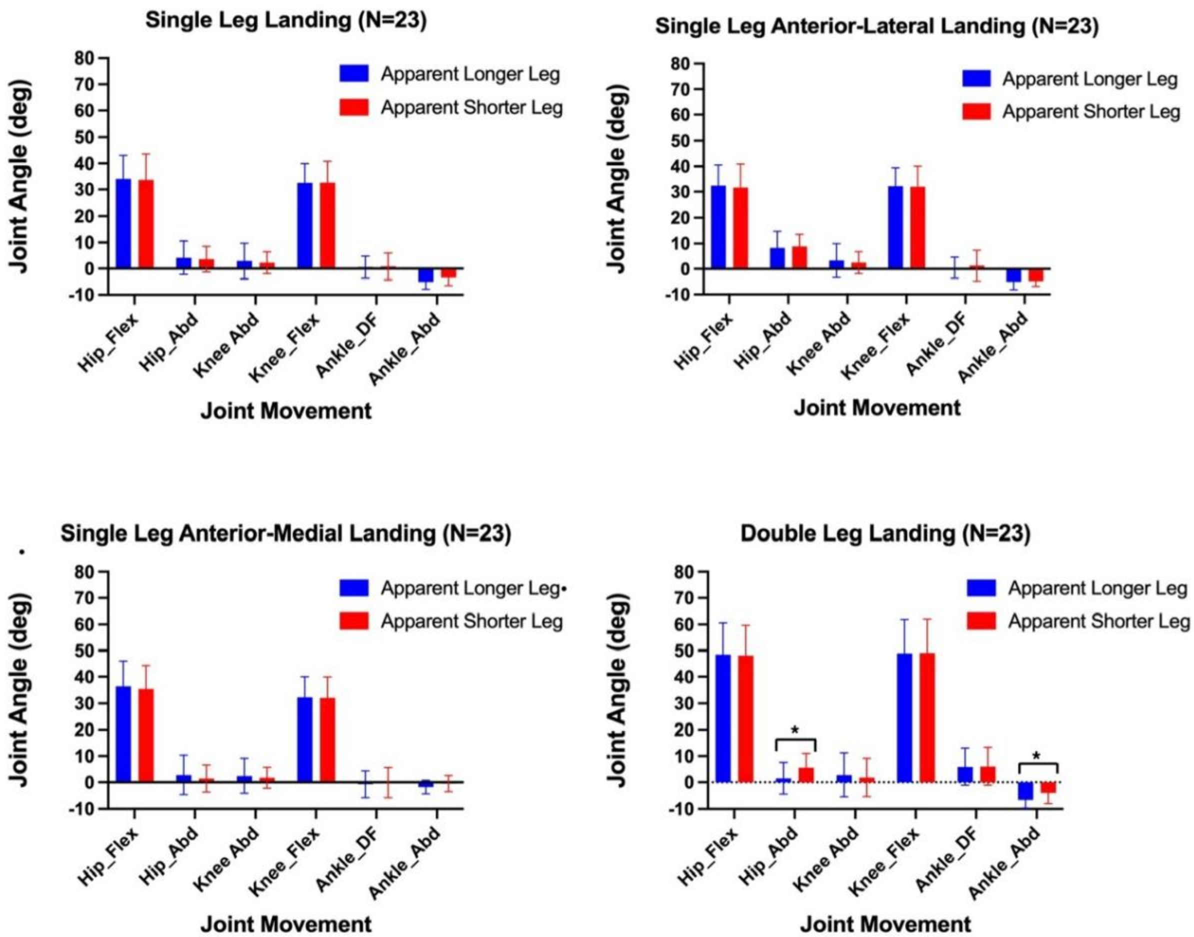

Figure 6

Bar graph representing the mean and standard deviation of joint kinematics for both apparent longer and short legs among four landing variations.

Note. The figure is generated by the author. *= P<0.05, **=P<0.01.

Table 3 above describes the results of the One-way repeated measures ANOVA with Greenhouse-Geisser correction revealing statistics significant differences in joint kinematics among three single-leg landing variations.

Hip Flexion was found to have a significant difference among all variations ($F=8.84$, $p<0.05$). SLAM showed the highest hip flexion in mean value (36.6° ± 9.11°) when compared to SLAL (32.35° ± 8.67°) and SL (34.46° ± 9.75°). In addition, hip abduction angle also shows significant differences among landing styles (**F = 91.01**, **p < 0.05**) while SLAL shows the highest mean (8.56° ± 4.67°) and SLAM shows the lowest (1.76° ± 5.5°). A significant difference was also found in ankle abduction (**F = 45.58**, **p < 0.05**). SLAM was showing the least negative mean angle (-1.05° ± 2.79°) while comparing to SL (-4.14° ± 2.52°) and SLAL (-4.14° ± 2.52°). On the other hand, there were observed no significant differences in vertical ground reaction (vGRF), knee abduction, knee flexion, and ankle dorsiflexion angles (**p > 0.05**).

Figure 5 represents the mean and standard deviation for each joint kinematics variable among all single-leg landing variations visually. The trends in Figure 5 are clearly described in the statistics results from Table 3. SLAM shows the highest hip flexion, SLAL shows the highest hip abduction, and SLAM shows the least negative ankle abduction.

Table 5 presents the statistical analysis of kinematic variables and vertical ground reaction forces (vGRF) between the apparent longer and shorter legs across four landing variations: single-leg landing (SL), single-leg anterior-lateral landing (SLAL), single-leg anterior-medial landing (SLAM), and double-leg landing (DL). The table includes p-values and effect sizes (Cohen's d), with statistical significance defined as **p < 0.05**.

Significant differences were identified in **hip abduction (Hip_Abd)** and **ankle abduction (Ankle_Abd)** during double-leg landing (DL). Hip abduction showed a statistically significant difference (**p = 0.02**) with a large effect size (**Cohen's d = -0.7**), indicating a greater degree of abduction in the shorter leg compared to the longer leg. Similarly, ankle abduction during DL exhibited a significant difference (**p = 0.01**) with a large effect size (**Cohen's d = -0.72**), reflecting reduced ankle abduction in the shorter leg.

For other variables, including vGRF, hip flexion (Hip_Flex), knee abduction (Knee_Abd), knee flexion (Knee_Flex), and ankle dorsiflexion (Ankle_DF), no statistically significant differences were observed across all landing variations (**p > 0.05**). The effect sizes for these variables were small, indicating minimal differences in kinematics between the two legs under these conditions.

Table 4 and Figure 6 provides a graphical and statistical representation of the mean and standard deviations of joint kinematics for both longer and shorter legs across the landing variations. Significant differences in hip abduction and ankle abduction during DL are visually marked with asterisks (**p < 0.05**). These data highlight measurable asymmetries in specific joint angles during double-leg landing.

Discussion

This study discovered the influence of functional leg length discrepancy (FLLD) on joint kinematics and vertical ground reaction forces (vGRF) across four landing variations—double-leg (DL), single-leg (SL), single-leg anterior-lateral (SLAL), and single-leg anterior-medial landing (SLAM). The findings revealed significant alterations in joint kinematics, particularly at the hip and ankle, in individuals with FLLD, while vGRF remained consistent across landing variations. These results highlight the critical role of biomechanical compensations due to FLLD and their potential implications for lower limb injury prevention, particularly anterior cruciate ligament (ACL) injuries.

The Kinematics of the Take-off Leg Across All Landing Variations

This study identified that single-leg anterior-medial landing (SLAM) elicited the highest hip flexion angle (36.6° ± 9.11°) compared to single-leg anterior-lateral landing (SLAL) (32.35° ± 8.67°) and single-leg landing (SL) (34.46° ± 9.75°). These findings highlight the unique biomechanical demands placed on the take-off leg during SLAM, may require greater energy absorption and stabilisation due to its dual-plane movement pattern (Haddas et al., 2016). The increased hip flexion observed during SLAM reflects the potential increased demand in control and stabilisation (Kunugi et al., 2020).

The kinematics of the take-off leg during SLAM suggest that higher hip flexion allows the gluteal and hamstring muscles to be more actively engaged, aiding in deceleration and trunk stabilisation under peak ground reaction forces (Blackburn & Padua, 2007). Moreover, hip flexion plays a crucial role in redistributing ground reaction forces across the lower extremity joints, reducing the mechanical load on the ankle and knee (Niu et al., 2011). Additionally, increased hip flexion during dynamic tasks has been associated with reduced anterior tibial translation, which may decrease stress on the anterior cruciate ligament (ACL) (Yoo & Marappa-Ganeshan, 2023). These results suggest that the take-off leg's higher hip flexion during SLAM functions as a protective mechanism to mitigate knee valgus and anterior tibial translation—two key risk factors for ACL injuries (Pollard et al., 2009).

Furthermore, the study findings align with previous research emphasizing the importance of hip flexion in landing mechanics. Lower hip flexion angles, as noted by Pollard et al. (2009), have been linked to decreased energy absorption and increased knee valgus, leading to compromised joint stability. The dual-plane demands of SLAM, involving both sagittal and frontal movements, necessitate precise biomechanical adaptations such as increased hip flexion to maintain stability and distribute forces effectively (Pierrynowski, 2011). This adaptation is especially significant for the take-off leg, which bears the primary responsibility for stabilising the body during challenging multidirectional landings.

In contrast to these findings, Orishimo et al. (2009) found no significant differences in hip flexion during single-leg landings. However, their study lacked consideration of directional landing variations and included participants with inconsistent athletic backgrounds, potentially explaining the divergence in results. Without accounting for the unique demands of movements like SLAM, their analysis may have overlooked critical kinematic differences in the take-off leg.

The Knee Valgus of Longer Leg in Double-Leg Landing

This study identified significant kinematic differences between the longer and shorter legs during double-leg (DL) landing, particularly in hip abduction. The longer leg exhibited lower hip abduction (1.54° ±

6.11° vs. 5.6° ± 5.44°) compared to the shorter leg. These findings suggest that the longer leg is at a greater risk of medial knee collapse, which increases knee valgus and predisposes the joint to instability and potential injury. Miyamoto et al. (2023) highlighted that reduced hip abduction directly compromises lateral stability, thereby increasing medial knee displacement during dynamic tasks like landing.

In the study of Quatman and Hewett (2009) stated that knee valgus is a known risk factor for anterior cruciate ligament (ACL) injuries, and the observed mechanics of the longer leg in this study align with this risk. The lower hip abduction in the longer leg may reduce the ability of the hip abductors, particularly the gluteus medius, to counteract medial knee movement, leading to greater knee valgus during landing. These findings emphasise the critical role of hip abduction in maintaining lateral stability and controlling knee alignment during high-impact activities (Ludwig et al., 2024).

In contrast, the shorter leg demonstrated greater hip abduction, which likely reflects a compensatory adjustment to address pelvic asymmetry caused by functional leg length discrepancy (FLLD) (Inacio et al., 2018). While this adaptation supports balance and stability for the shorter leg, the reduced hip abduction in the longer leg appears to shift the burden of stabilisation to the knee joint, increasing its vulnerability to valgus stress.

These results underscore the importance of addressing FLLD in injury prevention programs. As compensatory mechanisms in one leg can exacerbate biomechanical imbalances in the contralateral limb, targeted interventions focusing on improving hip abductor strength and correcting dynamic knee valgus in the longer leg are essential for reducing ACL injury risk (Khamis & Carmeli, 2017; Miyamoto et al., 2023).

Consistent Knee Motion Across All Landing Variations

The results showed no significant differences in knee flexion angles between the longer and shorter legs across all landing variations. For example, knee flexion during SLAM was nearly identical between the longer and shorter legs (32.32° ± 7.66° vs. 32.1° ± 7.78°, $p > 0.05$). These findings suggest that knee kinematics are less influenced by FLLD compared to hip and ankle joints. The consistent knee flexion may reflect the body's ability to prioritise knee stability during landing, despite asymmetries caused by FLLD (Wei et al., 2023).

Knee flexion is crucial for shock absorption and reducing vGRF during landing, thereby minimising the risk of ACL injuries (Hewett et al., 2006). The balanced knee kinematics observed in this study may indicate effective neuromuscular control strategies to compensate for FLLD. Hübscher et al. (2010) highlighted that neuromuscular training can enhance knee stability and reduce the risk of lower limb injuries. However, the lack of significant differences in knee flexion may also reflect the relatively mild FLLD in this study's population. Daneshmandi et al. (2011) reported that athletes with severe musculoskeletal malalignments exhibited significant alterations in knee kinematics, suggesting that the degree of discrepancy may play a role in determining its impact.

Vertical Ground Reaction Force (vGRF) in FLLD

Another notable finding was the absence of significant differences in vGRF between the longer and shorter legs across all landing variations. For instance, during SLAL, the shorter leg showed slightly higher vGRF (2617.83 ± 716.72 N) compared to the longer leg (2598.84 ±

674.08 N), but the difference was not statistically significant. These results suggest that FLLD primarily affects joint kinematics rather than force distribution during landing.

The lack of significant differences in vGRF aligns with previous studies that have documented the body's ability to adapt to leg length discrepancies through compensatory mechanisms. Safa et al. (2024) reported that the body adjusts joint kinematics to maintain symmetrical force distribution during dynamic activities. Similarly, Khamis and Carmeli (2017) noted that increased hip flexion and abduction in the shorter leg may serve as compensatory movements to absorb impact forces and prevent excessive loading of the support leg.

However, these findings may not be generalisable to individuals with severe leg length discrepancies (>2 cm). Gardas and Shah (2020) observed significant reductions in balance control and vGRF asymmetry in individuals with larger discrepancies, suggesting that compensatory mechanisms may become overwhelmed in such cases. Future research should explore the effects of varying degrees of FLLD on force distribution during landing to determine thresholds for effective compensation.

Comparing the Biomechanics of FLLD in Walking, Running and Landing

The compensatory mechanisms observed in this study are consistent with those reported in studies on running and walking biomechanics in individuals with FLLD. Running, a high-impact activity, often involves increased hip abduction and lateral pelvic tilt in the shorter leg to maintain stability during the stance phase (Khamis & Carmeli, 2017). These findings align with the current study, where increased hip abduction was observed in the shorter leg during DL. However, unlike running, landing requires sudden deceleration and stabilisation, which places greater demands on the hip and ankle joints (Hamner et al., 2010).

Walking, a lower-intensity activity, also reveals similar compensatory patterns. Yong and Park (2019) found that individuals with FLLD exhibit increased hip abduction and pelvic obliquity during walking, which parallels the findings of this study. However, the increased hip flexion observed during SLAM suggests that landing involves greater sagittal plane adjustments compared to running or walking (Kunugi et al., 2020). These findings underscore the need to consider activity-specific demands when designing injury prevention programs for individuals with FLLD.

Kinematic-Carryover from Low-Impact Tasks to High-Impact Tasks

This study revealed significant differences in hip abduction and ankle adduction between the shorter and longer leg during double-leg landing (DL), providing new insights into kinematic carryover. The shorter leg showed greater hip abduction (5.6° ± 5.44° vs. 1.54° ± 6.11°) and higher ankle adduction (-4.12° ± 3.8° vs. -6.61° ± 3.04°) compared to the longer leg. These asymmetries may relate to the movement patterns developed during low-impact tasks (LIT), such as walking, these patterns may persist and influence high-impact tasks (HIT) like landing, consistent with the concept of kinematic carryover (Chiddarwar et al., 2025).

Kinematic carryover explains how habitual motor patterns and joint kinematics established during LIT transfer to more dynamic tasks (Arhos et al., 2021). For individuals with functional leg length discrepancy (FLLD), asymmetrical movement strategies, such as increased pelvic obliquity and hip abduction in the shorter leg, are developed during LIT to maintain balance and stability (Yong & Park, 2019). In this study, the shorter leg's increased hip abduction during landing likely reflects lateral pelvic tilt and activation of the gluteus medius to counteract asymmetry, aligning with findings by Ludwig et al. (2024). Similarly, higher ankle adduction in the shorter leg may indicate a strategy to redistribute load and optimise postural alignment (Resende et al., 2016). Conversely, the longer leg exhibited lower hip abduction and higher knee abduction, potentially increasing knee valgus and ACL injury risk (Suzuki et al., 2015). This pattern suggests a potential maladaptive loading in the longer leg as a compensation for asymmetries originating from gait, consistent with Miyamoto et al. (2023).

Addressing these asymmetries is critical in injury prevention. By identifying and correcting kinematic imbalances during LIT, clinicians may reduce their impact on HIT, improve joint mechanics, and lower the risk of ACL injuries. In a systematic review by Stergiou et al. (2025), suggested incorporating neuromuscular training and motor learning interventions into rehabilitation programs may help optimise movement patterns across varying task intensities.

Limitations

While this study provides valuable insights into the biomechanical effects of FLLD, several limitations should be addressed in future research. First, the use of IMUs, while practical and cost-effective, may have limitations in measuring frontal plane movements compared to motion capture systems (Roggio et al., 2021). Future studies should incorporate gold-standard motion capture systems to validate these findings (Ceseracciu et al., 2014). Second, this study focused on healthy, active adults with mild FLLD, limiting the generalisability of the results to populations with more severe discrepancies or musculoskeletal conditions. Expanding the study to include diverse populations would provide a more comprehensive understanding of FLLD's impact.

Additionally, this study did not evaluate muscle activation during landing tasks. Electromyography (EMG) could provide valuable insights into the role of specific muscle groups in compensating for FLLD (Zellers et al., 2019). Finally, the long-term implications of FLLD-related compensations remain unclear. Longitudinal studies are needed to determine whether these compensations lead to overuse injuries or altered biomechanics over time.

Conclusion

This study emphasises the influence of functional leg length discrepancy (FLLD) and landing styles on joint kinematics, highlighting kinematic carryover can be an influence factor. The findings demonstrated that FLLD primarily affects hip and ankle kinematics, with the shorter leg showing greater hip abduction (5.6° ± 5.44° vs. 1.54° ± 6.11°) and higher ankle adduction (-4.12° ± 3.8° vs. -6.61° ± 3.04°) during double-leg landing. Conversely, the longer leg exhibited reduced hip abduction and increased knee abduction, which may indirectly contribute to knee valgus and instability. Notably, knee movements and vertical ground reaction forces were consistent across landing variations, reflecting the body's prioritisation of knee stability. The increased hip flexion of take-off leg observed during single-leg anterior-medial landing (SLAM) highlights the heightened biomechanical demands of multidirectional tasks. Overall, this study provides valuable insights into FLLD's impact on landing mechanics and offers clinical guidance for ACL injury prevention strategies.

Clinical Implications

The findings of this study provide valuable insights into the clinical management of functional leg length discrepancy (FLLD) and its role in injury prevention, particularly anterior cruciate ligament (ACL) injuries. The shorter leg's greater hip abduction and ankle adduction during landing suggest compensatory strategies to maintain stability, while the longer leg's decreased hip abduction and increased knee abduction highlight a higher risk of knee valgus and instability. These asymmetries, underpinned by the concept of kinematic carryover, suggest that patterns developed during low-impact tasks can persist and negatively influence high-impact activities like landing.

Clinicians should implement targeted neuromuscular training and motor learning interventions to address movement imbalances caused by Functional Leg Length Discrepancy (FLLD). Given the potential influence of kinematic carryover, these interventions should include not only high-impact tasks but also low-impact activities to address compensatory patterns that persist across different movement intensities. Exercises should prioritise strengthening the hip abductors, enhancing overall stability, and correcting dynamic knee valgus to effectively reduce the risk of ACL injuries. Furthermore, training programs should emphasise eccentric loading of the hip extensors to minimise lower limb impact during landing tasks, particularly in multidirectional movements such as single-leg anterior-medial landing (SLAM). Individualised rehabilitation strategies are essential, focusing on correcting asymmetrical movement patterns to optimise joint mechanics, enhance functional stability, and improve overall performance.

Reference List

1. Azizan, N. A., Basaruddin, K. S., & Salleh, A. F. (2018). The Effects of leg length discrepancy on stability and Kinematics-Kinetics deviations: A Systematic review. *Applied Bionics and Biomechanics*, *2018*, 1–22. https://doi.org/10.1155/2018/5156348

2. Arhos, E. K., Lang, C. E., Steger-May, K., Van Dillen, L. R., Yemm, B., & Salsich, G. B. (2021). Task-specific movement training improves kinematics and pain during the Y-balance test and hip muscle strength in females with patellofemoral pain. *Journal of ISAKOS Joint Disorders & Orthopaedic Sports Medicine*, *6*(5), 277–282. https://doi.org/10.1136/jisakos-2020-000551

3. Boden, B. P., Torg, J. S., Knowles, S. B., & Hewett, T. E. (2009). Video analysis of anterior cruciate ligament injury. *The American Journal of Sports Medicine*, *37*(2), 252–259. https://doi.org/10.1177/0363546508328107

4. Boden, B. P., & Sheehan, F. T. (2021). Mechanism of non-contact ACL injury: OREF Clinical Research Award 2021. *Journal of Orthopaedic Research®*, *40*(3), 531–540. https://doi.org/10.1002/jor.25257

5. Bemis, T., & Daniel, M. (1987). Validation of the long sitting test on subjects with iliosacral dysfunction. *Journal of Orthopaedic and Sports Physical Therapy*, *8*(7), 336–345. https://doi.org/10.2519/jospt.1987.8.7.336

6. Cooperstein, R., & Lucente, M. (2017). Comparison of supine and prone methods of leg length inequality assessment. *Journal of Chiropractic Medicine*, *16*(2), 103–110. https://doi.org/10.1016/j.jcm.2017.01.001

7. Ceseracciu, E., Sawacha, Z., & Cobelli, C. (2014). Comparison of Markerless and Marker-Based Motion Capture Technologies through Simultaneous Data Collection during Gait: Proof of Concept. *PLoS ONE*, *9*(3), e87640. https://doi.org/10.1371/journal.pone.0087640

8. Cheung, K., Hume, P. A., & Maxwell, L. (2003). Delayed onset muscle soreness. *Sports Medicine*, *33*(2), 145–164. https://doi.org/10.2165/00007256-200333020-00005

9. Chia, L., Andersen, J. T., McKay, M. J., Sullivan, J., Megalaa, T., & Pappas, E. (2021). Evaluating the validity and reliability of inertial measurement units for determining knee and trunk kinematics during athletic landing and cutting movements. *Journal of Electromyography and Kinesiology*, *60*, 102589. https://doi.org/10.1016/j.jelekin.2021.102589

10. Chiddarwar, V. V., Wilford, K. F., Hooper, T. L., James, C. R., Natesan, K., Likness, A., Seeber, G. H., & Sizer, P. S. (2025). Old habits die hard: kinematic carryover between Low- and High-Impact tasks in active females. *Sports*, *13*(6), 160. https://doi.org/10.3390/sports13060160

11. DiCesare, C. A., Bonnette, S., Myer, G. D., & Kiefer, A. W. (2019). Differentiating successful and unsuccessful Single-Leg Drop landing performance using uncontrolled manifold analysis. Motor Control, 24(1), 75–90. https://doi.org/10.1123/mc.2017-0076

12. Daneshmandi, H., Azhdari, F., Saki, F., & Daneshmandi, M. S. (2011). THE STUDY OF LOWER EXTREMITY ALIGNMENT IN ATHLETES WITH AND WITHOUT ACL RECONSTRUCTION. Brazilian Journal of Biomotricity, 5(4), 248–254. https://www.redalyc.org/pdf/930/93021532004.pdf

13. Fain, A., McCarthy, A., Nindl, B. C., Fuller, J. T., Wills, J. A., & Doyle, T. L. A. (2024). IMUs Can Estimate Hip and Knee Range of Motion during Walking Tasks but Are Not Sensitive to Changes in Load or Grade. Sensors, 24(5), 1675. https://doi.org/10.3390/s24051675

14. Gardas, S., & Shah, H. (2020). Influence of leg length discrepancy on balance and gait in post-stroke patients: a correlational study. Bulletin of Faculty of Physical Therapy, 25(1). https://doi.org/10.1186/s43161-020-00012-w

15. Hamner, S. R., Seth, A., & Delp, S. L. (2010). Muscle contributions to propulsion and support during running. *Journal of Biomechanics*, *43*(14), 2709–2716. https://doi.org/10.1016/j.jbiomech.2010.06.025

16. Haddas, R., Hooper, T., James, C. R., & Sizer, P. S. (2016). Volitional spine stabilization during a drop vertical jump from different landing heights: Implications for anterior cruciate ligament injury. *Journal of Athletic Training*, *51*(12), 1003–1012. https://doi.org/10.4085/1062-6050-51.12.18

17. Hewett, T. E., Myer, G. D., & Ford, K. R. (2006). Anterior cruciate ligament injuries in female athletes: Part 1, mechanisms and risk factors. The American journal of sports medicine, 34(2), 299–311. https://doi.org/10.1177/0363546505284183

18. Hübscher, M., Zech, A., Pfeifer, K., Hänsel, F., Vogt, L., & Banzer, W. (2010). Neuromuscular training for sports injury prevention. *Medicine & Science in Sports & Exercise*, *42*(3), 413–421. https://doi.org/10.1249/mss.0b013e3181b88d37

19. Inacio, M., Creath, R., & Rogers, M. W. (2018). Effects of aging on hip abductor-adductor neuromuscular and mechanical performance during the weight transfer phase of lateral protective stepping. *Journal of Biomechanics*, *82*, 244–250. https://doi.org/10.1016/j.jbiomech.2018.10.040

20. Kunugi, S., Koumura, T., Myotsuzono, R., Masunari, A., Yoshida, N., Miyakawa, S., & Mukai, N. (2020). Directions of single-leg landing affect multi-segment foot kinematics and dynamic postural stability in male collegiate soccer athletes. *Gait & Posture*, *80*, 285–291. https://doi.org/10.1016/j.gaitpost.2020.06.007

21. Khamis, S., Danino, B., Ovadia, D., & Carmeli, E. (2018). Correlation between Gait Asymmetry and Leg Length Discrepancy—What Is the Role of Clinical Abnormalities? *Applied Sciences*, *8*(10), 1979. https://doi.org/10.3390/app8101979

22. Khamis, S., & Carmeli, E. (2017a). A new concept for measuring leg length discrepancy. Journal of Orthopaedics, 14(2), 276–280. https://doi.org/10.1016/j.jor.2017.03.008

23. Khamis, S., & Carmeli, E. (2017b). The effect of simulated leg length discrepancy on lower limb biomechanics during gait. Gait & Posture, 61, 73–80. https://doi.org/10.1016/j.gaitpost.2017.12.024

24. Knutson, G. A. (2005). Anatomic and functional leg-length inequality: A review and recommendation for clinical decision-making. Part I, anatomic leg-length inequality: prevalence, magnitude, effects and clinical significance. Chiropractic & Osteopathy, 13(1). https://doi.org/10.1186/1746-1340-13-11

25. Koo, T. K., & Li, M. Y. (2016). A Guideline of selecting and Reporting Intraclass correlation coefficients for Reliability research. Journal of Chiropractic Medicine, 15(2), 155–163. https://doi.org/10.1016/j.jcm.2016.02.012

26. Ludwig, O., Dindorf, C., Kelm, S., Kelm, J., & Fröhlich, M. (2024). Muscular Strategies for Correcting the Pelvic Position to Improve Posture—An Exploratory Study. *Journal of Functional Morphology and Kinesiology*, *9*(1), 25. https://doi.org/10.3390/jfmk9010025

27. Mulla, D. M., & Keir, P. J. (2023). Neuromuscular control: from a biomechanist's perspective. *Frontiers in Sports and Active Living*, *5*. https://doi.org/10.3389/fspor.2023.1217009

28. Mattatia, J., Valentin, H., Fredj, P., Nguyen-Kim, P., Sanchez, G., Demir, R., & Roque, P. (2024). Leg length discrepancies (LLD): An etiology to be considered in its proper measure. A critical and historical review. Journal of Bodywork and Movement Therapies, 38, 391–398. https://doi.org/10.1016/j.jbmt.2024.01.036

29. Miyamoto, D., Saito, A., Kimoto, M., Terui, Y., & Okada, K. (2023). Relationship between the knee valgus moment and the hip abductor and adductor activity during single-leg landing. *Physical Therapy in Sport*, *61*, 129–134. https://doi.org/10.1016/j.ptsp.2023.03.009

30. Muller, K., & Cohen, J. (1989). Statistical Power Analysis for the Behavioral Sciences. *Technometrics*, *31*(4), 499. https://doi.org/10.2307/1270020

31. Neelly, K., Wallmann, H. W., & Backus, C. J. (2013). Validity of measuring leg length with a tape measure compared to a computed tomography scan. Physiotherapy Theory and Practice, 29(6), 487–492. https://doi.org/10.3109/09593985.2012.755589

32. Niu, W., Wang, Y., He, Y., Fan, Y., & Zhao, Q. (2011). Kinematics, kinetics, and electromyogram of ankle during drop landing: A comparison between take-off and non-take-off limb. Human Movement Science, 30(3), 614–623. https://doi.org/10.1016/j.humov.2010.10.010

33. Na, C., Siebers, H. L., Reim, J., Eschweiler, J., Hildebrand, F., Clusmann, H., & Betsch, M. (2024). Kinematic movement and balance parameter analysis in neurological gait disorders. *Journal of Biological Engineering*, *18*(1). https://doi.org/10.1186/s13036-023-00398-w

34. Orishimo, K. F., Kremenic, I. J., Pappas, E., Hagins, M., & Liederbach, M. (2009). Comparison of landing biomechanics between male and female professional dancers. *The American Journal of Sports Medicine*, *37*(11), 2187–2193. https://doi.org/10.1177/0363546509339365

35. Pierrynowski. (2011). Kinesiology of the Hip: a focus on muscular actions. *Yearbook of Sports Medicine*, *2011*, 71–72. https://doi.org/10.1016/j.yspm.2010.12.002

36. Pollard, C. D., Sigward, S. M., & Powers, C. M. (2009). Limited hip and knee flexion during landing is associated with increased frontal plane knee motion and moments. *Clinical Biomechanics*, *25*(2), 142–146. https://doi.org/10.1016/j.clinbiomech.2009.10.005

37. Quatman, C. E., & Hewett, T. E. (2009). The anterior cruciate ligament injury controversy: is "valgus collapse" a sex-specific mechanism? *British Journal of Sports Medicine*, *43*(5), 328–335. https://doi.org/10.1136/bjsm.2009.059139

38. Resende, R. A., Kirkwood, R. N., Deluzio, K. J., Morton, A. M., & Fonseca, S. T. (2016). Mild leg length discrepancy affects lower limbs, pelvis and trunk biomechanics of individuals with knee osteoarthritis during gait. *Clinical Biomechanics*, *38*, 1–7. https://doi.org/10.1016/j.clinbiomech.2016.08.001

39. Roggio, F., Ravalli, S., Maugeri, G., Bianco, A., Palma, A., Di Rosa, M., & Musumeci, G. (2021). Technological advancements in the analysis of human motion and posture management through digital devices. *World Journal of Orthopedics*, *12*(7), 467–484. https://doi.org/10.5312/wjo.v12.i7.467

40. Stergiou, M., Calvo, A. L., & Forelli, F. (2025). Effectiveness of Neuromuscular Training in Preventing lower limb soccer Injuries: A Systematic Review and Meta-Analysis. *Journal of Clinical Medicine*, *14*(5), 1714. https://doi.org/10.3390/jcm14051714

41. Suzuki, H., Omori, G., Uematsu, D., Nishino, K., & Endo, N. (2015, October 1). The influence of hip strength on knee kinematics during a single-legged medial drop landing among competitive collegiate basketball players. *International journal of sports physical therapy, 10(5), 592–601.*

42. Safa, A. T., Biswas, T., Ramakrishnan, A., & Bhandawat, V. (2024). Leg compliance is required to explain the ground reaction force patterns and speed ranges in different gaits. *bioRxiv (Cold Spring Harbor Laboratory)*. https://doi.org/10.1101/2024.09.23.612940

43. Schmitz-Hübsch, T., Giunti, P., Stephenson, D. A., Globas, C., Baliko, L., Saccà, F., Mariotti, C., Rakowicz, M., Szymanski, S., Infante, J., van de Warrenburg, B. P., Timmann, D., Fancellu, R., Rola, R., Depondt, C., Schöls, L., Zdzienicka, E., Kang, J. S., Döhlinger, S., Kremer, B., … Klockgether, T. (2008). SCA Functional Index: a useful compound performance measure for spinocerebellar ataxia. Neurology, 71(7), 486–492. https://doi.org/10.1212/01.wnl.0000324863.76290.19

44. Sabharwal, S., & Kumar, A. (2008). Methods for assessing leg length discrepancy. *Clinical Orthopaedics and Related Research*, *466*(12), 2910–2922. https://doi.org/10.1007/s11999-008-0524-9

45. Taylor, J. B., Ford, K. R., Nguyen, A., & Shultz, S. J. (2016). Biomechanical comparison of single- and Double-Leg jump landings in the sagittal and frontal plane. *Orthopaedic Journal of Sports Medicine*, *4*(6). https://doi.org/10.1177/2325967116655158

46. Thomas, J. M., & Kollock, R. O. (2022). The Reliability of Three-Dimensional Inertial Measurement Units in Capturing Lower-Body Joint Kinematics during Single-Leg Landing Tasks. *International Journal of Exercise Science*, *15*(1), 1306–1316. https://doi.org/10.70252/tsew4342

47. Tomescu, S. S., Bakker, R., Beach, T. A., & Chandrashekar, N. (2018). The effects of filter cutoff frequency on musculoskeletal simulations of High-Impact movements. *Journal of Applied Biomechanics*, *34*(4), 336–341. https://doi.org/10.1123/jab.2017-0145

48. Walsh, M., Connolly, P., Jenkinson, A., & O'Brien, T. (2000). Leg length discrepancy — an experimental study of compensatory changes in three dimensions using gait analysis. Gait & Posture, 12(2), 156–161. https://doi.org/10.1016/s0966-6362(00)00067-9

49. Wei, M., Fan, Y., Ren, H., Li, K., & Niu, X. (2023). Correlation between core stability and the landing kinetics of elite aerial skiing athletes. *Scientific Reports*, *13*(1). https://doi.org/10.1038/s41598-023-38435-9

50. Young, R. S., Andrew, P. D., & Cummings, G. S. (2000). Effect of simulating leg length inequality on pelvic torsion and trunk mobility. Gait & Posture, 11(3), 217–223. https://doi.org/10.1016/s0966-6362(00)00048-5

51. Yoo, H., & Marappa-Ganeshan, R. (2023, July 24). *Anatomy, bony pelvis and lower limb, knee anterior cruciate ligament*. StatPearls - NCBI Bookshelf. https://www.ncbi.nlm.nih.gov/books/NBK559233/

52. Yong, M., & Park, S. (2019). Leg Length Discrepancy to Influence on Kinematic Changes of the Pelvis and the Hip during Gait. *The Journal of Korean Physical Therapy*, *31*(6), 368–371. https://doi.org/10.18857/jkpt.2019.31.6.368

53. Yu, B., & Garrett, W. E. (2007). Mechanisms of non-contact ACL injuries. British Journal of Sports Medicine, 41(Supplement 1), i47–i51. https://doi.org/10.1136/bjsm.2007.037192

54. Zellers, J. A., Parker, S., Marmon, A., & Silbernagel, K. G. (2019). Muscle activation during maximum voluntary contraction and m-wave related in healthy but not in injured conditions: Implications when normalizing electromyography. *Clinical Biomechanics*, *69*, 104–108. https://doi.org/10.1016/j.clinbiomech.2019.07.007

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Research Article

A Comparative Analysis of Injury Risk Following NFL Games in Europe Versus Domestic Away Games

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Abstract

Background
As the National Football League (NFL) continues to expand its regular-season schedule internationally, concerns have been raised regarding the potential impact of long-distance travel and time zone disruption on player health. While prior research has examined overall injury trends related to scheduling and travel, limited evidence exists regarding short-term injury risk following international competition.

Purpose
The purpose of this study was to determine whether participation in an NFL regular-season game in Europe is associated with an increased risk of being listed on the injury report during the two-week period immediately following the international game, compared with other weeks for the same teams and with matched domestic control teams.

Methods
This retrospective cohort study analyzed weekly NFL injury report data from the 2019, 2021, and 2022 regular seasons. Teams that played a regular-season game in Europe (n = 10 games) were matched with divisional control teams that did not participate in international play. Weekly injury counts were recorded for each team across the season, with injuries counted once upon first appearance on the report or injured reserve list. Injury outcomes were compared using descriptive statistics, independent-samples *t* tests, and one-way ANOVA, with specific analyses focused on the two-week period following international games.

Results
No statistically significant increase in weekly injury counts was observed during the two-week period following international games compared with other weeks for the same teams (p = .374). Across individual seasons, international teams did not demonstrate consistently higher injury counts than matched control teams, and a combined-season ANOVA revealed no significant difference in injury counts between groups ($F(1, 662) = 1.33$, $p = .249$).

Conclusion
Participation in NFL regular-season games in Europe was not associated with an increased short-term risk of injury listing during the two weeks following international travel. These findings suggest that, within the seasons studied, international competition does not appear to elevate immediate injury risk beyond typical seasonal variation.

Keywords: *National Football League, international travel, injury surveillance, scheduling, athlete health*

1. Introduction

Starting in 2007, the National Football League (NFL) began regular season games in Europe. Since then, over 43 games have been played in England (39) and Germany (4) through 2024, with 6 additional games scheduled for 2025. Teams are no longer required to have a bye week following these games, though it has traditionally been common. During the 2023 season, while most teams playing in the UK did not have a bye week following their game, the four teams competing in Germany all took their bye the subsequent week. Despite the growing viewership and fan interest aimed at expanding the game globally, the impact of increased travel strain on player safety in relation to these games has not been adequately studied. Although international travel has been examined as a season-level risk factor in professional football, the immediate post-international period when physiological recovery and circadian disruption may be most pronounced has not been independently evaluated. (Angileri et al., 2023; Lawrence et al., 2016; Rossiter et al., 2024)

Globalization of the NFL presents unique logistical challenges related to international travel, which may impact player performance and increase injury risk compared to regular domestic away games. Traveling long distances across multiple time zones can lead to both physiological and psychological stress for athletes, potentially leading to a greater likelihood of injury in the period following a game in Europe. Key factors affecting NFL athletes during European trips include disruptions to their circadian rhythm (jet lag), prolonged inactivity during flights, dehydration, disturbances to their routine due to time zone shifts (sleep, nutrition, and training schedules), psychological stress from travel and time away from home, and unfamiliar playing conditions.(Lee, 2012) (Doherty et al., 2023; Thun et al., 2015; Youngstedt & O'connor, 2012)The significance of these factors varies among individual athletes, and teams employ various strategies to mitigate travel-related stress. However, the constraints of the NFL regular season schedule provide limited time for players to acclimate to local conditions before a game in Europe and require a rapid readjustment upon returning to the United States for subsequent games.(Leatherwood & Dragoo, 2013; Rossiter et al., 2022) This study's findings are timely as the NFL prepares for an expanded 2025 international schedule, including new markets like Spain and Ireland.

2. Literature Review

The National Football League (NFL) operates an eighteen-week regular season schedule, allowing one bye week per team during the season. To globalize its brand, each NFL team is guaranteed to play an international game at least once every eight years (Creating the NFL Schedule, n.d.). Due to the scheduling constraints, the process of creating the NFL schedule is difficult and requires a lot of planning to ensure players' safety and a competitive balance. The NFL schedule makers pay special attention to the international game and make efforts to alleviate the travel burdens on the participating team in a three-week period surrounding the game. Historically, teams have typically taken a bye week following their international game, but they are not required to do so. For instance, in the 2022 season, more teams are opting to play the week following their international game vs taking a bye week (Anderson, 2022). In the 2023 season, five international games took place with three hosted in the United Kingdom and two in Germany. Among the six teams playing in the UK, only one had a bye week following their game, while the four teams playing in Germany all had a bye week following the game. This evolving approach to scheduling reflects the NFL's ongoing efforts to balance the rigors of international travel with the demands of an eighteen-week season.

2.1 Key Studies for Research Question

Two pivotal studies were identified for review in relation to the research question "Is there an increased risk of being listed on the injury report in the two-week period following an NFL Europe game compared to other weeks for the same teams, or compared to matched control teams?" Although these two studies do not directly address the specific research question of this review, their methodologies and findings provide insight and are valuable for investigating this topic. These studies collectively inform the discussion on how travel and game scheduling potentially affect player health and safety in professional sports and point to gaps that can be explored in the context of the NFL Europe games.

The first significant study, was conducted by Angileri et al., (2023), titled "Association of Injury Rates Among Players in the National Football League with Playoff Qualification, Travel Distance, Game Timing, and the Addition of Another Game: Data from the 2017 to 2022 Seasons." This research examined the correlation between overall travel distance within the season, overseas play, and timing of bye weeks with higher injury rates in the NFL. Analyzing data from five recent seasons going from 2017 until 2022, the study found no significant association between travel distance or overseas play and injury rates. These findings suggest that playing overseas does not elevate risk of showing up on the injury report over the course of the season. Further research needs to be completed to determine if the period immediately following travel to Europe generates an increased rate of injury reporting in the two-week period following the game compared to periods following domestic away game.

The second critical study by Fuller et al., (2015), titled "Does Long-Distance Air Travel Associated with the Sevens World Series Increase Players' Risk of Injury?" investigated whether injury risk for rugby players increased following long distance air travel across multiple time zones in a five-year cohort study. The findings indicated that players who crossed six or more time zones or traveled via air for greater than ten hours were not at a higher risk of injury compared to players who traveled less. This study is particularly relevant to the literature review and research question since the authors were able to provide evidence that extensive air travel and jet lag did not increase injury risk for rugby athletes. This could imply that with appropriate recovery and management strategies, NFL players also might not experience increased injury risks from playing games in Europe despite the long travel and time zone changes. Additional

research is necessary to adapt these findings to NFL athletes, considering the unique NFL schedule requirements and physical demands during the regular season.

2.2 Injury Risk Associated with NFL

American football is a high-collision sport associated with a substantial risk of injury among participating athletes. Injury risk within the National Football League (NFL) has been well documented, with prior research demonstrating consistently high injury rates across multiple seasons (Bedard & Lawrence, 2021; Lawrence et al., 2015). To promote transparency, NFL teams are required to publicly disclose injuries through weekly injury reports published during the practice week preceding each game. These reports specify the injured body region and the player's participation status in practice and competition, creating a standardized and publicly accessible data source for injury surveillance and research (Tomaro, 2023).
Previous studies using official NFL injury reports have documented injury rates exceeding 400 injuries per 100 team games, underscoring the physical demands of the league and the cumulative burden placed on players throughout the regular season (Bedard & Lawrence, 2021; Lawrence et al., 2015). Additional research has highlighted the predominance of musculoskeletal injuries, particularly those affecting the lower extremity, and their impact on player availability and team performance (Mack et al., 2020).

While the epidemiology of NFL injuries is well established, less attention has been given to how external scheduling and travel-related factors may influence short-term injury patterns. Given the league's recent expansion into international competition, understanding whether participation in overseas games alters injury reporting trends particularly in the weeks immediately following international travel represents an important and understudied area of player safety research.

2.3 Impact of Travel on Athletes

The impact of international travel on athlete performance and recovery has been widely examined across multiple sports, though its specific implications for injury risk in the NFL remain incompletely understood. Travel-related stressors including extended flight durations, rapid time zone transitions, and limited opportunities for acclimatization may plausibly influence player health during and after international competition.
Early research in the NFL demonstrated that geographic location and time zone differences can affect team performance, establishing a framework for examining circadian influences in professional football (Jehue et al., 1992; Smith et al., 1997). Subsequent work has identified jet lag, circadian rhythm disruption, and psychological stress as key mechanisms by which long-distance travel may impair athlete well-being (Youngstedt & O'Connor, 1999). However, studies examining compressed schedules within the NFL such as Thursday Night Football have not consistently demonstrated increased injury rates, suggesting that recovery timelines alone may not fully explain injury risk (Baker et al., 2019).
Beyond the NFL, systematic reviews and experimental studies in elite athletes consistently report that long-haul travel

disrupts sleep quality, recovery, and subjective readiness, particularly following eastward travel across multiple time zones (Rossiter et al., 2022; Doherty et al., 2023). These disruptions may persist for several days and, in some cases, up to two weeks post-travel (Biggins et al., 2022). Physiological responses to air travel including reduced oxygen saturation and altered sleep patterns have also been documented and may further impair recovery (Humphreys et al., 2005; Pradzynska et al., 2024).

Clinical and applied reviews emphasize that international travel presents a multifactorial challenge for elite athletes, combining circadian misalignment, sleep disruption, nutritional challenges, and psychological stress (Leatherwood & Dragoo, 2013; Pipe, 2011). Although many professional teams employ mitigation strategies, the compressed nature of the NFL schedule limits opportunities for acclimatization both before and after international competition.

Collectively, this body of literature supports the hypothesis that international travel may influence short-term injury patterns in professional football. However, empirical evidence directly examining injury reporting trends following NFL international games is limited, reinforcing the need for targeted investigation into injury risk during the post-international competition period.

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evidence directly examining injury reporting trends following NFL international games is limited, reinforcing the need for targeted investigation into injury risk during the post-international competition period.

2.4 Travel and NFL Injury Risk

Research exploring the relationship between travel and injury risk is prevalent, with several studies addressing the issue within the NFL and with other sports. Teramoto et al. (2017) explored the association between game scheduling and rate of concussions in the NFL during the 2012-2015 seasons. The findings suggest that there was no correlation between number of rest days or game location and rate of concussions during that period.

2.5 Gaps in Literature, Future Research Direction, and Conclusion

While rugby and NBA studies provide insights into travel-related risks, the NFL's unique 18-week season, physical demands, and scheduling constraints may amplify these effects, necessitating sport-specific research. This literature review has established an understanding of the relationship between long haul travel and injury risk in NFL players. However, a gap remains concerning the specific question of "Is there an increased risk of being listed on the injury report in the two-week period following an NFL Europe game compared to other weeks for the same teams or compared to matched control teams?" and designing a study to examine and fill this gap is necessary. Addressing this gap is important for advancing understanding around the implications of international NFL games and player health. Results from this research would build on the body of knowledge and aid in answering the question of if there is or is not increased injury risk associated with NFL Europe games. The findings from future studies will not only benefit NFL teams and athletes by providing evidence-based recommendations but contribute to the broader global sports field by enhancing understanding of sports related travel impacts.

3. Methods

3.1 Study Design

This study employed a retrospective cohort design to analyze injury trends associated with international NFL games. Specifically, it examined whether teams that participated in regular-season NFL games played in Europe (United Kingdom or Germany) experienced elevated injury counts or injury rates in the weeks immediately following international travel, compared to similar teams that did not travel internationally during the same seasons.

The analysis focused on three NFL seasons in which international games occurred but were not interrupted by pandemic-related cancellations: 2019, 2021, and 2022. These three seasons featured a total of 10 international games involving 20 unique team appearances.

3.2 Participants

The sample comprised all NFL teams that participated in regular season games in Europe during the 2019, 2021, and 2022 seasons, totaling 10 international games across these years.

Specifically, there were four international games in 2019, two in 2021, and four in 2022. Each international team was paired with a control team from the same division that did not play internationally in the respective season. This intra-divisional matching ensured consistency in travel burden, schedule difficulty, and general exposure to environmental and competitive variables.

3.3 Data Sources

Injury data were sourced from official NFL injury reports, accessed via the NFL's website, and cross-verified with Pro-Football-Reference.com for accuracy. For each team, weekly injury reports were collected across the 17-week (2019) or 18-week (2021 and 2022) regular seasons. Injuries were recorded if a player was listed as "Questionable (Q)," "Doubtful (D)," "Out (O)," or placed on Injured Reserve (IR) for the first time that season. Players listed for personal reasons or already on IR at the start of the season were excluded to focus on new injuries attributable to the season's activities.
Data were compiled into a standardized Excel spreadsheet, capturing the following variables for each team and week: team name, week number, game date, opponent, game location, international game indicator, travel distance (in miles), and whether the week fell within two weeks post-international game. Athlete exposures (AEs) were calculated based on roster limits: 46 players per game in 2019 and 48 players per game in 2021 and 2022, multiplied by the number of games played.

3.4 Data Collection Procedure

For each team involved in the study, both from the international games and the control groups, injury reports were collected for every week of the regular NFL seasons from 2019 to 2023. Data were gathered on team-level weekly injury totals and practice participation status (Questionable, Doubtful, Out, IR). Individual player names, injury type, or positions were not analyzed. Distance traveled for each game were calculated using the "as the crow flies" method from each team's home stadium to the away stadium. Teams' bye weeks, during which no game was played and thus no injury report was required, were noted to ensure accuracy in data continuity and interpretation.

3.5 Injury Rate Calculation

To standardize injury risk across teams and weeks, in addition to total injuries, an injury rate per 1,000 athlete-exposures (AEs) was calculated for each week. The number of AEs was estimated based on the active game-day roster limit: 2019: 46 players per game, 2021–2022: 48 players per game. The injury rate will be expressed as the number of injuries per 1,000 athlete- exposures (AEs), where an athlete-exposure is defined as one athlete participating in one game where they are exposed to the possibility of an injury. This measure is chosen to standardize the injury risk across teams that may have different numbers of players participating in games. The formula to calculate the injury rate is as follows: Injury Rate = (Total Number of Injuries / Total Athlete-Exposures) ×1000. Total injuries were the sum of all recorded injuries per team, and total AEs were the product of roster size (46 or 48) and games played. This metric allowed for comparisons across seasons with different roster sizes and game counts.

3.6 Post-International Game Injury Window

To further assess the short-term impact of international travel on athlete health, the study isolated a two-week window immediately following each team's international game. Each international team's schedule was reviewed to determine the two weeks after returning from Europe.

A binary variable was created and applied to each row of the dataset to indicate whether that game occurred "within 2 weeks post-international game" (coded as "Y") or not (coded as "N"). For teams with a bye week immediately after the international game, the bye weeks were excluded from analysis, since injury reports are not published during that time.

Weekly injury counts and injury rates for international teams were then stratified by this two-week window and compared using an independent samples t-test:

- Group 1: Weeks within 2 weeks post-international game
- Group 2: All other weeks in the regular season for the same team

This analysis was used to determine whether injury rates are elevated during the immediate recovery period following international travel, offering a more focused assessment of short-term effects compared to full-season averages.

3.7 Statistical Analysis

Descriptive statistics, including means and standard deviations, were computed for two outcome measures: total weekly injury counts and injury rates per 1,000 AEs. Inferential analyses were conducted to compare these outcomes between groups:

1. Independent-samples t-tests assuming unequal variances were used to compare:
    - Mean weekly injury counts and injury rates between international and control teams for each season (2019, 2021, 2022).
    - Injury counts for international teams in the two weeks post-international game versus other weeks across the same season.
2. A one-way ANOVA was performed to assess differences in injury counts between international and control teams across all three seasons combined.

All descriptive and inferential statistics were performed in Microsoft Excel (Version 16.0) using built-in t-test and ANOVA functions, with a significance threshold of $p < .05$. This approach allowed for a comprehensive evaluation of injury risk associated with international games, with particular emphasis on the two-week post-travel period as a critical window for detecting differences.

4. Results

Descriptive statistics were calculated to summarize injury counts and injury rates per team, per game, across the 2019, 2021, and 2022 NFL regular seasons. Each game's total injuries were logged, and team type was designated as either international (teams that played a regular- season game in Europe) or control (matched teams that did not play internationally). The number of injuries per week and the injury rate per 1,000 athlete-exposures (AEs) were computed for each team. The injury rate was standardized to account for roster size differences across seasons: 46 AEs per team per game in 2019 and 48 AEs per team per game in 2021 and 2022.

In 2019, international teams averaged 4.80 injuries per game (SD = 2.27), while control teams averaged 4.89 (SD = 2.19). In 2021, international teams averaged 4.10 injuries (SD = 2.77) compared to 6.43 injuries (SD =

4.30) for control teams. In 2022, international teams averaged 6.17 injuries per game (SD = 3.28), while controls averaged 5.59 (SD = 3.22). These values are presented in Table 1 and visualized in Figure 1.

Injury Rates per 1,000 AEs:

Mean injury rates in 2019 were 104.28 for international teams and 106.32 for control teams. In 2021, injury rates were 85.48 and 133.88, respectively, while in 2022, rates were

128.52 for international and 116.42 for control teams. Full breakdowns of these injury rate statistics are available in Table 2.

Injury Counts per Game:

To assess whether international participation was associated with different injury burdens, independent samples t-tests assuming unequal variances were conducted for each season:

- 2019: No significant difference between international and control teams, $t(254) = -0.34$, $p = .737$.
- 2021: A significant difference was observed; international teams had fewer injuries, $t(114) = -3.74$, $p < .001$.
- 2022: No statistically significant difference, $t(270) = 1.47$, $p = .142$.

These results suggest that only in 2021 did international teams exhibit significantly lower weekly injury counts compared to control teams.

Injury Rates per 1000 AEs:

A similar analysis was conducted on injury rates:

- 2019: $t(254) = -0.34$, $p = .737$
- 2021: $t(114) = -3.74$, $p < .001$
- 2022: $t(270) = 1.47$, $p = .142$

Again, only the 2021 season showed statistically significant differences.
A one-way ANOVA was conducted to assess injury count differences between international and control teams across all three seasons (N = 664). The analysis revealed: $F(1, 662) = 1.33$, $p = .249$. There was no statistically significant difference in injury counts based on international game participation across all seasons combined. See Table 5 for the ANOVA summary.

Post-International Game Window Analysis
To determine whether teams experienced more injuries in the two weeks following international travel, a subset of the international team data was analyzed. A t-test compared the mean injury count during the two-week post-international window (n = 26) to all other weeks for international teams (n = 306). Results showed:

- Mean injury count in the two-week post-international window: M = 4.73 (SD ≈ 2.85)
- Mean injury count in other weeks: M = 5.26 (SD ≈ 2.95)
- $t(30) = -0.90$, $p = .374$

This difference was not statistically significant, indicating no acute spike in injury risk following international travel.

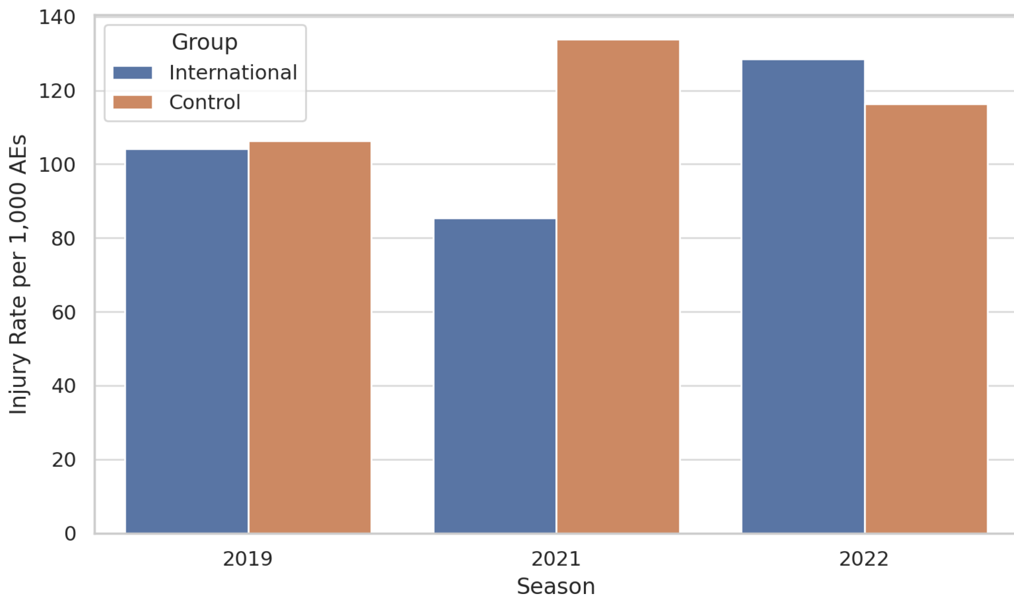

Figure 1. Mean injury rates per 1,000 athlete exposures (AEs) for international and control teams by season.

Table 1. Injury Count Descriptive Statistics by Season and Group

Season	Group	Mean Injuries	Standard Deviation	Number of Games
2019	International	4.8	2.27	128
2019	Control	4.89	2.19	128
2021	International	4.1	2.77	68
2021	Control	6.43	4.3	68
2022	International	6.17	3.28	136
2022	Control	5.59	3.22	136

Table 2. Injury Rate Descriptive Statistics by Season and Group

Season	Group	Mean Injury Rate (per 1,000 AEs)	Standard Deviation	Number of Games
2019	International	104.28	49.43	128
2019	Control	106.32	47.66	128
2021	International	85.48	57.72	68
2021	Control	133.88	89.65	68
2022	International	128.52	68.35	136
2022	Control	116.42	67.11	136

Injury Counts per Game:
To assess whether international participation a one-way ANOVA was conducted to assess injury count differences between international and control teams across all three seasons (N = 664). The analysis revealed: $F(1, 662) = 1.33$, $p = .249$. There was no statistically significant difference in injury counts based on international game participation across all seasons combined. See Table 5 for the ANOVA summary.

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- $t(30) = -0.90$, $p = .374$

This difference was not statistically significant, indicating no acute spike in injury risk following international travel.

5. Discussion and Practical Application

This study explored the potential relationship between international NFL travel and player injury counts by comparing weekly injury data from teams that participated in regular- season games in Europe against matched control teams across the 2019, 2021, and 2022 seasons. While previous literature has examined broader scheduling or cumulative travel effects, the current findings contribute a more targeted analysis of short-term post-international travel periods within a structured comparative framework. Based on the results of the descriptive and inferential analyses, statistically significant differences in injury counts were not observed consistently across seasons between international teams and their matched domestic control counterparts. Additionally, the two-week post-international travel window showed mixed results, with elevated rates in 2022 (107.14 vs. 129.91 for other weeks) but not in 2019 or 2021, suggesting context-specific effects

These results offer meaningful implications for NFL stakeholders including athletic trainers, sport scientists, and league schedulers. Specifically, the findings suggest that international travel, as currently scheduled, does not appear to significantly increase acute injury risk within the two weeks following a game played in Europe. For team decision makers and medical personnel, this may support maintaining current travel protocols and recovery planning without requiring drastic changes. Moreover, the lack of elevated injury rates during post-international periods may reinforce the feasibility of expanding international series games, provided recovery and load management strategies continue to be optimized.

However, the study also highlights important areas for future research and practical reflection. Notably, international games are frequently played on grass surfaces unlike many NFL stadiums in the United States, which utilize artificial turf. Given the growing discussion around the potential health benefits of grass fields, further research could examine whether field surface mediates injury outcomes in post-international games. Additionally, future studies should consider expanding the dataset to include the 2023 and 2024 seasons and analyze other variables such as injury severity, player position, and travel recovery protocols to offer a deeper understanding of the effects of international play on athlete health.

Several limitations should be considered when interpreting the findings of this study. First, injury data were derived from publicly available NFL injury reports, which reflect players listed on the report rather than clinically verified injuries. As a result, the data capture injury reporting behavior rather than injury incidence or severity, and variations in team reporting practices may introduce reporting bias. Second, injuries were aggregated as weekly counts, without differentiation by injury severity, time loss, or recurrence, which may obscure more nuanced health impacts of international travel. Third, while matched control teams were selected using divisional and scheduling criteria, unmeasured confounding variables such as team-specific medical practices, travel recovery strategies, roster depth, or coaching decisions could influence injury reporting patterns. Finally, the analysis focused on three NFL seasons (2019, 2021, and 2022), and findings may not generalize to other seasons, especially as international scheduling, roster rules, and injury reporting practices continue to evolve. These limitations suggest that results should be interpreted cautiously and highlight the need for future studies incorporating additional seasons, clinical injury data, and more granular measures of player exposure and recovery.

6. Conclusion

This study examined whether participation in NFL international regular-season games was associated with increased injury counts in the two weeks following those games, as well as over the course of the season. By analyzing data from 2019, 2021, and 2022 NFL seasons spanning 10 international games and their matched domestic controls no statistically significant differences in weekly injury counts or injury rates per 1,000 athlete exposures were found across groups. Additionally, there was no consistent evidence of elevated injury counts, though injury rates showed a mixed pattern, with an increase in 2022. This supports the finding that short-term injury risk in the two weeks following an international game does not appear to increase

While a significant difference was observed in the 2021 season, where control teams experienced more injuries than international teams, this trend was not consistent across seasons and did not hold when analyzing injury rates. These findings indicate that while international travel introduces logistical and physiological challenges, it may not inherently increase injury risk in the short term an insight that could help inform scheduling, recovery protocols, and league policies surrounding global expansion.

Future research should expand this work in several keyways. First, additional seasons, including the entire data set starting from the first games in 2007 should be analyzed to increase the sample size and statistical power. Second, future studies should incorporate injury severity and classify injuries by type and player position to determine if specific subgroups are disproportionately affected by international travel. Third, incorporating variables such as surface type (grass vs. turf), length of travel, and recovery protocols could help isolate mechanisms that mitigate or elevate injury risk. A promising future direction is the potential protective effect of grass surfaces in Europe compared to artificial turf commonly used in the U.S.

While this study does not suggest an increased injury risk following international NFL games under current conditions, it provides a foundation for ongoing examination of global travel's impact on elite athlete health and offers valuable insights as the league continues its international expansion.

Reference List

1. Anderson, B. (2022, October 4). *NFL London games: How do teams perform after with no bye week?* The Action Network. https://www.actionnetwork.com/nfl/nfl-london-games-how-do-teams-perform-after-with-no-bye-week

2. Angileri, H. S., McLoughlin, D. E., Owen, M. M., May, J. M., Terry, M. A., & Tjong, V. K. (2023). Association of Injury Rates Among Players in the National Football League With Playoff Qualification, Travel Distance, Game Timing, and the Addition of Another Game: Data From the 2017 to 2022 Seasons. *Orthopaedic Journal of Sports Medicine*, *11*(6). https://doi.org/10.1177/23259671231177633

3. Baker, H. P., Pirkle, S., Cahill, M., Reddy, M., Portney, D., & Athiviraham, A. (2021). The Injury Rate in National Football League Players Increased Following Cancellation of Preseason Games Because of COVID-19. *Arthroscopy, Sports Medicine, and Rehabilitation*, *3*(4), e1147–e1154. https://doi.org/10.1016/j.asmr.2021.05.002

4. Baker, H. P., Young-Hoon Lee, K., Dayton, S. R., Terry, M., & Tjong, V. K. (2019). Thursday Night Football's impact on all-cause injuries in NFL players during 2012–2017. *Physician and Sportsmedicine*, *47*(3), 350–352. https://doi.org/10.1080/00913847.2019.1587565

5. Bedard, G., & Lawrence, D. W. (2021). Five-Year Trends in Reported National Football League Injuries. *Clinical Journal of Sport Medicine*, *31*(3), 289–294. https://doi.org/10.1097/JSM.0000000000000741

6. Biggins, M., Purtill, H., Fowler, P., O Sullivan, K., & Cahalan, R. (2022). Impact of Long-Haul Travel to International Competition on Sleep and Recovery in Elite Male and Female Soccer Athletes. *International Journal of Sports Physiology and Performance*, *17*(9), 1361–1370. https://doi.org/10.1123/ijspp.2021-0165 *Creating the NFL schedule*. (n.d.). NFL.Com. Retrieved February 16, 2025, from https://operations.nfl.com/gameday/nfl-schedule/creating-the-nfl-schedule/

7. Doherty, R., Madigan, S. M., Nevill, A., Warrington, G., & Ellis, J. G. (2023). The impact of long haul travel on the sleep of elite athletes. *Neurobiology of Sleep and Circadian Rhythms*, *15*. https://doi.org/10.1016/j.nbscr.2023.100102

8. Edwards, B. J. (2025). Effects of one-night of partial sleep loss on the circadian rhythm of temperature, subjective tiredness, alertness, and standing broad jump performance; is there a sex difference? *Chronobiology International*. https://doi.org/10.1080/07420528.2024.2445722

9. Fowler, P., Duffield, R., & Vaile, J. (2014). Effects of domestic air travel on technical and tactical performance and recovery in soccer. *International Journal of Sports Physiology and Performance*, *9*(3), 378–386. https://doi.org/10.1123/IJSPP.2013-0484

10. Fowler, P., Duffield, R., & Vaile, J. (2015). Effects of simulated domestic and international

air travel on sleep, performance, and recovery for team sports. *Scandinavian Journal of Medicine and Science in Sports*, *25*(3), 441–451. https://doi.org/10.1111/sms.12227

11. Fowler, P. M., Knez, W., Crowcroft, S., Mendham, A. E., Miller, J., Sargent, C., Halson, S., & Duffield, R. (2017). Greater Effect of East versus West Travel on Jet Lag, Sleep, and Team Sport Performance. *Medicine and Science in Sports and Exercise*, *49*(12), 2548–2561. https://doi.org/10.1249/MSS.0000000000001374

12. Fuller, C. W., Taylor, A. E., & Raftery, M. (2015). Does long-distance air travel associated with the Sevens World Series increase players' risk of injury? *British Journal of Sports Medicine*, *49*(7), 458–464. https://doi.org/10.1136/bjsports-2014-094369

13. Humphreys, S., Deyermond, R., Bali, I., Stevenson, M., & Fee, J. P. H. (2005). The effect of high altitude commercial air travel on oxygen saturation. *Anaesthesia*, 60(5), 458–460. https://doi.org/10.1111/j.1365-2044.2005.04124.x

14. Huyghe, T., Scanlan, A. T., Dalbo, V. J., & Calleja-González, J. (2018). The negative influence of air travel on health and performance in the national basketball association: A narrative review. *Sports*, 6(3). https://doi.org/10.3390/sports6030089

15. Jehue, R., Street, D., & Robert, H. (1992). Effect of time zone and game time changes on team performance: National Football League. *Physical Fitness and Performance*, 127–131.

16. Lawrence, D. W., Comper, P., & Hutchison, M. G. (2016). Influence of Extrinsic Risk Factors on National Football League Injury Rates. *Orthopaedic Journal of Sports Medicine*, 4(3). https://doi.org/10.1177/2325967116639222

17. Lawrence, D. W., Hutchison, M. G., & Comper, P. (2015). Descriptive epidemiology of musculoskeletal injuries and concussions in the national football league, 2012-2014. *Orthopaedic Journal of Sports Medicine*, 3(5). https://doi.org/10.1177/2325967115583653

18. Leatherwood, W. E., & Dragoo, J. L. (2013). Effect of airline travel on performance: A review of the literature. In *British Journal of Sports Medicine* (Vol. 47, Issue 9, pp. 561–567). https://doi.org/10.1136/bjsports-2012-091449

19. Lee, A., & Galvez, J. (2012). *Jet Lag in Athletes*. https://doi.org/https://doi.org/10.1177/1941738112442340

20. Mack, C. D., Kent, R. W., Coughlin, M. J., Shiue, K. Y., Weiss, L. J., Jastifer, J. R., Wojtys, E. M., & Anderson, R. B. (2020). Incidence of Lower Extremity Injury in the National Football League: 2015 to 2018. *American Journal of Sports Medicine*, 48(9), 2287–2294. https://doi.org/10.1177/0363546520922547

21. McGuckin, T. A., Sinclair, W. H., Sealey, R. M., & Bowman, P. (2014). The effects of air travel on performance measures of elite Australian rugby league players. *European Journal of Sport Science*, 14(SUPPL.1). https://doi.org/10.1080/17461391.2011.654270

22. Olson, D., Sikka, R. S., Labounty, A., & Christensen, T. (2013). *Injuries in Professional Football: Current Concepts*. http://journals.lww.com/acsm-csmr

23. Pipe, A. L. (2011). International Travel and the Elite Athlete. *In Clin J Sport Med* (Vol. 21). www.cjsportmed.com

24. Pradzynska, M., Rylands, L. P., & Canham, D. C. (2024). Causes of sleep deprivation in competative athletes: A scoping review. In *Science and Sports* (Vol. 39, Issue 4, pp. 323–330). Elsevier Masson s.r.l. https://doi.org/10.1016/j.scispo.2023.01.008

25. Rossiter, A., Comyns, T. M., Sherwin, I., Nevill, A. M., & Warrington, G. D. (2024). Elite athletes' and support staffs' experiences and perceptions of long-haul travel, and the self-management strategies they use. *International Journal of Sports Science and Coaching*, 19(2), 698–709. https://doi.org/10.1177/17479541231170080

26. Rossiter, A., Warrington, G. D., & Comyns, T. M. (2022). Effects of Long-Haul Travel on Recovery and Performance in Elite Athletes: A Systematic Review. In *Journal of Strength and Conditioning Research* (Vol. 36, Issue 11, pp. 3234–3245). NSCA National Strength and Conditioning Association. https://doi.org/10.1519/JSC.0000000000004021

27. Schwellnus, M. P., Derman, W. E., Jordaan, E., Page, T., Lambert, M. I., Readhead, C., Roberts, C., Kohler, R., Collins, R., Kara, S., Morris, M. I., Strauss, O., & Webb, S. (2012). Elite athletes travelling to international destinations >5 time zone differences from their home country have a 2-3-fold increased risk of illness. *British Journal of Sports Medicine*, 46(11), 816–821. https://doi.org/10.1136/bjsports-2012-091395

28. Smith, R. S., Guilleminault, C., & Efron, B. (1997). Sports, Sleep, and Circadian Rhythms Circadian Rhythms and tnhanced Athletic performance in the National Football League. In *Sleep* (Vol. 20, Issue 5). https://academic.oup.com/sleep/article/20/5/362/2732132

29. Teramoto, M., Cushman, D. M., Cross, C. L., Curtiss, H. M., & Willick, S. E. (2017). Game Schedules and Rate of Concussions in the National Football League. *Orthopaedic Journal of Sports Medicine*, 5(11). https://doi.org/10.1177/2325967117740862

30. Thun, E., Bjorvatn, B., Flo, E., Harris, A., & Pallesen, S. (2015). Sleep, circadian rhythms, and athletic performance. In *Sleep Medicine Reviews* (Vol. 23, pp. 1–9). W.B. Saunders Ltd. https://doi.org/10.1016/j.smrv.2014.11.003

31. Tomaro, D. (2023, November 17). *What Is the NFL Injury Policy? Rules and Procedures for NFL Teams.* Profootballnetwork.Com. https://www.profootballnetwork.com/what-is-nfl- injury-policy-rules-and-procedures-for-nfl-teams/

32. Youngstedt, S. D., & O'Connor, P. J. (1999). *The Influence of Air Travel on Athletic Performance*.

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Exercise Highlight 1

Rethinking Stretching for Optimal Movement Quality

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1. Introduction

Stretching for flexibility and physical health fitness enhancement was widely promoted a long time ago (Behm et al., 2023; Konrad et al., 2024). It was also believed that stretching is a key to relieving muscle tightness and movement restriction issues for injury prevention (Zvetkova et al., 2023). However, the actual beneficial effects of stretching on injury prevention have been questioned and remain controversial (Warneke et al., 2025; Witvrouw et al., 2004). In this regard, previous studies showed acute negative effects on the strength and power performance, the potential increase of the risk of injuries (Warneke et al., 2025), and the increase of muscle damage-related biomarkers and delayed onset muscle soreness (Dupuy et al., 2018). On the other hand, there are also tons of evidence showing the increase of joint range of motion and flexibility after the use of various stretching methods (i.e., static stretch, proprioceptive neuromuscular facilitation – PNF, dynamic stretch, etc.) (Behm et al., 2023; Konrad et al., 2024; Warneke et al., 2025).

When simply answering the question "Should we stretch?" purely based on the research perspectives, the myths and confusions are not likely to be solved due to the limitations of research design and the large gaps between laboratory-based experiments and the realms of real-world practices (Ho et al., 2023; Short & Tuttle, 2020). In this regard, this article will make use of the hamstring stretching as an example and use a holistic lens to include both the considerations of research findings and real-life situations, to rethink the applications of stretching.

2. Practical Implications

Theoretically, the long or biarticular muscles, such as the hamstrings, are mostly affected and required to "stretch" due to the passive insufficiency (Gajdosik, Hallett, & Slaughter, 1994; Kawama et al., 2025). For example, when performing a power clean or the stiff leg deadlift exercise, the hamstring can restrict the normal anterior pelvic tilt and hip flexion if the knee joints are extended, whereas the muscle length is suboptimal. To achieve the full range of motion in performing the conditioning tasks, individuals may attempt using compensatory movement patterns such as posterior pelvic tilt and the reduced lumbar lordosis (or increased lumbar flexion). Similarly, athletes such as canoe polo frequently acquire a long sitting position can also place additional stress on their sacroiliac joint and lumbar spine, especially when the tight hamstring muscles are required to be maximally stretched. The increase of lumbar flexion in sitting or bent over position can further stress the ligamentous structures and intervertebral disc. Since our spine is stabilised by both the active, passive, and neural control subsystems (Panjabi, 1992), without enhancing the active and neuromuscular control, the weakened or damaged spinal ligaments and annulus fibrosus structures may make our spine more vulnerable to lower back pain and spinal injuries.

Figure 1 – Self static stretch on hamstring

Figure 2 – PNF stretch on hamstring

To prevent the development of the aforementioned faulty posture (i.e., lumbar flexion in long sitting) and movement (lifting the weight from the ground with posterior pelvic tilt and the loss of normal lumbar lordosis or stiffness in the bent over position), strength coaches or clinical practitioners may therefore prescribe evidence-based stretching methods such as passive static stretch or PNF (Figure 1 and 2) to increase the extensibility of the hamstrings and hence, the range of normal hip flexion without leading to any undesirable compensatory movements. Based on the literature, performing sets of stretching on the hamstring muscles can induce acute responses, including flexibility enhancement and potentially a temporary decline in force and power output. Theoretically, without performing high-intensity or explosive lifts using the "stretched" hamstring muscles after the stretching exercises, it may not lead to any observable performance impact. Moreover, an appropriate warm-up routine, such as the use of dynamic stretch, can partly or mostly (if not fully) dilute the negative effects after prolonged stretching activities.

Nevertheless, when individuals are required to move or exercise in a new body position, the lack of sensorimotor integration, stability, and motor control of this "new" position can become susceptible to injuries or pain syndromes. Likewise, when the athletes need to lift the barbell from the "new" bent-over position after tremendous hamstrings stretches and the increased range of anterior pelvic tilt or hip flexion position, the lumbo-pelvic-hip complex may not have sufficient "experience" of sensorimotor integration to optimise postural and movement control.

Similarly. If the canoe polo athletes practice the sports skill in a “new” long-sitting position after heavily stretching the hamstrings, the lumbar spine will be forced to work with suboptimal active and neural control subsystems. Therefore, to further enrich the neuromuscular control of our lumbo-pelvic-hip complex, it is highly recommended to perform postural control and dynamic stability exercises immediately after the stretching activities.

Figure 3 – Quadruped hold

Figure 4 – Quadruped hold with arm and leg lift

To mimic the postural control demand, the quadruped with (Figure 3) or without (Figure 4) arm and leg lift can be a good starting point to prepare the body in a bent-over lifting position. These exercises should highly emphasise the activation of deep and localised stabilisers such as transversus abdominis, internal oblique, and multifidus. The hip hinge with abdominal bracing (Figure 5) can be a progression to allow the body learning the lumbo-pelvic-hip stabilisation work in a stiff-leg deadlift position. Progression, such as single-leg Romanian deadlift (Figure 6) with or without adding the aeroplane variation (Figure 7a & 7b), can further enhance the multi-planar lumbo-pelvic-hip control. Similarly, for the athletes requiring a long-sitting position, the Pilates drills, such as the spine stretch forward (Figure 8a & 8b), with a thick towel or yoga block as a little seat, or the roll up (Figure 9a to 9c), can facilitate the abdominal and core stability engagement in sports-specific positional needs.

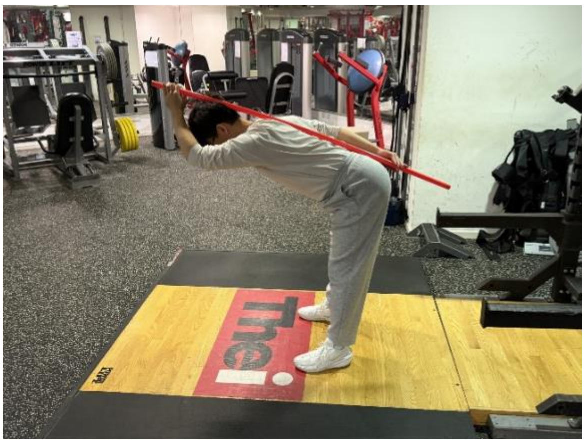

Figure 5 – Hip Hinge

Figure 6 – Single-leg Romanian Deadlift

Figure 7a & b – Single-leg Romanian Deadlift with the Aeroplane variation

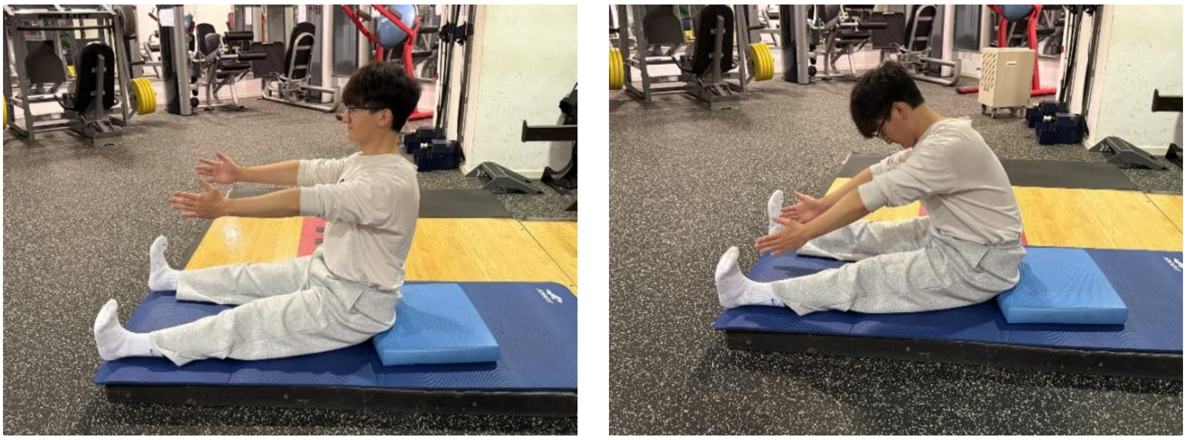

Figure 8a & b – Pilates Drill: Spine Stretch Forward

Figure 9a, b & c – Pilates Drill: Roll Up

3. Conclusion

Performing stretching exercises alone may only induce flexibility enhancement and a certain gain in movement range, but meanwhile potentially amplify the weakness in postural and movement control and hence the risk of injuries. By strategically integrating stability and postural control training as adjunct exercises, the practical beneficial effects of stretching can be fully unleashed for optimal movement quality.

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Reference List

1. Behm, D. G., Alizadeh, S., Daneshjoo, A., Anvar, S. H., Graham, A., Zahiri, A., Goudini, R., Edwards, C., Culleton, R., Scharf, C., & Konrad, A. (2023). Acute Effects of Various Stretching Techniques on Range of Motion: A Systematic Review with Meta-Analysis. *Sports medicine - open*, 9(1), 107. https://doi.org/10.1186/s40798-023-00652-x
2. Dupuy, O., Douzi, W., Theurot, D., Bosquet, L., & Dugué, B. (2018). An Evidence-Based Approach for Choosing Post-exercise Recovery Techniques to Reduce Markers of Muscle Damage, Soreness, Fatigue, and Inflammation: A Systematic Review With Meta-Analysis. *Frontiers in physiology*, 9, 403.
3. Gajdosik, R. L., Hallett, J. P., & Slaughter, L. L. (1994). Passive insufficiency of two-joint shoulder muscles. *Clinical biomechanics (Bristol, Avon)*, 9(6), 377–378.
4. Ho, I. M. K., Weldon, A., Yong, J. T. H., Lam, C. T. T., & Sampaio, J. (2023). Using Machine Learning Algorithms to Pool Data from Meta-Analysis for the Prediction of Countermovement Jump Improvement. *International Journal of Environmental Research and Public Health*, 20(10), 5881.
5. Kawama, R., Takahashi, K., Nobukawa, R., & Wakahara, T. (2025). Passive stiffness of the biarticular hamstring muscles could acutely decrease after eccentric-only resistance exercise, but not after passive muscle lengthening: Effects of exercise load. *Journal of sports sciences*, 43(22), 2740–2753.
6. Konrad, A., Alizadeh, S., Daneshjoo, A., Anvar, S. H., Graham, A., Zahiri, A., Goudini, R., Edwards, C., Scharf, C., & Behm, D. G. (2024). Chronic effects of stretching on range of motion with consideration of potential moderating variables: A systematic review with meta-analysis. *Journal of sport and health science*, 13(2), 186–194.
7. Panjabi M. M. (1992). The stabilizing system of the spine. Part I. Function, dysfunction, adaptation, and enhancement. *Journal of spinal disorders*, 5(4), 383–397.
8. Short, S., & Tuttle, M. (2020).The gap between research and clinical practice for injury prevention in elite sport: a clinical commentary. *International journal of sports physical therapy*, 15(6), 1229–1234.
9. Warneke, K., Thomas, E., Blazevich, A. J., Afonso, J., Behm, D. G., Marchetti, P. H., Trajano, G. S., Nakamura, M., Ayala, F., Longo, S., Babault, N., Freitas, S. R., Costa, P. B., Konrad, A., Nordez, A., Nelson, A., Zech, A., Kay, A. D., Donti, O., & Wilke, J. (2025). Practical recommendations on stretching exercise: A Delphi consensus statement of international research experts. *Journal of sport and health science*, 14, 101067.
10. Witvrouw, E., Mahieu, N., Danneels, L., & McNair, P. (2004). Stretching and injury prevention: an obscure relationship. Sports medicine (Auckland, N.Z.), 34(7), 443–449.
11. Zvetkova, E., Koytchev, E., Ivanov, I., Ranchev, S., & Antonov, A. (2023). Biomechanical, Healing and Therapeutic Effects of Stretching: A Comprehensive Review. *Applied Sciences*, 13(15), 8596.

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Exercise Highlight 2

Surfer's Most Common Chronic and Gradual-Onset Injury and Its Prevention

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Surfing is a water sport in which an individual, referred to as a surfer, uses a surfboard to catch a wave and ride its forward section, or face, employing skill and balance. Surfers must paddle in a prone position to reach the takeoff zone where wave peaks but not yet break. Once in position, they engage in short bursts of powerful paddling to match the wave's speed, transition to an upright stance on the board, and apply body weight and board control to effectively ride the wave and perform turning manoeuvres, commonly known as tricks.

According to the Surf Industry Members Association (2025), approximately 4.2 million people participated in surfing globally in 2024. The number of surfers continues to grow as surfing had made its debut in the 2020 Tokyo Olympics.

Time-motion analysis studies indicate that surfers devote 50% of their time to paddling and 45% to remaining stationary, with only 3–5% of their time spent riding waves (Meir et al., 1991). Undoubtedly, prolonged paddling (37.1%) accounted for most common mechanism of chronic surfing injury and chronic lower back pain (29.3%) has the highest frequency of injuries compared to other regions (Hanchard et al., 2021).

To facilitate an ergonomic paddling stroke, a proper prone paddling posture is required to lift the nose of the board out of the water, increase arm clearance during strokes, and allow the surfer to face forward in the direction of paddling which involves lumbar and thoracic spine extension (Furness et al., 2014; Nathanson, 2012) (See Figure 1).

As paddling position places the surfer in prolonged periods of isometric extension, the paraspinous muscles may experience local ischemia, restricting blood flow to the area (McArdle et al., 2015). This deficiency of oxygen and nutrients results in the buildup of metabolic byproducts, such as hydrogen ions, which activate pain receptors (McArdle et al., 2015). Spinal hyperextension, commonly seen during paddling and contributing to prolonged isometric works of the posterior chain, could potentially result in muscle imbalances (Hanchard et al., 2021). If a surfer experiences insufficient extension in the thoracic and cervical spine due to fatigue or limited flexibility, the lumbar spine may compensate and be placed under greater demands for extension, leading to an increased risk of injury (Furness et al., 2014). Moreover, maintaining a spinal extension posture elevates pressure within the intervertebral discs and between the facet joints. Prolonged maintenance of this position can contribute to dehydration of the discs over time (Kapandji, 2008). In the study conducted by Kojima et al. (2018), the prevalence of lumbar disc degeneration was reported at 50% among professional surfers experiencing low back pain (Kojima et al., 2018). However, the authors also noted that the occurrence of low back pain within this population may not be directly associated with disc degeneration (Kojima et al., 2018).

Figure 1. Surfer paddling. Noted that the thoracic and lumbar spine are in extension position.

In light of all the above, a tailored rehabilitative prevention is essential to enhance physical readiness and prevent low back pain injuries. However, if the lower back extensors, such as the large erector spinae muscles or smaller muscles like the quadratus lumborum, are already hypertonic or if muscle guarding is present due to lower back pain (LBP), it is crucial to address both the pain and hypertonicity as a priority. This approach helps to minimise unnecessary compensatory patterns and the inhibition of deep stabilisers, which can further exacerbate instability and contribute to a cycle of ongoing discomfort. By effectively treating these issues, we can promote better functional movement and support the overall recovery process.

A recent systematic review and meta-analysis revealed that core training modalities significantly improved both chronic nonspecific low back pain and functional status (Guo et al., 2025). Moreover, core stabilisation exercises have been proven effective in improving lumbar lordotic angle, reducing pain intensity, and enhancing functional abilities in patients with lumbar disc degeneration or disease (Ali et al., 2022; Kuligowski et al., 2021). For optimal outcomes, strengthening of the deep trunk muscles is recommended to alleviate chronic LBP (Hlaing et al., 2021). The following training strategies effectively target these deep trunk muscles:

1. **Trunk stabilisation exercise**
   (Akbari et al., 2013; Gatti et al., 2011)

Trunk stabilisation exercises incorporate various positions, including sitting, kneeling, quadruped, and supine. These exercises involve alternating between hard and soft supporting surfaces while instructing participants to move their heads or upper limbs with their eyes closed (See Figure 2).

Figure 2. In a quadruped position with one hand on a balance pad and extend one arm with eye closed.

2. **Stabilisation and Segmental stabilisation exercise**
   (Akbari et al., 2013; França et al., 2010)

Stabilisation exercises, along with segmental stabilisation and motor control exercises, are designed to retrain the motor control of deep trunk muscles. These exercises emphasise the importance of maintaining stability during movement. Segmental stabilisation exercises specifically target spinal stability by focusing on strengthening the transversus abdominis (TrA) and lumbar multifidus (LM) muscles. This targeted approach is crucial for enhancing overall spinal support.

Segmental Stabilisation	Exercise (Example)	Progression
Exercises for the TrA in 4-Point Kneeling	<u>Abdominal Draw-In</u> - Start in a 4-point kneeling position (hands under shoulders, knees under hips). - Inhale deeply, then exhale and gently draw in your belly button toward your spine without moving your back. - Hold for 5-10 seconds, focusing on engaging the TrA.	<u>Opposite Arm and Leg Reach</u>   - From the 4-point kneeling position, extend the right arm forward and the left leg back while maintaining a neutral spine. - Engage the TrA by drawing in the abdomen. - Hold for a few seconds, then switch sides.
Exercises for the TrA in Dorsal Decubitus with Flexed Knees	<u>Pelvic Tilt with Abdominal Activation</u> - Lie on your back with knees bent and feet flat on the floor. - Inhale, then exhale while flattening your lower back against the floor by engaging your TrA (drawing your belly button in). - Hold for 5-10 seconds, then relax.	<u>Single Knee Lift</u>   - In the same position, engage the TrA and lift one knee

		toward your chest while keeping the other foot on the floor. - Focus on maintaining tension in the abdominal muscles throughout the movement. - Lower the leg back down and repeat on the other side.
Exercises for the LM in Ventral Decubitus (Prone)	<u>Superman</u>   - Lie face down with arms extended in front. - Engage the LM and TrA by gently raising your right arm and left leg simultaneously, keeping the pelvis on the ground. - Hold for a few seconds, then switch sides.	<u>Prone Extension</u>  - From the ventral decubitus (prone) position, place your hands under your forehead. - Engage the LM and TrA then gently lift your chest off the ground while keeping your hips down. - Hold for a few seconds, then lower back down.
Co-Contraction of the TrA and LM in Upright Position	<u>Wall Sit with Abdominal Engagement</u>	<u>Standing March</u>

	 - Stand against a wall and slide down into a seated position, keeping your knees at a 90-degree angle. - Engage both the TrA and LM by drawing in your abdomen while maintaining the wall sit. - Hold for 20-30 seconds, focusing on stability.	 - Stand upright with feet hip-width apart. - Engage the TrA and LM, then lift one knee toward your chest as if marching. - Alternate legs while maintaining abdominal engagement throughout the exercise.

3. Motor control

Motor control training involves teaching participants to contract their muscles effectively. For example, they perform an abdominal draw-in maneuver while exhaling, gradually increasing the duration of breath-holding to 10 seconds during 10 contractions (Akbari et al., 2013). Following this, participants engage in dynamic exercises, such as the cat and camel positions, to further enhance their motor control (Akbari et al., 2013). To enhance sport-specific functional adaptations in surfing, exercises executed on an unstable surface, such as the Swiss ball balance and the dumbbell chest press performed on a Swiss ball, are strongly recommended for improving core stability and proprioceptive control of the core musculature, owing to the increased neuromuscular demands imposed by unstable-surface training (Everline, 2007).

Additionally, Cortell-Tormo et al. (2018) demonstrated the effectiveness of a periodised functional resistance training program as a therapeutic intervention for chronic low back pain. The program emphasised progressive overload, beginning with isometric strengthening of the deep trunk muscles with motor learning and advancing to specific exercise interventions with symmetric and asymmetry loads. It also accounted for adjustments in resistance based on participants' perceived exertion using the OMNI scale, ensuring proper technique throughout the training. This strategy can serve as a tool for both prevention and the proper execution of sport-specific movements during training.

Surfing is a dynamic water sport that challenges individuals to balance while riding waves. However, the physical demands, especially prolonged paddling, can lead to common injuries like chronic lower back pain. Maintaining proper paddling posture is crucial to prevent muscle imbalances and strain on the lumbar spine.

To address these risks, tailored rehabilitation strategies focusing on core strength and motor control are essential. Exercises targeting deep trunk muscles, such as trunk balance and stabilization training, effectively enhance physical readiness and prevent injuries. Additionally, a periodized functional resistance training program can promote progressive overload and proper technique. By prioritising injury prevention and conditioning, surfers can improve their performance and enjoy the sport more safely.

Reference List

1. Akbari, A., Khorashadizadeh, S., & Abdi, G. (2013). The effect of motor control exercise versus general exercise on lumbar local stabilizing muscles thickness: Randomized controlled trial of patients with chronic low back pain. *Journal of Back and Musculoskeletal Rehabilitation,* 26(3), 219–224. https://doi.org/10.3233/BMR-130405
2. Ali, A., Saleh, M., Abdelaraouf, N., & Elazizi, H. (2022). Effect of core stabilization exercises on lumbar lordotic angle in patients with lumbar disc degeneration. *Physiotherapy Quarterly*, 30(4), 87–95. https://doi.org/10.5114/pq.2022.121154
3. Cortell-Tormo, J. M., Tercedor Sánchez, P., Chulvi-Medrano, I., Tortosa-Martínez, J., Manchado-López, C., Llana-Belloch, S., & Pérez-Soriano, P. (2018). Effects of functional resistance training on fitness and quality of life in females with chronic nonspecific low-back pain. *Journal of Back and Musculoskeletal Rehabilitation*, 31(1), 95-105. https://doi.org/10.3233/BMR-169684
4. Everline, C. (2007). Shortboard performance surfing. *Strength and Conditioning Journal*, 29(3), 32–40. https://doi.org/10.1519/00126548-200706000-00004
5. França, F. R., Burke, T. N., Hanada, E. S., & Marques, A. P. (2010). Segmental stabilization and muscular strengthening in chronic low back pain: A comparative study. *Clinics (Sao Paulo)*, 65(10), 1013-1017. https://doi.org/10.1590/s1807-59322010001000015
6. Furness, J., Hing, W., Abbott, A., Walsh, J., Sheppard, J. M., & Climstein, M. (2014). Retrospective analysis of chronic injuries in recreational and competitive surfers: injury location, type, and mechanism. *International Journal of Aquatic Research and Education*, 8(3), 6.
7. Gatti, R., Faccendini, S., Tettamanti, A., Barbero, M., Balestri, A., & Calori, G. (2011). Efficacy of trunk balance exercises for individuals with chronic low back pain: A randomized clinical trial. *Journal of Orthopaedic & Sports Physical Therapy*, 41(8), 542-552. https://doi.org/10.2519/jospt.2011.3413
8. Guo, X. B., Lan, Q., Ding, J., Tang, L., & Yang, M. (2025). Effects of different types of core training on pain and functional status in patients with chronic nonspecific low back pain: a systematic review and meta-analysis. *Frontiers in Physiology*, 16. https://doi.org/10.3389/fphys.2025.1672010
9. Hanchard, S., Duncan, A., Furness, J., Simas, V., Climstein, M., & Kemp-Smith, K. (2021). Chronic and Gradual-Onset Injuries and Conditions in the Sport of Surfing: A Systematic Review. *Sports*, 9(2), 23. https://doi.org/10.3390/sports9020023
10. Hlaing, S. S., Puntumetakul, R., Khine, E. E., & Boucaut, R. (2021). Effects of core stabilization exercise and strengthening exercise on proprioception, balance, muscle thickness and pain related outcomes in patients with subacute nonspecific low back pain: A randomized controlled trial. *BMC Musculoskeletal Disorders*, 22(1). https://doi.org/10.1186/s12891-021-04858-6
11. Kapandji, I. A. (2008). *The physiology of the joints: The spinal column, pelvic girdle and head* (6th ed., Vol. 3). Churchill Livingstone.
12. Kojima, T., Kubo, S., Tajima, N., Mitsuhashi, R., Nozaki, S., & Chosa, E. (2018). Lumbar intervertebral disc degeneration in professional surfers. *Sports Orthopaedics and Traumatology*, 34(3), 261-264. https://doi.org/10.1016/j.orthtr.2018.06.006

13. Kuligowski, T., Cieślik, B., Kuciel, N., Dębiec-Bąk, A., & Skrzek, A. (2021). Effect of core stabilizing training on young individuals presenting different stages of degenerative disc disease—preliminary report. *International Journal of Environmental Research and Public Health*, 18(7), 3499. https://doi.org/10.3390/ijerph18073499
14. McArdle, W. D., Katch, F. I., & Katch, V. L. (2015). *Exercise physiology: Nutrition, energy, and human performance* (8th ed.). Wolters Kluwer Health.
15. Meir, R. A., Lowdon, B. J., Davie, A. J., Geebng, D. U., & Victoia, A. (1991). Heart Rates and Estimated Energy Expenditure During Recreational Surfing. *The Australian Journal of Science and Medicine in Sport*, 70-74.
16. Nathanson, A. T. (2012). *Surfing injuries. In Adventure and extreme sports injuries: Epidemiology, treatment, rehabilitation and prevention* (pp. 143-172). London: Springer London.
17. Surf Industry Members Association. (2025). Surfonomics. Surf Industry Members Association. https://surfindustry.org/pages/surfonomics

DECEMBER 2025
VOLUME 1, ISSUE 2

Exercise Highlight 3

Dynamic Neuromuscular Stabilisation for Low Back Pain: Integrating Core Stability Through Developmental Movement Patterns

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Introduction

Low back pain (LBP) remains one of the most prevalent musculoskeletal disorders globally, affecting individuals across athletic and general populations. Chronic non-specific low back pain (NSCLBP) extends beyond localised discomfort to substantially compromise functional capacity, occupational performance, and overall quality of life, often leading to prolonged disability and recurrent episodes (Rabieezadeh et al., 2024; Huang et al., 2025). Rather than focusing exclusively on pain reduction, effective management must address the underlying neuromuscular dysfunction and movement control deficits perpetuating symptoms. Dynamic Neuromuscular Stabilisation (DNS) is a novel therapeutic approach grounded in developmental kinesiology. By restoring optimal core stability and fundamental movement patterns, DNS offers evidence-based solutions for patients with low back pain (Kong et al., 2024; Kaushik & Ahmad, 2024)

Theoretical Foundation of DNS

The DNS framework is predicated on a fundamental principle: the human nervous system develops optimal stabilisation patterns during infancy and early childhood (Frank et al., 2013). These innate motor patterns—characterised by coordinated deep core activation, diaphragmatic breathing, and integrated kinetic chain function—often become disrupted through injury, poor postural habits, trauma, or cumulative stress. Rather than prescribing isolated strengthening exercises, DNS systematically retrains the neuromuscular system to reactivate these fundamental developmental sequences (Kong et al., 2024). Research comparing DNS to conventional exercise programs demonstrates superior improvements in pain intensity, functional disability, and quality of life outcomes (Rabieezadeh et al., 2024).

A critical component of DNS methodology involves intra-abdominal pressure regulation through proper diaphragmatic breathing. The diaphragm, functioning both as a respiratory muscle and core stabiliser, generates pneumatic stabilisation when breathing is appropriately coordinated with movement (Huang et al., 2025). This mechanism distributes spinal loading evenly across vertebral structures, reducing localised stress on intervertebral discs and facet joints. Importantly, DNS-mediated core stabilisation occurs through reflexive neural activation rather than conscious voluntary contraction, thereby bypassing compensatory movement patterns inherent in traditional approaches (Huang et al., 2025).

Meta-analytic evidence supports DNS efficacy in clinical practice. Systematic review of DNS interventions demonstrates statistically significant reductions in pain intensity (standardised mean difference SMD = −1.09; 95% confidence interval CI −1.74, −0.44; P = 0.001) and disability severity (SMD = −0.91; 95% CI −1.48, −0.34; P = 0.002) compared to conventional core stabilisation protocols (Kong et al., 2024). These improvements extend beyond pain reduction to encompass functional mobility and quality of life domains.

Clinical Application: Three Foundational DNS Exercises

Three exercises form DNS-based rehabilitation for low back pain management. Each exercise targets specific neuromuscular mechanisms while respecting developmental motor progression principles.

Oblique Sit Position with Breathing Integration

The oblique sit represents a developmental position critical for lateral core stability and integrated trunk control. Patient positioning involves sitting on one buttock with the supporting leg positioned beneath the body, while the non-supporting leg remains flexed with the foot on the ground. This asymmetrical loading pattern necessitates activation of lateral core musculature—particularly the external and internal obliques—to maintain upright posture and prevent lateral collapse (Kaushik & Ahmad, 2024).

The oblique sit differs fundamentally from traditional side-lying exercises in its neurophysiological demands. The inherently unstable position requires active engagement of both ipsilateral and contralateral trunk stabilisers to manage anterior-posterior and medial-lateral forces, producing comprehensive core activation exceeding isolated strengthening exercises (Kaushik & Ahmad, 2024). Integration of diaphragmatic breathing amplifies this effect. By breathing deeply into the abdominal cavity while maintaining postural alignment, patients generate intra-abdominal pressure that stabilises the lumbar spine. Research documenting diaphragmatic and core muscle changes during DNS exercises demonstrates the fundamental neurophysiological changes underlying these exercises (Yoon et al., 2020).

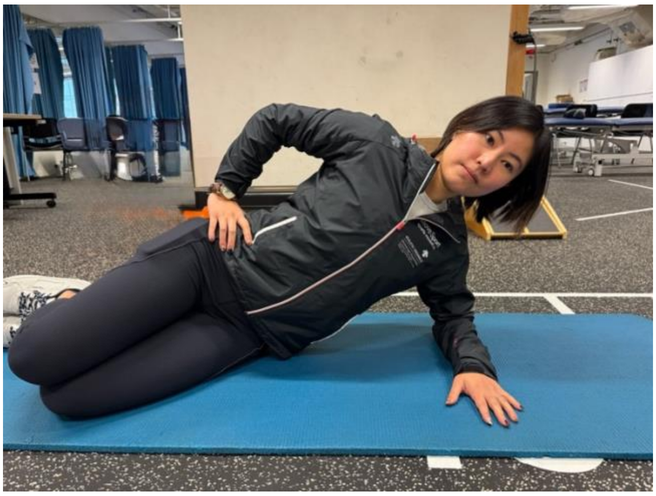

Figure 1. Oblique Sit Position with Breathing Integration.

Tripod Position for Hip Mobility and Spinal Integration

The tripod position bridges the developmental transition from quadrupedal patterns toward upright standing and dynamic weight-bearing. This position begins in quadrupedal alignment with hands positioned under shoulders and knees under hips. One leg then extends forward with the foot positioned just outside the ipsilateral hand, while the contralateral hand remains planted, creating a three-point base of support. This position demands simultaneous engagement of multiple systems: the extended leg must be stabilised at the hip through glute and external rotator activation; the support leg and arm must manage ground reaction forces; and the trunk must maintain elongation against gravity while resisting anterior flexion and lateral translation. (Kaushik & Ahmad, 2024)

The tripod position's therapeutic value extends beyond simple lower extremity strengthening. The asymmetrical weight-bearing configuration creates differential loading across the lumbar spine and demands continuous micro adjustments from the deep stabilising muscles to maintain neutral spine alignment. Crucially, the tripod activates muscles across the entire kinetic chain in an integrated pattern rather than in isolation. (Mahdieh et al., 2020) Clinical observations reveal that the tripod position produces distinct awareness of core engagement—patients report palpable activation through the abdominal region and oblique musculature without being instructed to "contract" these muscles. This reflects the DNS principle of reflexive neuromuscular activation. The position naturally teaches hip mobility and stability simultaneously, as the extended leg requires sufficient hip flexibility to position the foot ahead of the body while the supporting hip must maintain centration. For low back pain patients, the tripod addresses a critical deficit: many individuals with NSCLBP demonstrate impaired hip mobility that forces compensatory lumbar spine extension during movement. By retraining hip mobility and strength in the tripod pattern, the spine is protected during functional activities.

Figure 2. Tripod Position for Hip Mobility and Spinal Integration.

Bear Position with Anti-gravity Loading

The bear position, also termed the quadruped hold or low bear position, involves quadruped positioning with knees lifted slightly off the ground (typically 1-2 inches), creating a suspended loading pattern that demands maximal core stabilisation. Unlike a traditional plank, which can be executed with minimal core engagement due to postural compensation, the bear position makes core disengagement nearly impossible. Given that gravity continuously pulls the knees downward, requiring continuous abdominal bracing to maintain the lifted position. This exercise activates the full spectrum of core musculature through sustained isometric contraction (Karartı et al., 2023).

The bear position's utility in low back pain rehabilitation derives from three mechanisms. First, the position naturally promotes neutral lumbar spine alignment because flexion or extension leads to immediate loss of position stability or discomfort. Second, the anti-gravity loading creates reflexive rather than voluntary core activation—patients cannot "cheat" through compensation because the position's mechanical demands force proper engagement. Third, breathing coordination during the bear position—inhaling through the nose with belly expansion, then exhaling completely while supporting the lifted position—teaches the dynamic coordination between breathing and spinal stabilisation that defines DNS principles.

Clinical evidence supports the bear position's effectiveness in reducing pain and improving muscular endurance. Investigation of core stabilisation exercises incorporating bear-hold positions shows significant improvements in pain reduction and functional capacity in chronic low back pain patients. Notably, this pain reduction occurs through neurophysiological mechanisms rather than requiring weeks of adaptation. Furthermore, the bear position demonstrates remarkable transferability to functional activities. Because proper bear position mechanics require spinal elongation, anterior-posterior stability, and lateral trunk control—the identical stability demands required during everyday activities like lifting or bending—patients report substantial improvements in their ability to perform these activities without pain. (Karartı et al., 2023)

Figure 3. Bear Position with Anti-gravity Loading

Practical Implementation and Clinical Integration

The three DNS exercises described—oblique sit, tripod, and bear position—should be integrated into progressive rehabilitation programs that respect individual patient capabilities and pain tolerance. Exercise prescription typically begins with static holds in optimal positions, progresses to adding breathing coordination, and advances toward dynamic transitions between positions. Initial session duration ranges from 5-10 minutes focusing on 2-3 exercises; the program expands as patients demonstrate improved motor control and reduced pain. The evidence base indicates that DNS exercise programs should be delivered 3 times weekly for at least 4 weeks to produce significant improvements in pain and disability, with research demonstrating that 6-8 weeks may be optimal for sustained benefits. (Rabieezadeh et al., 2024) (Huang et al., 2025)

Research comparing DNS to conventional core stabilisation exercises reveals DNS superiority in specific neuromuscular outcomes. In a randomised controlled trial of chronic low back pain patients, the DNS group exhibited significantly greater improvements in core muscle contractility (measured via ultrasound assessment of transversus abdominis and diaphragm), postural control measured by centre of pressure displacement, and clinical outcomes including pain reduction and disability scores compared to patients receiving conventional core exercises. (Huang et al., 2025) These benefits extend beyond pain reduction to encompass functional movement quality. The transferability of DNS principles to diverse low back pain presentations merits emphasis. Whether managing acute postpartum low back pain, chronic pain in desk workers with postural dysfunction, or pain following disc-related symptoms, DNS protocols consistently demonstrate efficacy across patient demographics and pain aetiology. (Rabieezadeh et al., 2024) (Kong et al., 2024)

Reference List

1. Rabieezadeh, A., Mahdavinejad, R., Sedehi, M., & Adimi, M. (2024) The effects of an 8-week dynamic neuromuscular stabilization exercise on pain, functional disability, and quality of life in individuals with non-specific chronic low back pain: a randomized clinical trial with a two-month follow-up study. *BMC Sports Sci Med Rehabil*,16(1):161.
2. Huang, H., Xie, H., & Zhang, G. et al. (2025) Effects of dynamic neuromuscular stabilization training on the core muscle contractility and standing postural control in patients with chronic low back pain: a randomized controlled trial. *BMC Musculoskelet Disord*, 26:213.
3. Kong, L., Zhang, Z., & Li, Y. et al. (2024) Effects of Dynamic Neuromuscular Stabilization/Vojta Therapy on Pain Intensity and Physical Function in Individuals with Low Back Pain: A Systematic Review and Meta-Analysis. Iran J Public Health, 53(9):1910-1923.
4. Kaushik, M., & Ahmad, I. (2024) Bridging Dynamic Neuromuscular Stabilization Synergism with Movement Control Impairment Related Non-Specific Low Back Pain: Scoping Review. *J Musculoskelet Neuronal Interact*, 24(4):420-432.
5. Frank, C., Kobesova, A., & Kolar, P. (2013) Dynamic neuromuscular stabilization & sports rehabilitation. *Int J Sports Phys Ther*, 8(1):62-73.
6. Yoon, H.S., Cha, Y.J., & You, J.S.H. (2020) Effects of dynamic core-postural chain stabilization on diaphragm movement, abdominal muscle thickness, and postural control in patients with subacute stroke: A randomized control trial. *NeuroRehabilitation*, 46(3):381-389.
7. Mahdieh, L., Zolaktaf, V., & Karimi, M.T. (2020) Effects of dynamic neuromuscular stabilization (DNS) training on functional movements. *Hum Mov Sci*, 70:102568.
8. Karartı, C., Özsoy, İ., & Özyurt, F. et al. (2023) The effects of dynamic neuromuscular stabilization approach on clinical outcomes in older patients with chronic nonspecific low back pain: a randomized, controlled clinical trial. *Disabil Rehabil*, 45(14):2268-2277.

STJ DECEMBER 2025
VOLUME 1, ISSUE 2

Research Proposal Abstract 1

The Impact of Different Pre-Activation Methods and Fatigue Conditions on Jump Performance and Interlimb Asymmetry

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Abstract

This research aims to explore the effects on single-leg countermovement jump (SLCMJ) performance and interlimb asymmetry (IA) in trained endurance runners under fatigue conditions and from 2 pre-activation methods: 1) Bulgarian split squats (BSS) performed on both limbs 2) BSS on the weaker limb only. A total of 18 participants, each with a minimum of one year of resistance training experience, will be involved in four testing sessions. The first session will serve as familiarization session and participants will have baseline assessments for maximum repetitions, SLCMJ and physiological performance. The following three sessions will comprise one control session and two sessions where various pre-activation approach will be implemented alongside a fatigue protocol. These will assess changes in SLCMJ performance and interlimb asymmetry. Measurements will include peak landing force, jump height, and time to stabilization under different conditions, which all will be evaluated for reliability using the Intraclass Correlation Coefficient (ICC) and Standard Error of Measurement (SEM), while repeated-measures ANOVA will be employed to assess statistical differences between conditions. Post-hoc pairwise comparison and effect size will be observed to identify the magnitude of differences between conditions. It is hypothesized that both pre-activation methods can enhance SLCMJ performance while performing BSS on the weaker limb only can effectively reduce the magnitude of interlimb asymmetry.

Keywords: *Post-activation potentiation enhancement (PAPE), Bilateral, Unilateral, Fatigue Protocol*

STJ
DECEMBER 2025
VOLUME 1, ISSUE 2

Research Proposal Abstract 2

Effect of Compression Force Using a Massage Ball on Pain Threshold and Muscular Performance

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Abstract

Introduction

The effect of massage on pain perception and athletic performance is a well-documented area of research. However, a specific effect of compression focus using a massage ball on pain threshold and muscular performance is lacking in the current literature. A primary challenge in both clinical and research settings is determining the optimal massage force, which remains a common and unresolved issue. This is compounded by methodological limitations; existing techniques for quantifying massage force typically rely on non-portable, laboratory-based equipment. Consequently, force levels are often subjectively modulated based on recipient feedback rather than objective measurement. Therefore, a clear research gap exists for the development of a reliable and portable method to standardise the measurement of massage force. The purpose of this study is to identify the effect of compression force using a massage ball on pain threshold and muscular performance.

Methods

The load pad will be used to monitor the compression force using a massage ball in three different conditions: high force, low force, and control without compression. Pre- and post-tests will be arranged to measure the pain threshold and muscular performance, such as isometric strength and muscular endurance, before and after the three different conditions. Repeated-measures ANCOVA and effect size will be employed to examine the effects of three conditions in SPSS.

STJ DECEMBER 2025
VOLUME 1, ISSUE 2

Student Sports Therapist Research Proposal Highlight 1

Effects of Palm Cooling Versus Passive Rest on Fatigue Recovery and Vertical Jump Performance in Young Adults

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Introduction

This study will investigate whether palm cooling during recovery improves vertical jump performance and fatigue-related markers compared with passive rest in physically active young adults. The primary outcomes were countermovement jump height, blood lactate concentration, and ratings of perceived exertion (RPE) before and after the completion of the selected fatigue protocol.

Methods and Results

In this within-subject, repeated-measures design, participants will complete two sessions (control as CON and experimental as EXP) separated by at least seven days. Each session will consist of a standardised dynamic warm-up, a Functional Agility Short-Term Fatigue Protocol, and pre- and post-intervention assessments, including vertical jump height using Hawkin Dynamics force plates, blood lactate, and RPE. In the EXP session, the recovery will consist of 3 minutes of palm cooling via cold-water immersion (10–15°C), while in the CON session, participants will perform 3 minutes of passive seated rest. Results will be analysed using repeated-measures statistics to compare pre-post changes in performance and physiological variables, and the between-condition differences.

We hypothesise that palm cooling will better preserve or enhance post-fatigue vertical jump height and be associated with greater reductions in blood lactate and RPE compared with passive rest. This study can provide empirical evidence on the effectiveness and value of using palm cooling as a practical, low-cost strategy to accelerate recovery of lower-limb explosive performance during training or competition in young athletes.

DECEMBER 2025
VOLUME 1, ISSUE 2

Student Sports Therapist Research Proposal Highlight 2

Effects of Shoulder Muscle Fatigue on Throwing Accuracy in Amateur Cricketers: An EMG Study

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Introduction

This study investigates the effect of shoulder muscle fatigue on throwing accuracy in amateur cricketers using surface electromyography (sEMG) and inertial measurement units (IMU).

Methods and Results

A total of 10-15 amateur players from Hong Kong local clubs, with at least one year of cricket experience and no recent upper limb injuries, will perform three sets of 10 maximal-velocity throws (20.14m distance) at a standardised target throwing setup, with 2–3-minute rests between sets.

sEMG (at 1000Hz) electrodes will be placed on infraspinatus, middle deltoid, and pectoralis major per SENIAM guidelines, processed for RMS amplitude and median frequency (MDF) to compute muscle-specific and global fatigue indices (baseline from first three throws). IMU sensors on the upper thoracic, arm, and forearm of the throwing arm will capture peak angular velocity as a velocity proxy. Throwing accuracy (0-5 scores) will be calculated after the completion of each set, whereas the rating of perceived exertion (RPE) in the Borg scale will be recorded before and after each set of the throwing task.

Throwing accuracy is hypothesised to drop with progressive fatigue, marked by increased RMS and RPE, decreased MDF value, and throwing velocity estimated from IMU sensors, due to disrupted neuromuscular control in overhead actions. These insights will inform targeted rehabilitation protocols to enhance fatigue resistance and reduce injury risk in recreational cricket.

STJ DECEMBER 2025
VOLUME 1, ISSUE 2

Student Sports Therapist Research Proposal Highlight 3

Effects of a 6-Week 1080 Sprint and Cable Training Programme on Bowling Performance, Eccentric Strength, and Deceleration Power in Elite Cricket Bowlers

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Introduction

Fast bowling in cricket is among the most physically demanding roles in the sport, requiring high power generation during the delivery stride and ball release. Consequently, sports-specific progressive eccentric training is essential for both injury prevention and performance enhancement. This study aims to quantify the impact of progressive eccentric training using 1080 Sprint and Cable on critical strength and deceleration components underpinning elite fast-bowling performance.

Methods and Results

A total of 10 elite male cricket players will participate in this study. This experimental study will compare the pre- and post-test changes in terms of (1) shoulder external rotation eccentric peak torque (N·m), (2) eccentric hamstring-to-concentric quadriceps strength ratio, and (3) lower-limb deceleration power (W) after the completion of a 6-week eccentric progressive training using Cable 1080 and Sprin devices. One-way repeated measures ANOVA and pairwise comparison to examine pre-post differences and the effect sizes (Cohen's *d*) with 95% confidence intervals will be observed.

This study can provide empirical evidence on the effect of progressive eccentric training using 1080 devices for enhancing the sports-specific performance and injury prevention.

DECEMBER 2025
VOLUME 1, ISSUE 2

Student Sports Therapist Research Proposal Highlight 4

Comparisons of Muscle Activities in Shoulder Overhead Exercises Using Aqua Bag Resistance with Different Tempos and Shapes

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Introduction

Overhead athletes are highly demanded for shoulder and core stabilization to optimize the high-speed overhead throwing tasks. Traditional overhead lifting exercises using a barbell or dumbbells mostly address the prime movers without challenging the reactive and feedback control of the shoulder girdle. An aqua bag can be an alternative training equipment to potentially provide an unpredictable perturbation, and hence a higher demand on the activation of scapular, shoulder, and trunk stabilization muscles, in the overhead lifting tasks. Due to the very limited studies in this regard, the project aims to compare the activities of selected scapular, shoulder, and trunk stabilisers during overhead lifting tasks using an aqua bag under different conditions.

Methods and Results

A total of 20-30 healthy, active young male adults (age 18-30) will participate in this study. After the maximum voluntary isometric contraction test on the target muscles, such as lower trapezius, serratus anterior, infraspinatus, and external oblique, participants will randomly perform aqua bag overhead lifting exercises using different shapes of aqua bag and movement tempos. The muscle activities will be observed by surface electromyography.

Two-way repeated measure ANOVA (shapes and tempos) will be applied to identify any interaction effect with a significance level set at $p<0.05$. Post-hoc pairwise comparison will be conducted to assess the magnitude of differences by using the effect size Cohen's d values.

STJ
DECEMBER 2025
VOLUME 1, ISSUE 2

Student Sports Therapist Research Proposal Highlight 5

Acute Effects of Hamstring Foam Rolling on the Viscoelastic Properties and the Flexibility of Superficial Back Line, and Vertical Jump Performance

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Introduction

Our hamstring muscles play important roles in producing explosive propulsive movements, including sprinting and vertical jumping, as well as force absorption in deceleration tasks. Besides, tight or hyperactive hamstring muscles can restrict normal anterior pelvic rotation and hip flexion that may potentially induce compensatory movements in other regions, such as the lumbar spine. Moreover, previous studies show strong evidence on the structure of several myofascial lines, such as the superficial back line (SBL). Meanwhile, foam rolling (FR) was shown to be an effective modality to increase the range of motion without negatively altering the jumping performance. Therefore, it is speculated that performing FR on the hamstring muscle can induce viscoelastic and flexibility changes in the target muscle, fascia, as well as certain near components along the SBL. Therefore, this project aims to investigate the effects of FR on the viscoelastic properties and flexibility of the SBL, as well as the vertical jump performance.

Methods and Results

A total of 34 healthy, active adults (age 18-40) with at least one year of jumping or sprinting sports experience will participate in this study. Subjects will be randomly assigned to the control (CON) and foam rolling intervention (FR) groups. The FR will perform foam rolling on the hamstring for a total of 90 seconds, while the CON will passively rest in a supine lying position with equivalent duration. Before and after the intervention, the pre- and post-tests, including viscoelastic properties (tone, stiffness, and elasticity) of the hamstring, gastrocnemius, and plantar fascia, will be measured by the handheld MyotonPRO, while the flexibility and range of motion will be assessed by the sit and reach test, knee to wall test, and 90/90 active knee extension test. The countermovement jump relevant parameters, such as jump height, peak power, and limb symmetry index, will be observed by the Hawkin Dynamics force plate.

The relative and absolute reliability will be verified using the intraclass correlation coefficient (ICC) and the standard error of measurement (SEM), respectively. One-way repeated measure ANOVA will be used to examine the pre-post differences, while one-way ANCOVA will be adopted to identify any between-group differences after using the baseline value as the covariate. Post-hoc pairwise comparison will be conducted to assess the magnitude of differences by using the effect size Cohen's d values.

DECEMBER 2025
VOLUME 1, ISSUE 2

Student Sports Therapist Research Proposal Highlight 6

Predictions of Running-Related Injuries Amongst Recreational Runners Using AI-Driven Mobile App for Running Analysis: The Machine Learning Approach

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Introduction

The use of marker-less motion capture, such as the artificial intelligence (AI) driven mobile app, has been widely used for tracking running posture. These mobile apps can offer recreational athletes a time-and cost-effective method for biomechanical assessment to monitor running kinematics and detection of severe deviations. In the long term, it may be a feasible solution for big data predictive analytics. However, research focusing on the use of machine learning (ML) algorithms to pool data from these mobile apps for injury prediction remains limited. Therefore, this study aims to 1) pool biomechanical parameters from video-based marker-less motion analysis using a selected mobile application, alongside demographic, training, and injury data through surveys to develop ML models for predicting lower limb RRIs; and 2) determine the most impactful predictors of RRIs.

Methods and Results

A total of 200 recreational runners aged 18 to 64 with experience ranging >3 months to <7 years, targeting Tier 0+ to 1 athletes according to McKay's classification. Participants will complete an online survey consisting of 19 questions for demographic information, training-related data, and injury history. Subjects will run on the treadmill embedded with plantar pressure sensors (Zebris FDM-T) at a pace just below their lactate threshold estimated by the talk test and the rating of perceived exertion for a total of 30 seconds. Running posture will be video filmed from the posterior and the lateral views with 1080p and 30 fps using an iPhone device. Running parameters will be extracted from the app Ochy.

Machine learning classifiers, including XGBoost, Random Forest, Support Vector Machine, and Artificial Neural Network, will be developed using the Scikit-learn package in Python 3. The model performance will be assessed by AUC-ROC, F1-score, model accuracy, precision, and recall. Shapley Additive exPlanations (SHAP) value will be used to identify the impactful predictors on the best-performing ML model.

DECEMBER 2025
VOLUME 1, ISSUE 2

Student Sports Therapist Research Proposal Highlight 7

Will Adding Dual- or Multi-tasking During Single-Leg Drop Landing Alter the Joint Kinematics, Kinetics, and the Risk of Ankle Injury?

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Introduction

Athletes frequently perform complex tasks that require processing visual, auditory, and various cognitive information, such as managing external distractions and making decisions instantly. Previous studies showed that adding a dual task to a landing activity can potentially alter movement patterns, postural control, and biomechanics that may potentially increase the risk of ankle sprain. The primary aim of this study is to examine the influence of performing single-leg drop landing under dual- or multi-tasking conditions.

Methods and Results

A total of 50 participants (25 males and 25 females) with at least 1 year of jumping sports experience will participate in this study. It is a repeated measure study that participants will perform four single-leg drop landing (SLDL) conditions (SLDL without a dual task as the CON, SLDL with an arithmetic cognitive task as D-COG, SLDL with a ball catching motor task as D-MOT, and the SLDL with both cognitive and motor tasks as the multi-task as the MUL). Joint kinematics such as knee valgus and hip flexion angles will be observed during the initial contact and the moment of maximum vertical ground reaction force (vGRF) by the inertial measurement units (IMU) sensors whereas the joint kinetics (e.g., vGRF) and time-to-stabilisation (TTS) will be assessed by the force plate. One-way repeated measures ANOVA with a significance level set at $p<0.05$ and pairwise comparison to examine the effect sizes (Cohen's d) with 95% confidence intervals will be observed.

This study can provide empirical evidence on the effect of adding dual- or multi-tasking (cognitive and/or motor tasks) to SLDL activities on biomechanical alterations and the risk of ankle sprain in terms of balance performance.