Original Paper

Biomedical Human Kinetics, 17, 164–172, 2025
DOI: 10.2478/bhk-2025-0016

Evaluating the acute impact of diagonal mobilization on knee flexor and extensor strength in young soccer players: a randomized double-blind trial

Rafał Studnicki[1,2], Urszula Tomaszewicz[2], Rita Hansdorfer-Korzon[1], Adam Kawczyński[3]

[1] Department of Physiotherapy, Medical University of Gdańsk, Poland; [2] Student Scientific Circle of Orthopaedic Manual Therapy, Medical University of Gdańsk, Gdańsk, Poland; [3] Department of Sport Science, University School of Physical Education in Wroclaw; Wrocław, Poland

Abstract

Study aim: This study aimed to assess the acute effects of manual therapy, focusing on knee, hip, and sacroiliac joint mobilization (DM), on knee extension (KE) and flexion (KF) strength in young soccer athletes, with the goal of determining the impact of these critical factors on performance.
Material and Methods: A randomized double-blind trial was conducted involving 32 regional-level soccer players aged 14 to 16. Participants were randomly allocated to either receive DM treatment or a placebo condition, serving as the control group. Assessments were conducted before and after intervention, measuring standing KE and KF strength using the ForceFrame Strength Testing System.
Results: Results following DM showed significantly better outcomes compared to the control condition for KE average force ($p = 0.002$), KE maximal force ($p = 0.032$), and KF maximal force ($p = 0.021$), while no significant difference was observed in KF average force ($p = 0.107$).
Conclusions: The results demonstrated significant improvements in both KE and KF strength following the DM intervention, highlighting its potential as a strategy to enhance athletic readiness and performance. This approach could be utilized before matches or training, particularly for athletes requiring individualized intervention, such as those recovering from injuries or in key moments of the season.

Keywords: Soccer – Musculoskeletal manipulations – Muscle strength dynamometer – Biomechanics

Introduction

In young soccer players, appropriate muscle strength in the knee extensors (KE) and flexors (KF) plays a pivotal role in ensuring physical readiness, enhancing physical performance (Jones et al., 2022), and mitigating the risk of injuries (Olivares-Jabalera et al., 2021). The KE, primarily comprising the quadriceps muscles, are crucial for actions such as kicking, sprinting, or jumping, which are fundamental components of soccer performance (Lehance et al., 2009). Optimal strength in these muscles enables players to generate greater force during movements, leading to improved acceleration and sprint, and overall athletic performance (Suchomel et al., 2016). Similarly, the KF, including the hamstring muscles, are vital for stabilizing the knee joint and controlling movements such as deceleration, cutting, and changing directions, all of which are integral to soccer movements (Arumugam & Häger, 2022). Insufficient strength in these muscles can compromise joint stability and increase susceptibility to injuries such as anterior cruciate ligament tears and hamstring strains, which are prevalent in soccer (Croisier et al., 2008).

Scientific research indicates that targeted strength interventions focusing on KE and KF not only enhance muscle strength but also contribute to neuromuscular coordination and proprioception, further reducing injury risk (Hubscher et al., 2010). Therefore, fostering appropriate muscle strength in KE and KF is paramount for optimizing physical readiness, elevating performance levels, and safeguarding the well-being of young soccer players (Śliwowski et al., 2021).

Author's address Rafał Studnicki, Department of Physiotherapy, Medical University of Gdańsk, 7 Dębinki Street, 80-211 Gdańsk, Poland rafal.studnicki@gumed.edu.pl

Acute interventions, such as manual mobilization, hold promise for enhancing muscle strength readiness in KE and KF among soccer players (Monteiro et al., 2021). Manual mobilization techniques, commonly administered by qualified therapists or trainers, involve targeted manipulation of soft tissues and joint structures to promote physiological adaptations conducive to improved muscle function (Weber et al., 2020). Scientific evidence suggests that manual mobilization can elicit acute changes in muscle architecture, enhancing muscle length, flexibility, and blood flow, consequently optimizing muscle readiness for subsequent physical activities (Weber et al., 2022).

Moreover, manual mobilization techniques have been shown to modulate neural excitability and proprioceptive feedback, potentially enhancing motor control and coordination in the targeted muscle groups (Bialosky et al., 2018). By promoting these acute physiological responses, manual mobilization interventions offer a viable strategy for priming KE and KF muscles, thereby enhancing muscle strength readiness and reducing injury risk in soccer players. For instance, a study conducted on young soccer players revealed that tissue mobilization improved athletic performance characteristics by decreasing fatigue and increasing fitness and muscle power. Specifically, the experimental group receiving soft tissue mobilization demonstrated significantly better knee extension and flexion at speeds of 60 and 180º/s (Kim & Yim, 2018). Moreover, manual therapies targeting the posterior thigh muscles have been shown to impact the ten-repetition maximum performance test. Monteiro et al. (2021) observed that participants achieved higher maximum load lifts in the ten-repetition maximum test after receiving manual massage and muscle energy interventions. Also, Ghanbari & Kamalgharibi (2013) explored mobilization effects on KE strength, leaving a gap in understanding the impacts of low-velocity diagonal mobilization on knee flexors and extensors in healthy soccer players.

Despite the research described, a gap exists in the literature concerning the immediate effects of diagonal mobilization (DM) on KE and KF strength in young soccer players. DM differs from other manual mobilization techniques due to its unique focus on multidirectional, cross-patterned movement that targets both the joint and surrounding soft tissues in a more dynamic, functional manner. Unlike traditional manual mobilization techniques, which often focus on isolating specific joints or muscle groups in a linear or static fashion, DM incorporates a diagonal approach that engages multiple planes of motion. This technique works across the body's natural movement patterns, mimicking the functional demands of sports such as soccer, where athletes frequently perform dynamic, multidirectional movements. DM targets the knee, hip, and sacroiliac joints, which are critical for stabilizing the lower extremities during high-intensity activities. By engaging these key joints in a coordinated manner, DM may enhance the neuromuscular coordination and proprioception of the KE and KF, improving overall muscle strength and joint stability. Thus, understanding the acute effects of DM on KE and KF strength could offer a more tailored, effective approach for optimizing athletic performance and injury prevention in soccer players. Thus, this study aimed to assess the acute effects of manual therapy, focusing on knee, hip, and sacroiliac joint mobilization (DM), on knee extension (KE) and flexion (KF) strength in young soccer athletes, with the goal of determining the impact of these critical factors on performance.

The findings from this study may have important practical applications in both training and rehabilitation for soccer players. By showing the acute effects of DM on KE and KF strength, this intervention could be incorporated into pre-training or pre-match routines to optimize muscle readiness and improve performance. For example, implementing DM as part of a warm-up may enhance strength, joint mobility, and neuromuscular coordination, better preparing athletes for high-intensity movements.

Material and methods

Study design

Employing a double-blind randomized controlled design, the present study ensured that both participants and evaluators remained unaware of the intervention allocation. Randomization took place prior to the initial assessment, preserving allocation concealment, and was facilitated through a simple randomization method via the research randomizer website. The randomization was performed by a member of the research team who was blinded to the interventions and did not participate in data collection or treatment administration. Throughout the study, evaluators were kept blind to participants' group assignments, maintaining the integrity of the blinding process. The intervention involved a single session wherein participants in the DM experimental group received authentic manual therapy, while those in the control group underwent a simulated intervention. In the simulated intervention, therapists replicated the placement of hands on the same contact point used during active mobilization, mimicking real mobilization with minimal movement (1st degree).

Sample size, eligibility criteria and recruitment

Determination of the sample size a priori was conducted using G*Power software (version 3.1.9.6., Universität Düsseldorf, Germany). This entailed setting a power of 0.85 for a two-group ANOVA repeated measures design, considering two evaluations, within-between interaction, an effect size of 0.3 (medium), and a significance level of 0.05. The outcome of this process recommended a sample size of 28 individuals.

Recruitment efforts were centered at the Varsovia Football Academy within the Central Junior League, employing a method of convenience sampling. Initially, a pool of 50 potential participants was identified and screened against eligibility criteria. These criteria encompassed: (i) individuals aged between 14 to 16 years old, engaging in regular soccer practice; (ii) absence of lower limb and lumbar spine surgery or injuries within the preceding 6 months (pertaining to the hip, knee, ankle), absence of current pain in these joints, no hypermobility of the lower limb joints, and no history of neurological or connective tissue disorders; and (iii) availability for both assessment time points. Following the exclusion of 12 participants based on age criteria and 6 due to recent injuries within the last month, a total of 32 participants were deemed eligible for random assignment to study groups (Fig. 1).

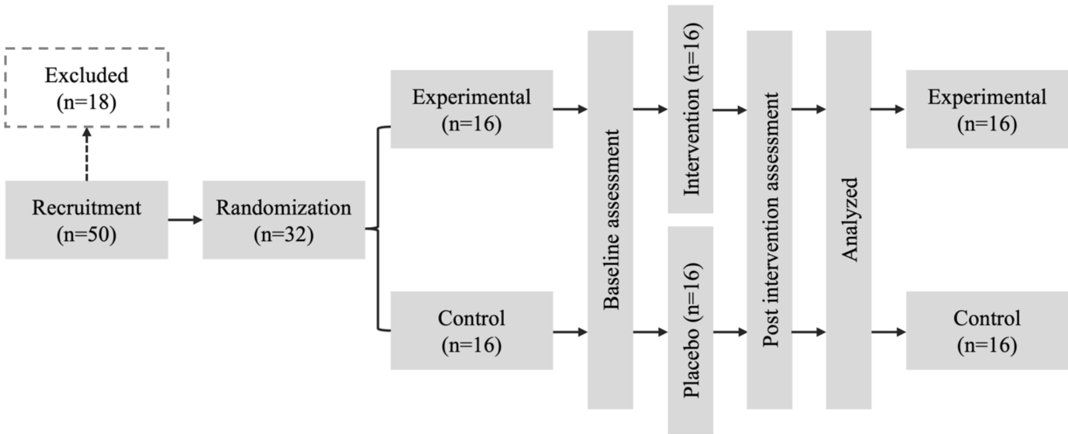

Figure 1. Participants flowchart

Participants

Thirty-two young football players, comprising both males and females, with an average age of 15.0 ± 0.9 years, who were actively competing at the regional level, chose to participate in the study on a voluntary basis. These participants committed themselves to a schedule that included three weekly training sessions in addition to a weekend match. Each training session, lasting between 80 to 90 minutes, encompassed a sequence of activities starting with general physical conditioning, followed by individual technical training, and concluding with tactical exercises.

Ethical requirements

Approval for the study was granted by the Independent Bioethics Committee for Scientific Research at the Medical University of Gdańsk (approval dated July 7, 2023, Resolution No. NKBBN 392/2023), in conjunction with the AZS Central Academic Sports Center in Gdańsk. Prior to their involvement, participants received a detailed overview of the study's purpose, procedures, and protocols. Written informed consent was procured from either the parent or legal guardian of each participant. The study followed the ethical principles for human research as outlined in the Declaration of Helsinki.

Training intervention

In the context of the study, a single intervention session was administered to participants, preceded by pre-intervention evaluation and immediately followed by post-intervention assessment. These sessions consistently occurred on the same weekday, following a 48-hour rest period to ensure reproducibility. Participants underwent an active intervention (DM) involving passive rhythmic gliding mobilization, aiming to enhance planned mobility.

Before the intervention, participants received verbal instructions regarding the procedure. The active intervention comprised diagonal mobilization, incorporating a three-dimensional movement pattern to enhance mobility. The intervention protocol involved the participant assuming a supine position with the upper limbs positioned along the torso. The therapist executed mobilization on the upper ankle joint by sliding the calcaneus in the direction of valgus (laterally, cranially, ventrally) and mobilization of the knee joint by sliding the proximal tibia to improve internal rotation (medially, cranially, dorsally). In the pronated position, mobilization of the hip joint was conducted by sliding the femoral head (ventrally, medially, cephalad), and mobilization of the sacroiliac joint was performed by sliding the sacrum to improve nutation (ventrally, cephalad, laterally). Each diagonal glide was executed in stage II until tissue tension was achieved, ensuring that the participant experienced the sensation of tissue tension before releasing it. The therapist ensured that the participant remained comfortable throughout and conducted mobilization for a duration of 2 minutes. The duration of 2 minutes per mobilization was selected to provide sufficient time for the targeted joints and tissues to experience the necessary level of tension, allowing the mobilization to be effective in enhancing mobility without causing discomfort. This duration also strikes a balance between providing enough time to achieve the desired effects on muscle strength and performance, while minimizing fatigue or overstimulation in young soccer athletes. The therapeutic procedure was performed once for each subject, with a total therapy time of 8 minutes.

Participants in the placebo group received verbal instructions and were positioned identically to those in the active intervention, ensuring consistency in the setting. The therapist placed their hands on the same anatomical landmarks as in the DM intervention but performed only minimal movements (i.e., 1st degree mobilization), which did not elicit the same tissue tension or therapeutic effect as the active mobilization. This approach ensured that the placebo group experienced a similar tactile sensation and procedural steps as the experimental group, while preventing any significant physiological response. The therapist also maintained the same duration of 8 minutes for both active and placebo interventions, ensuring consistency across sessions. By implementing this placebo technique, the study aimed to control for potential psychological effects while isolating the specific impact of the diagonal mobilization on knee extension and flexion strength (Gómez et al., 2020).

Assessment procedures

The evaluation took place both 5 minutes before and after the intervention, all conducted on the same day and in a tranquil setting. The room was maintained at a temperature of 23ºC and relative humidity of 55%, regulated by an air conditioning system. Initially, demographic and anthropometric information was gathered from the participants. Following this, participants were provided with a thorough verbal elucidation of the study's procedures. An initial practice run of the test, without recording results, was allowed. To ensure a balanced comparison and control for potential limb differences, the limb selection for assessment was randomized, allowing for a fair representation of each participant's strength and performance. This randomization was implemented to minimize bias and ensure that any observed effects were not influenced by natural asymmetries between limbs. Selection of the limb for assessment was randomized using a "coin toss" method (Prior et al., 2014). Supervision of the tests was carried out by two members of the research team. They ensured adherence to the prescribed testing sequence and offered verbal encouragement to the volunteers throughout the evaluations. Subsequently, the collected data were uploaded onto a digital platform. Consistency prevailed in the sequence of assessments for all participants, beginning with the KE standing assessment, which involved three contractions lasting 5 seconds each with a 30-second rest period between each contraction. Subsequently, participants proceeded to the KF standing assessment, also consisting of three contractions lasting 5 seconds each with a 30-second rest period between contractions.

Assessment isometric knee strength

Participants underwent testing using the ForceFrame Strength Testing System (Vald Performance Brisbane, Australia) to evaluate the KE and KF muscles. For the KE assessment, participants stood on the non-tested leg while the other leg, bent at a 30° angle, was positioned in the dynamometer's center to measure force using 50 Hz sensors. The KF assessment was conducted with participants in a standing position and the knee flexed at 30°, with the front part of the lower leg placed in the dynamometer's center to record force using 50 Hz sensors, while the opposite leg remained straight and acted as the supporting limb.

Each movement (KE and KF) underwent maximum voluntary contractions, consisting of three five-second trials with a 30-second rest period between repetitions. Data on maximum force (N) and average force (N), for both limbs, were collected for analysis. The average of the three recorded values was considered the result for each participant and subsequently uploaded to the VALD ForceFrame digital platform (Wrona et al., 2023).

Statistical analysis

The evaluation of the sample distribution's normality was conducted and confirmed utilizing the Kolmogorov-Smirnov test (with a p-value > 0.05). Moreover, the homogeneity assumption was validated via Levene's test (again with a p-value > 0.05). Considering the study's framework, which encompasses two evaluations across three distinct groups, a mixed ANOVA was deployed to explore the interactions between time and groups. Additionally, within this analysis, partial eta squared (η_p^2) was calculated to gauge effect sizes. Furthermore, after this analysis, post-hoc comparisons were made utilizing the Bonferroni test. Effect size was calculated using Cohen's standardized effect size. The magnitude of the effect size (ES) was interpreted using the following thresholds: trivial (< 0.02), small (0.2-06), medium (0.6-1.2), and large (>1.2). The statistical computations were conducted using JASP software (version 0.18.3, University of Amsterdam, The Netherlands), with a predetermined significance level set at $p < 0.05$.

Results

Pre-intervention assessments revealed no significant between-group differences for KE average force ($F_{1,30} = 1.333$; $p = 0.257$; $\eta_p^2 = 0.043$), KF average force ($F_{1,30} = 2.517$; $p = 0.123$; $\eta_p^2 = 0.077$), and KF maximal force ($F_{1,30} = 0.240$; $p = 0.628$; $\eta_p^2 = 0.008$), although a significant difference was found for KE maximal force ($F_{1,30} = 9.864$; $p = 0.004$; $\eta_p^2 = 0.247$). Table 1 presents the descriptive statistics of the groups for both pre- and post-intervention assessments.

Significant time × group interactions were found in KE average force ($F_{1,30} = 28.768$; $p < 0.001$; $\eta_p^2 = 0.490$), KE maximal force ($F_{1,30} = 47.060$; $p < 0.001$; $\eta_p^2 = 0.611$), KF average force ($F_{1,30} = 14.916$; $p < 0.001$; $\eta_p^2 = 0.332$), and KF maximal force ($F_{1,30} = 5.218$; $p = 0.030$; $\eta_p^2 = 0.148$).

Table 1. Descriptive statistics (mean ± standard deviation) of the kinematic variables obtained pre and post intervention

	Experimental group (n = 16)	Control Group (n = 16)	EG vs. Control
KE average force (N)			
Pre	314.7 ± 69.1	344.6 ± 77.1	ES = 0.409, small
Post	393.1 ± 90.4	299.5 ± 61.5	ES = 1.232, large
Post vs. pre ES	ES = 0.983, moderate	ES = 0.651, moderate	
KE maximal force (N)			
Pre	282.4 ± 66.4	360.4 ± 73.8	ES = 1.113, moderate
Post	384.7 ± 90.0	320.8 ± 69.3	ES = 0.802, moderate
Post vs. pre ES	ES = 1.308, large	ES = 0.553, small	
KF average force (N)			
Pre	174.3 ± 58.2	214.6 ± 83.5	ES = 0.569, moderate
Post	249.0 ± 85.3	198.2 ± 87.2	ES = 0.589, moderate
Post vs. pre ES	ES = 1.041, moderate	ES = 0.192, trivial	
KF maximal force (N)			
Pre	223.6 ± 82.0	209.1 ± 85.3	ES = 0.173, trivial
Post	264.1 ± 77.2	198.0 ± 76.8	ES = 0.858, moderate
Post vs. pre ES	ES = 0.509, small	ES = 0.137, trivial	

KE: knee extension; KF: knee flexion; ES: effect size; EG: experimental group

Post-intervention assessments revealed significant differences between groups in KE average force ($F_{1,30}$ = 11.740; p = 0.002; η_p^2 = 0.281), KE maximal force ($F_{1,30}$ = 5.070; p = 0.032; η_p^2 = 0.145), and KF maximal force ($F_{1,30}$ = 5.910; p = 0.021; η_p^2 = 0.165), although no significant difference was found for KF average force ($F_{1,30}$ = 2.768; p = 0.107; η_p^2 = 0.084).

Within-experimental group analysis (post-pre) revealed significant differences in KE average force (78.4 N; p < 0.001), KE maximal force (102.3 N; p < 0.001), KF average force (74.7 N; p < 0.001), and KF maximal force (40.6 N; p = 0.017). Within-group analysis of the control group revealed significant differences in KE average force (45.1 N; p = 0.010) and KE maximal force (39.6 N; p = 0.011), although no significant differences in KF average force (16.4 N; p = 0.334) and KF maximal force (11.1 N; p = 0.494) were found. Figures 2 and 3 illustrate the within- and between-group analysis.

Discussion

The findings from our experimental study revealed that soccer players exposed to DM significantly benefited from acute effects on both average and maximal force in both KE and KF. Furthermore, comparisons between groups also revealed that, in KE strength, the experimental group demonstrated significantly better results than the control group after the intervention. However, no significant differences between groups were found in KF strength after the intervention. The results of this study support the initial hypothesis, demonstrating that grade II diagonal mobilization of the ankle, knee, hip, and sacroiliac joints leads to an immediate post-intervention increase in both average torque and maximum strength of KE compared to the placebo technique (grade I), as well as producing significant improvements in the experimental group in KE and KF. This highlights the potential effectiveness of such mobilization techniques in enhancing muscle readiness, shedding light on possible immediate performance enhancement in soccer players.

While not specifically investigated in sport athletes, our findings are consistent with a study by Ghanbari & Kamalgharibi (2013), which aimed to improve KE muscle strength following mobilization of the knee joint. The authors noted an 18.7% increase in KE muscle strength from pre- to post-intervention assessments. This strength elevation further rose to 23.6% after a 30-minute interval.

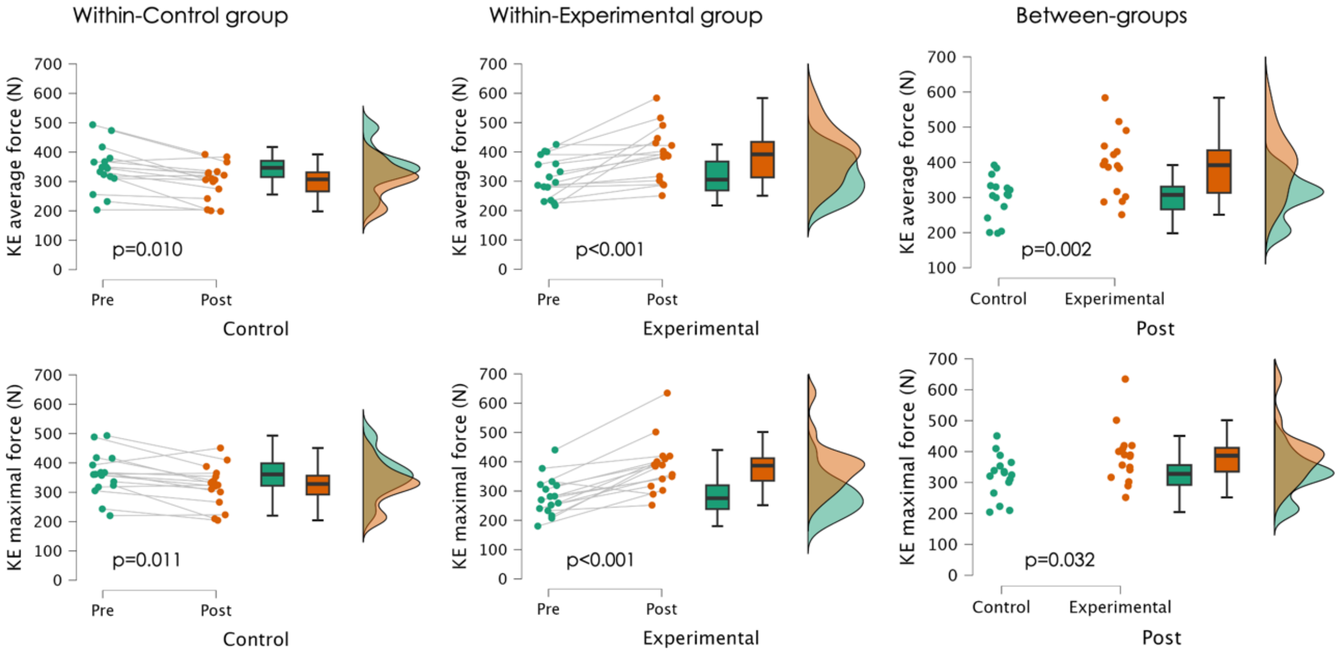

Figure 2. Descriptive statistics of within- and between-group analysis for knee extension (KE) measures

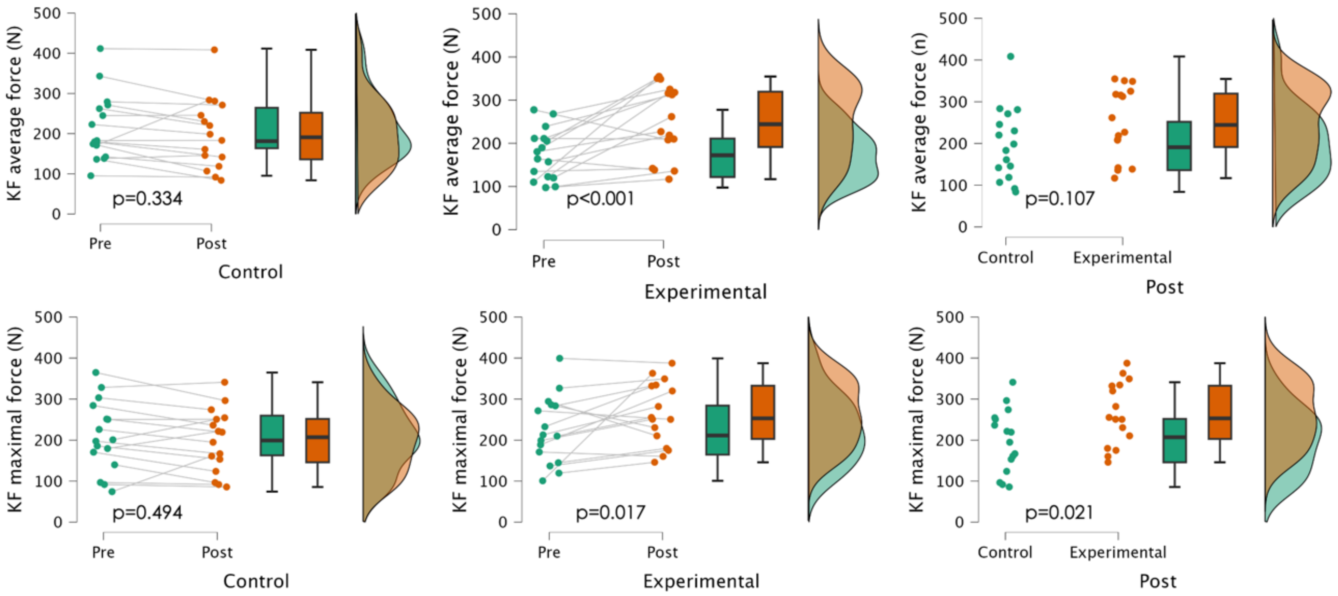

Figure 3. Descriptive statistics of within- and between-group analysis for knee flexion (KF) measures

Similarly, in another study (Pfluegler et al., 2021) investigating the impacts of various low-velocity hip mobilization techniques in healthy individuals, positive effects on gluteal muscle strength were observed immediately after mobilization, albeit with variations in the reported magnitude of change. Subjects exhibited a significant average increase in eccentric iliac muscle strength by 7.73% (Pfluegler et al., 2021). Additionally, a study focusing on hip joint mobilization in patients with knee injuries demonstrated a 15.3% enhancement in gluteus maximus muscle strength (Silva Neto et al., 2019).

The activation of mechanoreceptors during DM, such as Pacinian corpuscles and Golgi tendon organs, likely facilitated proprioceptive feedback that enhanced motor control and muscle activation in the KE muscles. This increased neural input could have optimized the recruitment of motor units, resulting in more efficient force production and improved KE strength. Furthermore, the reflex arcs stimulated by DM, including both spinal and supraspinal pathways, might have contributed to the heightened muscle activation seen in the KE group. To elucidate the underlying mechanisms driving these enhancements, it is imperative to explore the complex interaction between joint mobilization and neuromusculoskeletal physiology. Joint mobilization techniques, such as grade II DM, are theorized to exert neurophysiological effects by modulating afferent input from joint mechanoreceptors (Gyer et al., 2019). These specialized sensory receptors, including Pacinian corpuscles, Ruffini endings, and Golgi tendon organs, relay crucial information regarding joint position, movement, and tension to the central nervous system (Efstathiou et al., 2022).

Upon application of grade II DM, the stimulation of these mechanoreceptors elicits proprioceptive feedback that may influence motor control and muscle activation patterns (Hertel, 2002). This phenomenon may facilitate the optimization of neural pathways associated with muscle recruitment, resulting in more efficient force production during dynamic movements such as KE and KF (Needle et al., 2014). Furthermore, the mobilization-induced stimulation of mechanoreceptors may trigger neuroplastic changes within the central nervous system (Kaminski et al., 2007), including synaptic plasticity and cortical reorganization.

For instance, Cibulka et al. (1986) effectively mobilized the dysfunctional sacroiliac joint, restoring the normal length-to-tension relationship of the KF tendons and consequently amplifying the primary torque produced. The findings from Cleland et al.'s study (2004) revealed a significantly larger increase in lower trapezius muscle strength in the thoracic spine manipulation group (14%) than the control group (3%). Disruptions in mechanoreceptor functionality can both facilitate and inhibit muscle activity concurrently, resulting in non-functional muscle activity that may exacerbate dysfunction within the knee joint in such cases (Buckthorpe, 2021).

Another mechanism that may explain our results is associated with the possibility that joint mobilization techniques activate reflex arcs involving both spinal and supraspinal pathways (Gyer et al., 2019). By stimulating mechanoreceptors, grade II DM initiates reflexive muscle contractions via monosynaptic or polysynaptic pathways, thereby leading to heightened muscle activation and force generation (Riemann et al., 2002). Moreover, the activation of reflex arcs facilitates reciprocal inhibition of antagonist muscles, fostering optimal muscle coordination and power output during movements (Zehr, 2006). Another crucial aspect of grade II DM is its potential to modulate muscle tone through alterations in alpha motor neuron excitability and muscle spindle sensitivity (Myers & Lephart, 2000).

The lack of significant effects on KF strength after DM could be explained by the fact that the mobilization technique used in this study primarily targeted the structures associated with KE, with less emphasis on the specific neurophysiological mechanisms that influence KF strength. Since the KE muscles are more directly engaged in dynamic movements such as kicking and sprinting in soccer, the acute effects of mobilization may have been more pronounced in these muscles. Another potential hypothesis is that the KF muscles, particularly the hamstrings, may require different mobilization strategies or more focused interventions to achieve similar improvements in strength. Additionally, the duration and intensity of the DM intervention might not have been sufficient to elicit significant changes in KF strength, as the mobilization protocol was more generalized across multiple joints.

Despite the findings of our experimental study, some limitations warrant acknowledgment and suggest directions for future research. One limitation is the focus solely on acute effects, without considering the longer-term impact of DM on muscle strength and performance. Without assessing the persistence of these effects, it is difficult to determine whether the observed improvements in KE and KF strength are transient or have lasting benefits. Additionally, the study sample consisted of young soccer players, which may limit the applicability of the results to athletes in different age groups, training levels, or sports. Future research should aim to include a more diverse range of participants to better understand how DM may affect various populations, including older athletes, those with different injury histories, or individuals from other sports requiring distinct movement patterns. Furthermore, the study did not explore the combined effects of DM with other interventions, such as dynamic stretching or post-activation potentiation, which could yield synergistic or antagonistic interactions. Investigating these combinations in future studies could help clarify the optimal application of DM for enhancing performance and preventing injury. Addressing these gaps will provide a more comprehensive understanding of the long-term and context-dependent effects of DM, enhancing its relevance to broader athletic populations.

The findings of our study suggest practical implications for practitioners working with soccer players or athletes in similar sports contexts. Incorporating grade II DM techniques into pre-competition warm-up routines may offer immediate benefits in enhancing KE and KF strength, potentially leading to improved performance during matches or training sessions. Practitioners should consider individual athlete characteristics, such as training status or context of intervention, when implementing DM protocols to maximize effectiveness.

Conclusions

In this study, acute improvements in knee extensor (KE) strength were noted among soccer players following grade II diagonal mobilization (DM), showing significant advantages over a control group. However, no significant differences in post-intervention knee flexor (KF) strength were found. Nonetheless, the experimental group demonstrated significant improvements across all outcomes compared to pre-intervention levels. Despite these findings, it is crucial to exercise caution in extrapolating results to different contexts, training statuses, and competitive levels. Practical implications indicate that integrating grade II DM into pre-competition warm-ups may augment both KE and KF strength, potentially leading to enhanced performance, taking into account individual athlete characteristics and training environments. Nevertheless, further research is necessary to evaluate long-term effects and refine intervention strategies for optimal outcomes.

Conflict of interest: Author state no conflict of interest

References

1. Arumugam, A., & Häger, C. K. (2022). Thigh muscle co-contraction patterns in individuals with anterior cruciate ligament reconstruction, athletes and controls during a novel double-hop test. *Scientific Reports*, *12*(1), 8431. https://doi.org/10.1038/s41598-022-12436-6
2. Bialosky, J. E., Beneciuk, J. M., Bishop, M. D., Coronado, R. A., Penza, C. W., Simon, C. B., & George, S. Z. (2018). Unraveling the Mechanisms of Manual Therapy: Modeling an Approach. *Journal of Orthopaedic & Sports Physical Therapy*, *48*(1), 8–18. https://doi.org/10.2519/jospt.2018.7476
3. Buckthorpe, M. (2021). Recommendations for Movement Re-training After ACL Reconstruction. *Sports Medicine*, *51*(8), 1601–1618. https://doi.org/10.1007/s40279-021-01454-5
4. Cibulka, M. T., Rose, S. J., Delitto, A., & Sinacore, D. R. (1986). Hamstring Muscle Strain Treated by Mobilizing the Sacroiliac Joint. *Physical Therapy*, *66*(8), 1220–1223. https://doi.org/10.1093/ptj/66.8.1220
5. Cleland, J., Selleck, B., Stowell, T., Browne, L., Alberini, S., St. Cyr, H., & Caron, T. (2004). Short-Term Effects of Thoracic Manipulation on Lower Trapezius Muscle Strength. *Journal of Manual & Manipulative Therapy*, *12*(2), 82–90. https://doi.org/10.1179/106698104790825284
6. Croisier, J.-L., Ganteaume, S., Binet, J., Genty, M., & Ferret, J.-M. (2008). Strength Imbalances and Prevention of Hamstring Injury in Professional Soccer Players. *The American Journal of Sports Medicine*, *36*(8), 1469–1475. https://doi.org/10.1177/0363546508316764
7. Efstathiou, M. A., Giannaki, C. D., Roupa, Z., Hadjisavvas, S., & Stefanakis, M. (2022). Evidence of distorted proprioception and postural control in studies of experimentally induced pain: a critical review of the literature. *Scandinavian Journal of Pain*, *22*(3), 445–456. https://doi.org/10.1515/sjpain-2021-0205
8. Ghanbari, A., & Kamalgharibi, S. (2013). Effect of knee joint mobilization on quadriceps muscle strength. *Int J Health Rehabil Sci*, *2*(4), 186–191.
9. Gómez, F., Escribá, P., Oliva-Pascual-Vaca, J., Méndez-Sánchez, R., & Puente-González, A. S. (2020). Immediate and Short-Term Effects of Upper Cervical High-Velocity, Low-Amplitude Manipulation on Standing Postural Control and Cervical Mobility in Chronic Nonspecific Neck Pain: A Randomized Controlled Trial. *Journal of Clinical Medicine*, *9*(8), 2580. https://doi.org/10.3390/jcm9082580
10. Gyer, G., Michael, J., Inklebarger, J., & Tedla, J. S. (2019). Spinal manipulation therapy: Is it all about the brain? A current review of the neurophysiological effects of manipulation. *Journal of Integrative Medicine*, *17*(5), 328–337. https://doi.org/10.1016/j.joim.2019.05.004
11. Hertel, J. (2002). Functional Anatomy, Pathomechanics, and Pathophysiology of Lateral Ankle Instability. *Journal of Athletic Training*, *37*(4), 364–375.
12. Hubscher, M., Zech, A., Pfeifer, K., Hansel, 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
13. Jones, P. A., Dos'Santos, T., McMahon, J. J., & Graham-Smith, P. (2022). Contribution of Eccentric Strength to Cutting Performance in Female Soccer Players. *Journal of Strength and Conditioning Research*, *36*(2), 525–533. https://doi.org/10.1519/JSC.0000000000003433
14. Kaminski, T. W., Kahanov, L., & Kato, M. (2007). Therapeutic Effect of Joint Mobilization: Joint Mechanoreceptors and Nociceptors. *Athletic Therapy Today*, *12*(4), 28–31. https://doi.org/10.1123/att.12.4.28
15. Kim, J., & Yim, J. (2018). Instrument-assisted Soft Tissue Mobilization Improves Physical Performance of Young Male Soccer Players. *International Journal of Sports Medicine*, *39*(12), 936–943. https://doi.org/10.1055/a-0649-1074
16. Lehance, C., Binet, J., Bury, T., & Croisier, J. L. (2009). Muscular strength, functional performances and injury risk in professional and junior elite soccer players. *Scandinavian Journal of Medicine & Science in Sports*, *19*(2), 243–251. https://doi.org/10.1111/j.1600-0838.2008.00780.x
17. Monteiro, E. R., Victorino, A., Muzzi, R., de Oliveira, J. C., & Cunha, M. (2021). Manual Therapies for Posterior Thigh Muscles Enhanced Ten-Repetitions Maximum Test Performance and Hip Flexibility in Young Soccer Players. *Perceptual and Motor Skills*, *128*(2), 766–780. https://doi.org/10.1177/0031512520983683
18. Myers, J. B., & Lephart, S. M. (2000). The role of the sensorimotor system in the athletic shoulder. *Journal of Athletic Training*, *35*(3), 351–363.
19. Needle, A. R., Baumeister, J., Kaminski, T. W., Higginson, J. S., Farquhar, W. B., & Swanik, C. B. (2014). Neuromechanical coupling in the regulation of muscle tone and joint stiffness. *Scandinavian Journal of Medi-*

cine & Science in Sports, *24*(5), 737–748. https://doi.org/10.1111/sms.12181
20. Olivares-Jabalera, J., Fílter-Ruger, A., Dos'Santos, T., Afonso, J., Della Villa, F., Morente-Sánchez, J., Soto-Hermoso, V. M., & Requena, B. (2021). Exercise-Based Training Strategies to Reduce the Incidence or Mitigate the Risk Factors of Anterior Cruciate Ligament Injury in Adult Football (Soccer) Players: A Systematic Review. *International Journal of Environmental Research and Public Health*, *18*(24), 13351. https://doi.org/10.3390/ijerph182413351
21. Pfluegler, G., Borkovec, M., Kasper, J., & McLean, S. (2021). The immediate effects of passive hip joint mobilization on hip abductor/external rotator muscle strength in patients with anterior knee pain and impaired hip function. A randomized, placebo-controlled cross-over trial. *Journal of Manual & Manipulative Therapy*, *29*(1), 14–22. https://doi.org/10.1080/10669817.2020.1765625
22. Prior, S., Mitchell, T., Whiteley, R., O'Sullivan, P., Williams, B. K., Racinais, S., & Farooq, A. (2014). The influence of changes in trunk and pelvic posture during single leg standing on hip and thigh muscle activation in a pain free population. *BMC Sports Science, Medicine and Rehabilitation*, *6*(1), 13. https://doi.org/10.1186/2052-1847-6-13
23. Riemann, B. L., Myers, J. B., & Lephart, S. M. (2002). Sensorimotor system measurement techniques. *Journal of Athletic Training*, *37*(1), 85–98.
24. Silva Neto, J. B., Ismania, C., de Freitas, D. G., Cazarini Jr, C., Martin, R. L., & Fukuda, T. Y. (2019). The effect of a single high velocity low amplitude hip mobilization on strength in subjects with knee injuries. *Musculoskeletal Science and Practice*, *44*, 102051. https://doi.org/10.1016/j.msksp.2019.102051
25. Śliwowski, R., Marynowicz, J., Jadczak, Ł., Grygorowicz, M., Kalinowski, P., & Paillard, T. (2021). The relationships between knee extensors/ flexors strength and balance control in elite male soccer players. *PeerJ*, *9*, e12461. https://doi.org/10.7717/peerj.12461
26. Suchomel, T. J., Nimphius, S., & Stone, M. H. (2016). The Importance of Muscular Strength in Athletic Performance. *Sports Medicine*, *46*(10), 1419–1449. https://doi.org/10.1007/s40279-016-0486-0
27. Weber, P., Graf, C., Klingler, W., Weber, N., & Schleip, R. (2020). The feasibility and impact of instrument-assisted manual therapy (IAMT) for the lower back on the structural and functional properties of the lumbar area in female soccer players: a randomised, placebo-controlled pilot study design. *Pilot and Feasibility Studies*, *6*(1), 47. https://doi.org/10.1186/s40814-020-00592-3
28. Weber, P., Klingler, W., Schleip, R., Weber, N., & Joisten, C. (2022). The Influence of a Single Instrument-Assisted Manual Therapy (IAMT) for the Lower Back on the Structural and Functional Properties of the Dorsal Myofascial Chain in Female Soccer Players: A Randomised, Placebo-Controlled Trial. *Journal of Clinical Medicine*, *11*(23), 7110. https://doi.org/10.3390/jcm11237110
29. Wrona, H. L., Zerega, R., King, V. G., Reiter, C. R., Odum, S., Manifold, D., Latorre, K., & Sell, T. C. (2023). Ability of Countermovement Jumps to Detect Bilateral Asymmetry in Hip and Knee Strength in Elite Youth Soccer Players. *Sports*, *11*(4), 77. https://doi.org/10.3390/sports11040077
30. Zehr, E. P. (2006). Training-induced adaptive plasticity in human somatosensory reflex pathways. *Journal of Applied Physiology*, *101*(6), 1783–1794. https://doi.org/10.1152/japplphysiol.00540.2006

Received 20.08.2024
Accepted 14.04.2025