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Section I – Kinesiology

Bilateral, Unilateral, and Split-Load Leg Press Relation to Prime Movers Muscles Net Force

by
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This study examined whether isokinetic strength of the hip and knee muscles would influence one-repetition maximum (1RM) performance across bilateral, unilateral, and split-load leg press variations. Thirty-one resistance-trained males underwent isokinetic testing of hip extensors and knee flexors/extensors, followed by the assessment of 1RM performance in multiple leg press modalities of a 45° plate-loaded linear leg press. Pearson correlations and multiple regression analyses were employed to explore predictive relationships between muscular force and 1RM outcomes. Significant correlations were found between dominant leg knee flexor strength and 1RM performance in the bilateral ($r = 0.495$, $p < 0.01$), the split-load ($r = 0.473$, $p < 0.01$), and the unilateral dominant leg press ($r = 0.481$, $p < 0.01$). Non-dominant knee extensor strength also correlated with 1RM across all modalities ($r = 0.408–0.448$, $p < 0.05$). Multiple regression analysis identified dominant knee flexor force as the strongest predictor of bilateral 1RM ($\beta = 0.895$, $p = 0.017$, $R^2_{adj} = 0.291$). For the unilateral non-dominant leg press, the combined strength of non-dominant knee flexors and extensors significantly predicted performance ($\beta = 0.631$, $p = 0.046$, $R^2_{adj} = 0.227$). Split-load performance was best explained by dominant knee flexor ($\beta = 0.473$, $p = 0.007$) and non-dominant extensor force ($\beta = 0.728$, $p = 0.026$). Non-dominant hip extensor strength showed moderate correlation with unilateral 1RM ($r = 0.398$, $p < 0.05$), but was not a significant predictor. These findings underscore the leg press as a knee-dominant exercise and highlight the importance of balanced strength development across limbs and muscle groups.

Keywords: *leg press biomechanics; isokinetic strength; knee extensor contribution; unilateral and bilateral force production*

Introduction

Muscular strength significantly influences performance in resistance exercises, playing a crucial role in both athletic performance and rehabilitation settings (Townsend, 2022). Among various resistance exercises, the leg press is particularly beneficial due to its versatility and effectiveness in targeting multiple lower limb muscle groups, such as the quadriceps, hamstrings, and gluteal muscles (Martín-Fuentes et al., 2022). By adjusting foot placement and employing variations such as bilateral, unilateral, or split-load techniques, athletes and clinicians can specifically target muscle imbalances, promoting balanced muscular development and minimizing injury risk (Escamilla et al., 2001). Furthermore, the leg press is frequently recommended as a safer alternative to squats, particularly for individuals with back issues or limited mobility, due to its ability to provide greater support and reduced spinal loading (Escamilla et al., 2001).

Understanding the distinctions between bilateral, unilateral, and split-load leg presses is essential to comprehensively investigate their relationship with isokinetic force measures. The bilateral leg press involves simultaneous use of both legs on a single platform, maximizing overall

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force output but potentially masking individual limb strength imbalances (Jones and Bampouras, 2010). In contrast, unilateral leg press exercises target each limb separately, allowing precise assessment and correction of asymmetrical strength development, thus reducing injury risks linked to muscular imbalances (McCurdy et al., 2005). The split-load leg press, involving simultaneous but independent loading for each leg, uniquely combines elements of bilateral and unilateral training. It requires coordinated movement and balanced strength distribution, effectively highlighting functional disparities between limbs that may not be evident during purely bilateral or unilateral exercises (Zhao et al., 2023).

From a biomechanical perspective, knee extensors are the principal contributors to force production during leg press movements. Their large physiological cross-sectional area, an advantageous lever arm, and high force-generating potential make them a dominant muscle group in both the initiation and the completion of the concentric phase of the lift. Electromyographic analyses have consistently demonstrated high quadriceps activation across leg press variants, confirming their central role in load displacement and movement control (Escamilla et al., 2001; Martín-Fuentes et al., 2020). Moreover, the relatively constrained range of motion used in the leg press—particularly the 90° knee flexion adopted in this study—further accentuates quadriceps involvement while limiting compensatory hip extension strategies (Hahn, 2011). Given this biomechanical profile, it is plausible that knee extensor strength would be a critical determinant of 1RM performance across bilateral, unilateral, and split-load leg press variations. Despite this, the extent to which isolated knee extensor force correlates with or predicts performance in different leg press modalities has not been fully investigated.

Hip and knee muscle force can significantly impact one-repetition maximum (1RM) performance in leg press exercises due to their crucial roles in generating force, providing joint stability, and maintaining optimal biomechanical alignment throughout the movement (Martín-Fuentes et al., 2020). The hip extensors are essential for controlling substantial hip flexion angles and contribute to effective force transfer during the concentric phase of the leg press (Martín-Fuentes et al., 2020). Considering the biomechanical complexity of leg press variations—bilateral, unilateral, and split-load—it is essential to clarify how force in the hip and knee might influence 1RM performance. It is unclear whether balanced strength between knee extensors and flexors is necessary to achieve optimal force distribution, potentially reducing performance deficits and minimizing injury risks associated with strength asymmetries (Zhao et al., 2023). The present study aimed to fill this gap by investigating how the isokinetic force of hip extensors, knee flexors, and knee extensors influences one-repetition maximum performance in bilateral, unilateral, and split-load leg press exercises.

We hypothesized that hip and knee force would significantly impact 1RM performance in different leg press modalities. Examining these relationships would provide insight into the joint-specific force contributions underlying leg press performance and help clarify whether traditional bilateral testing adequately reflects the demands of more functionally complex lower-limb tasks. This understanding can inform both assessment strategies and exercise prescription for strength development and rehabilitation.

Methods

Design

This cross-sectional repeated-measures study included one familiarization session followed by two experimental sessions conducted in randomized order. During the familiarization session, participants underwent basic anthropometric measurements, practiced various leg press techniques of the 45° plate-loaded linear leg press by performing two sets of three repetitions for each method, received methodological instructions, and provided informed consent.

The experimental sessions took place at intervals of no less than 48 hours and no more than 72 hours apart. During each session, participants performed a series of exercises, including: unilateral leg press exercise with a dominant leg (determined via a behavioral questionnaire asking which leg participants preferred to use when kicking a ball), unilateral leg press exercise with a non-dominant leg, bilateral leg press exercise, split-load leg press exercise with both legs moving

simultaneously, isokinetic hip extension, knee flexion, and knee extension (Figure 1). In total, participants took part in three visits to the laboratory: one familiarization and two experimental sessions.

Participants

A total of 31 resistance-trained males were recruited for this investigation (age: 22 ± 4.2 years; body mass: 88.9 ± 20.2 kg; body height: 170 ± 22 cm). All participants had a minimum of one year of prior experience in strength training, including the leg press exercise, and were free from injuries for at least six months prior to enrolment. Participants were instructed to refrain from lower limb resistance training throughout the study duration while maintaining their habitual dietary and sleep patterns. Additionally, they were required to abstain from using any dietary supplements or stimulants 24 hours before testing.

Participation in the study was entirely voluntary, with individuals retaining the right to withdraw at any stage. Before signing an informed consent form, all participants were thoroughly briefed on the study's potential benefits and risks. This study was conducted following the principles of the Declaration of Helsinki, and approved by the Ethics Committee of the Charles University, Faculty of Physical Education and Sport, Prague, Czech Republic (approval code: SK104/2024, approval date: 04 October 2024). The required sample size for this study was determined a priori using G*Power software (version 3.1.9.3, Düsseldorf, Germany) for a linear multiple regression: fixed model, R^2 deviation from zero. Parameters included statistical power of 0.9, the level of significance of 0.05, and an effect size of r = 0.698. Based on these criteria, a minimum of 22 participants was required. The effect size used for the sample size calculation was derived from Jones and Bampouras (2010).

Methodology

Familiarization Session

During the familiarization session, participants signed written informed consent and received detailed instructions regarding the study's methodology. Following this the collection of anthropometric data began, including body mass, height, and pelvic width. The pelvic width was measured with the tape positioned at the *spina iliaca anterior superior*, and with the tape fully extended, the measurement was taken across the pelvis to the contralateral *spina iliaca anterior superior*. This width was used to standardize foot placement on the leg press machine. This session also included leg press exercise where participants were introduced to the leg press machine and familiarized themselves with all variations of the exercise protocol, executed at a 2-1-0-0 tempo. A metronome set at 60 beats per minute regulated the pace, participants were instructed to complete the eccentric phase in two seconds, pause for one second at a knee flexion angle of 90°—a position chosen due to its comparability to isolated knee extension in quadriceps activation (Alkner et al., 2000)—and then perform the concentric phase immediately. The pause was intended to alleviate the effect of cumulative elastic energy (Marcos-Pardo et al., 2019). In order to maintain knee flexion consistency across all trials, the adhesive tape was placed on the leg press machine in a 90° knee flexion position, as measured by a goniometer. The distance from the bottom frame to the tape's edge was recorded in centimetres for precise repositioning in subsequent sessions, ensuring uniformity in the range of motion across all conditions. Participants also practiced both unilateral and bilateral leg press exercises with independent footplate movement, ensuring that both legs moved simultaneously. This step was designed to familiarize participants with the equipment and movement patterns required for the experimental trials.

Experimental Sessions

Each experimental session commenced with a standardized warm-up. The general warm-up consisted of 10 min of stationary cycling at 100 W with a cadence of 80 revolutions per minute. This was followed by a specific warm-up tailored to the exercise performed in the session. Evidence suggests that combining general and specific warm-ups enhances strength performance, particularly in 1RM leg press assessments (Abad et al., 2011).

Leg Press Session

For sessions beginning with leg press testing, participants transitioned directly to the leg press machine following the general warm-up. The LAX Fitness Systems 45° plate-loaded linear leg

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press machine was used, positioning participants in a seated posture. To ensure biomechanical consistency, foot placement was standardized according to individual pelvic width, with adhesive markers on the footrest indicating the proper stance width. Participants were instructed to maintain an external foot rotation between 0° and 30°, aligning their heels with their glutes to promote optimal knee alignment and muscular activation. This setup aimed to enhance standardization, facilitating reliable data acquisition. The specific warm-up commenced with eight bilateral repetitions at 50% of estimated 1RM, initially approximated as 175% of body weight (Roitman, 1998). If participants completed these repetitions with in a fully controlled manner and with proper technique, the load for the subsequent warm-up set was increased to 70% of the estimated 1RM for three repetitions. If the proper technique condition was not met, the estimated 1RM was adjusted downward, recalculating from 175% to 150% of body weight. Rest intervals between warm-up sets ranged from 60 to 90 s, with a 3-min rest before the main trials. If participants reported fatigue, they received a longer rest interval or measurement was postponed for another day.

The first recorded trial in the bilateral leg press was performed at a resistance level derived from warm-up performance. If the selected weight did not match the participant's true 1RM, it was adjusted according to subjective effort, and additional attempts were conducted. Rest intervals of three to five minutes were implemented between trials, during which participants were encouraged to walk. A valid trial required strict adherence to the 2-1-0-0 tempo and a full descent to the predetermined 90° knee flexion checkpoint. In unilateral leg press trials with independent footplates, only trials demonstrating symmetrical movement of both legs, without visible discrepancies in force output, were included in the final analysis. The number of trials required to determine the 1RM was monitored. Participants required an average of 3.5 ± 1.2 trials for the unilateral dominant condition, 3.25 ± 0.9 for the unilateral non-dominant condition, 4.5 ± 1.5 for the split-load condition, and 3.5 ± 1.2 for the bilateral condition.

Isokinetic Session

If the experimental session commenced with isokinetic testing, participants proceeded directly to a structured warm-up on the isokinetic dynamometer (Humac Norm, Stoughton, MA, USA). The warm-up consisted of an initial repetition at 50% of perceived maximal effort, followed by a 30-s rest interval. This was succeeded by a trial at 70% of maximal effort, another 30-s rest interval, and a final familiarization trial at 100% of perceived effort to acclimate participants to testing conditions.

Isokinetic assessments were performed at an angular velocity of 60°/s, with three repetitions of knee flexion and extension using concentric contractions and three repetitions of hip extension incorporating both concentric and eccentric actions (Stastny et al., 2018). A two-minute recovery period followed the warm-up before maximal effort trials commenced. To ensure measurement accuracy, the limb's mass was recorded before each test to account for gravitational effects and isolate true torque values. Participants received verbal encouragement and real-time visual feedback on force-position curves to enhance motivation and maintain consistency. For knee flexion and extension, participants were seated, executing movements within a 0° to 90° range of motion. For hip extension assessments, participants assumed a prone position, with the exercising leg secured to the lever arm, the knee flexed at 90° and aligned with the seat edge. The lever arm rotated within a 5° to 75° range of motion (ROM). This protocol was based on prior research identifying optimal resistance settings for 1RM testing in individuals with overpronation, ensuring reliability and consistency in data collection (Taylor and Fletcher, 2013). The highest peak torque value recorded was used for subsequent analysis.

Statistical Analysis

All statistical analyses were conducted using SPSS (version 30.0, IBM, Chicago, IL, USA) and MATLAB R2023b software. A two-way ANOVA was conducted to examine differences between leg press and dynamometer performance measures. Descriptive statistics, including means and standard deviations (SD), were computed for all variables. A 95% confidence interval (CI) was calculated for all key outcomes. To evaluate the

influence of hip and knee muscle isokinetic force on 1RM performance across different leg press variations, the Pearson correlation two tailed test and a series of multiple backwards analyses were performed. The dependent variables were the 1RM bilateral leg press, the 1RM bilateral split-load leg press, the 1RM unilateral left (uni non-dominant) leg press, and the 1RM unilateral right (uni dominant) leg press, while the independent variables included knee flexion for the right leg (knee dominant FLX) and for the left leg (knee non-dominant FLX) along with knee extension for the right leg (knee dominant EXT) and for the left leg (knee non-dominant EXT) force, the hip concentric test for the left leg (hip non-dominant EXT CON), the hip concentric test for the right leg (hip dominant EXT CON), the hip eccentric test for the left leg (hip non-dominant EXT ECC), and the hip eccentric test for the right leg (hip dominant EXT ECC). The Gaussian distribution was initially verified by the Shapiro-Wilk test, and a normal distribution was ensured for all independent and dependent variables. In all analyses the level of statistical significance was set at $p < 0.05$. The ES, expressed as the Pearson's correlation coefficient, was interpreted as small ($r < 0.20$), moderate ($0.21 > r < 0.79$) or large ($r > 0.80$) (Cohen, 2013).

Results

Descriptive statistics of participants' outcomes are presented in Table 1. Normality was assessed with the Shapiro-Wilk test and results showed that except for the leg press results, all data were normally distributed ($p > 0.05$). Pearson correlation analysis showed a significant relationship between 1RM performance and isokinetic outcomes. Multiple backwards regression was performed to evaluate whether hip and knee force significantly predicted 1RM performance. Multicollinearity among predictors was assessed using tolerance and variance inflation factor (VIF) values. All VIF values were below the commonly accepted threshold of 10, with most ranging between 2.2 and 4.8, indicating low to moderate multicollinearity. Only one variable (peak knee flexion-dominant) showed a VIF above 6.5, which was considered acceptable given its biomechanical relevance. The tolerance values ranged from 0.15 to 0.45, supporting the independence of predictors. Two-way ANOVA revealed no significant differences between the 1RM performance in the bilateral connected and bilateral separated conditions ($p = 0.675$). Similarly, no significant differences were found between the unilateral 1RM performances of the dominant and non-dominant legs ($p = 1$). In contrast, isokinetic tests showed significant differences between the dominant and non-dominant legs for both knee extension and flexion tasks. However, no significant side-to-side differences were observed in hip extension performance under either concentric or eccentric conditions (Figure 1).

Significant correlations were observed between both knee non-dominant extensors force, knee dominant flexors force and 1RM in all types of leg press variations and between non-dominant hip extension and 1RM measured on the bilateral connected and unilateral non-dominant leg press, as shown in Table 2.

The backwards multiple regression model significantly predicted performance on the bilateral leg press 1RM. The final model (Model 2) was statistically significant ($F(7,23) = 2.762$) and explained 45.7% of the variance ($R^2_{adj} = 0.291$). Among the predictors, knee flexion on the dominant leg had a significant positive effect ($B = 3.058$, $SE = 1.19$, $\beta = 0.895$, $p = 0.017$), while knee flexion on the non-dominant leg had a negative but non-significant effect ($B = -2.026$, $SE = 1.059$, $\beta = -0.531$, $p = 0.068$). Other predictors did not show statistically significant effects ($p > 0.05$).

Backward multiple linear regression analyses were conducted to examine the influence of knee and hip force of the dominant leg on the spilt-load leg press 1RM. The final model from the backward regression explained a 35.5% proportion of the variance ($R^2_{adj} = 0.226$). Among these, the summary of net force from knee flexion and extension on the non-dominant leg emerged as a significant predictor ($B = 1.135$, $SE = 0.481$, $\beta = 0.728$, $p = 0.026$), while hip extension concentric load on the non-dominant leg had a non-significant effect ($B = 0.701$, $SE = 0.392$, $\beta = 0.517$, $p = 0.086$).

Similarly, backward regression was applied to explore how knee and hip strength contributed to 1RM performance in the unilateral non-dominant leg press. It showed a single significant predictor, i.e., the sum of knee flexor and extensor force ($B = 0.483$, $SE = 0.23$, $\beta = 0.631$, $p = 0.046$) which explained 33% of the variance ($R^2_{adj} = 0.227$).

For unilateral dominant leg press

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performance, backwards multiple linear regression revealed that knee flexion force significantly predicted performance, explaining 29.4% of the variance (R^2_{adj} = 0.185). Knee flexor force was a significant positive predictor (B = 1.293, SE = 0.493, β = 0.747, p = 0.014).

For the summary of unilateral leg press performance, backwards regression indicated significant effect of knee flexors on the dominant leg (B = 2.506, SE = 1.132, β = 0.771, p = 0.037), explaining 45.7% of the variance (R^2_{adj} = 0.291).

Table 1. Leg press performance and dynamometer results.

	mean ± SD	min	max	95% CI
Bilateral leg press (kg/BM)	3.94 ± 0.82	2.31	5.81	3.64–4.24
Split-load leg press (kg/BM)	3.55 ± 0.73	2.55	5.58	3.29–3.82
Unilateral non-dominant leg press (kg/BM)	2.03 ± 0.36	1.39	2.85	1.89–2.16
Unilateral dominant leg press (kg/BM)	2.13 ± 0.42	1.45	3.26	1.97–2.28
Knee extension non-dominant 60°/s (N·m/BM)	2.53 ± 0.38	1.80	3.30	2.4–2.67
Knee flexion non-dominant 60°/s (N·m /BM)	1.32 ± 0.26	0.87	1.89	1.22–1.41
Knee extension dominant 60°/s (N·m /BM)	2.67 ± 0.56	1.55	3.80	2.47–2.88
Knee flexion dominant 60°/s (N·m /BM)	1.41 ± 0.29	0.84	2.14	1.3–1.52
Hip extension concentric dominant 60°/s (N·m /BM)	2.42 ± 0.69	1.22	4.28	2.16–2.67
Hip extension eccentric dominant 60°/s (N·m /BM)	4.44 ± 1.25	1.76	6.91	3.98–4.9
Hip extension concentric non-dominant 60°/s (N·m/BM)	2.41 ± 0.67	1.12	3.73	2.17–2.66
Hip extension eccentric non-dominant 60°/s (N·m/BM)	4.06 ± 1.15	1.38	7.41	3.64–4.49

Note: SD: standard deviation; CI: coefficient interval; BM: body mass

Table 2. Correlation coefficient between leg press 1RM performance and force output.

	Bilateral leg press	Split-load leg press	Unilateral non-dominant leg press	Unilateral dominant leg press	Unilateral leg press sum
Knee extension non-dominant	0.408*	0.434*	0.448*	0.440*	0.447*
Knee flexion non-dominant	0.253	0.292	0.222	-	0.256
Knee extension dominant	0.122	0.123	-	0.172	0.138
Knee flexion dominant	0.495*	0.473*	-	0.481*	0.481*
Hip extension concentric dominant	0.185	0.117	-	0.185	0.184
Hip extension eccentric dominant	0.04	0.007	-	0.021	0.033
Hip extension concentric non-dominant	0.363*	0.332	0.398*	-	0.372*
Hip extension eccentric non-dominant	0.03	0.047	0.037	-	0.029
Extensors sum dominant	0.177	0.135	-	0.202	0.184
Extensors sum non-dominant	0.421*	0.411*	0.462*	-	0.444*
Knee flexion and extension summary dominant	0.275	0.268	-	0.307	0.284
Knee flexion and extension summary non-dominant	0.415*	0.451*	0.43*	-	0.445*

*Note: * significant correlation ($p < 0.05$)*

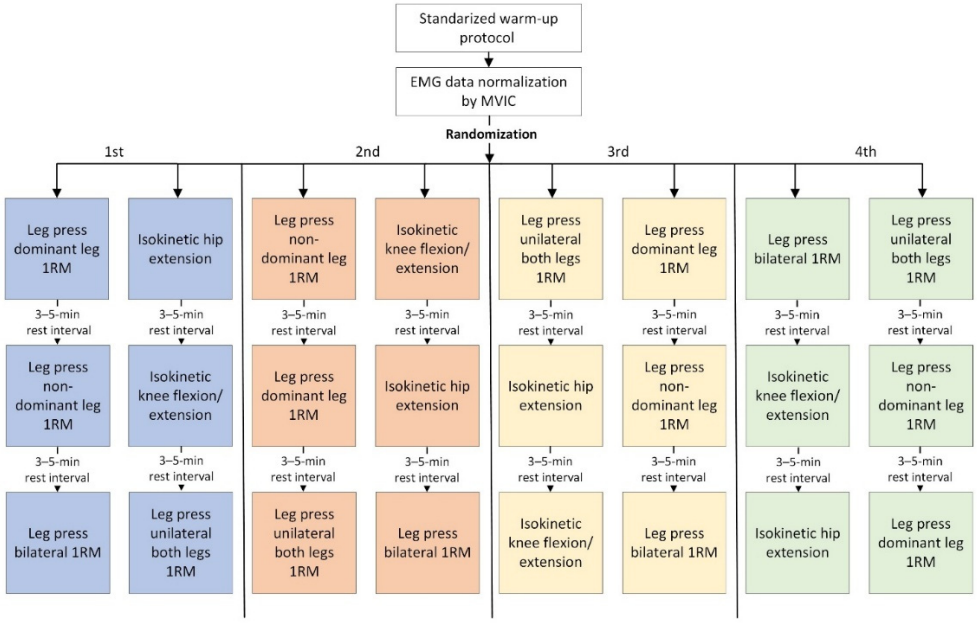


Figure 1. Schematic representation of the study design.

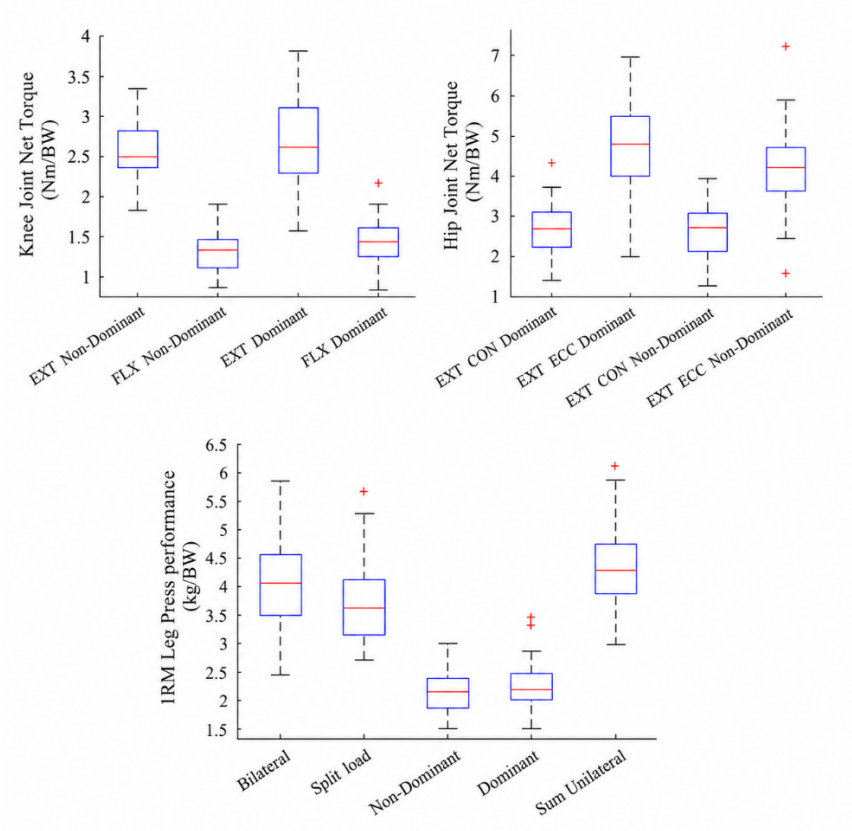


Figure 2. 1RM leg press performance (kg) across five loading conditions (bilateral, split load, dominant leg, non-dominant leg, and sum of unilateral efforts) and peak knee and hip joint net torque (Nm/BW) during concentric and eccentric contractions of the extensors and flexors in the dominant and non-dominant limbs.
Outliers are marked with red crosses. EXT: extensors, FLX: flexors, ECC: eccentric, CON: concentric

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Discussion

The main aim of this study was to assess how knee flexor, knee extensor, and hip extensor strength influence leg press performance across different variations. Supporting our hypothesis, dominant-side knee flexor force significantly predicted 1RM in bilateral, split-load, and unilateral dominant leg press exercises, showing strong correlations with bilateral ($r \approx 0.50$, $p < 0.01$) and split-load 1RM ($r \approx 0.47$, $p < 0.01$). Additionally, dominant-side knee flexor strength was significantly associated with 1RM performance under the bilateral, split-load, and unilateral dominant leg press conditions. Moderate to strong correlations were observed for the bilateral ($r \approx 0.5$, $p < 0.01$) and split-load ($r \approx 0.47$, $p < 0.01$) variants, indicating a potential role of the hamstrings in force production during these tasks. While statistical significance confirmed the presence of these relationships, their practical magnitude is also important. The correlation with bilateral 1RM performance ($r = 0.50$) presented a moderate-to-large effect size, suggesting that even modest increases in hamstring strength could meaningfully enhance lower-limb force output. Similarly, moderate correlations ($r = 0.42$–0.47) between non-dominant hip extension strength and unilateral 1RM performance point to the importance of posterior chain strength and inter-limb coordination when each leg contributes independently. These findings offer relevant guidance for training and rehabilitation by highlighting the potential benefit of strengthening the knee flexors and hip extensors, particularly on the non-dominant side. This interpretation aligns with previous research showing that hamstrings assist in hip extension torque and contribute to knee joint stability under high loads (Wirth et al., 2016). Although these results suggest that hamstring strength may play a meaningful role in high-load leg press performance—especially through stabilization and posterior chain support—future studies are needed to confirm these relationships and clarify causality. Their role may be additionally accentuated by the limited ROM used (90° knee flexion), which increases biceps femoris activation (Hahn, 2011).

In contrast, non-dominant knee extensor and flexor strength showed stronger associations with unilateral and split-load leg press performance. Non-dominant extensor force correlated significantly with single-leg 1RM ($r \approx 0.45$, $p < 0.05$) and moderately with split-load 1RM ($r \approx 0.43$, $p < 0.05$), indicating that strength of the weaker limb may influence performance when each leg works independently or semi-independently. Additionally, the non-dominant hip extensor force demonstrated a positive, although moderate, correlation with unilateral leg press outcomes (e.g., non-dominant hip extension concentric force vs. non-dominant single-leg 1RM: $r \approx 0.40$, $p < 0.05$), reinforcing the role of posterior chain engagement during unilateral loading. Further regression analysis indicated that the concentric force of the non-dominant hip extensors was a borderline significant predictor of unilateral leg press performance (B = 0.701, SE = 0.392, $\beta = 0.517$, $p = 0.086$), hinting at a complex role of hip stability and control during single-leg efforts (Martín-Fuentes et al., 2020).

The isokinetic results indicated that knee flexor strength, particularly on the dominant side, was the strongest predictor of 1RM performance, while hip extensor strength showed only weak to moderate correlations. This suggests that the hamstrings contributed primarily through their knee-flexor function, stabilizing the joint and assisting in load control, rather than through hip extension. Although the hamstrings are bi-articular muscles capable of producing torque across both joints, the 45° seated leg press position limited hip range of motion and reduced gluteal and proximal hamstring involvement (Hahn, 2011).

Taken together, these results emphasize the leg press as a predominantly knee-driven exercise, with performance closely tied to strength of the knee flexors and extensors, depending on the leg and the movement type. Bilateral leg press performance can be maximized by enhancing dominant leg knee flexor strength, while improvements in non-dominant extensor strength are critical for unilateral and split-load tasks. This distinction supports using unilateral formats in both assessment and training to expose and address muscular imbalances that may not be evident in bilateral lifts. These underlying strength characteristics bear structural relevance to broader athletic movement profiles. Just as asymmetric lower-limb force capacity maps directly to unilateral leg press demands, asymmetrical functional demands are heavily visible during landing tasks, where drop jumps from higher

elevations exacerbate inter-limb asymmetries and demand greater eccentric control from the non-dominant knee extensors (Wang et al., 2025).

These outcomes align with prior literature on limb asymmetry and exercise modality. It is well established that bilateral exercises can mask individual limb strength imbalances, since stronger limbs may compensate for weaker ones when both contribute simultaneously (Gonzalo-Skok et al., 2017). In this study, the bilateral leg press variation likely allowed participants to generate maximal force by letting the dominant limb shield a slightly weaker non-dominant limb. This mechanical compensation explains why dominant-leg flexor force—which is typically higher than that of the non-dominant side—emerged as a primary predictor of performance. Furthermore, this mechanics-driven shielding effect is highly integrated with an athlete's neuromuscular fatigue state. Acute physical stress alters coordinating neural structures across bilateral systems; for example, successive combat bouts have been shown to amplify the bilateral strength deficit during maximal vertical tracking actions (Kons et al., 2026). In contrast, unilateral exercises eliminate this cooperative compensation by isolating each limb's independent contribution, thereby clearly exposing true asymmetries in strength and force production (Sarabon et al., 2020). The split-load leg press, combining bilateral and unilateral features, demands coordinated force from each leg and is thus sensitive to imbalances (Zhao et al., 2023). Indeed, our data showed that both the dominant flexor and non-dominant extensor force were significant correlates of split-load 1RM, reinforcing the idea that this variant can reveal functional disparities between limbs that might remain hidden in a purely bilateral lift. To accurately isolate these functional disparities without access to complex multi-joint setups, field-based measurement fidelity becomes critical. The cross-sectional validation of hand-held units against open-chain isokinetic frameworks ensures that clinicians can reliably evaluate these isolated knee flexor and extensor imbalances across a full range of motion right at the training floor (Kosti et al., 2026). These findings corroborate the notion that training and testing in unilateral formats can be invaluable for diagnosing and addressing inter-limb imbalances, as confirmed by previous studies linking asymmetric strength development to increased injury risk (Escamilla et al., 2001).

From a programming standpoint, integrating both unilateral and bilateral resistance exercises can enhance muscular balance and performance. Bilateral exercises are efficient for developing overall force production (Medicine, 2009), while unilateral exercises are especially effective for addressing asymmetries, enhancing balance, and improving sport-specific movements, and they may even outperform bilateral exercises in certain performance metrics such as sprinting ability (Liao et al., 2022). When structural training modifications are needed to balance these unilateral gaps without exposing the athlete to extreme mechanical joint overloads, specialized execution modalities become highly valuable. Implementing blood flow restriction protocols serves as a powerful means to stimulate robust gains in lower extremity maximum dynamic strength and isolated isokinetic profiles (Li et al., 2025). Additionally, acute performance in these testing or training formats can be maximized via physiological optimization strategies, such as utilizing a high-dose caffeine mouth rinse to transiently elevate acute isokinetic strength output during explosive extensions (Vural et al., 2025). Single-joint exercises target specific muscles and may lead to greater hypertrophy in isolated muscles, compared to multi-joint movements (Mannarino et al., 2019). However, multi-joint exercises tend to be more time-efficient and effective for overall strength gains and training economy (Goncalves et al., 2019). Strategic programming that includes a mix of these exercise types enables both generalized and specific adaptations, making training more effective across diverse fitness goals (Speirs et al., 2016).

Additionally, recovery strategies should consider that knee extension (single-joint) and leg press (multi-joint) exercises exhibit different muscle recovery timelines. Muscle edema and performance recovery after single-joint exercises can be delayed compared to multi-joint movement, requiring tailored recovery periods and monitoring between sessions (Dourado et al., 2023). To support recovery, incorporating modalities like post-exercise infrared sauna sessions has shown promise in accelerating neuromuscular recovery and reducing muscle soreness after resistance training (Ahokas et al., 2023). By acknowledging these differences, coaches

and practitioners can optimize training load management and recovery to improve performance and reduce injury risk.

We acknowledge several limitations in this study that temper the interpretation of the results. First, all participants were male and of similar training background. Including only males, however, helped ensure greater homogeneity of the sample, as well as improved internal validity and statistical power by limiting between-subject variability. Second, while we identified correlations and predictive strength measures, our cross-sectional design cannot establish causality. It remains to be established whether specific training to improve dominant-leg knee flexor force or non-dominant knee extensor force will directly cause a proportional improvement in the leg press 1RM. Additionally, we assessed isokinetic force at specific joint actions and at particular angular velocities and modes. It is possible that other strength qualities (e.g., higher velocities, or hip abductor strength for lateral stability) also play a role in unilateral leg performance. Given the modest sample size, caution is warranted when interpreting regression findings. Although multicollinearity diagnostics (VIF and tolerance) were within acceptable limits, the presence of moderately correlated predictors may still influence coefficient stability. Additionally, due to the cross-sectional nature of the study, all associations should be interpreted as correlational rather than causal. Future longitudinal or interventional studies are necessary to determine whether strengthening specific muscle groups leads to performance improvements.

In summary, 1RM performance in different leg press variations is differentially influenced by specific muscle group strengths and is primarily driven by the knee musculature, with knee flexors and extensors acting as the main determinants of force production. Dominant knee flexors drive performance under bilateral and split-load conditions, while the non-dominant sum of knee flexors/extensors is essential in unilateral tasks. Hip extensor force plays a supportive role, particularly in single-leg tasks where stability is at a premium. Notably, knee extension exercises—commonly used by sprint coaches—are frequently integrated into resistance training programs as complementary movements for performance enhancement, injury prevention, and rehabilitation following muscle or joint injuries or surgeries (Loturco et al., 2024).

Practical Implications

These findings offer practical insights for strength coaches, physiotherapists, and rehabilitation specialists. The strong link between dominant-side knee flexor strength and bilateral leg press performance highlights the importance of targeted posterior chain training to boost bilateral lower-body strength. Similarly, the predictive role of non-dominant extensor strength in unilateral and split-load presses underscores the need to assess and correct inter-limb asymmetries through unilateral training. The split-load leg press also proves valuable as both a diagnostic and training tool, revealing hidden imbalances while maintaining bilateral coordination.

Conclusions

Knee and hip strength influence leg press performance differently across exercise variations. Dominant knee flexors are key in bilateral tasks, while non-dominant extensors drive unilateral performance. These findings underscore the importance of assessing and training both limbs independently to enhance performance and address asymmetries that may contribute to injury risk.

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