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Posterior Chain Strength and Countermovement Jump Performance in Female Volleyball Players: A Comparison of Ratio and Allometric Scaling Approaches

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Abstract

The relationship between posterior-chain maximal strength and countermovement jump (CMJ) performance may be influenced by how body size is accounted for when strength is expressed and analyzed. This study examined the cross-sectional association between Hip Thrust maximal strength and CMJ height in semi-professional female volleyball players and evaluated whether this relationship was represented differently using conventional ratio scaling and allometric log-linear modeling. Twenty-five semi-professional female volleyball players from the Turkish Women's Volleyball 2nd League participated in the study. Posterior-chain maximal strength was assessed using the Hip Thrust one-repetition maximum (1RM), and CMJ height was determined using smartphone-based flight-time analysis. Hip Thrust strength was examined in absolute terms, relative to body mass using conventional ratio scaling (1RM/body mass), and within an allometric log-linear model including Hip Thrust 1RM and body mass. Absolute Hip Thrust 1RM was not significantly associated with CMJ height ($r=0.117$, $p=0.579$). Ratio-scaled Hip Thrust strength was also not significantly associated with CMJ height ($r=0.253$, $p=0.222$), and the corresponding regression model was not statistically significant ($R^2=0.064$, $p=0.222$). Similarly, the allometric log-linear model was not statistically significant ($R^2=0.075$, $p=0.426$). Within this model, neither Hip Thrust 1RM ($\beta=0.094$, $p=0.654$) nor body mass ($\beta=-0.266$, $p=0.210$) showed a significant association with CMJ height. Hip Thrust maximal strength was not significantly associated with CMJ height in this sample, regardless of whether strength was expressed using conventional ratio scaling or examined within an allometric model accounting for body mass. The present small sample did not provide evidence favoring one scaling approach over the other; however, this should not be interpreted as demonstrating equivalence or comparable appropriateness of the two methods. These findings suggest that Hip Thrust maximal strength and body mass alone account for limited inter-individual variation in CMJ height and should be interpreted within the constraints of the small, cross-sectional sample.

Keywords: *countermovement jump; hip thrust; body mass; female volleyball players; ratio scaling*

Introduction

Vertical jumping represents a fundamental performance characteristic in volleyball, as decisive offensive and defensive actions, particularly spiking and blocking, depend substantially on an athlete's ability to rapidly elevate the body and execute repeated high-intensity jumps (Sattler et al., 2015; Sheppard et al., 2009). Accordingly, the countermovement jump (CMJ) is widely used to evaluate lower-body explosive performance in athletic populations (Cormie et al., 2011). Maximal muscular strength is considered an important component of this capacity because greater force-generating ability is generally associated with favorable force time characteristics and performance in explosive athletic tasks (Suchomel et al., 2016). Nevertheless, the extent to which strength developed or expressed in a specific resistance exercise translates to a distinct athletic task depends on the mechanical characteristics of both movements.

The Hip Thrust is a hip-dominant resistance exercise that enables substantial loading of the hip-extensor musculature and has become widely used for posterior-chain strength development. However, evidence regarding its transfer to vertical-jump performance is not unequivocal. Training studies have demonstrated substantial improvements in Hip Thrust strength without consistently observing corresponding improvements in vertical-jump performance (Contreras et al., 2017; González-García et al., 2019). More recently, a systematic review and meta-analysis similarly indicated that improvements following Hip Thrust training appear to be more consistent for exercise-specific strength than for vertical-jump performance (Lin et al., 2026). These findings suggest that maximal Hip Thrust strength and CMJ performance should not necessarily be regarded as interchangeable manifestations of the same physical capacity and support further examination of their relationship in athletic populations.

A further consideration when examining strength–performance relationships is the influence of body size. Absolute muscular strength is inherently associated with body dimensions, and direct comparisons of absolute strength may therefore partly reflect differences in body size (Jaric, 2002; Nevill et al., 1992). Conventional ratio scaling attempts to account for this influence by dividing an absolute strength measure by body mass. Although practical, this procedure assumes proportionality between the variables and may not adequately represent relationships when strength does not increase linearly with body mass (Batterham & George, 1997). Accordingly, ratio scaling can alter the apparent relationship between strength and performance, particularly when athletes differ in body size (Comfort & Pearson, 2014; Crewther et al., 2011). This issue is relevant when investigating jumping performance because body size itself may influence the observed relationships among neuromuscular variables and jump outcomes (Jones et al., 2020; Marković et al., 2014).

Allometric scaling offers an alternative means of accounting for body size by estimating the relationship between performance and anthropometric variables through empirically derived exponents rather than assuming direct proportionality (Hart, 2024; Vanderburgh et al., 1995). Such approaches have been used to examine strength and jump-related performance while accounting for differences in body size (Cunha et al., 2017; Dal Pupo et al., 2021). However, the purpose of applying allometric scaling should not be to presume its superiority over conventional ratio scaling (Jacobson et al., 2013). Rather, comparing the approaches can determine whether the interpretation of a strength–performance relationship is sensitive to the method used to account for body size. This distinction is particularly important for CMJ height, which represents the outcome of interacting neuromuscular and biomechanical determinants rather than maximal strength alone (Marković et al., 2014; Ramirez-Campillo et al., 2020).

Despite the practical relevance of both Hip Thrust strength and CMJ performance, limited evidence has examined whether their cross-sectional relationship is influenced by the method used to account for body size, particularly in female volleyball players. Therefore, the present study aimed to examine the association between Hip Thrust maximal strength and CMJ height in semi-professional female volleyball players and to determine whether the representation of this relationship differs between conventional ratio scaling and allometric log-linear modeling. It was hypothesized that greater Hip Thrust maximal strength would be associated with greater CMJ height; however, the magnitude of this association was expected to vary depending on the scaling approach used to account for body size.

Material and methods

Participants

Twenty-five semi-professional female volleyball players (age: 23.8±2.9 years; height: 173.2±6.1 cm; body mass: 67.4±7.8 kg; BMI: 22.5±2.1 kg·m^{-2}) voluntarily participated in the study. Inclusion criteria were: (a) being between 18 and 30 years of age, (b) having at least three years of structured volleyball training experience, (c) regularly participating in team training and official competitions, and (d) having no musculoskeletal injury or medical condition that could limit maximal strength or jumping performance. Participants were excluded if they reported a lower-extremity injury within the previous six months or failed to complete the testing procedures.

All participants were fully informed about the study procedures and provided written informed consent prior to participation. The study was conducted in accordance with the principles of the Declaration of Helsinki and received approval from the relevant institutional ethics committee (Decision No. 2026-07-48; 12 June 2026).

Anthropometric measurements

Body height was measured to the nearest 0.1 cm with participants standing barefoot in the anatomical position using a wall-mounted stadiometer. Body mass was measured to the nearest 0.1 kg using a calibrated digital scale, with participants wearing light sports clothing and barefoot. Body mass index (BMI) was calculated by dividing body mass (kg) by the square of height (m^2) and expressed as kg·m^{-2}.

Experimental procedures and testing protocols

Performance testing was conducted during a period in which the athletes had refrained from high-intensity exercise for at least 48 h to minimize the potential influence of acute fatigue on the measurements. To reduce variability associated with circadian rhythms, all assessments were performed within the same time window (10:00–13:00 h) at a university fitness center.

The data collection process was divided into two testing sessions, separated by a 48-h recovery period. Anthropometric measurements and countermovement jump (CMJ) assessments were performed during the first testing session, whereas the Hip Thrust one-repetition maximum (1RM) strength test was conducted during the second session.

Before each testing session, participants completed a standardized dynamic warm-up protocol consisting of 5 min of light jogging, dynamic lower-extremity mobility exercises (forward and lateral stepping, high-knee drills, and dynamic hamstring mobilization), followed by three consecutive submaximal CMJ trials.

Countermovement jump assessment

Countermovement jump (CMJ) performance was assessed using the MyJump2 application (MyJumpLab, Madrid, Spain). Participants performed three maximal CMJ trials with their hands placed on their hips throughout the movement to minimize the contribution of arm swing. Participants were instructed to rapidly descend to a self-selected countermovement depth and subsequently jump vertically with maximal effort. A 60-s passive recovery period was provided between trials, and the highest jump height was retained for statistical analysis.

All CMJ trials were recorded using an iPhone 15 Pro (Apple Inc., Cupertino, CA, USA) at 240 frames per second. The smartphone was positioned on a tripod approximately 1.5 m from the participant and 30 cm above floor level, perpendicular to the sagittal plane. Take-off and landing frames were manually identified within the application, and CMJ height was determined from flight time. Smartphone-based flight-time analysis has demonstrated high concurrent validity and intra-rater reliability for the assessment of CMJ height compared with force-platform measurements (Balsalobre-Fernández et al., 2015; Stanton et al., 2017).

Hip thrust 1RM strength test

During the second testing session, a Hip Thrust one-repetition maximum (1RM) strength test was performed to determine the participants' posterior-chain maximal strength. All measurements were conducted using a standard weight bench and an Olympic barbell. Participants were positioned with the inferior border of the scapula supported against the edge of the bench and their feet placed flat on the floor at shoulder-width apart. After the barbell was positioned over the junction of the proximal femur and pelvis, a repetition was considered technically valid when full hip extension was achieved and the trunk and thighs were aligned parallel to the floor. Movement technique was visually monitored by the investigators throughout the testing procedure.

In accordance with the National Strength and Conditioning Association (NSCA) guidelines, participants first completed submaximal warm-up sets of 5–10 repetitions using approximately 50–70% of their estimated 1RM, after which the actual 1RM was determined within a maximum of 3–5 attempts. A 3-min rest interval was provided between attempts (Contreras et al., 2017; Haff & Triplett, 2016). Absolute Hip Thrust 1RM was recorded in kilograms and subsequently expressed relative to body mass using conventional ratio scaling (1RM/body mass, $kg \cdot kg^{-1}$).

Statistical analysis

All statistical analyses were performed using SPSS Statistics (Version 26.0; IBM Corp., Armonk, NY, USA). The normality of continuous variables was assessed using the Shapiro–Wilk test, with skewness and kurtosis coefficients additionally examined to characterize the distributions. The bivariate associations among Hip Thrust 1RM, ratio-scaled Hip Thrust strength, and CMJ height were evaluated using Pearson's correlation coefficients. All statistical tests were two-tailed, and statistical significance was set at $p<0.05$.

The association between Hip Thrust maximal strength and CMJ height was examined using complementary absolute, ratio-scaled, and allometric approaches. First, the bivariate association between absolute Hip Thrust 1RM (kg) and CMJ height (cm) was quantified using Pearson's correlation coefficient. Conventional ratio-scaled Hip Thrust strength was calculated as absolute 1RM divided by body mass (1RM/body mass, $kg \cdot kg^{-1}$), and its association with CMJ height was subsequently examined using simple linear regression. Pearson correlation coefficients were retained to describe the direction and strength of the bivariate associations, whereas simple linear regression was used to estimate the regression coefficient, 95% confidence interval, and explained variance for the ratio-scaled model, thereby facilitating comparison with the allometric regression framework.

For the allometric analysis, natural logarithm (ln) transformations were applied to CMJ height, absolute Hip Thrust 1RM, and body mass. A multiple log-linear regression model was then constructed with ln(CMJ height) as the dependent variable and ln(Hip Thrust 1RM) and ln(body mass) entered simultaneously as independent variables:

$$\ln(\text{CMJ height}) = \ln(a) + b_1 \cdot \ln(\text{Hip Thrust 1RM}) + b_2 \cdot \ln(\text{body mass})$$

This model was used to examine the association between Hip Thrust maximal strength and CMJ height while explicitly accounting for body mass within the log-linear framework. The ratio-scaled and allometric analyses were treated as alternative statistical representations of the strength-CMJ relationship rather than as formal tests of superiority between scaling methods. Model results were therefore interpreted descriptively with respect to regression coefficients, coefficients of determination (R^2), and statistical significance.

Regression assumptions and diagnostics were evaluated before interpretation of the models. Normality of residuals was assessed using the Shapiro-Wilk test and Q-Q plots, and homoscedasticity was evaluated using the Koenker test and inspection of residual scatterplots. For the multiple log-linear regression model, multicollinearity was assessed using variance inflation factor (VIF) and tolerance values, with VIF <5.0 and tolerance >0.20 considered acceptable. Potentially influential observations were examined using Cook's distance and leverage values. No observations were excluded solely on the basis of these diagnostics. The coefficient of determination (R^2) was reported to describe the proportion of variance in CMJ height accounted for by each regression model. Ninety-five percent confidence intervals were reported for the regression coefficients to indicate the precision of the estimates.

Power analysis

Given the fixed sample of 25 participants, an a priori power calculation was not used to determine sample size. Instead, a sensitivity analysis was performed using G*Power

(Version 3.1.9.7; Heinrich Heine University Düsseldorf, Germany) to characterize the magnitude of effect that the available sample could detect in the multiple regression model. For a fixed-model multiple linear regression with two predictors [ln(Hip Thrust 1RM) and ln(body mass)], $\alpha=0.05$, statistical power $(1-\beta)=0.80$, and $N=25$, the minimum detectable effect size was Cohen's $f^2=0.387$, corresponding to approximately $R^2=0.279$. Accordingly, the study was sufficiently sensitive to detect relatively large multivariable associations but had limited sensitivity for smaller effects.

Results

Descriptive values for all variables included in the main analyses were as follows: Hip Thrust 1RM, 71.31±12.19 kg; relative Hip Thrust strength, 1.08±0.23 $1RM \cdot kg^{-1}$; body mass, 66.98±10.57 kg; and CMJ height, 30.52±4.75 cm.

The correlation analysis showed a strong positive association between absolute Hip Thrust 1RM and relative Hip Thrust strength. In contrast, neither absolute nor relative Hip Thrust strength was significantly associated with CMJ height (Table 1).

Table 1. Correlations among strength and CMJ height variables

Variables	1. Hip Thrust 1RM	2. Relative Hip Thrust	3. CMJ Height
1. Hip Thrust 1RM	1		
2. Relative Hip Thrust	0.759	1	
3. CMJ Height	0.117	0.253	1

Note. 1RM = one-repetition maximum; CMJ = countermovement jump. Hip Thrust 1RM is expressed in kg, relative Hip Thrust strength as $1RM \cdot kg^{-1}$, and CMJ height in cm.

Ratio-scaled Hip Thrust strength was not significantly associated with CMJ height in the simple linear regression model (Table 2).

Table 2. Association between ratio-scaled hip thrust strength and CMJ height

Model	B	SE	95% CI for B	β	t	p
Constant	22.09	5.34	[11.04, 33.14]	—	4.14	<0.001
Relative Hip Thrust	5.676	4.523	[−3.681, 15.033]	0.253	1.255	0.222

Note. $R^2 = 0.064$; adjusted $R^2 = 0.023$; $F(1, 23) = 1.574$, $p = 0.222$. Dependent variable: CMJ height (cm). CMJ = countermovement jump; 1RM = one-repetition maximum.

The allometric log-linear model was not statistically significant, and neither Hip Thrust 1RM nor body mass showed a significant association with CMJ height (Table 3).

Table 3. Allometric log-linear model for the association between hip thrust strength and CMJ height

Model	B	SE	95% CI for B	β	t	p
Constant	3.635	1.075	[1.406, 5.864]	—	3.381	0.003
ln(Hip Thrust 1RM)	0.098	0.216	[−0.350, 0.546]	0.094	0.454	0.654
ln(Body Mass)	−0.319	0.248	[−0.833, 0.195]	−0.266	−1.291	0.210

Note. $R^2 = 0.075$; adjusted $R^2 = -0.010$; $F(2, 22) = 0.888$, $p = 0.426$. Dependent variable: ln(CMJ height). CMJ = countermovement jump; 1RM = one-repetition maximum.

Discussion

The present study examined the cross-sectional association between Hip Thrust maximal strength and CMJ height in semi-professional female volleyball players and evaluated whether this relationship was represented differently when conventional ratio scaling and allometric log-linear modeling were applied. Hip Thrust maximal strength was not significantly associated with CMJ height when expressed in absolute or ratio-scaled terms, and the allometric model including Hip Thrust 1RM and body mass was also not statistically significant. Thus, the hypothesized positive association between greater Hip Thrust maximal strength and CMJ height was not supported. These findings should be interpreted as evidence of a limited cross-sectional association within the present sample rather than as evidence that maximal strength is unimportant for jumping performance. Maximal muscular strength is generally considered an important physical quality underlying explosive athletic performance, with stronger athletes often demonstrating advantages in force production and high-intensity movement tasks (Cormie et al., 2011; Suchomel et al., 2016). Nevertheless, the absence of a significant association between Hip Thrust 1RM and CMJ height in the present study indicates that maximal strength expressed in a specific resistance exercise may not necessarily correspond closely to performance in a distinct explosive task. This interpretation is consistent with Contreras et al. (2017), who reported substantial improvements in Hip Thrust strength following Hip Thrust training without corresponding improvements in vertical jump performance. More recently, Lin et al. (2026) similarly concluded in a systematic review and meta-analysis that Hip Thrust training produces clear exercise-specific strength improvements, whereas its effects on vertical jump performance are comparatively limited. Collectively, this evidence indicates that Hip Thrust maximal strength and vertical-jump performance do not necessarily change in parallel, providing relevant context for the weak cross-sectional association observed between Hip Thrust 1RM and CMJ height in the present sample. Accordingly, this finding should be interpreted in the context of task specificity rather than as evidence against the broader importance of muscular strength for athletic performance.

A possible explanation for the weak association between Hip Thrust maximal strength and CMJ height relates to the mechanical specificity of the two tasks. The Hip Thrust is primarily a hip-extension exercise performed with substantial anteroposterior loading characteristics, whereas the CMJ requires coordinated lower-extremity actions to generate vertical impulse and elevate the body's center of mass. Loturco et al. (2018) reported that the orientation of force application may influence the relationships between resistance exercise performance and sport-specific tasks, with horizontally and vertically directed exercises showing different associations with sprint performance. Similarly, Marković et al. (2014) demonstrated that the relationship between muscular power and jumping performance is influenced by biomechanical factors, including body size and countermovement depth. Therefore, although Hip Thrust 1RM provides an indicator of maximal hip-extension strength, differences in this measure may not directly correspond to differences in CMJ height, which reflects the coordinated contribution of multiple joints and movement-specific mechanical characteristics. The present findings consequently reinforce the importance of considering task specificity when interpreting associations between resistance-exercise strength and vertical-jump performance.

Accounting for body size is particularly relevant when strength measures are compared across individuals because absolute strength is partly influenced by differences in body dimensions (Hart, 2024; Jaric, 2002). Conventional ratio scaling addresses this issue by expressing strength relative to body mass; however, this approach assumes a proportional relationship between strength and body mass, an assumption that may not hold uniformly across populations or performance measures (Batterham & George, 1997). Previous research has demonstrated that the interpretation of strength–performance relationships can depend on the scaling procedure applied (Comfort & Pearson, 2014; Crewther et al., 2011). In the present sample, ratio scaling did not reveal a statistically significant association between Hip Thrust strength and CMJ height. Accordingly, the present findings do not provide evidence that conventional ratio scaling introduced systematic body-mass-related bias in this relationship.

The allometric analysis provided a complementary framework in which Hip Thrust strength and body mass were entered simultaneously rather than incorporating body mass as a fixed denominator. Allometric approaches are commonly used to examine performance variables while allowing the relationship with body size to be represented through empirically estimated scaling coefficients (Nevill et al., 1992; Vanderburgh et al., 1995). In the present study, the allometric model did not provide evidence of a statistically significant association between Hip Thrust maximal strength, body mass, and CMJ height. Importantly, this should not be interpreted as demonstrating equivalence or superiority of either scaling method. Rather, the allometric model provided an alternative statistical representation of the strength–jump relationship while explicitly incorporating body mass.

The limited variance in CMJ height accounted for by the present models also emphasizes that jump height should not be interpreted as a direct reflection of a single strength characteristic. Vertical-jump performance represents the outcome of several interacting mechanical and neuromuscular characteristics, and the relationship between a given physical capacity and jump height may be influenced by factors inherent to the jumping task (Cormie et al., 2011; Ramirez-Campillo et al., 2020). Marković et al. (2014), for example, demonstrated that body size and countermovement depth can substantially influence relationships between mechanical variables and vertical-jump performance, highlighting the complexity of interpreting CMJ outcomes from isolated performance characteristics. In volleyball specifically, Ziv and Lidor (2010) reviewed observational and experimental evidence demonstrating the importance of vertical-jump ability while also identifying considerable variation in testing and training approaches used to characterize this performance quality. Accordingly, the limited proportion of variance accounted for by the present models should not be interpreted as evidence that Hip Thrust strength or body size is irrelevant to jumping performance. Rather, it indicates that these variables alone were insufficient to account for substantial inter-individual variation in CMJ height within this sample. Because other potential determinants were not directly assessed, their contribution to the unexplained variation cannot be established from the present data.

Study limitations

Several limitations should be considered when interpreting the findings of the present study. First, the sample consisted of 25 semi-professional female volleyball players who participated voluntarily. Although the relatively homogeneous sample reduced variability related to sex, sport, and competitive level, the small sample size limits statistical sensitivity and the generalizability of the findings. The sensitivity analysis indicated that the available sample was adequately powered to detect relatively large multivariable associations but had limited sensitivity for smaller effects. Consequently, the absence of statistically significant associations should not be interpreted as evidence that associations between Hip Thrust strength, body mass, and CMJ height are absent in the broader population. The findings should therefore be considered specific to the characteristics of the present sample and require confirmation in larger and more diverse athletic populations.

Second, the cross-sectional design precludes causal or longitudinal interpretations. The observed associations cannot establish whether changes in Hip Thrust maximal strength would result in corresponding changes in CMJ height, nor can the present data determine the effects of strength training or changes in body mass on jumping performance. Longitudinal and intervention studies are required to determine whether changes in posterior-chain strength are associated with subsequent changes in vertical jump performance.

Third, posterior-chain maximal strength was represented by a single exercise-specific measure, the Hip Thrust 1RM. Although this assessment provides a practical measure of maximal hip-extension strength, it does not represent all strength characteristics potentially relevant to vertical jumping. Similarly, CMJ performance was represented by jump height derived from flight time and did not include direct kinetic or neuromuscular measurements. Therefore, the present findings are limited to the association between Hip Thrust 1RM, body mass, and CMJ height and should not be generalized to other strength assessments or dimensions of jump performance.

Finally, the ratio-scaled and allometric models examined alternative statistical representations of the strength-CMJ relationship but were not designed as a formal validation or superiority comparison between scaling methods. The relatively limited sample size also restricts the precision with which allometric coefficients can be estimated. Accordingly, the present results should not be interpreted as establishing the superiority of either ratio or allometric scaling. Future studies with larger samples and broader variation in body size are warranted to evaluate the stability of scaling coefficients and to determine whether different scaling approaches materially influence the interpretation of strength performance relationships.

Conclusions

The present study found no statistically significant association between Hip Thrust maximal strength and CMJ height in semi-professional female volleyball players, whether strength was expressed in absolute terms, relative to body mass using conventional ratio scaling, or examined within an allometric log-linear model that included body mass. Although ratio and allometric scaling represent body size differently, the present small sample did not provide evidence favoring one approach over the other. These findings should not be interpreted as demonstrating equivalence or comparable appropriateness of the two scaling methods. Rather, they indicate that Hip Thrust maximal strength and body mass alone account for a limited proportion of inter-individual variation in CMJ height. These results emphasize that Hip Thrust 1RM should not be interpreted in isolation as an indicator of vertical-jump performance and that conclusions regarding strength performance relationships should consider both task specificity and the method used to account for body size. Given the small, specific sample and cross-sectional design, these findings should be interpreted within the studied population and confirmed in larger athletic cohorts.

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Conflict of Interest
The authors declare no conflict of interest.

AI Tools Usage
During the preparation of this manuscript, the authors used ChatGPT (OpenAI) for language editing, grammar correction, and phrasing improvement. The authors reviewed and revised all AI-assisted content and take full responsibility for the final manuscript.

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