THE INFLUENCE OF EXPLOSIVE LOWER LIMB PERFORMANCE, MUSCLE MASS, AND TRAINING EXPERIENCE ON OLYMPIC WEIGHTLIFTING PERFORMANCE

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Abstract:

Explosive lower limb performance, muscle mass, and training experience are considered critical factors in determining Olympic weightlifting performance, yet most studies have focused on single performance levels (such as elite-level athletes) or on only one or two of these performance factors. This study aimed to provide a more holistic analysis of these determinants by evaluating their influence across three performance levels: fitness-based weightlifting, competitive weightlifting, and national team athletes. Twenty-nine weightlifters (16 males, 13 females) participated, with performance assessed via the Sinclair score. Explosive lower limb performance was measured using countermovement jump (CMJ) height on a force plate, muscle mass was evaluated via bioelectrical impedance analysis, and training experience was calculated as a function of years, weeks, and weekly sessions. Multiple regression analysis identified CMJ height as the strongest predictor of the Sinclair score, followed by training experience, while muscle mass showed no significant influence. The model accounted for 66.7% of the variance in Sinclair scores, highlighting power and training experience as key performance drivers. These findings suggest that training programs should prioritize explosive lower limb performance development and training frequency to optimize weightlifting outcomes, while muscle mass appears to play a lesser role.

Keywords: *Olympic weightlifting, performance, muscle mass, training experience, snatch, clean & jerk*

Introduction

The sport of Olympic weightlifting involves two technical demanding disciplines: the snatch and the clean and jerk. They are characterized by rapid force production and coordination, demanding a strong interplay between physical attributes and neuromuscular efficiency. Three primary factors—explosive lower limb performance, muscle mass, and training experience—have been identified as key determinants of performance in weightlifting (Storey & Smith, 2012; Zaras, et al., 2021).

Olympic weightlifters demonstrate some of the highest peak power outputs ever recorded, particularly during the snatch and clean and jerk. For instance, male athletes achieve power output values as high as 6981 W, respectively, during the second pull phase of these lifts (Garhammer, 1993). Additionally, weightlifters demonstrate superior isometric peak force (approximately 15-20% greater) and contractile rate of force development (approximately 13-16% greater) compared to athletes in other strength and power sports (Storey & Smith, 2012).

These findings emphasize the unique neuromuscular characteristics of weightlifters, which contribute to their ability to generate explosive force with their lower limbs in these highly technical lifts.

Lean body mass, particularly in the lower body, seems to be a crucial determinant of success in Olympic weightlifting (Zaras, et al., 2021). Additionally, weightlifters possess significantly higher proportions of type IIA muscle fibers and relative myosin heavy chain IIA isoform content compared to recreationally active individuals (Fry, et al., 2003). General scientific consensus states that these fast-twitch muscle fibers are associated with rapid force generation and explosive movements, essential for the snatch and clean and jerk. Furthermore, weightlifting performance correlates strongly with the percentage of type IIA fibers ($r = 0.94$) and the percentage of muscle area occupied by these fibers ($r = 0.83$) (Fry, et al., 2003). This evidence highlights how specific skeletal muscle adaptations, driven by resistance training, play a central role in influencing performance.

Long-term training (several months to years) in Olympic weightlifting significantly enhances both strength and explosivity through neuromuscular adaptations. Improvements in peak force (PF) and contractile rate of force development (RFD) have been observed in male and female weightlifters after moderate- to long-term training (Haff, et al., 2008; Häkkinen, Pakarinen, Alen, Kauhanen, & Komi, 1988).These adaptations are largely attributed to the frequent high-intensity training performed by weightlifters, which not only increases muscular strength but also improves neural activation of motor units and preferential recruitment of fast-twitch fibers (Aagard, Simonsen, Andersen, Magnusson, & Dyhre-Poulson, 2002; Ewing, Wolfe, Rogers, Amundson, & Stull, 1990).

However, no studies have comprehensively explored the relationship between explosive lower limb performance, muscle mass, and training experience in Olympic weightlifting as a unified model. Most research examines these factors in isolation, often focusing on only one or two at a time, which limits a comprehensive understanding of their relative importance. This fragmented approach risks misinterpreting key success factors. For example, a study focusing solely on lower limb explosivity might conclude that it is a definitive predictor of success, overlooking the possibility that other factors, such as muscle mass or training experience, might play equally or more significant roles.

Furthermore, instead of focusing solely on elite-level athletes, we included athletes from different performance levels to obtain a more holistic view of the factors influencing success in weightlifting. For instance, if less successful athletes also demonstrate strong lower limb explosivity such as elite-level athletes, but still underperform, it could indicate that lower limb explosivity alone is not a decisive success factor.

By integrating all these aspects into a single comprehensive analysis, this study aims to identify which of these determinants—explosive lower limb performance, muscle mass, or training experience—has the most significant influence on Olympic weightlifting performance. It is hypothesized that explosive lower limb performance, followed by muscle mass and training experience will emerge as the strongest determinants of success.

Methods

Subjects

A total of twenty-nine weightlifters (16 males, 13 females; age: 29.4 ± 8.2 years; body mass: 76.3 ± 12.6 kg) participated in this study. Participants were stratified into three performance levels to represent different stages of expertise:

– Fitness-level (n=12; age: 34.2. ± 5.6 years; body mass: 70.3 ± 8.2 kg): Recreational lifters engaged in fitness-based weightlifting.
– Competitive-level (n=7; age: 29.3 ± 9.4 years; body mass: 78.0 ± 12.0 kg): Competitive athletes who participate in regional or national-level competitions.
– Elite-level (n=10; age: 23.7 ± 6.8 years; body mass: 82.3 ± 14.9 kg): Elite athletes from the Austrian national team.

All participants were healthy and free of injury or medical conditions that could impair performance.

Study design

This cross-sectional study aimed to evaluate the influence of explosive lower limb performance (ELLP), skeletal muscle mass and training experience on Olympic weightlifting performance. All measurements were conducted on three test days, with each level being tested in one day. Participants were divided into nine groups of 3-4 subjects. Each group completed the following protocol:

– Initial assessments: Bioelectrical impedance analysis (BIA) to measure skeletal muscle mass, conducted in a fasted state in the morning.
– 15 min break and warm-up: A 10-minute standardized warm-up, including dynamic stretches and movement preparation.
– ELLP testing: 3 maximal countermovement jumps (CMJ) with arm-swing and 1-minute break in between were conducted using a piezoelectrical force plate.
– Training Experience Questionnaire: Participants reported their training history, including years of training and average number of weekly sessions.
– Olympic weightlifting performance was conducted using the Sinclair score.

To ensure ecological validity, the performance test was conducted during active training phases. National team athletes were assessed during centralized training camp as part of their competition preparation phase. Similarly, competitive-level athletes were tested while in regular in-season training, aligned with their competition calendar. Recreational fitness lifters, who do not follow periodized competition schedules, were tested during their typical year-round training routine which does not include formal tapering or rest periods.

Study methods

Muscle mass was measured using the seca mBCA 525 bioelectrical impedance analysis (BIA) device (seca Gmbh & Co. KG, Hamburg, Germany). Participants were measured in the morning in a fasted state following standardized BIA procedures. This included lying supine for at least 10 minutes prior to testing, shaving hair at electrode placement sites, and performing electrode placement and data acquisition in the supine position. BIA device has been validated against dual-energy X-ray absorptiometry (DXA) for accuracy (Lopez-Gonzalez, Wells, & Clark, 2022). To cancel out body weight differences between subjects, we used relative skeletal muscle mass (RSMM) for our analysis:

$$RSMM = \frac{Skeletal\ Muscle\ Mass\ (kg)}{Body\ Weight\ (kg)}$$

After the measurement of muscle mass, participants had a 15 min break after which they started the 10 min warm-up for testing the ELLP. The warm-up consisted of easy running (3 min), world's greatest stretch (10 repetitions per side), bodyweight squats (10 repetitions), shoulder circling (10 repetitions forward and backwards), push-ups with shoulder taps in between (10 repetitions), dynamic hamstring and quadriceps stretch (10 repetitions) and 5 consecutive counter movement jumps. ELLP was assessed using countermovement jump (CMJ) height. Participants performed three maximal CMJs with arm swing and one-minute rest intervals between jumps. For measuring the CMJ height, we used the piezoelectric force plate Kistler Quattro Jump® Typ 9290DD (Kistler Instrumente AG, Winterthur, Switzerland), which is validated for reliability in assessing jump performance metrics (Mauch, Rist, & Kaelin, 2024). The highest recorded jump height was used for our analysis.

When participants completed the CMJ test, they were asked about their training experience. Training experience was quantified by multiplying self-reported years of Olympic weightlifting practice (snatch and clean and jerk) and by the average number of weekly training sessions and the number of weeks in a year.

$$Training\ Experience = Total\ Training\ Sessions = Training\ Years\ x\ Average\ number\ of\ sessions\ per\ week\ x\ 52$$

Finally, Olympic weightlifting performance was assessed using the Sinclair score. This score system is a widely accepted metric in Olympic weightlifting competition that adjusts an athlete's total lifted weight (snatch + clean and jerk) according to their body weight and sex, allowing for fair comparison of performance across different weight classes and between sexes. For competitive and elite-level athletes, the Sinclair scores from the current time span of January to March 2024 were accessed via the Austrian Weightlifting Federation's online database. Fitness-level participants and other participants who did not have official records of their current Sinclair score and therefore maximal weight lifted in the snatch and clean and jerk had to proceed with the following 1RM warm-up protocol on a self-selected day soon (Sheppard & Triplett, 2016, p.495):

1. Instruct the athlete to warm up with a light resistance that allows for 5 to 10 easy repetitions.
2. Take a 1-minute rest.
3. Estimate a warm-up load with which the athlete can perform 3 to 5 repetitions by adding approximately 10%.
4. Take a 2-minute rest.
5. Estimate a conservative, near-maximal load that allows the athlete to complete 2 to 3 repetitions by adding approximately another 10%.
6. Take a 2-to-4-minute rest.
7. Increase the load by approximately 10%.
8. Instruct the athlete to attempt a 1RM.
9. If the attempt is successful, take a 2-to-4-minute rest and return to step 7. If the attempt is unsuccessful, take a 2-to-4-minute rest, reduce the load by approximately 5%, and return to step 8. Continue increasing or decreasing the weight until the athlete can complete one repetition with the correct technique.

Ideally, the athlete's 1RM should be identified within three to five testing sets.

After completing this test for the snatch first, a 10-minute rest period should be observed before proceeding with the clean and jerk max test. This sequence closely reflects realistic conditions in Olympic weightlifting competition.

The Sinclair score is calculated by summing the maximal snatch and clean and jerk weights and applying the Sinclair coefficient based on sex and body weight (KSC ARGOS & AK HERMANN, n.d.).

Men's Sinclair score calculation:

$$(10^{\left(0{,}722762521 \times LOG\left(\frac{Bodyweight}{193{,}609}\right)^{2}\right);4)} \times (Snatch\ Weight\ [kg] + Clean\ \&\ Jerk\ Weight\ [kg])$$

Women's Sinclair score calculation:

$$(1{,}5\ \times (10^{\left(0{,}787004341 \times LOG\left(\frac{Bodyweight}{153{,}757}\right)^{2}\right);4)} \times (Snatch\ Weight\ [kg] + Clean\ \&\ Jerk\ Weight\ [kg])$$

Statistics

All statistical analyses were performed using Jamovi (Version 2.5.7.0, The Jamovi Project, Sydney, Autralia), JASP (Version 0.18.3, JASP Team, Amsterdam, Netherlands) and MATLAB

(Version R2024b, MathWorks, Natick, MA, USA). A multiple linear regression model was employed to determine the influence of ELLP (CMJ height), muscle mass (RSMM), and training experience (total training sessions) on Olympic weightlifting performance. Sex (coded as female = 0, male = 1) was included as a control variable.

To ensure the validity of the statistical analysis, key assumptions were tested and confirmed. Linearity was verified through an examination of residuals versus fitted values plots, ensuring a consistent relationship between predictors and the outcome variable. Homoscedasticity was assessed by evaluating the spread of residuals, confirming their consistency across levels of the predictor variables. The absence of multicollinearity was determined using the variance inflation factor (VIF), with all values remaining below the threshold of 5, indicating no significant collinearity among predictors. Finally, the normality of residuals was evaluated using a Q-Q plot and further supported by the results of the Shapiro-Wilk's test (p=.296), confirming that the residuals followed a normal distribution. These steps ensured the robustness and reliability of the statistical model.

In addition to the unstandardized coefficients (b), standardized coefficients (β), t- and p-values, we used the following equation to calculate the semi-partial correlation (sr) values. This allowed us to assess the unique contribution of each predictor variable to the criterion variable (Sinclair score), independent of the other predictors.

$$sr_i = t_i \times \sqrt{\frac{1 - R^2}{n - k - 1}}$$

Results

Descriptive statistics

Values for relative skeletal muscle mass (RSMM), countermovement jump (CMJ) height, training experience (total number of training sessions), and Sinclair score across all subjects and performance levels are presented in Table 1.

Regression analysis

The analysis showed that CMJ height and the number of training sessions were significant predictors of the Sinclair score (p<.05). Overall, the 4-predictor model was able to explain approximately 66.7% of the variance in the Sinclair score (adjusted $R^2 = 0.611$, $R^2 = 0.667$, $F(4,24) = 12.0$, p<.001). CMJ height proved to be the strongest predictor with a positive relationship to the Sinclair score ($t(24) = 4.25$, p<.001), followed by the number of training sessions (t(24 = 3.39, p=.002). However, RSMM had no significant influence on the Sinclair score ($t(24) = -0.81$, p=*.428)*.

Table 1. Mean (± SD) values of relative skeletal muscle mass (RSMM), countermovement jump (CMJ) height, training experience (total number of training sessions), and Sinclair score of all subjects and performance levels

Variables	All subjects	Fitness-level	Competitive-level	Elite-level
RSMM [%]	40.3 ± 3.9	40.2 ± 3.7	41.7 ± 3.9	39.5 ± 4.1
CMJ height [m]	0.38 ± 0.10	0.31 ± 0.7	0.41 ± 0.09	0.44 ± 0.10
Training experience	2035 ± 2380	767 ± 490	1033 ± 620	4259 ± 2942
Sinclair score	275.10 ± 75.53	208.53 ± 23.99	264.00 ± 30.09	362.76 22.76

Table 2. Results of multiple linear regression of relative skeletal muscle mass (RSMM), countermovement jump (CMJ) height, training experience (total number of training sessions), and sex (coded: female = 0; male = 1) on Sinclair score in Olympic weightlifters (dependent variable)

Variables	***b***	***β***	***sr***	***sr^2***	***t***	**p**
RSMM [%]	-3.28 [-11.6757, 5.1200]	-0.17 [-0.6058, 0.2569]	-0.09 [-0.3391, 0.1493]	0.01 [0, 0.0223]	-0.81	.43
CMJ height [m]	6.5339 [3.3579, 9.7100]	0.9653 [0.5022, 1.4284]	0.5002 [0.2495, 0.7508]	0.2502 [0.0622, 0.5637]	4.2460	<.001
Training experience	0.0177 [0.0069, 0.0285]	0.4911 [0.2074, 0.7749]	0.3993 [0.1463, 0.6524]	0.1595 [0.0214, 0.4256]	3.3901	.002
Sex	-77.0891 [-142.1084, -12.0698]	-0.5379 [-0.9890, -0.0869]	-0.2882 [-0.5389, -0.0376]	0.0831 [0.2904, 0.0014]	-2.4470	.022
						$R^2 = 0.667$ [0.3839, 0.7372] Adjusted $R^2 = 0.611$

Note. 95% confidence intervals are reported in parentheses.

This analysis results in the following multiple linear regression equation:

$$\text{Sinclair score} = 159.2439 - 3.2778 \times \text{Muscle Mass} + 6.5339 \times \text{ELLP} + 0.0177 \times \text{Training Experience} - 77.0891 \times \text{Sex}$$

Discussion and conclusion

The primary objective of this study was to examine the influence of muscle mass (measured as relative skeletal muscle mass, RSMM), explosive lower limb performance (ELLP; assessed via CMJ height), and training experience (quantified by the total number of training sessions) on the Sinclair score in Olympic weightlifting. To account for potential sex-related differences, the factor sex was included as an additional predictor in the regression model. The analysis revealed CMJ height and training experience as significant predictors of Sinclair score, while RSMM did not demonstrate a significant impact.

CMJ height emerged as the strongest predictor of the Sinclair score, explaining 25.0% of its variance. This finding aligns with previous research highlighting the critical role of ELLP in weightlifting performance (Storey & Smith, 2012; Travis, Goodin, Beckham, & Bazyler, 2018; Ulupınar & İnce, 2021). The second pull phase of the snatch and clean and jerk relies heavily on rapid force generation, which is captured effectively through CMJ performance (Garhammer, 1993). Athletes with superior ELLP are better equipped to achieve the high velocities required for successful lifts, reinforcing the importance of explosive-centric training strategies in weightlifting.

Training experience, quantified as the total number of training sessions, also significantly contributed to the Sinclair score, accounting for 16.0% of its variance. This finding supports the principle of specificity, where consistent and focused training enhances technical proficiency and neuromuscular adaptations (Panayotov & Yankova, 2022; Stone, Hornsby, Suarez, Duca, & Pierce, 2022). Weightlifting is not only a display of power but also a skill-dependent sport, where regular, high-quality training facilitates improvements in movement patterns, motor coordination, and efficiency.

Conversely, RSMM did not significantly predict the Sinclair score. This result is consistent with the understanding that, while muscle mass provides the structural foundation for force production, other factors— such as neuromuscular efficiency and technique—might play more dominant roles in elite performance (Zaras, et al., 2021).

A few limitations of this study must be acknowledged. First, muscle mass was assessed as total body relative skeletal muscle mass, which does not differentiate between upper- and lower-body musculature. Given the dominant role of the lower body in Olympic weightlifting, this broader measure may have diluted the specific contribution of lower-body muscle mass to performance outcomes (Vidal Pérez, Martínez-Sanz, Ferriz-Valero, Gómez-Vicente, & Ausó, 2021). Additionally, the homogeneity of muscle mass among the trained athletes in this study likely minimized variability, reducing its statistical significance as a predictor. Most participants were experienced athletes, and it is possible that some compensated for lower levels of lower-body muscle mass with relatively greater upper-body development. This potential compensation could have influenced the results, although further research would be needed to confirm this explanation.

Second, training experience was quantified as the total number of training sessions, which simplifies the complex nature of training variables. More detailed measures could include the volume and intensity an athlete dedicates to specific lifts. For instance, a more specific approach might be tracking the total number of repetitions performed at 80-90% of the one-repetition maximum (1RM: the maximum weight an individual can lift for one repetition) in the snatch and clean and jerk across all training years. These variables could provide deeper insights and should be incorporated into future research to better understand their influence.

However, this study underscores the critical role of ELLP and training frequency in determining Olympic weightlifting performance, while challenging the traditional emphasis on muscle mass as a primary predictor of success. ELLP, as measured by countermovement jump (CMJ) height, emerged as the strongest predictor of the Sinclair score, accounting for the largest portion of explained variance. This finding reinforces the importance of explosive strength in generating the high forces and velocities required during the snatch and clean and jerk. Training experience also significantly contributed to performance, highlighting the value of consistent, structured practice in fostering neuromuscular adaptations and technical proficiency.

These findings emphasize the need for training programs to focus not only on muscle mass development but also on enhancing the functional application of that muscle through ELLP-focused and skill-specific exercises. Training recommendations based on these findings include prioritizing conditional development through plyometric exercises such as countermovement jumps and Olympic lifting variations (Hackett, Davies, Soomro, & Halaki, 2016; Ulupınar & İnce, 2021). For exercises like the power clean and hang power clean, utilizing heavier loads (≥70% of 1RM) has been shown to produce greater peak power outputs (Soriano, Jiménez-Reyes, Rhea, & Marín, 2015). To enhance training experience, a regular training frequency of 4–6 sessions per week, incorporating progressive overload and consistent technical refinement, is essential for optimizing neuromuscular adaptations and performance improvements in most athletes. (Panayotov & Yankova, 2022; Sheppard & Triplett, 2016, p. 490; Stone, et al., 2022,). Elite-level athletes may train more frequently, often twice per day.

Future research should refine assessments of muscle mass by focusing specifically on lower-body musculature and its architectural properties. Additionally, exploring detailed training variables such as volume and intensity will provide deeper insights into optimizing training protocols for weightlifters across all levels.

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