

Jump height and peak power prediction based on the maximal back squat result in resistance-trained men

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Abstract:

Power is a crucial ability in many sport disciplines, yet the prediction of power, based on maximal load measure during the barbell back squat remains unclear. This study aimed to establish the prediction efficiency of jump height and peak power output based on maximal full back squat results, as a strength measure in absolute and relative ways. The study sample consisted of 28 physically active males with an average age of 21.7 ± 3 and minimal 2 years' experience in resistance training. Body height and weight were assessed. The participants performed the back squat (BSQ) to determine their 1-repetition max (1RM) using the force-velocity method, which assessed absolute strength in the back squat. Additionally, a countermovement jump (CMJ) was conducted to measure jump height (JH), and peak power (PP) was calculated using the Sayers formula. Pearson correlations were calculated between the strength and power variables, both in absolute terms and relative to body weight. Linear regression analysis was performed with the strength indicators as independent variables and power as the dependent variables. 1RM BSQ linked to PP ($r=0.50$; $p<0.01$). The relative strength (1RM BSQ/body weight) correlated with JH ($r=0.45$; $p=0.08$) and relative PP ($r=0.47$; $p=0.01$). Linear regression showed relative strength predict JH ($\beta=0.59$ $p=$), PP ($\beta=0.66$; $p<0.01$) and relative PP ($\beta=0.52$; $p=0.04$). Absolute strength predicts only PP ($\beta=1.19$ $p<0.01$). Strength significantly influences power, with relative strength proving particularly useful in predicting power properties. However, it is suggested to consider other potentially associated factors that may impact the strength-power relationship. Further research should explore these factors to understand the strength-power association better.

Key Words: strength; power; jump height; back squat; body mass

Introduction

Strength and power are fundamental motor abilities that significantly impact sport competition results and play a crucial role in injury prevention (Haff & Nimphius, 2012; Maesteroni et al., 2020; Koźlenia et al., 2022). In training periodization, strength is a foundation for developing other abilities, particularly power (Slimani et al., 2018). In classic model of periodization strength is developed before power abilities (Haff & Nimphius, 2012). Whereas strength is an ability to resist an applied load, power is a measure of force multiplied by the velocity of movement (Kawamori & Haff, 2004). However, it is essential to recognize that power abilities are influenced by various factors beyond strength, including energy expenditure, mental focus, movement technique, and inter and intramuscular coordination (Cormie et al., 2011a; 2011b). These factors collectively contribute to an individual's overall power output and should be considered when designing training programs to enhance physical performance.

The improvement in the mentioned area may be achieved through resistance training (Slimani et al., 2018). Typically, resistance training is initially focused on muscle hypertrophy, then intensity grows, and maximal strength becomes the main target. Then gained abilities are translated into power. It is worth noting that resistance training programs should be tailored to individual needs, goals, and sport-specific demands (Slimani et al., 2018; Lindberg et al., 2021). Generally it is suggested to use 2-6 sets, with 2-6 repetition with load 87-95% or even higher when maximal strength is a target, but with appropriate adjustments in volume (Haff & Triplett, 2015). In power development programs it is suggest using 2-5 sets with 2-5 repetition with intention to develop maximal velocity of movement with load in range 30-85% what is dependent on chosen exercise (Kawamori & Haff, 2004).

Strength measurements in sports often involve various tests and assessments, depending on the specific requirements of the sports discipline. These measurements can include tests such as the mid-thigh pull, dynamometers to assess force output, or isokinetic measures to evaluate muscle strength at different speeds. Additionally, multipoint exercises like squats or bench presses are commonly used to determine overall strength and muscle function, considering multiple muscle groups (Grgic et al., 2020). Similarly, power testing

encompasses a range of measures. Given that many sports heavily rely on lower limb movements, power assessments often prioritize lower limb performance. Therefore, tests such as horizontal or vertical jumps are frequently used to evaluate power output (Pupo et al., 2020). These tests provide valuable insights into an individual's ability to generate explosive force from the lower body, which is crucial in many athletic movements (Lindberg et al., 2022).

By incorporating strength and power assessments that align with the demands of the sport, coaches, and trainers can gain valuable information about an athlete's capabilities and areas for improvement. This knowledge can then be used to design targeted training interventions that address specific performance needs and enhance overall athletic performance (Grandou et al., 2020). Testing performance is crucial during the off-season to assess an athlete's actual physical fitness. The assessment helps in making appropriate decisions regarding training loads. Additionally, it is essential during subsequent training periods for monitoring purposes, allowing for necessary corrections in the training process when needed (Dzimbova & Ivanov, 2023).

While the association between strength and power has been extensively studied in athletes, relatively limited research is available regarding amateurs or individuals at lower performance levels (Del Vecchio et al., 2019; Bartolomei et al., 2021). Consequently, there is a lack of clear understanding regarding the specific indicators that can be valuable for assessing the strength-power relationship in sports. Witmer et al. (2010) demonstrated that acute efforts based on back squat results could improve power output and jump height. Additionally, Yapici et al. (2023) found improvements in strength and power after several weeks of resistance training incorporating loaded squats. Monitoring these abilities could also have utility in predicting injury risk (Case et al., 2020). Also, power abilities can be enhanced immediately after high-intensity resistance effort due to post-activation performance enhancements phenomena (Blazevic & Babault, 2019).

Jump height strongly depends on muscle strength, as indicated by a study by Kraska et al. (2009). The study found that individuals with greater strength exhibited less of a decrease in jump height when additional loads were applied. Furthermore, Fischer et al. (2017) confirmed an association between power and strength, albeit using isokinetic measurements. However, whether a one-repetition max back squat is, a valuable indicator of jump height and power levels remains unclear. This information would be beneficial in understanding the utility of back squat measurements in power development within middle and long-term training programs.

Additional research is needed to explore further the relationship between strength, power, and their respective indicators, mainly focusing on amateurs and individuals at lower performance levels. By better understanding, these associations, coaches, trainers, and researchers can design more effective training programs and assessments to enhance power development and performance in individuals at various skill levels.

This study aimed to determine the prediction efficiency of maximal full back squat results on jump height and peak power output. Specifically, the study investigated the association between maximal full back squat results in both absolute and relative approaches with jump height and power. Furthermore, the study aimed to assess the predictive ability of back squat strength measurements on jump height and power output. The findings of this study have potential implications for monitoring and sports testing, as well as informing appropriate approaches in training programming.

Material and methods

Participants

The present research received ethical approval from the Ethics Committee of the Wrocław University of Sport Health Sciences (06/2023) and adhered to the ethical principles outlined in the Declaration of Helsinki. Before their participation, all participants were provided with detailed information regarding the research procedures and potential risks involved in the experiment. Informed consent was obtained from each participant, who voluntarily agreed to participate by providing written permission. Participants were also informed of their right to withdraw from the study at any point if they wished to do so.

A total of 28 male individuals who met the specified eligibility criteria were selected to participate in the study. The inclusion criteria included being between the ages of 19 and 25, having no musculoskeletal injuries within 8 weeks before the study, no presence of any other medical contraindications, possessing a minimum of 1 year of experience in strength training, and no usage of prohibited substances such as anabolic-androgenic steroids. Before the measurements, participants were instructed to refrain from strenuous physical activity for 48 hours and to maintain their normal eating, drinking, and sleeping patterns. However, participants were specifically instructed to avoid the consumption of ergogenic compounds, including caffeine, within 24 hours leading up to the measurement sessions.

Body morphology

Body morphology

Height measurements were conducted using an anthropometer (GPM Anthropological Instruments, DKSH Ltd., Zürich, Switzerland). Body mass measurements were obtained using the InBody230 device (InBody Co., Ltd., Cerritos, CA, USA), known for its strong reliability, according to a study by McLester et al. (2020).

With the collected height and body mass data, the Body Mass Index (BMI) was calculated using the following formula: $BMI = \text{body mass (kg)} / \text{body height (m)}^2$. This widely used formula provides a standardized

measure of body composition based on an individual's weight and height. The BMI calculation allows for assessing body weight relative to height and roughly estimates overall body composition.

Back squat one maximum repetition testing

To determine the participants' 1-RM (one-repetition maximum) for the full-back squat, the Vitruve velocity-based training (VBT) device from Vitruve, SPEED4LIFTS S.L., Madrid, Spain, was used. This method relies on the relationship between load and velocity, ensuring precise and safe measurements (Jidovtseff et al., 2011; Signore, 2021). The VBT device's reliability has been confirmed in previous research (Martinez-Cava et al., 2020). Before the 1-RM protocol, participants completed a standardized warm-up consisting of a 5-minute run at 6 km/h, dynamic joint mobilization exercises, and two sets of ten repetitions of body squats, lunges, and hip thrusts with a 60-second rest period between sets. This warm-up aimed to prepare the muscles and joints and reduce the risk of injury.

Following the warm-up, participants performed a maximal deep back squat with an empty bar to establish their maximum depth while maintaining proper technique and safe body positioning. The depth achieved during this test was maintained throughout the 1-RM protocol, controlled by parallel settings based on individual height. An investigator ensured proper form and repeatability. The warm-up sets included 12-15 repetitions with an empty bar, followed by 10-12 repetitions at 50% of the estimated one-repetition maximum, targeting a mean velocity of 1.0-1.2 m/s after a brief rest period. Participants then performed two to three sets of five repetitions at 60-80% of their estimated one-repetition maximum, aiming for a mean velocity of 0.5-0.75 m/s. Once the desired velocity was achieved, a progressive incremental test began. The initial load was set at 80% of the estimated one-repetition maximum, and three repetitions were performed. Load increments of 5%-10% were added as the test progressed. Adjustments were made if the mean velocity dropped below specific thresholds, with subsequent sets performed for fewer repetitions. The test continued for up to five sets or until failure, with rest periods of three to five minutes between sets.

Countermovement jump

The Countermovement Jump's (CMJ) height was measured using the OptoJump device (Microgate, Bolzano, Italy) with a sampling frequency of 1,000 Hz. Previous studies by Słomka et al. (2017) have confirmed the validity and reliability of the OptoJump device. During the CMJ, participants jumped without arm swings and depth restrictions. The calculation of jump height was based on the equation: $\text{Jump height} = 9.81 \times (\text{flight time})^2 / 8$.

To calculate the absolute peak power (PP) during the CMJ, the equation developed by Sayers et al. (1999) was used: $\text{PP} = 60.7 \times \text{jump height(cm)} + 45.3 \times \text{body mass(kg)} - 2055$

The relative peak power was calculated based on the value from the above equation divided by the subject's body mass: $\text{Relative PP} = \text{PP/body mass}$

Statistics

The normality distribution of the data was assessed using the Shapiro-Wilk test. Descriptive statistics, including means, standard deviations, and 95% confidence intervals (95% CI), were calculated for the variables analyzed. Pearson rank correlation was used to examine the relationships between the strength and power measures. Linear regression analysis determined the predictive value of the relative and absolute strength measures obtained during back squats on jump height and power. The significance level was set at $p < 0.05$. Statistical analyses were conducted using Statistica v13.3 (Statsoft Polska, Cracow, Poland).

Results

Table 1 is presented descriptive statistics of study participants considering their body morphology, training experience, and strength and power parameters in absolute and relative.

Table 1. Descriptive statistics of study participants.

Variable	Mean±SD (95%CI)
Age [year]	21.7±3 (20.6 -22.8)
Body Height [m]	1.8±0.3 (1.7 -1.8)
Body Weight [kg]	78.8±9.4 (75.4 -82.3)
Body Mass Index [kg/m ²]	24.4±2.1 (23.6 -25.2)
gym experience [years]	4±2.1 (3.2-4.8)
Weekly training volume [min/week]	313.5±136 (263.7 -363.4)
Back squat 1-repetition max [kg]	109.3±28.7 (99 -119.6)
Relative strength back squat[1RM/BW]	1.4±0.3 (1.3-1.5)
CMJ height [cm]	35.8±6.5 (33.4 -38.2)
Peak power [W]	3689.9±511.6 (3502.3-3877.6)
Relative power [W/body weight]	46.9±5.4 (44.9-48.9)

Table 2 are presented the results of the Pearson correlation between strength and power parameters. The back squat results representing absolute strength were associated with peak power, also considered in an absolute way. Relative strength, which represents the ratio between back squat results adjusted for body mass, was associated with jump height and relative power.

Table 2. Pearson correlation results between strength and power parameters. *Statistically significant $p < 0.05$.

Variable	Statistics	Jump height	Peak power	Relative power
Back squat	Pearson coefficient	0.31	0.50*	0.34
	p-value	$p = 0.08$	$p < 0.01$	$p = 0.06$
Relative strength	Pearson coefficient	0.45*	0.10	0.47*
	p-value	$p < 0.01$	$p = 0.58$	$p = 0.01$

In the linear regression analysis, it was found that relative strength significantly predicts jump height ($\beta = 0.58$, $p = 0.04$), peak power ($\beta = 0.66$, $p < 0.01$), and relative peak power ($\beta = 0.52$, $p = 0.04$). On the other hand, absolute strength only predicts peak power ($\beta = 1.19$, $p < 0.01$).

Table 3. Linear regression results. *Statistically significant $p < 0.05$.

Independent Variable	Dependent Variable	β	β SE	B	B SE	p
Back squat	CMJ height [cm]	0.16	0.28	0.05	0.09	0.58
Relative strength		0.59	0.28	4.12	6.70	0.04*
Back squat	Peak power [W]	1.19	0.22	29.05	5.43	< 0.01 *
Relative strength		0.66	0.22	-10.20	8.53	< 0.01 *
Back squat	Relative power [W/body weight]	-0.08	0.28	-0.02	0.07	0.78
Relative strength		0.52	0.28	10.38	5.66	0.04*

Discussion

Despite the well-known association between strength and power, there is often confusion regarding which measures are most useful, particularly among amateur or recreational individuals regarding prediction ability. Our study aimed to clarify this issue and found that the results obtained from one-repetition maximum (1RM) testing showed a significant association with jump height and power. Interestingly, the relative approach, specifically adjusting the back squat results for body weight, was the most effective in predicting power.

In the training process of athletes, testing and monitoring play a crucial role in effectively guiding athletic development (Pupo et al., 2020). Since strength is the foundation for improving other motor abilities, including power, understanding an individual's strength abilities becomes vital. In practical terms, one of the simplest and most widely used tests in a gym setting is the squat exercise. By incorporating such tests, coaches, and trainers can gain valuable insights into an individual's strength potential and subsequently tailor their training programs for optimal motor ability development.

In line with our observations, the results provided by Lindberg et al. (Nysether et al., 2023) demonstrate a correlation between lower limb strength and vertical jump performance. Furthermore, Franca et al. (Franca et al., 2023) found that lower limb strength and overall strength, as indicated by handgrip, sit-ups, or push-ups, are associated with countermovement jump (CMJ) height. Additionally, body fat was found to be related to jump height, suggesting the significance of other associated factors. These findings support the observations made by Abidin & Adam (2013), who emphasized the role of body dimensions in jump and power performance. Therefore, it is crucial to consider a comprehensive training approach encompassing various factors rather than solely focusing on strength development, although it remains one of the most critical factors.

Furthermore, when discussing strength, it is essential to recognize that it is not only maximal strength that matters but also the rate at which strength is developed, which directly impacts power ability (Jimenez-Reyes et al., 2017). However, higher maximal strength levels predispose individuals to generate greater amounts of force more quickly, which can be reflected in their jump performance ability (Marcote-Pequeño et al., 2019). However it is also worth that plyometric training may increase both strength and power abilities what indicate multidirectional associations (Ioannides et al., 2020).

Jump height is a valuable indicator of physical performance and is crucial in numerous sports. Miller et al. (2022) have demonstrated that variables related to strength are predictive of jump height. Consistent with these findings, our study reinforces the significant role of strength in determining jump height. However, it is essential to recognize that the timing of strength development also plays a critical role, as indicated in previous research (Miller et al., 2022).

Furthermore, incorporating bar velocity measurements, particularly with loaded jump squats, has shown promise in predicting jump height by considering the force-velocity relationship (Morin & Samozino, 2016). While strength remains a major determining factor, it is essential to acknowledge that jump height can be influenced by various other factors, including anthropometric characteristics, as highlighted by Abidin et al. (2013). It is important to note the limitations of our study. We did not directly measure power using a force platform, which could have provided more comprehensive insights. Additionally, including other strength tests, such as the mid-thigh pull, could have further enriched our observations. Furthermore, our study only focused on male participants, limiting the generalizability of our findings to a broader population. Future studies should consider the optimal values of strength measures to maximize power performance. Therefore, further investigations are needed to meet this demand.

Conclusion

Strength development plays a crucial role in improving power. While a strong association exists between strength and power, it is also essential to consider other potentially related factors. Both absolute and relative strength are linked to power variables and can be used to predict power output. However, relative strength appears to be more valuable due to its broader associations. Therefore, it is suggested to also consider body weight as a co-factor. Our study supports the notion that strength is the foundation for power development and highlights the significance of relative strength in predicting power outcomes. This information can be applied in sports practice for diagnostic and testing purposes. In this case 1-RM back squat is related to CMJ results due to similarity in movement pattern, and this relationship could be use in training process as well in monitoring and performance development.

Conflicts of interest

No conflict of interest to declare.

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