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RESEARCH

# Optimum power load profile in squat and countermovement jump protocols

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## Abstract

**Purpose** The study aimed to analyze the optimal power load in the squat jump (SJ) and countermovement jump (CMJ) protocols considering raw values and scaled by body mass (BM), and in addition, to determine the mean propulsive velocity (MPV) associated at the optimum power load in SJ and CMJ.

**Methods** Twenty-two recreationally active men performed the CMJ and SJ considering different loads (0, 10, 20, 30, 40 and 50% of BM). Analysis of variance for repeated measures with Bonferroni post hoc test was used to compare the CMJ and SJ metrics among different conditions (0% to 50% of BM) with the level of significance set at 5%.

**Results** In general, there was a decrease in CMJ and SJ performance metrics (jump height, peak and mean power output relative and absolute, and MPV) at higher loads ($p < 0.05$).

**Conclusion** We concluded that the optimum power load for CMJ and SJ were at 0% BM taking peak power output and mean power output as outcome variables. The identification of optimum power zone did not differ if using absolute or relative power (scaled by BM). The MVP related to the optimum power load zone differed between CMJ and SJ.

**Keywords** Power output · Optimal load · Mean propulsive velocity · Vertical jump

## Introduction

In a range of different sports, muscle power is essential for the execution of several motor actions involved in sport-specific technical and locomotor activities, such as jumps and sprints, with or without change of direction and accelerations [1]. For this reason, strength and conditioning coaches have searched training methods capable of improving athletes' power production capacity. The specific workload in which power production is maximized has been called optimum power load. The optimum power may be determined using any device capable of measuring or estimating mechanical power in a given exercise, providing progressive increments of load (generally body mass—BM) until a clear decrease in power production is consistently observed [2]. Power production in lower body exercises is generally optimized under unloaded conditions (i.e., 0% BM) when considering the "system power", i.e., body + bar with a possible extra load, traditionally performed using force plates. However, when considering only the "bar-power", in which the aim is to assess the power production directly from the bar using a linear position transducer, the values are usually maximized at moderate loads (i.e., 30–60% of one-repetition maximum—1RM) [2–5].

The search for the ideal or optimal load for maximization of the muscle power has been widely studied in recent years, using different analysis methods and exercises [6–9]. The squat jump (SJ) and countermovement jump (CMJ) exercises are widely used by strength and conditioning (S and C) coaches in power training and assessment programs. Besides the feasibility, power production and performance in SJ and CMJ have presented significant correlations with performance in several sports tasks [10–12] , justifying their use on training and assessments. However, the specificity of the mechanical characteristics of these tasks (e.g., fast or slow and the presence

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of elastic energy or not) [5] may lead to different strategies for maximizing jump performance, resulting in different power load profiles in SJ and CMJ. It is known that exercises that involve the use of stretch-shortening cycle (SSC), as the CMJ, present greater speed of movement and can result in higher force development and power output, unlike the SJ [13].

Another aspect to be discussed is the outcome variable. Mean power (MPO) and peak power output (PPO) collected during the upward portion of the jumps are widely used to assess sport performance and to optimize training strategies. PPO obtained during the vertical jump corresponds to a specific moment close to the take-off, while MPO represents the entire push-off phase; therefore, these measures seem to represent different mechanical principles and may have different sensitivity to detect neuromuscular adaptations from training [14]. Loturco et al. [6] point out that despite their extensive use as reference values of muscle power, the varied spectrum of loads used to assess these variables produces large dissimilarity in the outputs obtained. In addition, the use of a fixed velocity value (i.e., mean propulsive velocity—MPV) obtained at the optimum power load is another variable outcome proposed in the literature [6]. Some studies have reported that the maximum power production is achieved at velocities close to 1 $ms^{-1}$ both in the bench press [15] and squat [3] exercises. However, the load capable of maximizing the power output is dependent on the method and exercise used to find this variable; therefore, we need to test if a same value may be obtained in SJ and CMJ.

Other external factors that should be considered to understand the optimum power load in the CMJ are the individual characteristics, as strength level and training status, which have demonstrated great intra-individual variation [16, 17]. Moreover, the individual's BM strongly influences the determination of the optimum power load. According to Jaric and Markovic [5] and Morin et al. [18], the optimum load in maximum vertical jumps correspond to the mass of one's own body; on the other hand, it is suggested that due to individual characteristics (e.g., very light or very heavy individuals), some individuals may have the optimum power load that differs from their own BM [18]. Considering this issue, the influence of body mass needs to be removed in order to understand its possible influence in determining the optimum power load. Traditionally, power output has been scaled for BM using a ratio standard (i.e., linear relation) [19], but, it is necessary to test how BM is related with power output (linear or allometric) for adequately scaling it.

Therefore, the current study aimed to analyze the optimal power load (0, 10, 20, 30, 40, and 50% of body mass) in the SJ and CMJ protocols considering raw values and scaled by BM. Moreover, we aimed to determine the MPV associated at the optimum power load in SJ and CMJ. We hypothesized that participants would perform better in the condition of 0% load (i.e., BM), considering the findings of previous studies [16, 20] regardless the type of exercise (SJ or CMJ).

## Methods

### Study design

This is a cross-sectional descriptive study design, in which participants performed two visits to the laboratory. On both visits, the subjects were familiarized with the CMJ and SJ protocols and their preferred squat depth during the jump was determined. On the first visit, the CMJ test was performed under the conditions: unloaded jump (0% BM) and with loads corresponding to 10, 20, 30, 40, and 50% of body mass (loaded jumps). After an interval of from 48 to 72 h, the SJ test was applied with the same loads performed in the CMJ. The optimal power load was analyzed taking peak and mean power output (relative and absolute), mean propulsive velocity, and jump height as outcome variables.

## Participants

Twenty-two recreationally active men participated in this study, with the following characteristics: age 22.7 ± 4.07 years, height 179 ± 7.0 cm, and weight 77.2 ± 12.2 kg. All participants were undergraduate students and were not engaged in any club, collegiate, or professional sport. Participants were: (a) physically active (i.e., practice strength training, running, and/or sports involving jumps, such as volleyball, basketball, judo, and soccer) three to five times a week for at least 1 year; and (b) had no injuries or pathologies that would preclude maximum effort in the tests. Participants read and signed the informed consent and were familiar with the CMJ movement from their routine recreational training. The university's Institutional Review Board approved this project (CAEE: 57615022.7.0000.0121) according to the declaration of Helsinki. During the procedures, individuals were required to wear athletic clothing and shoes.

### Procedures

#### Determination of power load profile in vertical jump

Before the vertical jump assessment, the subjects participated in a familiarization/warm-up, involving 30 s of jumping on a trampoline, 3 series of 10 jumps on the ground, and 5 submaximal CMJs. For the CMJ, participants started from a static standing position and were instructed to perform a counter movement (descent phase) followed by rapid and vigorous extension of the lower limb joints (ascent phase).

During the jump, the participants were asked to keep their trunk as vertical as possible, and the hands holding an iron bar on the shoulders with the previously determined loads. In the condition without external load (i.e., 0% BM), the individual supported a rigid plastic pipe weighing close to 200 g and measuring 2 m, with the objective of adopting the same position as with the iron bar. The athletes were then instructed to jump as high as possible. In the SJ, the subjects started the jump from a static position, with the knees at an angle of approximately 90°, and the jump was performed without any countermovement. To control the preferred squat depth during the CMJ and SJ, a light elastic band was attached to a vertical support at the height corresponding to the preferred squat depth (identified in familiarization), as suggested by Gheller et al. [21]. The vertical jumps were performed on a piezoelectric force platform (9290AD, 500 Hz, Kistler, Quattro Jump, Winterthur, Switzerland). In addition, a linear encoder (*Ergonauta*) was attached using a waist belt to measure the MVP during the jumps.

The load power profile was tested using six different external loads (0, 10, 20, 30, 40, and 50% of BM). Each participant completed two attempts at each load, and in cases where there was a coefficient of variation greater than 5%, a third attempt was performed. The highest jump height was used for the analyses. A 1 min rest was provided between each jump, with a 3 min rest between each load. It is believed that this rest time is sufficient to recover the phosphagen system and avoid fatigue [16, 22].

## Data analysis

The ground reaction force (GRF) obtained from the force plate was double integrated to calculate jump height, as detailed below:

(a) Jump height: first, the acceleration curve was obtained by dividing the GRF values by the body mass (measured by the force plate) of each individual. Next, a trapezoidal integration of the acceleration curve was used to obtain the velocity curve, with the latter integrated again to obtain the distance at each time point of the movement. The greatest vertical distance was considered as the highest jump height.
(b) Power output: calculated by multiplying GRF by velocity at the concentric phase of the jump. The peak (PPO) and mean (MPO) values of the curve were used for analysis.
(c) Mean propulsive velocity (MPV): calculated as the average of the velocity values corresponding to the propulsive phase of the movement (concentric phase), that is, from the first positive value of velocity until the acceleration is lower than gravity ($-9.81$ m/s$^2$). The MPV was calculated using an *Ergonauta* encoder, previously validated [23].

### Allometric modeling of power output

The power output derived from vertical jumps was adjusted for body mass (BM) using specific allometric exponents to account for potential effects of body dimensions on performance. Log-linear regressions were established for each variable [Eq. (1)] based on the natural logarithms (ln) of BM (kg) and MPO or PPO, composed of the constant (a) and the slope of the regressions (b; allometric exponents):

$$\ln PPO_{ADJ} = (\ln a) + (b x \ln BM) \quad (1)$$

To test the quality of the log-linear regression, the follow criteria were used [24]: (a) the absence of significant correlation between scaled variable and BM ($R^2 < 0.1$) as main criteria; (b) the distribution normality of the residuals using the Shapiro–Wilk test; (c) the homoscedasticity of residuals using Pearson's correlation between raw residuals and the independent BM (lnBM). After this, scaled MPO or PPO by BM was calculated for each variable according to Eq. (2). Thus, the adjusted MPO ($MPO_{ADJ}$) or PPO ($PPO_{ADJ}$) and BM were correlated to test whether the allometric scaling was satisfactory to remove the BM effect:

$$MPO\ or\ PPO_{ADJ} = MPO\ or\ PPO\ x\ BM^{-b} \quad (2)$$

## Statistical analysis

Data are reported as means and standard deviations. The Shapiro–Wilk test was used to verify the normality of the residual data. The sphericity of the data was verified according to the Mauchly's test ($p > 0.05$) and the equality of variances assumption using the Levene's test. Analysis of variance with repeated measures (within-subject ANOVA) and Tukey post hoc tests were used to compare the vertical jump metrics (power output, jump height and mean propulsive velocity) among different conditions of external load (0–50% of BM) for both CMJ and SJ. Significant comparisons were followed up using post hoc analysis of the adjusted residuals using Tukey corrections [25]. The effect sizes (ES) for ANOVA were calculated using partial eta squared ($\eta_p^2$), with < 0.01 (small), 0.01–0.06 (medium), and 0.06–0.14 (large), respectively [26]. For all analyses, the significance level was set at 0.05 and JASP software was used.

# Results

The allometric scaling of power output revealed b-values (exponents) close to "1" (CMJ = 1.1; SJ = 0.83), allowing for to use the ratio standard to normalize this variable for further analysis. Thus, PPO and MPO were presented relatively to body mass of each participant.

The variables of relative and absolute power output (PPO and MPO) (Fig. 1), and jump height and MPV (Fig. 2) are presented for different external loads (0, 10, 20, 30, 40, and 50% of BM) in the CMJ. Significant differences were found for relative PPO ($F_{5,105} = 38.61$; $p < 0.001$; $\eta p^2 = 0.637$ [large]), absolute PPO (F5,105 = 47.80; $p < 0.001$; $\eta p^2 = 0.685$ [large]), absolute MPO ($F_{5,105} = 40.70$; $p < 0.001$; $\eta p^2 = 0.665$ [large]), relative MPO (F5,105 = 45.63; $p < 0.001$; $\eta p^2 = 0.655$ [large]), jump height (F5,105 = 31.52; $p < 0.001$; $\eta p^2 = 0.935$ [large]), and MPV (F5,105 = 34.12; $p < 0.001$; $\eta p^2 = 0.859$ [large]). The post hoc analysis showed high values at 0% load compared to the other loads (10, 20, 30, 40, and 50%) for relative and absolute power output (PPO and MPO), jump height and MPV. For relative and absolute power output, considering the 10% load, significant differences were found compared to 30, 40, and 50% ($p < 0.001$). The 20% load was higher compared to 40% ($p < 0.001$, only for MPO) and 50% ($p < 0.001$) and 30% were higher compared to 50% ($p < 0.001$). The post hoc detected a progressive decrease in jump height and MPV throughout the load conditions ($p < 0.001$).

Figure 3 shows the relative and absolute power output (PPO and MPO), while Fig. 4 shows the jump height and MPV in different external loads (0, 10, 20, 30, 40, and 50% of BM) in the SJ. Significant differences were found in the relative PPO ($F_{5,105} = 43.22$; $p < 0.001$; $\eta p^2 = 0.954$ [large]), absolute PPO ($F_{5,105} = 40.07$; $p < 0.001$; $\eta p^2 = 0.323$ [large]), absolute MPO ($F_{5,105} = 42.00$; $p < 0.001$; $\eta p^2 = 0.655$ [large]), relative MPO ($F_{5,105} = 47.80$; $p < 0.001$; $\eta p^2 = 0.675$ [large]), jump height ($F_{5,105} = 25.67$; $p < 0.001$; $\eta p^2 = 0.925$ [large]), and

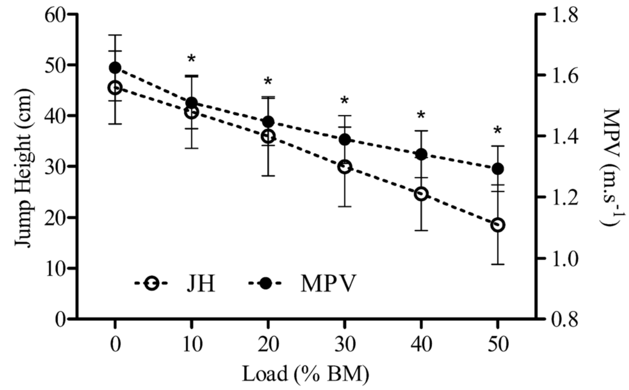


**Fig. 2** Comparison of MVP and jump height among different external loads (0, 10, 20, 30, 40, and 50% of BM) in the CMJ. *JH* jump height, *MPV* mean propulsive velocity. * significantly different from 0%

MPV ($F_{5,105} = 30.86$; $p < 0.001$; $\eta p^2 = 0.595$[large]). The Bonferroni post hoc analysis demonstrated higher values of relative and absolute power output (PPO and MPO) in the 0% load compared to 30 ($p = 0.003$), 40 ($p = 0.007$), and 50% ($p = 0.006$). High values were found for 10% compared to 30 ($p = 0.024$), 40 ($p = 0.038$), and 50% ($p = 0.008$). Finally, high values were detected at 20% compared to 40% ($p = 0.002$) (only for PPO and 50%). For jump height, the post hoc detected progressive decreases throughout the loaded conditions ($p < 0.001$). For MPV, high values were found in the 0% load compared to 10, 20, 30, 40, and 50% ($p = 0.002$), and high values were found for the 10% load compared to 30, 40, and 50% ($p = 0.005$ for all). In addition, the 20% load was higher compared to 40 ($p < 0.001$) and 50% ($p = 0.002$).

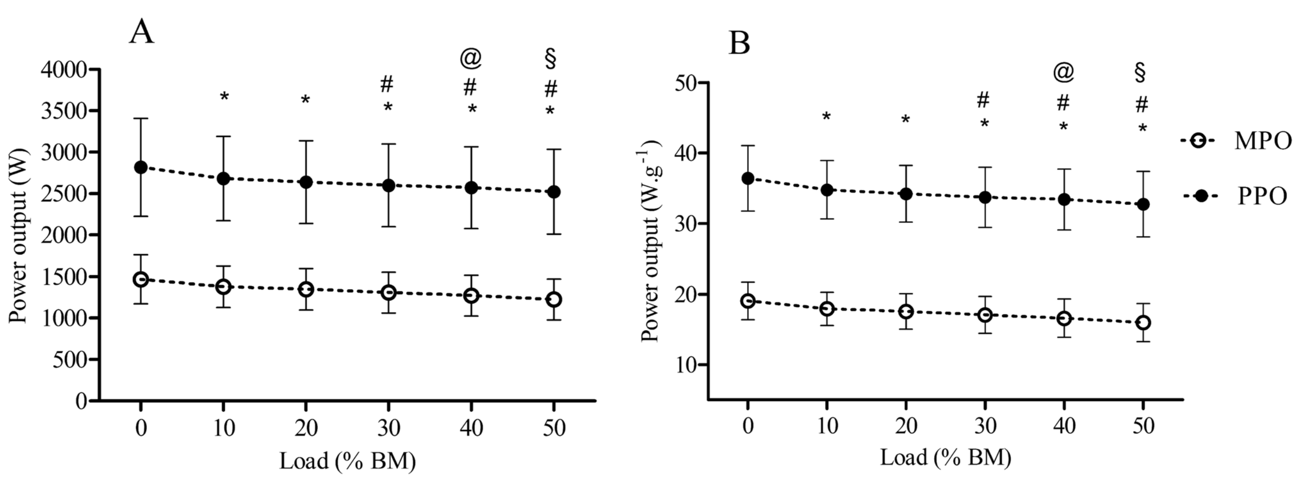


**Fig. 1** Comparison of power output (peak—PPO and mean—MPO) among different external loads (0, 10, 20, 30, 40, and 50% of BM) in the CMJ. Panel **A**: absolute power; Panel **B**: relative power. *PPO* peak power output, *MPO* mean power output. * significantly different from 0%, # significantly different from 10%, @ significantly different from 20%;§ significantly different from 30%

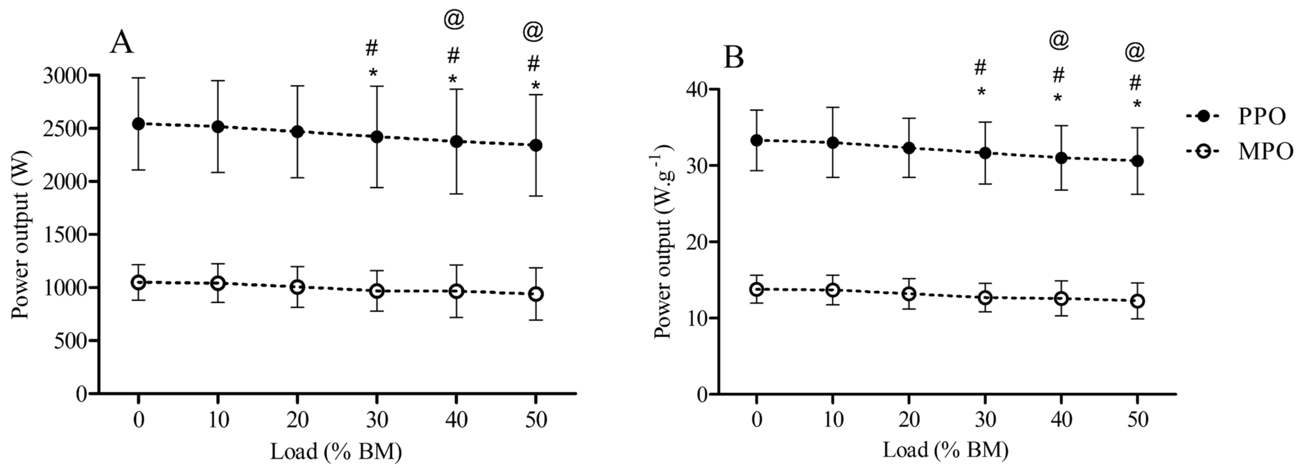


**Fig. 3** Comparison of power output (PPO and MPO) among different external loads (0, 10, 20, 30, 40, and 50% of BM) in the SJ. Panel **A**: absolute power; Panel **B**: relative power. *PPO* peak power output, *MPO* mean power output. * significantly different from 0%, # significantly different from 10%, @ significantly different from 20%

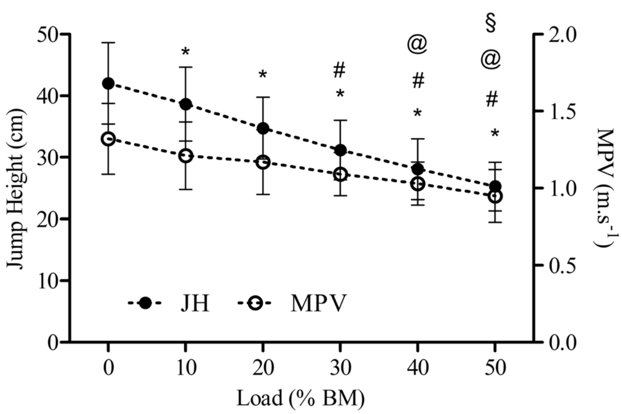


**Fig. 4** Comparison of MPV and jump height among different external loads (0, 10, 20, 30, 40, and 50% of BM) in the SJ. *JH* jump height, *MPV* mean propulsive velocity. * significantly different from 0%, # significantly different from 10%, @ significantly different from 20%; § significantly different from 30%

## Discussion

The aim of this study was to analyze the optimal power load profile (0–50% of BM) in two different protocols of vertical jump protocols (CMJ and SJ). Our hypothesis was accepted, since the participants presented the optimum power at 0% BM (unloaded condition) regardless the type of exercise (SJ or CMJ). We verified that body mass did not influence in the optimum power load profile. MPV presented significant decreases as load increases in both CMJ and SJ protocols.

The results of the present study were similar to those observed in previous studies (using force plate to determine power output), in which the optimum load to generate maximum power in CMJ was found in the unloaded condition (i.e., only with BM) [9, 20, 27]. According to Jaric and Markovic [28], lower limbs are designed to produce maximum power output in rapid movements when loaded only by its own body. In other study of the same authors [29], it was found that the peak power output was higher when the participants performed the CMJ without external load or with a negative load (– 30% of body mass), while there was a decrease in peak power with positive external loads (~ 15 and 30% of body mass). Moir et al. [30], when analyzing 0% and up to 85% of 1RM, verified that the peak power output occurred at the 0% load accompanied by a progressive reduction in this variable with increased load during the jump squat.

Analyzing the jump height and MPV, the optimal external load was identified at the 0% load with significant decreases in these variables with load increases in both CMJ and SJ protocols. Several studies found similar results when performing vertical jumps with external load (e.g., decrease in performance with higher loads) [2, 9, 31–33]. The decrease in jump height in the vertical jump protocols is expected, because during the jumping movement, the neuromuscular system is overloaded by the inertia of the body mass and body segments [5]. However, when the vertical jump is performed with external load there is additional inertia, with an increase in total inertia, decreasing the ability to perform the jump and the velocity of the movement [34]. Assuming that every repetition is performed with maximal voluntary effort, velocity unintentionally declines as fatigue develops [15]. Thus, the linear decline of MPV and CMJ height may support the validity of MPV to objectively quantify the load during jump vertical training [35].

An important aspect is the identification of MPV at the optimal external load, as proposed by some authors [6, 36]. According to Loturco et al. [6], the optimum power load is found when the MPV measured by a linear transducer is close to 1 $ms^{-1}$ during the jump squat in the Smith machine. In the present study the MPV correspondent to the optimum power load was 1.61 $ms^{-1}$ for CMJ and 1.30 $ms^{-1}$ for SJ. These differences may be explained by the different methodologies adopted, such as the type of vertical jump performed and the use or not of equipment (Smith) to perform the jumps. As pointed out by Loturco et al. [6], the usage of a fixed and known velocity related to the optimum power zone may help sport scientists who use linear encoders and/or accelerometers to determine the optimum loads for their athletes, which may significantly reduce the time spent assessing power.

Lastly, we verified that there was no significant difference in the optimum load when considering absolute and relative power, showing no influence of BM, i.e., regardless of the BM of subjects (lighter or heavier), the highest power is achieved when loaded only by its own body. Similar to previous studies [14, 37], our results supported the use of ratio standard for power output (PPO or MPO) scaling, thus being able to remove the BM effect.

As the main limitation of the study, we can point the absence of analysis of jumps with a negative load (e.g., − 10% and − 20% of BM), not allowing to test whether some individuals could obtain their maximum power with loads below the BM. As strengths, our study showed important results for S and c coaches who use vertical jump protocols in the training routines, as optimizing power is essential to improve performance, in this case having only the body mass as an external load. Furthermore, when using the average propulsive speed metric to control the power training load, 1 m/s cannot be taken as a fixed reference, as we found a different value. We recommend that futures studies analyze upper limb exercises, and consider to assess female individuals for test the optimal load.

## Conclusion

We concluded that the optimum power load for CMJ and SJ was at 0% BM (i.e., unloaded condition) taking peak power output and mean power output as outcome variables. The identification of optimum power zone did not differ if using absolute or relative power (scaled for BM). The MPV related to the optimum power load zone differed between CMJ (1.6 $ms^{-1}$) and SJ (1.3 $ms^{-1}$), presenting higher values considering the currently value suggested in the literature (~ 1 $ms^{-1}$).

**Author contributions** RGG, RLK, JD and DD contributed to the study conception and design; RGG and RLK conducted the experiments; WK, JD and DD analyzed the data; RLK and JD prepared the figures; RGG, RLK, WK, JD and DD contributed the drafting of the manuscript and editing and revising manuscript. All the authors contributed equally to the manuscript and read and approved the final version of the manuscript.

**Data availability** The datasets generated during and/or analyzed during the current study are available from the correspondingauthor on reasonable request.

## Declarations

**Conflict of interest** The authors declare no competing interests.

**Ethical approval and Informed consent** The project was approved by the Human Research Ethics Committee of the Federal University of Santa Catarina under protocol number CAEE: 57615022.7.0000.0121.

## References

1. Cronin J, Sleivert G (2005) Challenges in understanding the influence of maximal power training on improving athletic performance. Sport Med 35:213–234
2. Loturco I, McGuigan MR, Freitas TT et al (2021) Performance and reference data in the jump squat at different relative loads in elite sprinters, rugby players, and soccer players. Biol Sport 38:219–227. https://doi.org/10.5114/BIOLSPORT.2020.98452
3. McBride JM, Haines TL, Kirby TJ (2011) Effect of loading on peak power of the bar, body, and system during power cleans, squats, and jump squats. J Sports Sci 29:1215–1221. https://doi.org/10.1080/02640414.2011.587444
4. Loturco I, Pereira LA, Abad CCC et al (2017) Bar velocities capable of optimising the muscle power in strength-power exercises. J Sports Sci 35:734–741. https://doi.org/10.1080/02640414.2016.1186813
5. Jaric S, Markovic G (2013) Body mass maximizes power output in human jumping: a strength-independent optimum loading behavior. Eur J Appl Physiol 113:2913–2923
6. Loturco I, Nakamura FY, Tricoli V et al (2015) Determining the optimum power load in jump squat using the mean propulsive velocity. PLoS ONE. https://doi.org/10.1371/journal.pone.0140102
7. Markovic G, Vuk S, Jaric S (2011) Effects of jump training with negative versus positive loading on jumping mechanics. Int J Sports Med 32:365–372. https://doi.org/10.1055/s-0031-1271678
8. Morin JB, Samozino P (2016) Interpreting power-force-velocity profiles for individualized and specific training. Int J Sports Physiol Perform 11:267–272
9. Mundy PD, Smith NA, Lauder MA, Lake JP (2017) The effects of barbell load on countermovement vertical jump power and net impulse. J Sports Sci 35:1–7. https://doi.org/10.1080/02640414.2016.1236208
10. Dal Pupo J, Arins FB, Antonacci Guglielmo LG et al (2013) Physiological and neuromuscular indices associated with sprint running performance. Res Sport Med 21:124–135. https://doi.org/10.1080/15438627.2012.757225
11. Detanico D, Dal Pupo J, Franchini E, Giovana dos Santos S (2012) Relationship of aerobic and neuromuscular indexes with specific actions in judo. Sci Sport 27:16–22. https://doi.org/10.1016/j.scispo.2011.01.010

12. Loturco I, Pereira LA, Cal Abad CC et al (2015) Vertical and horizontal jump tests are strongly associated with competitive performance in 100 m Dash events. J Strength Cond Res 29:1966–1971. https://doi.org/10.1519/JSC.0000000000000849
13. Cormie P, McGuigan MR, Newton RU (2010) Changes in the eccentric phase contribute to improved stretch-shorten cycle performance after training. Med Sci Sports Exerc. https://doi.org/10.1249/MSS.0b013e3181d392e8
14. Dal Pupo J, Ache-dias J, Kons RL, Detanico D (2021) Are vertical jump height and power output correlated to physical performance in different sports? an allometric approach. Hum Mov 22:60–67. https://doi.org/10.5114/hm.2021.100014
15. Izquierdo M, Häkkinen K, Gonzalez-Badillo JJ et al (2002) Effects of long-term training specificity on maximal strength and power of the upper and lower extremities in athletes from different sports. Eur J Appl Physiol 87:264–271. https://doi.org/10.1007/s00421-002-0628-y
16. Mundy PD, Smith NA, Lauder MA, Lake JP (2017) The effects of barbell load on countermovement vertical jump power and net impulse. J Sports Sci. https://doi.org/10.1080/02640414.2016.1236208
17. Baker D, Nance S, Moore M (2001) The load that maximizes the average mechanical power output during jump squats in power-trained athletes. J Strength Cond Res 15:92–97. https://doi.org/10.1519/1533-4287(2001)015%3c0092:TLTMTA%3e2.0.CO;2
18. Morin JB, Jiménez-Reyes P, Brughelli M, Samozino P (2019) When jump height is not a good indicator of lower limb maximal power output: theoretical demonstration, experimental evidence and practical solutions. Sport Med 49:999–1006. https://doi.org/10.1007/s40279-019-01073-1
19. Jaric S, Mirkov D, Markovic G (2005) Normalizing physical performance tests for body size: a proposal for standardization. J Strength Cond Res. https://doi.org/10.1519/R-15064.1
20. Sheppard JM, Cormack S, Taylor KL et al (2008) Assessing the force-velocity characteristics of the leg extensors in well-trained athletes: The incremental load power profile. J Strength Cond Res 22:1320–1326. https://doi.org/10.1519/JSC.0b013e31816d671b
21. Gheller RG, Dal Pupo J, Ache-Dias J et al (2015) Effect of different knee starting angles on intersegmental coordination and performance in vertical jumps. Hum Mov Sci 42:71–80. https://doi.org/10.1016/j.humov.2015.04.010
22. Suchomel TJ, McKeever SM, Sijuwade O et al (2019) The effect of load placement on the power production characteristics of three lower extremity jumping exercises. J Hum Kinet 68:109–122. https://doi.org/10.2478/hukin-2019-0060
23. Gheller RG, Kons RL, Wladymir K et al (2023) Validity and reliability of ergonauta encoder to assess countermovement jump performance. J Sport Eng Technol Eng Technol. https://doi.org/10.1177/17543371231171192
24. Batterham AM, George KP (1997) Allometric modeling does not determine a dimensionless power function ratio for maximal muscular function. J Appl Physiol 83:2158–2166. https://doi.org/10.1152/jappl.1997.83.6.2158
25. MacDonald PL, Gardner RC (2000) Type I error rate comparisons of post hoc procedures for I × J chi-square tables. Educ Psychol Meas 60:735–754. https://doi.org/10.1177/00131640021970871
26. Cohen J (1988) Statistical power analysis for the behavioural sciences. Hillside, NJ Lawrence Earlbaum Assoc
27. Nuzzo JL, McBride JM, Dayne AM et al (2010) Testing of the maximal dynamic output hypothesis in trained and untrained subjects. J Strength Cond Res 24:1269–1276. https://doi.org/10.1519/JSC.0b013e3181d68691
28. Jaric S, Markovic G (2009) Leg muscles design: the maximum dynamic output hypothesis. Med Sci Sports Exerc. https://doi.org/10.1249/MSS.0b013e31818f2bfa
29. Markovic G, Jaric S (2007) Positive and negative loading and mechanical output in maximum vertical jumping. Med Sci Sports Exerc 39:1757–1764. https://doi.org/10.1249/mss.0b013e31811ece35
30. Moir GL, Gollie JM, Davis SE et al (2012) The effects of load on system and lower-body joint kinetics during jump squats. Sport Biomech 11:492–506. https://doi.org/10.1080/14763141.2012.725426
31. Jimenez-Reyes P, Cuadrado-Peñafiel V, Páreja-Blanco F et al (2016) Carga que maximiza a potencia de saida no salto com contramovimento. Rev Bras Med do Esporte. 22:13–16
32. Kang S (2018) Difference of neuromuscular responses by additional loads during plyometric jump. J Exerc Rehabil. 14:960–967. https://doi.org/10.12965/jer.1836428.214
33. Pérez-Castilla A, Jiménez-Reyes P, Haff GG, García-Ramos A (2021) Assessment of the loaded squat jump and countermovement jump exercises with a linear velocity transducer: which velocity variable provides the highest reliability? Sport Biomech 20:247–260. https://doi.org/10.1080/14763141.2018.1540651
34. Leontijevic B, Pazin N, Bozic PR et al (2012) Effects of loading on maximum vertical jumps: selective effects of weight and inertia. J Electromyogr Kinesiol 22:286–293. https://doi.org/10.1016/j.jelekin.2011.12.002
35. Sánchez-Medina L, González-Badillo JJ (2011) Velocity loss as an indicator of neuromuscular fatigue during resistance training. Med Sci Sports Exerc 43:1725–1734. https://doi.org/10.1249/mss.0b013e318213f880
36. Rodríguez-Zamora L, Padial P, Schoenfeld BJ, Feriche B (2019) Mean propulsive velocity is a viable method for adjusting the resistance-training load at moderate altitude. Front Sport Act Living 1:52. https://doi.org/10.3389/fspor.2019.00052
37. Ache-Dias J, Dellagrana RA, Teixeira AS et al (2015) Effect of jumping interval training on neuromuscular and physiological parameters: a randomized controlled study. Appl Physiol Nutr Metab 41:20–25. https://doi.org/10.1139/apnm-2015-0368