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# Half-Squat and Jump Squat Exercises Performed Across a Range of Loads: Differences in Mechanical Outputs and Strength Deficits

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## Abstract

Loturco, I, McGuigan, MR, Freitas, TT, Bishop, C, Zabaloy, S, Mercer, VP, Moura, TBMA, Arruda, AFS, Ramos, MS, Pereira, LA, and Pareja-Blanco, F. Half-squat and jump squat exercises performed across a range of loads: differences in mechanical outputs and strength deficits. *J Strength Cond Res* 37(5): 1052–1056, 2023—The aim of this study was to compare the peak force (PF), peak power (PP), and peak velocity (PV) outputs produced during half-squat (HS) and jump squat (JS) exercises executed at 20, 40, 60, and 80% of 1 repetition maximum (1RM) in the HS (HS 1RM) and to compute and compare the strength deficit (SDef) achieved in these exercises across these loads. Twenty-four national rugby union players (age: 25.7 ± 3.6 years) performed HS 1RM and a progressive loading test in the HS and JS exercises. The PF, PP, and PV values were obtained in all loads for both exercises, and the SDef was calculated as the percentage difference between the PF at distinct relative intensities and the PF at HS 1RM. The differences in HS and JS variables were determined using an analysis of variance with repeated measures. Higher PF, PP, and PV outputs were generated in the JS in comparison with the HS exercise ($p < 0.05$); moreover, the SDef magnitudes were significantly lower in the JS ($p < 0.01$), for all loading conditions. Importantly, the differences in SDef, and as a consequence, PF, PP, and PV decreased progressively with increasing load. Overall, the loaded JS exhibited increased levels of PF, PP, and PV and reduced levels of SDef when compared to the traditional HS performed across a range of loads. The JS is indicated to reduce the SDef and improve the athletes' ability to apply force at higher velocities. Nevertheless, with heavier loads (i.e., ≥80% HS 1RM), its potential advantages and effectiveness may be seriously compromised.

**Key Words:** athletic performance, team sports, ballistic exercises, muscle power, maximum strength

## Introduction

Resistance training sessions are usually composed of multiple exercises, performed with different objectives and intensities (26,31). Among these exercises, the squat and its variations are often the most frequently used by coaches from a variety of sports (14,33). The usefulness of squat-based movements may be attributed to multiple factors, including similarity with sporting activities, functional aspects, and, especially, their positive impact on lower-limb strength and independent measures of athletic performance (e.g., power output and rate of force development) (5,12,13,27). Indeed, several studies conducted with athletes from a range of sports and competitive levels have confirmed the effectiveness of this "traditional lift" in increasing physical qualities, such as sprinting, jumping, and change of direction speed (1,2,4).

Despite the huge variation in techniques (e.g., front, back, full, parallel, half, quarter, and overhead squats, among others), there are 2 types of squat-based movements that seem to be preferred by practitioners and researchers for training and testing purposes: half-squat (HS) and jump squat (JS) (9,17). In fact, mechanical variables (e.g., bar velocity and bar power) recorded during the execution of these exercises have been shown to be closely associated with numerous sport-specific tasks and being sensitive to detect performance changes (15,23,24). For example, bar-power outputs collected in both HS and JS exercises were found to be significantly related to linear sprint speed (from 5 to 60 m) and jump height (for both squat and countermovement jumps) in athletes from 4 different sports (i.e., track and field, soccer, bobsled, and rugby sevens) (24). Nonetheless, in general, these correlations were stronger for JS compared with HS measures ($r = 0.68–0.72$ and 0.64–0.67, respectively, for average mean and peak power values), suggesting that this ballistic lift

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might be more indicated to improve sport performance (8). A previous investigation with Olympic boxing athletes confirmed that the "transference effect coefficient" (TEC) with respect to punching impact was higher for JS (TEC = 0.93, on average) than for HS (TEC = 0.66, on average), which means that gains in JS power can be transferred more effectively to punching ability (21). Another study on transference demonstrated that the JS is superior to the push press exercise (i.e., a type of nonballistic exercise) for increasing speed and power capacities (TEC = 1.04 and 0.20, on average, for JS and push press, respectively) in elite young soccer players (22). This apparent advantage may be due to the mechanical characteristics of JS because ballistic movements require athletes to accelerate the barbell throughout the entire range of motion, thus avoiding any deceleration component during the concentric portion of the lift (8).

The mechanical differences between JS and HS may also influence their loading patterns and, consequently, their respective 1 repetition maximum (1RM) loads (16). Using this rationale, a recent study proposed a new strategy to determine the 1RM load in the JS, which should be based on a relative percentage of the HS 1RM (16). From a mechanical standpoint, the JS can only be executed when the athlete is able to jump with the added resistance (e.g., weighted barbell) at the end of the concentric phase (7). This only occurs when light-to-moderate loads (i.e., $<70\%$ HS 1RM) are rapidly moved, allowing for continued acceleration from the beginning of the lift until the take-off point (8). By contrast, at heavier loading conditions (i.e., $\geq 80\%$ HS 1RM), the barbell acceleration is close to zero, which results in a reduced movement velocity across the range of motion (i.e., $\leq 0.4\ \text{m}\cdot\text{s}^{-1}$) (16,30). This decreased velocity precludes the existence of the "braking phase" (i.e., portion of the concentric phase at which the deceleration is greater than would be expected due to gravity, as a result of the subject applying force in the opposite direction of the lifting to stop the barbell) (30) and prevents any jump attempt (16). Therefore, when the braking phase no longer exists, the concentric phase becomes entirely propulsive, and it is mechanically impossible to jump. For the HS exercise, this "mechanical transition" occurs at ~85% HS 1RM—the relative load that must be defined as the JS 1RM (16).

Besides the differences in loading patterns, there is another issue that should be considered when comparing HS and JS: although the JS is entirely propulsive, in the HS, athletes usually spend a substantial time of the concentric phase braking the barbell (and thus generating negative force and power outputs) (16,30). Importantly, when lighter loads are used with the intention of increasing HS velocity, the relative contribution of the braking phase also increases (16,30). Hence, stronger and more powerful athletes may experience longer braking phases throughout the lifting, which produces an interesting (and potentially problematic) phenomenon: faster movements resulting in more aggressive decelerations at the final stages of the concentric phase (10,30). Accordingly, Loturco et al. (16) observed that the relative duration of braking phases for HS performed at 40 and 60% 1RM ranged from 18 to 8%, respectively (in relation to total concentric time). As a consequence, the mechanical differences between HS and JS tend to be smaller at heavier loads; on the other hand, at lighter loads (and higher velocities), there is an increased tendency toward larger differences, which certainly affect force and power production.

More recently, the "strength deficit" (SDef) (i.e., a variable that represents the difference between the force produced at the 1RM and any other submaximal force value) has been used by researchers to evaluate the athlete's capacity to apply force against lighter relative loads (i.e., % 1RM), which may be an indication of superior performance (11,18,20,34). It has been shown that athletes with lower levels of SDef and higher levels of relative strength tend to sprint faster and jump higher than their weaker peers (20,34). It is, therefore, reasonable to conclude that improving relative strength and reducing SDef are important goals to achieve in elite sport settings, mainly when high-velocity and explosive movements are required. Nevertheless, this does not always occur and a previous study with team-sport athletes indicated that the SDef level may even increase after a resistance training intervention (18). A "potential solution" to this dilemma would be to consistently prescribe exercises that present lower levels of SDef at similar relative loads (e.g., 20–80% 1RM) during different training phases.

To date, no studies have compared the differences in SDef between a ballistic (JS) and a traditional nonballistic (HS) exercise over a wide range of loads. This comparison is important to determine and quantify the differences in SDef (and other mechanical outputs) between these exercises, thus allowing a better understanding of their applications and effects. Thus, the aims of this study were to (a) compare peak force (PF), peak power (PP), and peak velocity (PV) values produced during HS and JS attempts executed at 20, 40, 60, and 80% HS 1RM and (b) compute and compare the SDef achieved in these exercises across this range of loads. Given the mechanical aspects highlighted above, we hypothesized that (a) all mechanical outputs would be maximized and the SDef would be reduced in the ballistic JS compared with HS and (b) the differences in the SDef between both exercises would be higher at lighter loads and higher velocities.

## Methods

### Experimental Approach to the Problem

This cross-sectional study was designed to compare a number of mechanical parameters between HS and JS across a range of loads (i.e., 20–80% HS 1RM). Because of the constant training and testing in our facilities, all athletes were familiarized with testing procedures. Athletes were instructed to refrain from consuming caffeine and alcohol and from participating in any intensive training session 24 hours before testing. The assessments were performed on 2 consecutive days, in the following order: (day 1) HS 1RM and (day 2) progressive loading test in the HS and JS exercises. Before the measurements, the rugby players performed standardized warm-up protocols including general (i.e., running at a moderate self-selected pace for 10 minutes, followed by 3 minutes of lower-limb dynamic stretching and mobility exercises) and specific exercises (i.e., submaximal attempts of HS and JS executed on the Smith machine, using only the barbell as resistance).

### Subjects

Twenty-four rugby union players from the Brazilian National Team (age [range 20–34]: 25.7 ± 3.6 years; height: 180.8 ± 8.4 cm; body mass [BM]: 100.5 ± 15.6 kg) participated in this study. Players were tested in the final phase of preparation for the South American Rugby Union Championship, and all of them were free of injuries or any associated deficit that could affect their performance during the strength-power measurements. The study was approved by the Ethics Committee of the Federal University of São Paulo, and all subjects were informed of the inherent risks and benefits associated with study participation before signing written informed consent forms.

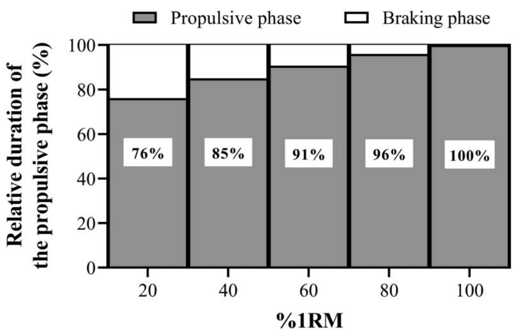

**Figure 1.** Percentage of the propulsive and braking phases during the concentric portion of the movement in the half-squat (HS) exercise across the loads. %1RM = percentage of HS 1RM.

### Procedures

Maximum dynamic strength was assessed in the HS exercise executed on a Smith machine device (Hammer Strength Equipment, Rosemont, IL), as described previously (16,19). On the second day, athletes performed sequential HS and JS with loads corresponding to 20, 40, 60, and 80% HS 1RM also on a Smith machine. Athletes were required to move the barbell as fast as possible during the concentric phase of the lift in all attempts (16). The measurements were conducted by an experienced evaluator who standardized the degree of the knee flexion (i.e., 90° knee angle) through visual inspection (16). A 3-minute rest interval was provided in all trials (16). The PF was obtained for all attempts, for both exercises, using a force platform (AccuPower, AMTI, Watertown, MA), sampling at a rate of 1,000 Hz. In addition, the PV, PP, and the percentage of the propulsive phase during the concentric portion of the lift were continuously assessed at a sample frequency of 1,000 Hz using a linear velocity transducer (T-Force Dynamic Measurement System; Ergotech Consulting S.L., Murcia, Spain) attached to the barbell (16). For both exercises, the SDef was calculated as the percentage difference between the PF at distinct relative intensities (i.e., % HS 1RM) and the PF at HS 1RM (11,20). The 1RM, PF, and PP values were normalized by the BM (i.e., RS; PF = $N \cdot kg^{-1}$, PP = $W \cdot kg^{-1}$).

### Statistical Analyses

Data are presented as mean ± *SD*s. Data normality was confirmed using the Shapiro-Wilk test. Differences in the HS and JS variables over the distinct range of loads were determined using an analysis of variance (ANOVA) with repeated measures, followed by Bonferroni post hoc pairwise comparisons. The level of significance was set at $p < 0.05$. The magnitude of the differences was analyzed using Cohen's *d* effect sizes (ES) (3). The ES values were interpreted using the thresholds proposed by Rhea (29) for highly trained subjects, as follows: <0.25, 0.25–0.50, 0.50–1.00, and >1.00 for trivial, small, moderate, and large, respectively. Statistical power was calculated for all variables using G*Power software (v. 3.1.9.7) and exceeded 80% for all of them. All tests used in this study displayed high levels of absolute and relative reliability (i.e., intraclass correlation coefficients >0.90 and coefficients of variation <10%).

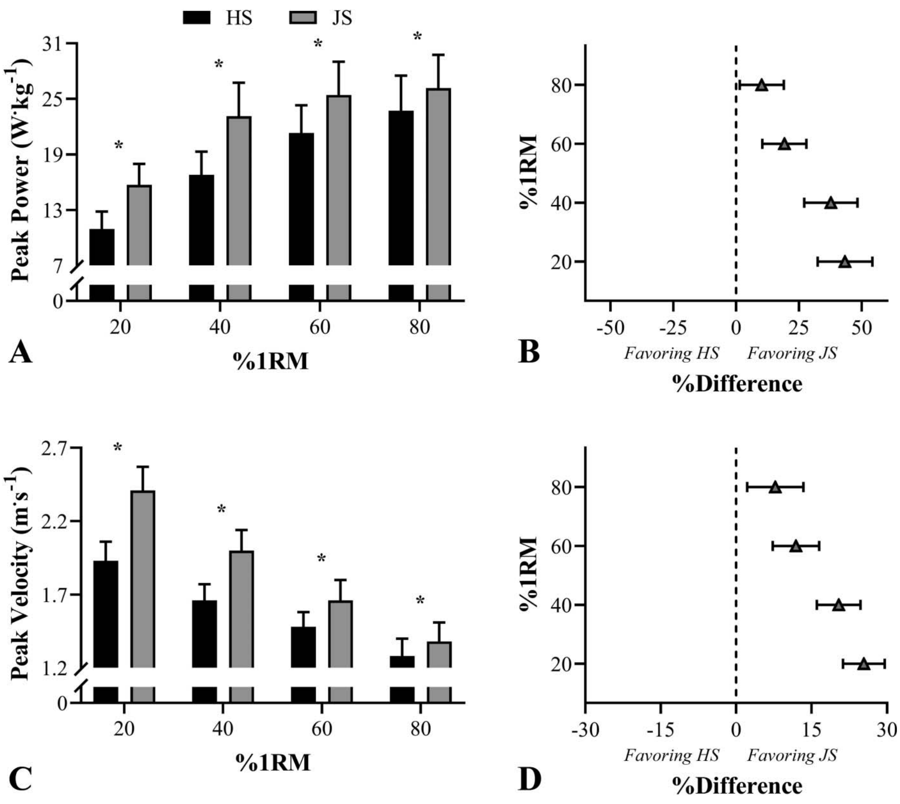

**Figure 2.** Comparison of the peak power and peak velocity between the half-squat (HS) and jump squat (JS) exercises across loads. *Indicates significant differences between the 2 exercises ($p < 0.05$). Panels (A and C) mean and *SD*s and panels (B and D) % difference and 95% confidence limits. %1RM = percentage of HS 1RM.

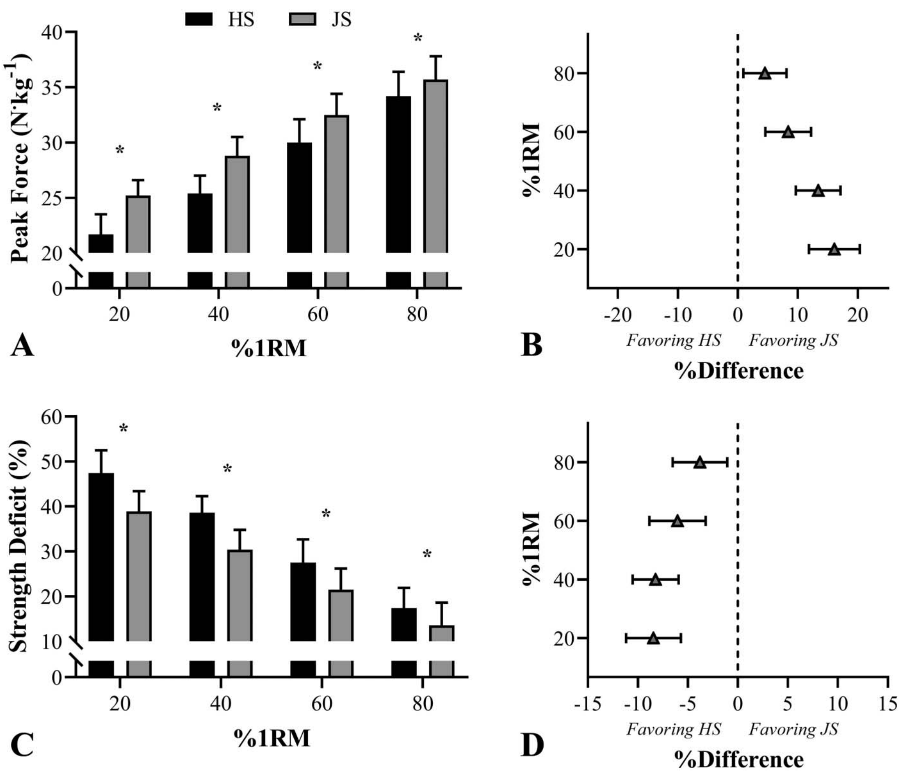

**Figure 3.** Comparison of peak force and strength deficit between the half-squat (HS) and jump squat (JS) exercises across loads. *Indicates significant differences between the 2 exercises ($p < 0.05$). Panels (A and C) mean and *SD*s and panels (B and D) % difference and 95% confidence limits. %1RM = percentage of HS 1RM.

## Results

The relative strength of the athletes in this study was 2.22 ± 0.28. Figure 1 depicts the percentage of the propulsive and braking phases during the concentric portion of the movement in the HS exercise over the distinct loads assessed. Figure 2 shows the comparison of PP and PV between the HS and JS exercises over the range of loads assessed. Higher PP and PV values in the JS exercise were noticed for the distinct loads tested in comparison to the HS (ES ranging from 0.66 to 2.26 for PP and from 0.79 to 3.29 for PV outputs; $p < 0.05$). Figure 3 depicts the comparison of PF and SDef between the HS and JS exercises in the distinct loads tested. The JS PF was significantly higher than the HS PF (ES ranging from 0.72 to 2.15; $p < 0.01$) while the JS SDef was significantly lower than the HS SDef (ES ranging from 0.79 to 1.75; $p < 0.01$) for all load intensities.

## Discussion

We compared the mechanical outputs of HS and JS exercises across a wide range of loads. Overall, PF, PP, and PV values were maximized in the JS, for all loading conditions. In addition, as expected, the SDef level was reduced in the JS, and these differences decreased with increasing load. These results confirm that the JS exercise is very effective in optimizing the force application and the relative use of the maximum strength capacity, especially with light loads and at high movement velocities. Coaches should be aware of these findings when selecting exercises for lower-body strength and power development.

The differences in force and power production between JS and HS exercises have been consistently reported in previous studies (6,25,32). Recently, Thompson et al. (32) compared the mechanical demands of free-weight back squat and JS and showed that the JS produces greater kinetic and kinematic outputs than its "nonballistic equivalents," regardless of phase determination (i.e., "propulsion vs. concentric") or loading intensity (30–60% 1RM). Other investigations reported similar findings for comparisons involving JS and HS and revealed that the differences in favor of JS are independent of the calculation method used (i.e., bar, body, or system force and power) and of the use of the body mass in the force and power computation (6,25). As mentioned earlier, the ballistic JS allows for continued force production during its execution which, in turn, results in higher levels of acceleration and velocity across the range of motion (8,32). Pérez-Castilla et al. (28) confirmed these results by contrasting the velocity outputs of 4 distinct variations of the HS exercise. In general, the velocities associated with relative loads (30–100% 1RM) were higher for the "ballistic variation"; nonetheless, these differences decreased as the load increased. Thus, the higher rates of continued acceleration (generating higher bar velocities) in the JS may explain the greater values of force and power production commonly observed in this explosive exercise. However, it is worth noting that these differences are extremely reduced at heavier loading intensities, especially when the relative load is getting closer to the JS 1RM (i.e., 86% HS 1RM) (16).

In fact, at intensities ≥80% 1RM, the concentric phase in the HS exercise is almost entirely propulsive (Figure 1). This means that the athlete does not have to decelerate the barbell to return to zero velocity as movement velocity at the end of the concentric phase is very low (16,30). Such an increased loading condition may not only hamper (or even preclude) any jump attempt but also reduce the differences in kinetic and kinematic parameters between HS and JS (16). Figure 2 shows, for example, that differences in PP and PV decrease progressively as a function of loading. Under the same perspective, the lower rate of bar acceleration at heavier loads (i.e., 80% HS 1RM) compromises the relative difference in force production between both squat variations (Figure 3A, B). As a consequence, the differences in SDef are higher at lighter loads (Figure 3C, D), and much smaller at loads equal to (or above) 80% HS 1RM. From these data it is possible to state that (a) the regular use of loaded JS constitutes an effective strategy to reduce the SDef and increase the ability to produce force against lighter loads and at higher velocities in elite athletes and (b) the potential "advantages" over the traditional HS may be drastically reduced at heavier loading intensities.

In summary, we confirmed previous findings showing that the JS exhibits higher kinetic and kinematic outputs (i.e., PF, PP, and PV) than the traditional HS, across a comprehensive range of loads. Nevertheless, for the first time, we demonstrated that these differences are larger at light-load conditions, which greatly affects the SDef. Coaches who wish to reduce the SDef level of elite athletes while improving their ability to apply force at higher velocities should take into account that the potential benefits of loaded jumps may be compromised at heavier loading intensities (i.e., ≥80% HS 1RM). As cross-sectional research, this study is limited by its inability to establish causality between variables (i.e., examining the effects of performing JS or HS at similar loads on the SDef level). Hence, future studies should be conducted to compare the effects of using HS-based and JS-based training schemes on the physical performance of elite athletes.

## Practical Applications

Ballistic JS is strongly indicated to improve the ability to apply force at higher velocities (8). However, when performed with heavier loads (i.e., ≥80% HS 1RM), the effectiveness of this exercise may be undermined. Therefore, to preserve the mechanical characteristics and potential benefits of this explosive exercise, coaches and practitioners are advised to prescribe JS using light-to-moderate load intensities (i.e., 20–60% HS 1RM). Under these conditions, the loaded JS exhibits reduced levels of SDef and increased levels of PF (compared with the traditional HS executed with similar loads). These optimized mechanical aspects may be decisive when selecting exercises and load ranges capable of maximizing athletic performance.

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