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Analysis of Power Output During the Countermovement and Split-Squat Jump Across Loads and High-Volume Repetitions in Elite Athletes

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ABSTRACT

Understanding the rate of peak power (PP) loss in a set can be used to determine appropriate exercise prescription to improve maximum peak power (PPmax) and power endurance (PE). The primary purpose of this study was to determine the rate of PP loss during the countermovement jump (CMJ) and split-squat jump (SSJ) across various loads within a set of high repetitions. Eleven collegiate track and field athletes who had several years of resistance training experience and were trained in the two types of jumps completed the study. The participants completed a familiarization session and two data collection sessions. The CMJ and SSJ were completed in random order during session one and two separated by a minimum of 72 hours. Three loads using dumbbells took place in random order with each session including body weight only (BW0), body weight plus 15% (BW15) and body weight plus 30% BW(30) for the SSJ and BW(0), BW(25), and BW(50) for the CMJ. PP was determined using the PUSH 2.0 3D accelerometer worn at the waist, which was connected to an ipad app using Bluetooth. The participants completed 14 repetitions each set with eight min rest between sets. Repetition three demonstrated the highest mean PP (PPmax) within the set. No significant decrease in PP was observed until repetition six (3.6% below PPmax) during the SSJ and repetition eight (5.2% below PPmax) during the CMJ. These data indicate that five or less repetitions should be completed during the SSJ and seven or less for the CMJ when training for PP. Based on these thresholds when fatigue begins in a set, the transition to training PE occurs after repetition five in the SSJ and eight for the CMJ with large decrements of PP occurring at repetition 10 and 12, respectively.

Keywords: peak power, power endurance, ballistic jumps, fatigue

INTRODUCTION

The ability to produce peak power (PP) has been shown to be a characteristic of elite athletes in many anaerobic sports (13). While power output can occur across a wide range of loads, a primary goal in many sports is to create the greatest PP possible (PPmax) with relatively light loads (i.e. jump height in basketball and volleyball against only body weight or swinging a bat in baseball) with movement at high velocities and minimal time. PP is also expressed during team sports involving accelerations and change of directions. Some events also require power endurance (PE), which is the ability to repeat

PP at or near PPmax for as many repetitions as possible. A bilateral, countermovement jump (CMJ) and the more unilateral dominant jump such as the split-squat jump (SSJ) are exercises implemented to improve power output (15). PPmax most commonly occurs during jumps with light loads ranging from 0-30 % of the 1RM squat or similarly light loads near one's body mass (29). As a result, these loads are commonly prescribed when training to improve PPmax and PE (2,15). However, PP outputs across repetitions with these exercises are not clearly understood. Assessing PP change across repetitions and loads can contribute to advancing exercise prescription for both PPmax and PE improvement.

In PP training, an accepted principle is to perform each repetition at or near PPmax by moving the load at maximum velocity (10,14,19,24,28), which involves the precise application of maximum force given the time constraint. As fatigue occurs, force and movement velocity is reduced due to decreased motor unit firing rates, which decreases PP (7). Technique may also be altered as fatigue occurs most likely resulting in training undesired motor units and movement patterns. Thus, the number of repetitions typically prescribed for PPmax improvement is based on avoiding repetitions performed in a fatigued state. With variations in each type of resistance exercise, the repetition when fatigue takes place likely differs among exercises. For Olympic lifts, commonly used in training for power, research has shown that ≤ five repetitions are the optimum number of repetitions prior to fatigue (10). With limited studies and inconsistency in research designs, further research is needed to better understand the rate of PP loss using body weight and weighted jumps (4,9,14,21). Similar or greater improvements in strength and PPmax after short-term training have been found when minimizing fatigue compared to traditional sets to failure (8,24). Hence, it is important to understand when PP is reduced in a set for each exercise to provide optimum exercise prescription to improve PPmax.

A gap in the literature exists analyzing the rate of PP loss at higher repetitions needed to train for PE. In a systematic review on PE, Natera et al (22) concluded that research indicates 10-20 repetitions are necessary to improve PE; however, none of the studies analyzed the rate of PP loss during jump assessment within this repetition range. Studies have analyzed fatigue with very high repetitions (~60) (6,23), but this type of training only applies to athletes requiring extremes levels of muscular endurance at lower levels of power output, which is not the goal of PE training. Apanukul et al. (2) trained tennis players for 8 weeks with 20 repetitions at 30% 1RM speed squats and found greater PPmax and PE compared to training only with tennis conditioning drills alone. Periera et al. (25) studied the amount of rest needed to maintain PP for a high volume of jumps in volleyball players, but the continuous CMJ was not investigated. Due to limited data, a better understanding of PP loss above 10 repetitions is warranted and ecologically valid when training for PE in many team sports.

Few studies have investigated the rate of PP loss used during continuous CMJ (4,14,21) and we are not aware of any for the SSJ. Continuous CMJs rely on the stretch-shortening cycle involving active and passive tissues that store and release elastic energy, which appears to be energy efficient. This type of continuous jump likely produces different rates of PP loss than squat jumps that involve a pause at the bottom position before producing only concentric contractions and CMJs that reset each repetition before jumping studied by Hansen et al. (9) and Thomasson and Comfort (27), respectively. The continuous CMJ was studied by Baker and Newton (4) who used an absolute load of 60 kg, by Moreno et al. (21) using only body weight, and by Koefoed et al. (14) using 40% body mass, which demonstrates inconsistent designs and limited existing data. In addition, the rate of PP loss across a range of loads during the CMJ is currently unclear, yet five repetitions or less is suggested during CMJ training with limited distinction for the technique or type of jump used.

The SSJ entails a narrow, medial-lateral base of support with the majority of the load supported on the lead leg. This difference in technique requires more frontal plane stability and neuromuscular demand that may differ when fatigue takes place in the set compared to the CMJ. Yet, the rate of PP loss across loads within a set of SSJs has not been studied. Therefore, the primary aim of this study was to investigate the rate of PP loss during a SSJ and CMJ set of high volume repetitions and to analyze the effect of load on this rate of loss. Training with a load that produces the maximum power output is common practice to improve PPmax; thus. a secondary aim was to determine the load that produced the greatest power output during each exercise.

METHODS

Subjects

Ten collegiate, track and field athletes (age = 21.45 ± 1.63 years; height = 182.88 ± 7.79 cm; weight = 106.2 ± 27.75 kg) were recruited for the study. The participants (throwers, jumpers and sprinters) had several years of training experience with ballistic activity (jumping, agility, or running) and resistance training. Criteria for exclusion included any previous lower limb injury within the past six months or neuromuscular condition that would have prevented maximum effort and successful execution of jump performance. Each participant read and signed an informed consent form, which was approved by the university's internal review board. Completion of the study was on a volunteer basis.

Familiarization session

From pilot data testing the calibration of the instruments, large effect sizes (partial $\eta^2 > 0.18$ and Cohen's $d > 0.80$) were observed across loads and repetitions. Based on a sample size analysis using these large effect sizes, a sample size of 10 subjects was determined adequate for observing the effects being investigated. The subjects provided age, height and weight that was measured during a familiarization session. Technique of the CMJ and SSJ was also practiced using a progression of loads from body weight to ~20% and 10% body weight, respectively. The subjects were informed to refrain from lower extremity resistance training and any strenuous exercise a minimum of 72 hours prior to reporting for all test sessions. The participants were also instructed to maintain normal dietary habits, get a normal and adequate amount of sleep, and eliminate the consumption of alcohol and caffeine 24 hours before data collection. Finally, subjects were also instructed to wear similar clothing typically worn for exercise and athletic performance in each session.

Jump Testing

The participants reported for two data-collection sessions in randomized order and separated by a minimum of 72 hours. Each session, participants performed either the CMJ or SSJ using three different loads. Body weight only BW(0), body weight plus 25% BW(25), and body weight plus 50% BW(50) were loads used during the CMJ and body weight only BW(0), body weight plus 15% BW(15), and body weight plus 30% BW(30) were used during the SSJ in random order. With less stability in the frontal plane and a unilateral execution during the SSJ, less load was used compared to the CMJ.

Prior to the jumps, a 5-minute jog was completed followed by a 10-minute dynamic warm-up and light stretching. After securing a belt containing a small sensor around the waist, the participants completed 15 continuous vertical jumps. Hands were held on the hips with no added load and dumbbells held to the side of the body were used as added load. Each set of 15 repetitions was separated with eight minutes of rest. Fourteen repetitions were used to analyze PP since the first repetition was removed. We found that PP during the first repetition was approximately 40% less than the following repetitions due to the slower eccentric phase without a prior landing from a jump. Thus, all repetitions were similar by involving the landing phase from the jump.

The CMJ was completed with a hip-width stance. A successful jump was determined if the participant jumped and landed in the same location while continuously jumping without hesitation or losing balance. The participants were instructed to give maximum effort with each jump while reaching a comfortable depth that would produce the highest jump. Maintaining elbow extension, holding the dumbbells to the side of the body, and eliminating a shoulder shrug were also monitored as criteria for a successful jump. Similar procedures occurred during the SSJ, but the subject started with the preferred leg as the lead leg without cycling. The anterior-posterior stance length was determined for the SSJ by the subject squatting to 90° at the knee and adjusting the stance until the lead knee was directly above the toes.

IMU technology

PUSH Band 2.0 is a wearable sensor with a three-axis accelerometer and gyroscope providing six degrees of freedom to measure vertical velocity and calculate PP from proprietary algorithms. The data was captured on an iPad (Apple Inc.) using Bluetooth through an application (Application version 7.18.0). The data was collected at a sampling rate of 1000 Hz and smoothed using a Butterworth filter. No calibration was required. PP from the 14 repetitions was compared across each repetition to determine the degree of fatigue across repetitions. Prior to the exercise tests, a pilot study was conducted for determining the test-retest reliability of the PP measures for both the SSJ and CMJ. The ICCs ranged from .86 to .99 and the coefficients of variation ranged from 2-8% for the SSJ and CMJ. These values are consistent with those reported in recent research on the relative and absolute reliability of PP measures during the SSJ and CMJ (McCurdy et al., 2022). Montalvo et al. (20) found PUSH 2.0 be a valid measure during the CMJ comparing results to force plate measures. Based on these values, the PP measurements for both jumps were determined to be suitable for analysis.

Statistical Analyses

The dependent variable in this study was PP for the SSJ and CMJ. The two independent variables were: 1) type of load: BW(O), BW(15) or BW(25), and BW(30) or BW(50), and 2) number of repetitions (1-14). Both of these independent variables were within-subjects (repeated) variables. There were no between-subjects independent variables.

Bartlett's test for equal variances was used to determine whether the comparisons across repetitions and loads met the assumption of equal variances required for ANOVA. The Shapiro-Wilk test was used to determine whether the comparisons across repetitions and loads met the basic assumption of normality.

For both the SSJ and CMJ, a two-way ANOVA with repeated measures was used to determine differences across the three types of load, the 14 repetitions, and the interaction between loads and repetitions. Greenhouse-Geisser epsilon was used to adjust probability values for any variation in sphericity among PP values across loads and repetitions. Partial η^2 was used to determine effect size for each statistical test based on the recommendation of Bakeman (3) for repeated measures ANOVA.

For any significant differences observed from the ANOVA results, paired t-tests were used as post-hoc comparisons across loads and repetitions. For all post-hoc comparisons, the overall alpha level was defined as $p < .05$. The overall alpha level was controlled by using the Bonferroni correction for each individual post-hoc test. For the post-hoc tests comparing the types of load, two comparisons were made: 1) BW(0) versus BW(15) for the SSJ or BW(0) versus BW(25) for the CMJ, and 2) BW(15) versus BW(30) for the SSJ, or BW(25) versus BW(50) for the CMJ. The adjusted alpha level for these tests was .05/2 = .025. Since the BW(0) load was the highest PPmax for each analysis, and BW(30) or BW(50) loads were the lowest PPmax for each analysis, no post-hoc comparison was needed between these two loads following a significant ANOVA result.

For the post-hoc tests comparing repetitions, any attempt to compare all repetitions, or even each repetition to PPmax (repetition three), would result in an adjusted alpha level that would be much too small to be practical. Also, the purpose of the study was to determine the number of repetitions that resulted in a significant decrease from PPmax and once that was determined, any further tests of significance would be unnecessary. Consequently, we committed to a minimum of four comparisons: repetition three versus repetition four-seven. The adjusted alpha level for these tests was .05/4 = .0125. Additional post-hoc comparisons would only be conducted if a significant difference below PPmax was not detected from these first four tests, and then the overall alpha level would be adjusted accordingly.

RESULTS

Bartlett's test was used to determine whether the basic assumptions of equal variances were satisfied for conducting the ANOVA for the following: PP measurements across repetitions for the SSJ, $chi^2(13) = 3.63$, $p = .99$, PP measurements across repetitions for the CMJ, $chi^2(13) = 4.04$, $p = .99$, PP measurements across loads for the SSJ, $chi^2(2) = 1.91$, $p = .41$, and PP measurements across loads for the CMJ, $chi^2(2) = 3.15$, $p = .18$. As a requirement for ANOVA, the assumption of equal variances was satisfied for all comparisons. To test for the basic assumption of normality for each comparison, the Shapiro-Wilk test was conducted for each repetition at each type of load. Some repetitions were excluded from further analysis since normality is a basic assumption for ANOVA including BW(30) Rep one ($p = .01$), BW(15) Rep six ($p = .02$), BW(15) Rep nine ($p = .01$), and BW(0) Rep 13 ($p = .04$) for the SSJ, and BW(50) Rep seven ($p = .01$), BW(50) Rep 12 ($p = .02$), and BW(25) Rep 10 ($p = .03$) for the CMJ. Figure 1 illustrates the PP values for each repetition across all three loads for the SSJ.

For the PP measurements during the SSJ, repeated measures ANOVA indicated a significant difference among types of load, $F(2,18) = 11.8$, Greenhouse-Geisser epsilon = 0.68, $p = .003$, Cohen's $d = 0.98$, a very large effect. Further, the analysis also indicated a significant difference among repetitions, $F(13,117) = 12.8$, Greenhouse-Geisser epsilon = 0.23, $p < .001$, Cohen's $d = 0.99$, also a very large effect.

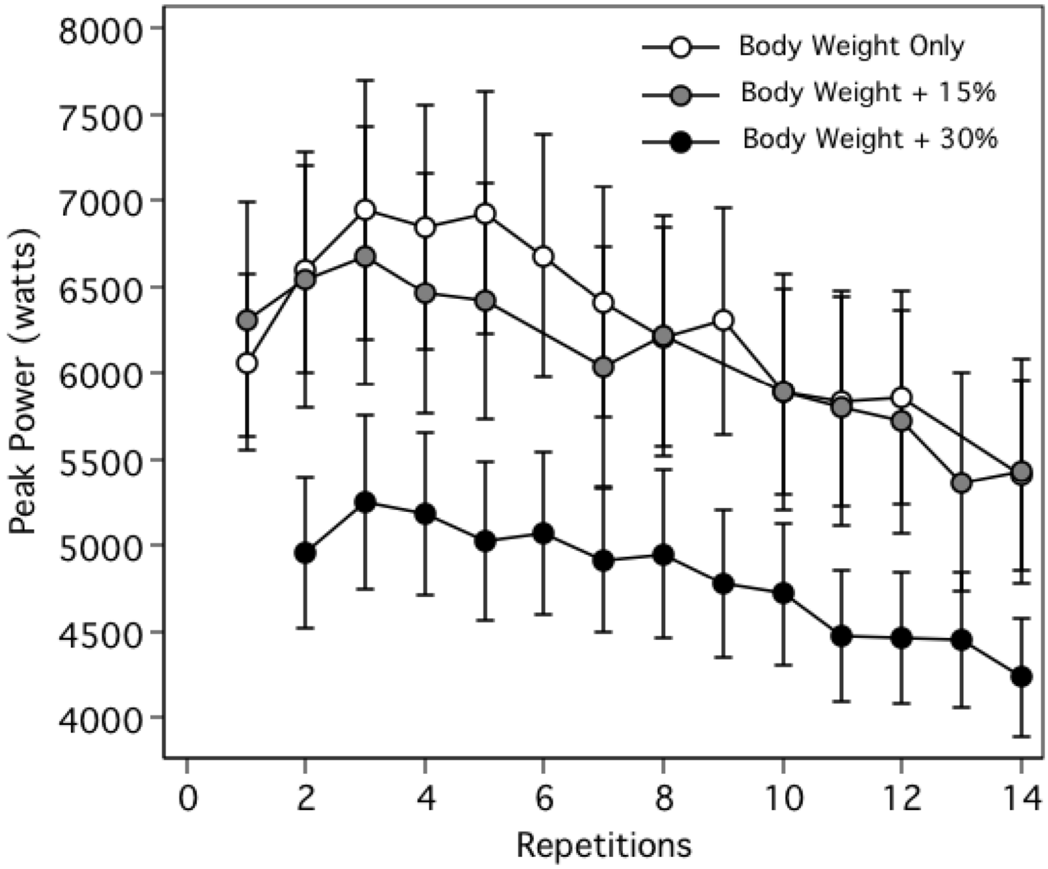

Figure 1. Peak power during the split squat jump.

Lastly, there was no significant interaction between loads and repetitions F(22,198) = 1.0, Greenhouse-Geisser epsilon = 0.07, *p* = .364, Cohen's *d* = 0.32, a small effect. Since there was no significant interaction between loads and repetitions, the differences in PP across repetitions are the same for each load for the SSJ.

Table 1 reports the descriptive statistics across all three loads for PP during both the SSJ and CMJ. For SSJ, the BW(30) load had the lowest PP while the BW(0) load had the highest PP. The ANOVA indicates that the BW(0) load results in a significantly higher PP than the BW(30) load for SSJ. Also, post-hoc tests indicated that the BW(15) load was significantly higher than the BW(30) load, t(9) = 3.2, *p* = .006, Cohen's *d* = 1.01, a very large effect, but not significantly lower than the BW(0) load, t(9) = 0.3, *p* = .376, Cohen's *d* = 0.09, a very small effect. This analysis indicates that the BW(30) load results in significantly lower PP than either the BW(15) load and the BW(0) load, but the BW(15) load and the BW(0) load do not differ in PP during the SSJ.

Table 2 reports the descriptive statistics for each of the 14 repetitions averaged across all three loads combined for PP during the SSJ. PPmax occurred at repetition three, and there appears to be a consistent decrease in PP as the number of repetitions increase beyond repetition three. Post hoc tests with an adjusted alpha of 0.0125 revealed no significant decrease in PP between repetition three and repetition four, t(9) = 1.1, *p* = .142, Cohen's *d* = 0.35, a small effect, or between repetition three and repetition five, t(9) = 1.6, *p* = .13, Cohen's *d* = 0.51, a moderate effect. However, a significant decrease in mean PP was observed between repetition three and repetition six, t(9) = 2.9, *p* = .008, Cohen's *d* = 0.92, a large effect, and between repetition three and repetition seven, t(9) = 5.8, *p* < .001, Cohen's *d* = 1.83, a very large effect. This analysis indicates that there are no significant differences in PP between the PPmax in repetition three, and the next two repetitions, including repetition five; however, repetition six does result in significantly lower PP than repetition three during the SSJ.

Figure 2 illustrates the PP values for each repetition across all three loads for the CMJ.

For the CMJ, the results were similar to those for the SSJ. Repeated measures ANOVA indicated a significant difference among types of load, F(2,20) = 14.5, Greenhouse-Geisser epsilon = 0.69, *p* = .001, Cohen's *d* = 1.20, a very large effect. Further, the analysis also indicated a significant difference among repetitions, F(13,130) = 5.7, Greenhouse-Geisser epsilon = 0.16, *p* = .011, Cohen's *d* = 0.75, a moderately large effect. Lastly, there was no significant interaction between loads and repetitions F(23,230) = 0.5, Greenhouse-Geisser epsilon = 0.15, *p* = .706, Cohen's *d* = 0.22, a small effect. Since there was no significant interaction between loads and repetitions, the differences in PP across repetitions are the same for each load for the CMJ.

Table 1 also reports the descriptive statistics across all three loads during the CMJ. The BW(50) load had the lowest mean PP, while the BW(0) load had the highest mean PP. The ANOVA indicates that the BW(0) load results in a significantly higher PP than the BW(50) load. Also, post-hoc tests indicated that the BW(25) load was significantly higher than the BW(50) load, t(10) = 4.0, *p* = .001, Cohen's *d* = 1.26, a very large effect, but significantly lower than the BW(0) load, t(10) = 2.6, *p* = .012, Cohen's *d* = 0.82, a large effect, during the CMJ.

Table 3 reports the descriptive statistics for each of the 14 repetitions averaged across all three loads combined during the CMJ. PPmax occurred at repetition three, and there appears to be a consistent decrease in PP as the number of repetitions increase beyond repetition three. Post hoc tests with an adjusted alpha of 0.0125 revealed no significant decrease in PP between repetition three and repetition four, t(10) = 1.9, *p* = .046, Cohen's d = 0.60, a moderate effect, between repetition three and repetition five, t(10) = 0.4, *p* = .355, Cohen's d = 0.13, a very small effect, between repetition three and repetition six, t(10) = 0.9, *p* = .120, Cohen's d = 0.28, a small effect, and between repetition 3 and repetition seven, t(10) = 1.7, *p* = .060, Cohen's d = 0.54, a moderate effect. However, a fifth post hoc test

Table 1. Descriptive Values for Loads Across All Repetitions for Peak Power.

	n	Mean	Standard Error	Standard Deviation	95% Confidence Interval
Split Squat Jump					
BW(30): Body Weight + 30%	10	4978	477.1	1509	(3899, 6057)
BW(15): Body Weight + 15%	10	6114	675.5	2136	(4586, 7642)
BW(0): Body Weight Only	10	6190	621.4	1965	(4784, 7596)
Countermovement Jump					
BW(50): Body Weight + 50%	11	4502	327.4	1086	(3772, 5231)
BW(25): Body Weight + 25%	11	5541	355.4	1179	(4749, 6333)
BW(0): Body Weight Only	11	6778	658.6	2184	(5310, 8245)

Table 2. Descriptive Values for Repetitions Across All Loads for Peak Power During the Split Squat Jump.

	n	Mean	Standard Error	Standard Deviation	95% Confidence Interval	% Below PPmax*
Rep 1	10	5844	537.5	1700	(4629, 7060)	
Rep 2	10	6097	591.9	1872	(4758, 7436)	
Rep 3	10	6312	649.1	2053	(4844, 7780)	
Rep 4	10	6197	604.2	1911	(4830, 7564)	1.2
Rep 5	10	6104	592.1	1973	(4764, 7443)	2.6
Rep 6	10	6074	624.0	1872	(4662, 7485)	3.6
Rep 7	10	5820	577.1	1825	(4515, 7126)	7.3
Rep 8	10	5819	581.7	1840	(4504, 7136)	7.4
Rep 9	10	5751	584.3	1848	(4429, 7073)	8.6
Rep 10	10	5546	541.7	1713	(4320, 6771)	11.6
Rep 11	10	5413	537.7	1700	(4197, 6630)	13.7
Rep 12	10	5368	518.4	1639	(4195, 6541)	14.2
Rep 13	10	5196	495.6	1567	(4075, 6317)	16.7
Rep 14	10	5105	495.2	1566	(3985, 6225)	18.2

** Percent mean difference below PPmax at Rep 3*

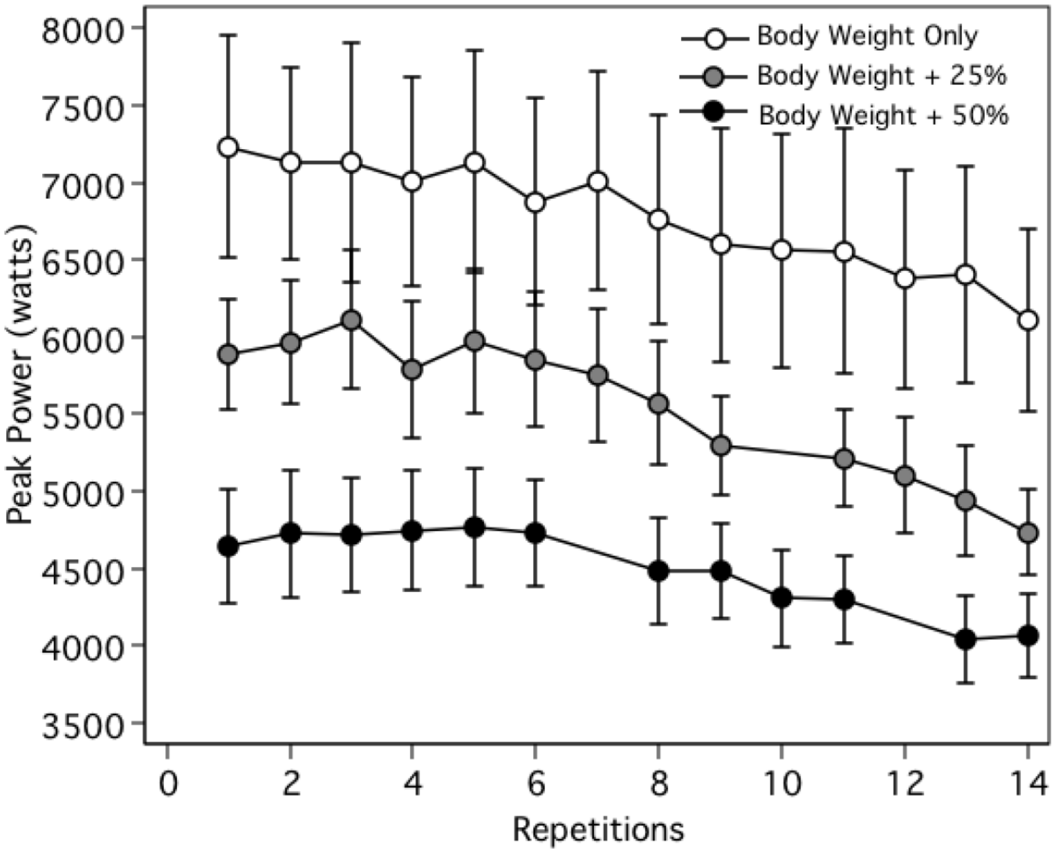

Figure 2. Peak power during countermovement jump.

Table 3. Descriptive Values for Repetitions Across All Loads for Peak Power During the Countermovement Jump.

	n	Mean	Standard Error	Standard Deviation	95% Confidence Interval	% Below PPmax*
Rep 1	11	5924	456.0	1512	(4908, 6939)	
Rep 2	11	5939	435.3	1444	(4969, 6909)	
Rep 3	11	5987	481.3	1596	(4915, 7059)	
Rep 4	11	5849	451.8	1498	(4842, 6855)	1.9
Rep 5	11	5957	464.1	1539	(4923, 6991)	0.5
Rep 6	11	5823	439.1	1468	(4845, 6802)	2.0
Rep 7	11	5861	442.8	1456	(4874, 6847)	1.0
Rep 8	11	5608	402.1	1334	(4712, 6504)	5.2
Rep 9	11	5459	413.0	1370	(4539, 6380)	7.5
Rep 10	11	5413	402.1	1334	(4517, 6309)	8.1
Rep 11	11	5356	403.9	1340	(4456, 6256)	8.7
Rep 12	11	5222	412.3	1368	(4303, 6140)	11.2
Rep 13	11	5127	400.1	1327	(4236, 6019)	12.2
Rep 14	11	4970	325.6	1080	(4245, 5696)	13.7

** Percent mean difference below PPmax at Rep 3*

with an adjusted alpha of 0.05 / 5 = 0.01 revealed a significant decrease in PP between repetition three and repetition eight, t(10) = 3.1, p = .006, Cohen's d = 0.98, a large effect. The results of these tests indicate that there are no significant differences in PP during the CMJ between the highest value in repetition three and repetitions four-seven; however, repetition 8 does result in significantly lower mean PP than repetition three.

DISCUSSION

Based on our data, we specifically recommend completing seven repetitions or less during the loaded and unloaded CMJ when training for PPmax improvement and five repetitions or less on the SSJ. Recent research indicates that maintaining a level near PPmax for all repetitions in a set is important to maximize PPmax improvement (8,19). Improvement is thought to occur through maximum neuromuscular activation and movement velocity with precise technique and avoidance of overtraining by stopping the set prior to failure. Previous studies included the power clean (10) and traditional squat (12,19,28) using loads ranging from 60-80% 1RM to make these recommendations, which are not applicable to jump training at relatively lighter loads. With inconsistent and limited research designs analyzing PP loss during jumps, practitioners currently rely on anecdotal evidence to determine proper exercise prescription. The squat jump with no eccentric phase (27), non-continuous CMJs (9), and a CMJ with only one absolute load (4,14,21) reveal differences among studies all with different subject populations. Our study included two common types of jumps across several loads that are typically used in training for maximum improvement of PPmax and PE in elite athletes. Our data contribute to a better understanding for prescribing set repetitions at various loads in athletic populations who typically produce power at multiple loads and velocities.

Based on limited data, it is generally accepted when training for PPmax to stop the set if 5-10% of peak power is lost compared to PPmax in a set (4). While significant loss of power (6%) in a set has been determined to occur at repetition six using 60% 1RM squat during a squat jump (27), less is known about the rate of loss at higher repetitions for improved PE. Our data revealed that SSJ PPmax significantly decreased at repetition six (3.6%) and doubled at repetition seven (7.3%). Small decrements occurred at eight and nine and another large decrease at repetition 10 (11.6% total loss from repetition three) (Table 4). In the CMJ, PPmax significantly decreased at rep eight (5.2%), nine (7.5%), and 10 (8.1% total loss from repetition 3) (Table 5). In comparison, Baker and Newton (4) found a very similar 3.4% loss of CMJ PPmax at repetition six and 6.9% loss at rep 10 using a 60 kg load. Greater loss was found by Moreno et al. (21) in recreational, resistance-trained participants during the CMJ BW(0) with a 5% reduction after repetition five and 12% at repetition 10. This greater loss in PP may be due to the training status and level of athlete in these studies.

Training for PE has been determined to improve both PPmax and PE (2), which is also important to emphasize in training for many sports. In a systematic review investigating PE, Natera et al. (22) recommended sets between 10-20 reps based on the combined results from all studies included. Yet, this recommendation is based on limited data analyzing rate of power loss after 10 reps. Our study revealed a reduction of ~9-14% from PPmax during the CMJ and ~14-18% during the SSJ in repetitions 11-14. Similar in set repetitions to our study, Hester et al (11) found 18-22% drop in mean power in each set during five sets of 16 repetitions, but the exercise included was a non-ballistic, back squat at 40% 1RM. Light loads during non-ballistic squats have a large deceleration phase while ballistic jumps have a demand to control the landing and transition a stretch-shortening cycle that appears to be energy efficient with reliance on stored elastic energy. Based on these data, the efficiency of the stretch-shortening cycle with light loads may reduce fatigue compared to non-ballistic resistance exercises.

This is the first known study to analyze the rate of PP loss during the SSJ. With the narrow base created by the anterior-posterior stance, instability is produced in the frontal plane. This has been shown to produce greater activation in the hip abductors, gluteus maximus and hamstrings in comparison to the traditional squat that has the same stance as the CMJ (16,18). In support of these findings, at repetition six a 5.2% decline occurred during the SSJ compared to 2% during the CMJ. The rate of PP loss increased during most repetitions after repetition six in the SSJ compared to the rate of loss during the CMJ. This may be explained by the greater demand to control the load in the frontal plane. Due to the instability, lighter loads were used in the SSJ. We used dumbbells to add load, which arguably improves the stability of the exercise by lowering the center of mass. Previous studies analyzing weighted jumps have used the trap bar (29) and load on the shoulders with either a smith machine or free weight bar (4,27). These differences may have an effect on power output and fatigue within a set but further research is needed.

Research data analyzing PE across higher repetitions above those included in our study are also scarce (1,6,23). In contrast to measuring PPmax and PP of each repetition, Alemany et al. (1) found a mean power loss of ~ 20% and ~40% after 15 and 30 reps, respectively during a barbell-loaded, CMJ at 30% 1RM squat. Mean power has also been analyzed across 60 reps during the CMJ (6,19). Patterson et al. (23) included elite Alpine skiers to develop a test of power across 60 reps in 2.5 min. with 2.5 sec rest between each repetition with 40% body weight. Average power was calculated every 30 s with non-consecutive jumps, thus comparison with our data is limited. In a similar design, Bosco et al. (6) also reported mean power every 15 s for 60 s as participants completed 60 continuous repetitions, but PP was not measured to determine the rate of loss from PPmax. The design of these studies also do not meet the goal of PE by not intending to produce each repetition at or near PPmax and involve a pacing of power output making comparison to our data limited.

Our data indicate that the rate of fatigue is similar from 0 to 50% body mass for the CMJ and from 0 to 30% for the SSJ. Baker and Newton (4) reported less PP loss using a 60 kg load (~35% 1RM) (5% after rep 10) than data from Hansen et al. (9), who reported 12% power loss after rep 6 during the CMJ using 40kg. These findings demonstrate that at lighter loads during jumps progression of greater loads does not produce a greater rate of fatigue within a set. However, with the use of absolute loads in these studies, training status could be a confounding factor. Greater loss in power has been shown with heavier loads used in resistance training (12). Izquierdo et al. (12) showed significant loss in peak velocity at repetition five with 75% 1RM but not until rep 15 at 60% 1RM during the squat. Thomasson and Comfort (27) investigated PP loss during the squat jump at 0, 20, 40, and 60% 1RM and found a significant loss only at 60% 1RM squat at repetition six. The participants had to pause two seconds at the bottom position and perform only a concentric contraction, which may have increased the rate of fatigue at this heavier load. This differs from our study, which used a continuous countermovement that incorporates the stretch-shortening cycle.

Many different modes of exercise and intensities are used to train for power including jump training with and without added load to the body mass. Recommended optimum loads to improve power vary with each exercise type based primarily on the load that produces the greatest power output. In contrast to the Olympic lifts and resistance exercise like the squat (8), the greatest power output during the CMJ has been shown to occur at lighter loads that are close to one's body weight (5,29). In agreement, our study found that the highest PPmax was produced at BW(0) during the CMJ while the highest PPmax occurred at BW(0) and BW(15) during the SSJ. Sleivert and Taingahue (26) found the greatest PPmax during the SSJ at 30-60% 1RM squat but did not test at loads less than 30%, which was the only study found to compare for this exercise.

Limitations of this study included the use of a percentage of the participant's body mass to determine the load. As a result, relative intensity based on strength was not determined. The use of body mass to determine the load is common in practice when PP is trained using jumping exercises. In addition, the use of 1RM from the squat may not represent the same relative intensity during repeated jumps using light loads while measuring power. Our data did not include multiple sets; however, research has shown that a two-min rest between sets is sufficient to maintain mean power output for following sets using this rep range (19). The participants were collegiate track and field athletes and results may differ with other athletes based on training status and ability. The participants were instructed to use maximum effort, descend to a depth that produced the highest jump, and jump vertically and land in the same spot every repetition that was monitored subjectively. Finally, during the SSJ, the participants' lead leg was not cycled, thus further research is needed on the cycled SSJ.

CONCLUSION

When training to improve PPmax with the continuous SSJs and CMJs, five and seven repetitions or less, respectively are recommended. This corresponds to the repetition when a significant reduction of PPmax occurred in trained athletes. When training for PE, the percent loss in PPmax between repetition 12-14 during the CMJ (11.2 to 13.7%) would indicate that this repetition range would be effective. PE is trained earlier at repetition 10 (11.6% loss) and to a greater extent at repetition 14 (18.2%) during the SSJ. With the range of loads used in this study, the rate of PP loss is similar at all loads within a set. While all loads used in this study could be used in training for PP and PE depending on the specificity goal, the greatest PPmax was found using BW(0) during the CMJ and at BW(0) and BW(15) during the SSJ. Thus, these loads arguably would be given priority when including the CMJ and SSJ in a training program for PPmax and PE.

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