International Journal of Sport, Exercise and Health Research 2023; 7(2): 46-53

Research Article

IJSEHR 2023; 7(2): 46-53
© 2023, All rights reserved
www.sportscienceresearch.com
Received: 22-08-2023
Accepted: 18-10-2023
DOI: 10.31254/sportmed.7204

Upright versus Horizontal Squat Jumps: A comparison of peak force, peak velocity, peak power and muscle activity in male athletes

Derek Ferley [1] Matthew Vukovich [2], Erik Hanson [3]

[1] Director of Sports Sciences Avera Human Performance Center Avera McKennan Hospital and University Health Center Sioux Falls, South Dakota, USA

[2] Professor and Associate Dean of Research, College of Education and Human Sciences, South Dakota State University, Brookings, South Dakota USA

[3] Athletic Trainer, Avera Human Performance Center, Avera McKennan Hospital and University Health Center, Sioux Falls, South Dakota USA

Abstract

Sports performance coaches and rehabilitation specialists commonly prescribe explosive squat jumps (SJ) in the upright position to improve lower body power using loads based upon an individual's one-repetition maximum (1RM) back squat. Recently, using a horizontal leg press to perform SJ has become popular purportedly due to its less technical nature. To date, little research exists comparing upright and horizontal SJ. Therefore, this investigation examined peak force, peak velocity, peak power and muscle activity of upright versus horizontal SJ using loads based upon each condition's respective 1RM. Twelve males completed two sets of three repetitions of SJ at 20%, 30%, 40%, 50% and 60%1RM. Statistical significance was set to $P \leq 0.05$. No significant differences existed between trial 1 and 2 for any measures. Two-way analysis of variance revealed a) no significant difference in peak force between the SJ conditions at any intensity; b) significantly greater peak velocity during upright SJ at all intensities; c); significantly greater peak power during upright SJ at all intensities; and d) no difference in muscle activity between SJ conditions. In conclusion, in a key measure of performance, power output during upright SJ was significantly greater than during horizontal SJ.

Keywords: Squat, Leg press, Vertical jump, Triple extension, Electromyography.

***Corresponding author:**
Dr. Derek Ferley
Director of Sports Sciences Avera Human Performance Center Avera McKennan Hospital and University Health Center Sioux Falls, South Dakota, USA
Email derek.ferley@avera.org

INTRODUCTION

Many sports involve short burst sprints, vertical jumps and repeated changes of direction [1, 2, 3]. The demands of these lower body movements highlight the importance of a properly designed, comprehensive sports performance training program to improve lower body power [4, 5, 6]. A key and commonly used exercise in athlete strength development is the back squat. Generally performed at slower movement velocities its effect is greatest on the slow velocity/high force segment of the force-velocity curve [7]. For athletes with resistance training experience, however, this training approach appears not to maximize power performance [8, 9]. In contrast, the benefit of low-load, high-velocity training for improved lower body power in well-trained individuals has been established [4]. A commonly used exercise to develop lower body power is the squat jump (SJ) [2, 3, 10]. Squat jumps are traditionally performed with a barbell across the top of the back and involve single or repeated explosive jumps using a load based on a percentage of the individual's one repetition maximum (1RM) back squat. From previous research, peak power during upright SJ occurs when using a load ranging 0-60%1RM [3, 5, 10, 11, 12].

In recent years, using a horizontal leg press to perform SJ has become popular, with purported advantages being its less technical nature and relative ease to learn compared to the upright SJ [13]. Despite its growing use among sports performance coaches and rehabilitation specialists, a literature review indicates a paucity of research with respect to horizontal SJ. Padulo et al. [14] reported SJ with a horizontal leg press demonstrated lower peak velocity and peak power compared to an upright condition (using a Smith machine-like device); further, Samozino et al. [13] reported a higher peak velocity in body mass-based horizontal versus upright SJ. Based on our knowledge, however, no research exists comparing SJ involving the traditional free-weight, upright approach to that on a horizontal leg press. Therefore, the purpose of this investigation was to compare peak force, peak velocity, peak power and muscle activity of SJ performed in a traditional free-weight, upright position to that involving a horizontal leg press machine.

Based on previous research, we hypothesized there would be no difference in the outcome measures between the two SJ conditions.

METHODS

Experimental Approach to the Problem

The present investigation used a "cross-over" observational design consisting of 4 sessions separated by a minimum of 5-7 days. Session 1 included anthropometric measurements (body height and body mass), countermovement (CMJ) and broad jump tests, a back squat 1RM assessment, and familiarization trials for upright SJ using the percentages of 1RM involved in the present investigation (20%, 30%, 40%, 50% and 60%). Session 2 was a horizontal leg press 1RM assessment, followed by familiarization trials for horizontal SJ in the same manner. Sessions 3 and 4 were randomized and involved collecting kinetic and muscle activity outcomes while performing either upright or horizontal SJ. All SJ trials during sessions 3 and 4 were randomized by selecting notecards on which the %1RM condition was written on the reverse side. Based on previous research [14] comparing absolute and relative power output of SJ performed in the upright and horizontal position, we calculated 12 subjects were needed to achieve a power of 80% with an alpha value of 0.05. The independent variables were jump condition; dependent variables were peak force, peak power, peak velocity and muscle activity.

Subjects

Subject characteristics are listed in Table 1. Twelve strength trained males between 18 and 35 years of age voluntarily enrolled to participate in this investigation after providing informed consent. A pre-study questionnaire provided details of the subjects' physical activity habits. The results showed all subjects had ≥4 years of previous strength training experience, and completed ≥3.0 resistance training sessions·wk^{-1} in the previous 12 months. The subjects had various experiences as recreational and competitive athletes in sports such as baseball, basketball, American football, track and field sprinting and jumping events, powerlifting and Olympic weightlifting. Inclusion criteria required subjects to be between 18-35 years of age. Individuals who had experienced a lower body injury in the previous 3 months were excluded. Approval from Avera McKennan Hospital and University Health system's Institutional Review Board was obtained before the start of the investigation.

Table 1: Subject Characteristics

	(n = 12)
Height (cm)	180.0 ± 4.2
Body mass (kg)	92.8 ± 11.1
Age (y)	24.1 ± 3.9
Training Experience (y)	6.5 ± 1.5
Weekly Strength Training (d·wk^{-1})	4.1 ± 0.9
Countermovement Jump (cm)	73.4 ± 13.6
Broad Jump (m)	2.5 ± 0.4
1RM_Back Squat (kg)	173.9 ± 23.2
Back Squat 1RM-to-Body Mass Ratio	1.9 ± 0.3
1RM_Leg Press (kg)	254.5 ± 23.7
Leg Press 1RM-to-Body Mass Ratio	2.8 ± 0.4

Training Experience = average number of years of resistance training; Weekly Strength Training = average number of days per week performing resistance training in previous 12 months; Data are means (±SD).

Procedures

This study involved four test sessions, with participants required to complete each of their test sessions at the same time of day. Subjects were instructed to arrive at each test session well-rested and having avoided caffeine, alcohol and strenuous exercise in the previous 24 hours. Session 1 began by weighing and measuring each subject using a physician's scale calibrated prior to each use (Detecto; Cardinal Detecto, Webb City, MO, USA), followed by warming up on a rowing ergometer (Concept2; Concept2 Inc., Morrisville, VT, USA) or elliptical cross-trainer (Precor EFX 885; Precor, Woodinville, WA, USA) for 5 minutes at a self-selected intensity. After warm up, subjects learned a series of dynamic drills. These drills included high knees, butt kicks, carioca, A-skips, jumping jacks, body weight squats, and leg swings in the sagittal and frontal planes. The same warm up and dynamic drills were performed at the start of each test session.

Countermovement Jump and Broad Jump Testing. Session 1 began with subjects completing a CMJ test using a vertical jump measuring device (Vertec; Sports Imports, Hilliard, OH), following standard procedures described previously [15]. Briefly, standing reach height was first determined, followed by a maximum jump height. Countermovement depth was self-selected and arm swing was allowed; the highest jump of 3 trials was used for data analysis. Next, broad jump was performed on a portable runway (Plyorobic Runway; Ecore, Inc., Lancaster, PA) measuring 1.2 m x 12.2 m x 1.1 cm in a manner similar to previous investigations [15]. For broad jump, subjects stood on the runway with their feet 20-30 cm apart before completing a maximum effort jump in the forward direction. The distance from a line on the floor to the subject's heel closest to the line was used for data analysis.

Maximal Strength Testing. Session 1 concluded with a back squat 1RM assessment using procedures described previously [16]. In brief, subjects completed a progressive warm up protocol and were given up to 5 maximal attempts to achieve a 1RM. Squat depth was standardized, with the subjects instructed to achieve a point where the top of the thigh was parallel to the floor. Rest periods of 3-5 minutes were given between all 1RM efforts [16]. Session 2 involved an assessment of 1RM on a horizontal leg press (Plyo Press; Athletic Republic, Park City, UT, USA) using the same 1RM assessment protocol [16]. Prior to testing, the leg press seat was positioned so the subjects' feet placed the hip and knee joint angles at approximately 90°. According to the leg press manufacture, its cam-lever design provides a variable resistance such that at the beginning of the press the load is reduced 20% relative to weight stack load; at 45° knee flexion the load is 100% to that of the weight stack; and at full knee extension the load is 120% of that of the weight stack.

Squat Jump Testing. Session 3 began by randomly selecting either the upright or horizontal SJ condition. The condition not selected was used for test session 4. For each test condition, subjects completed 2 sets of 3 continuous repetitions at each intensity in a randomized order. Three repetitions during each set were completed based on previous reports that maximal power may not be demonstrated on the first repetition [2]. Sets were separated by a 1-2 minute rest, while trials were separated by 3-5 minutes [16]. For each test condition the depth of the countermovement during SJ was self-selected by the subjects, with an emphasis placed on generating a maximum effort during the concentric phase of each repetition. For upright SJ trials a portable force plate was used (AccuPower; AMTI, Watertown, MA, USA). The AccuPower force plate measures 60 cm x 90 cm x 12 cm, and has been used previously for research purposes [17, 18]. Decking was added around the AccuPower to provide additional landing space. For horizontal SJ a Plyo Press with a frame-mounted force plate measuring 74 x 61 cm was used (PPFP-3; AMTI, Watertown, MA, USA). A previous investigation has demonstrated the reliability of the Plyo Press-force plate combination for reporting on the positive and negative neuromuscular characteristics of SJ [19]. Peak force during upright SJ was defined as being equal to the maximal vertical force value between jump start and takeoff; during horizontal SJ it was the vector sum of the vertical and horizontal forces applied to the force plate (relative to its position) during takeoff. Peak velocity during upright SJ was defined as being equal to the velocity of movement during ascension and occurred just prior to takeoff; during horizontal SJ it was the velocity of movement of the weight stack as measured by the displacement transducer using the First Central Difference method. Peak power during upright SJ was defined as the maximum watt value during the ascension phase, when velocity was positive; during horizontal SJ it was the maximum watt value associated with power generation during the takeoff phase. The same software program (AccuPower 2.0.; AccuPower Solutions, Park City, UT, USA) was used to determine peak force, peak velocity and peak power for both SJ conditions.

Figure 1: Examples of upright (left) and horizontal (right) squat jumps involving force plates.

Muscle Activity. Muscle activity measurements were assessed with a wireless surface electromyography (EMG) system (Delsys Trigno; Delsys, Inc., Natick, MA). Skin preparation and sensor placement procedures followed SENIAM guidelines [20]. In brief, sensor sites were first shaved, abraded and wiped clean with rubbing alcohol. Next, fourteen 37 mm x 26 mm x 15 mm EMG sensors were attached bilaterally (left, L; right, R) using double-sided tape over the muscle bellies of the vastus medialis oblique (L_VMO; R_VMO), vastus lateralis (L_VL; R_VL), gluteus maximus (L_GM; R_GM), medial hamstrings (L_MH; R_MH), bicep femoris (L_BF; R_BF) and lateral gastrocnemius (L_Gastroc; R_Gastroc). All sensors were placed parallel to the muscle fibers and wrapped with elastic tape (PowerFlex; Andover HealthCare, Inc; Salisbury, MA) for added stability. Maximum voluntary isometric contractions (MVIC) were captured at the beginning of test session 3. All MVICs were 3 seconds and captured in the following order and sequence: right and left quadriceps; right and left hamstrings; right and left gastrocnemius; and right and left gluteus maximus. Quadriceps MVIC were collected with the subject seated on a knee extension machine (Cybex VR3; LifeFitness, Inc., Franklin Park, IL) and lever arm set to a fixed angle of 120° and shank pad just superior to the malleoli [21, 22]. Hamstring MVIC were collected in the prone position using a leg curl machine (Cybex VR3; LifeFitness, Inc., Franklin Park, IL) with the lever arm set to a fixed angle of 60° degree of knee flexion and shank pad just superior to the malleoli [22]. Gastrocnemius MVIC were collected using a Smith-machine and with the subject standing with 0° knee flexion (straight leg) in a manner to procedures described previously [23]. Finally, gluteus maximus MVIC were captured while performing hip extension in a prone position on an exam table with the knee flexed to 90° and the thigh secured to the table via a seatbelt strap [24, 25]. Muscle activity data were captured at 2000 Hz using an acquisition and analysis software program (EMGworks; Delsys, Inc., Natick, MA) and then converted to C3D files before being exported to a custom-designed processing script (Visual 3D; C-Motion, Inc., Germantown, MD). EMG signals were digitally filtered with a fourth-order zero-lag Butterworth filter (bandpass 10-250 Hz), and the root mean square (RMS) was used for rectifying and smoothing the signal. The mean RMS value of the MVIC of each muscle was used to normalize all SJ trials. Similar to previous research [26] a threshold value of 15% of the MVIC across all SJ trials was chosen as the onset and offset criterion. The integrated muscle activity profile for each muscle between onset and offset was used for analytical purposes. To ensure sensor placement was consistent between sessions 3 and 4, a surgical marker was used to trace the outline of each sensor and subjects were given instructions to highlight the trace each day until returning for session 4.

Statistical Analyses

The statistical analysis program MedCalc (v. 22.003 MedCalc Software LTD, Belgium) was used for all data analysis. Descriptive statistics of each outcome variable including means, standard deviations, and tests of normality (Kolmogorov-Smirnov test) were determined. All subjects performed two trials of each jump exercise to ensure familiarization. A paired Student's t-test was used to test for differences between trials 1 and 2 of all upright and horizontal squat jumps. There were no significant differences in peak force, peak power, peak velocity, and muscle activity between trial 1 and trial 2 of any condition. Based on these findings the measures from trial 2 were used for two-way ANOVA analysis. A two-way analysis of variance (ANOVA) (resistance vs jump) was used to assess the peak force, peak velocity, peak power, and muscle activity of all trial 2 conditions. A significance level of $p \leq 0.05$ was set for all statistical analyses. Where significance was found a Bonferroni corrected post hoc test was performed to locate differences.

RESULTS

Loads for the Weight Squat Jump Conditions

Loads for the SJ test conditions are listed in Table 2. Total load used during upright SJ trials was defined as the average of each back squat load plus average body mass minus average shank mass, which has been estimated as 12% of total body mass [3]. Alternatively, total load used during horizontal SJ trials was defined as the average of each leg press load plus 20% to account for the cam lever design as described above. Total load used during upright SJ was significantly greater than horizontal SJ at 20%, 30%, 40%, and 50%1RM. There was no difference between upright and horizontal total load at 60%1RM.

Table 2: Total loads for the two squat jump conditions.

	Upright SJ Loads (n = 12)		**Horizontal SJ Loads (n = 12)**	
(%1RM)	**Avg Barbell Load (kg)**	**Total Upright Load (kg)**	**Avg Stack Load (kg)**	**Total Horizontal Load (kg)**
20	34.8 ± 4.6	115.6 ± 12.0*	50.9 ± 4.7	61.1 ± 5.7
30	52.2 ± 7.0	133.0 ± 13.7*	76.4 ± 7.1	91.6 ± 8.5
40	69.5 ± 9.3	150.3 ± 15.5*	101.8 ± 9.5	122.3 ± 11.4
50	86.9 ± 11.6	167.7 ± 17.4*	127.3 ± 11.9	152.7 ± 14.2
60	104.3 ± 13.9	185.1 ± 19.4	152.7 ± 14.2	183.3 ± 17.1

Avg Barbell Load = average mass of barbell load for each intensity (%1RM); Total Upright Load = average mass of barbell load plus average body mass for each intensity (%1RM). Avg Stack Load = average mass of leg press weight stack for each intensity (%1RM); Total Horizontal Load = average mass of stack load lifted for each intensity (%1RM) plus 20% for changes in variable resistance at full knee extension.
*Significantly greater than total horizontal SJ load ($p < 0.05$). Data are means (±SD)

Peak Force

The peak force responses by trial and intensity are highlighted in Figure 2. By trial, there was no significant difference in peak force between the two conditions at any intensity. By intensity, 20%1RM was significantly less than 40%, 50% and 60%1RM; 30%1RM was significantly less than 50% and 60%1RM; and 40%1RM was significantly less than 60%1RM.

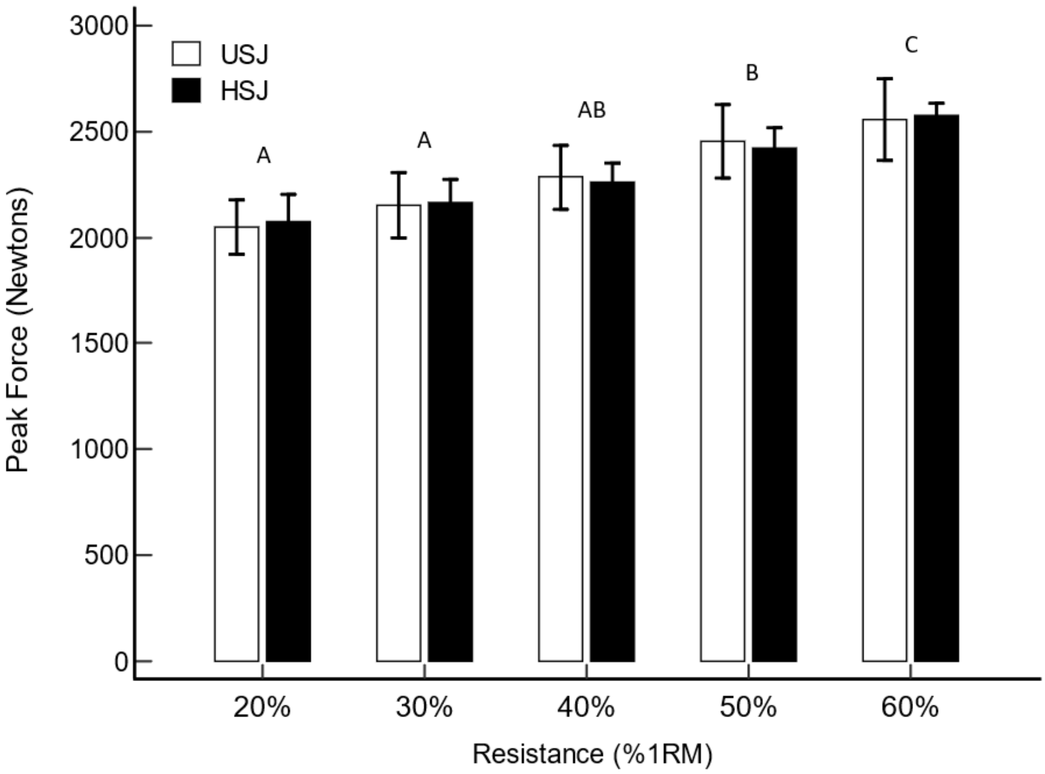

Figure 2: Two-way analysis of variance comparing the peak force (N) of the two jump conditions. Peak force values are the mean ± 95% CI. The intensities are based upon everyone's respective condition's one-repetition maximum. USJ and HSJ are not different from each other. Intensity (%1RM) not connected by the same letter are significantly different. $P \leq 0.05$; n = 12.

Peak Velocity

The peak velocity responses by trial and intensity are listed in Figure 3. By trial, peak velocity was significantly greater during upright SJ at all intensities. By intensity, peak velocity was significantly greater at 20%1RM than 30%, 40%, 50% and 60%1RM; 30%1RM was significantly greater than 40%, 50% and 60%1RM; 40%1RM was significantly greater than 50% and 60%1RM; and 50%1RM was significantly greater than 60%1RM.

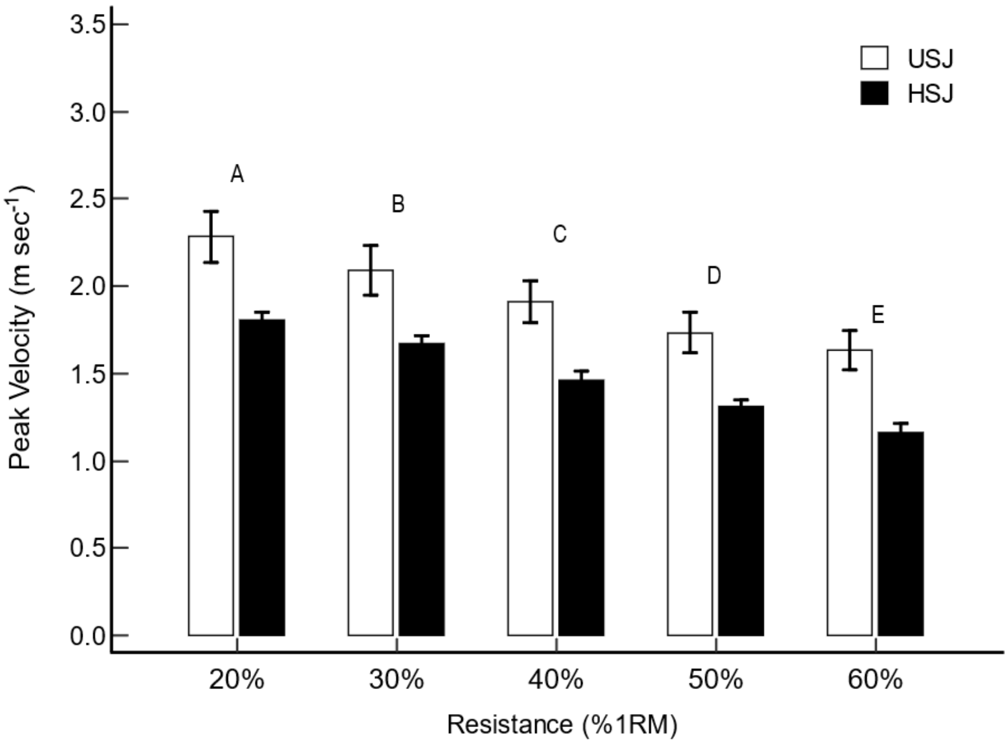

Figure 3: Two-way analysis of variance comparing the peak velocity (m·sec^{-1}) of the two jump conditions. Peak velocity values are the mean ± 95% CI. The intensities are based upon everyone's respective condition's one-repetition maximum. Peak velocity was greater ($p > 0.05$) in USJ compared to HSJ. Intensity (1RM) not connected by the same letter are significantly different. $P \leq 0.05$; n = 12.

Peak Power

The peak power responses by trial and intensity are listed in Figure 4. By trial, upright SJ peak power was significantly greater at all intensities. By intensity, there were no significant differences in peak power across intensities for either SJ condition.

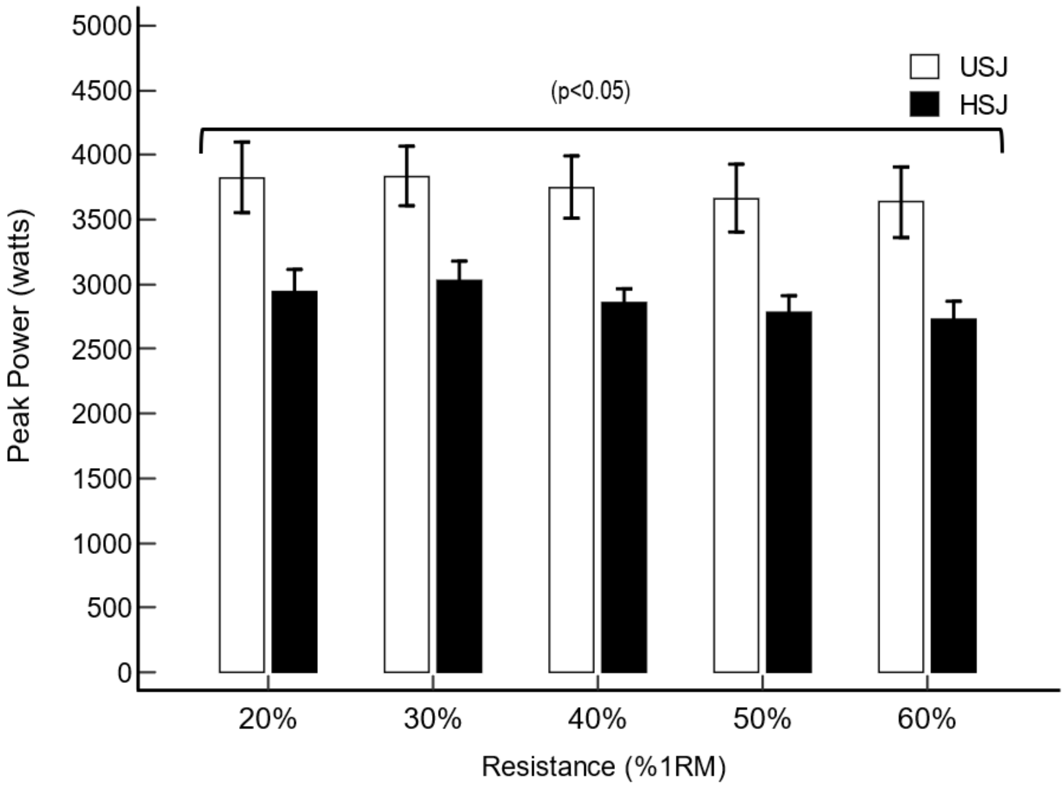

Figure 4: Two-way analysis of variance comparing the peak power (watts) of the two jump conditions. Peak power values are the mean ± 95% CI. The intensities are based upon everyone's respective condition's one-repetition maximum. Peak power was greater ($p < 0.05$) in USJ compared to HSJ. There was no difference in peak power across intensities (1RM). $P \leq 0.05$; n = 12.

Muscle Activity

The muscle activity by trial and intensity are listed in Table 3. The muscle activity profiles revealed few significant differences by trial or intensity. Of the significant differences reported (6 of 132 profiles) five occurred in R_BF and indicated horizontal SJ was significantly less than upright SJ; and one occurred in R_SM and indicated horizontal SJ was significantly less than upright SJ. Based on these non-uniform results we conclude there were no differences in muscle activity between SJ trials or intensities examined.

Table 3: EMG activity (% MVIC) of left and right lower body muscles while performing upright and horizontal squat jumps.

	L_BF	L_Gastroc	L_GM	L_MH	L_VL	L_VMO	R_BF	R_Gastroc	R_GM	R_MH	R_VL	R_VMO
20%1RM												
UP	14.0 (11.0)	18.0 (7.0)	18.0 (9.0)	6.0 (1.0)	51.0 (27.0)	45.0 (17.0)	17.0 (9.0)	16.0 (7.0)	15.0 (9.0)	7.0 (3.0)	38.0 (19.0)	51.0 (29.0)
HOR	10.0 (9.0)	18.0 (6.0)	20.0 (7.0)	5.0 (6.0)	47.0 (20.0)	44.0 (15.0)	12.0 (16.0)	12.0 (5.0)	18.0 (13.0)	4.0 (3.0)	44.0 (24.0)	55.0 (42.0)
30%1RM												
UP	13.0 (9.0)	18.0 (6.0)	22.0 (0.14)	5.0 (2.0)	51.0 (27.0)	45.0 (22.0)	13.0 (4.0)	18.0 (4.0)	18.0 (12.0)	0.06 (0.02)	43.0 (27.0)	52.0 (28.0)
HOR	8.0 (5.0)	16.0 (6.0)	27.0 (4.0)	5.0 (2.0)	52.0 (23.0)	51.0 (16.0)	*9.0 (3.0) HOR<UP*	16.0 (6.0)	23.0 (15.0)	4.0 (3.0)	48.0 (19.0)	55.0 (31.0)
40%1RM												
UP	15.0 (12.0)	19.0 (7.0)	21.0 (12.0)	7.0 (2.0)	58.0 (27.0)	52.0 (26.0)	15.0 (5.0)	17.0 (6.0)	19.0 (11.0)	7.0 (2.0)	50.0 (34.0)	63.0 (46.0)
HOR	9.0 (5.0)	17.0 (8.0)	32.0 (18.0)	4.0 (1.0)	60.0 (31.0)	*59.0 (22.0)*	*9.0 (3.0) HOR<UP*	16.0 (4.0)	27.0 (19.0)	*4.0 (2.0) HOR<UP*	55.0 (28.0)	63.0 (37.0)
50%1RM												
UP	15.0 (11.0)	21.0 (8.0)	28.0 (17.0)	8.0 (3.0)	71.0 (42.0)	*61.0 (31.0)*	17.0 (5.0)	19.0 (5.0)	23.0 (15.0)	8.0 (3.0)	54.0 (33.0)	70.0 (47.0)
HOR	11.0 (8.0)	17.0 (6.0)	32.0 (16.0)	4.0 (2.0)	58.0 (25.0)	56.0 (24.0)	*9.0 (3.0) HOR<UP*	18.0 (6.0)	32.0 (26.0)	5.0 (2.0)	59.0 (27.0)	67.0 (40.0)
60%1RM												
UP	19.0 (14.0)	24.0 (9.0)	31.0 (17.0)	8.0 (3.0)	*74.0 (36.0)*	*65.0 (35.0)*	*20.0 (6.0) HOR<UP*	21.0 (9.0)	24.0 (16.0)	9.0 (4.0)	59.0 (40.0)	78.0 (46.0)
HOR	12.0 (8.0)	19.0 (8.0)	35.0 (23.0)	5.0 (1.0)	65.0 (26.0)	*63.0 (22.0)*	*10.0 (4.0) HOR<UP*	17.0 (6.0)	29.0 (15.0)	5.0 (2.0)	64.0 (25.0)	74.0 (46.0)

Up = Upright Squat Jump; HOR = Horizontal Squat Jump. L_BF; R_BF = left and right bicep femoris, respectively; L_Gastroc; R_Gastroc = left and right gastrocnemius, respectively; L_GM; R_GM = left and right gluteus maximus, respectively; L_MH; R_MH = left and right medial hamstrings, respectively; L_VL; R_VL = left and right vastus lateralis, respectively; L_VMO; R_VMO = left and right vastus medialis, respectively. 20%1RM, 30%1RM, 40%1RM, 50%1RM and 60%1RM = squat jump load. Values in italics are statistically significant. Data are means (± SD) $P < 0.05$

DISCUSSION

The primary purpose of this investigation was to compare peak force, peak velocity, peak power and muscle activity of SJ performed in the traditional upright position utilizing free-weights to that involving a horizontal leg press machine. The main findings of this investigation were: 1) no significant differences in peak force between the two SJ conditions at any intensity; 2) significantly greater peak velocity during upright SJ at all intensities; 3) significantly greater peak power during upright SJ at all intensities; and 4) no uniform significant differences in muscle activity between the two SJ conditions. As peak power represents a key measure in athletic performance, and upright SJ led to significantly greater power at all intensities, we reject our hypothesis of there being no difference between the two conditions. To the best of our knowledge, the present investigation is the first to compare SJ using the traditional free-weight, upright approach to a horizontal leg press condition.

Upright Squat Jumps. Our findings revealed peak force increased significantly with increasing loads during upright SJ, which is consistent with previous investigations [3, 4]. Specifically, in the present investigation peak force increased 24.7% from 20%1RM (2048.7 ± 214.3 N) to 60%1RM (2553.7 ± 318.7 N) compared to 28.6% [3] and approximately 24.7% [27] in studies of upright SJ using the same intensities. Regarding peak velocity, 20%1RM was significantly greater than other loads, and with increased load, peak velocity slowed significantly; these results support the findings of previous research of upright SJ [3, 10, 27, 28]. More specifically, in the present investigation peak velocity decreased 41% from 20%1RM (2.28 ± 0.25 $m \cdot sec^{-1}$) to 60%1RM (1.63 ± 0.19 $m \cdot sec^{-1}$) compared to 40.3% [27] and approximately 25.0% [10] reported by previous investigators investigating the same loads. For peak power, in the present investigation there was no significant difference between the loads tested during upright SJ. This finding is in contrast to previous investigations in which smaller loads resulted in greater power output during upright SJ [3, 4, 11, 12, 27]. As with a previous investigation of upright SJ, however, we cannot rule out that in the present investigation an even lower %1RM load for upright SJ (e.g. 0% or 10%1RM) would not have resulted in significantly greater peak power [29]. In contrast, Sleivert and Taingahue [28] reported peak power during upright SJ occurred at 60%1RM; however, no eccentric component was included as part of the SJ. Previous research indicates the eccentric phase of a SJ contributes significantly to concentric phase power output [30, 31]. Regarding muscle activity, there were no significant differences in upright SJ muscle activity profiles at any load, which supports the findings of previous research of upright SJ [32].

Horizontal Squat Jumps. Our findings revealed peak force increased significantly at each load tested. With respect to peak velocity, significant differences were demonstrated at each load, with each increase in load leading to a slower peak velocity. Regarding peak power, no significant differences were found between intensities. The findings of the present investigation regarding peak force, peak velocity and peak power during support those of a previous investigation into horizontal SJ involving the Plyo Press and loads ranging 30-60%1RM [19]. In that investigation by Ferley and Vukovich [19], peak force was significantly greatest at 60%1RM; peak velocity was significantly slower with each increase in load tested; and there was no significant difference in peak power among intensities tested. Finally, with respect to muscle activity, in the present investigation there were no significant differences in horizontal SJ muscle activity profiles at any load, a finding consistent with previous research of upright SJ [32] but which we believe the present investigation is the first to report with respect to horizontal SJ.

Regarding the specific comparison of upright to horizontal SJ, little research exists. Padulo et al. [14] examined single, concentric-only upright SJ using a Smith machine-like device compared to horizontal SJ involving a leg press with a seatback positioned approximately +10° and +35° from the horizontal and vertical plane, respectively. For horizontal SJ, this seatback configuration placed the user in hip flexion throughout the movement, which changes the moment-angle relationship of the hip extensors during knee extension [33]. Compared to the present investigation, Padulo et al. [14] reported upright SJ resulted in an average peak force, peak velocity and peak power of 3394 ± 824 N, 1.66 ± 0.3 m·sec^{-1} and 1366 ± 384 W, respectively, while those same measures in their horizontal SJ were 3850 ± 672 N, 0.88 ± 0.2 m·sec^{-1} and 835 ± 164 W. With little reported about the participants' training background, two key observations are: 1) both SJ conditions resulted in much higher peak forces compared to either SJ condition in the present investigation; and 2) both SJ conditions resulted in much lower peak velocities compared to either SJ condition in the present investigation. Additionally, the loads used in Padulo et al. [14] were not based on a predetermined 1RM, which makes direct comparisons to the results of the present investigation more challenging. In a different study, Samozino et al. [13] reported significantly greater peak force during a single upright, concentric-only SJ (body mass only; or body mass plus 60% of body mass) compared to a single concentric-only horizontal SJ performed on a modified mechanic's sled that had a 0° incline relative to the horizontal or vertical plane and rolled on the ground. The leg press used in the present investigation has a sled/seatback position of 0° and 16° relative to the horizontal and vertical plane, respectively; it also has a variable resistance cam-lever (described above) designed to optimize force output throughout the range of motion. Based on the findings reported by Padulo et al. [14] and Samozino et al. [13], if using a horizontal leg press for SJ, it appears the leg press used in the present investigation, with its less steep seatback position, is superior to a device with a steeper seatback position due to the mechanics of achieving higher peak velocities, and therefore greater peak power. Additionally, the leg press used in the present investigation also appears preferential to a device such as a mechanic's roller sled, which has no seatback inclination and no capacity for added weight, because although the peak velocities during horizontal SJ reported by Samozino et al. [13] were much greater than those demonstrated by the leg press condition in the present investigation, a much smaller peak force was achieved. Specific to the present investigation, the main difference between upright and horizontal SJ appears to be the difference in movement velocity. That is, there was no significant difference in peak force between the two conditions at any intensity, while peak velocity was 21%, 20%, 23%, 25% and 29% greater during upright SJ (at 20%, 30%, 40%, 50% and 60%1RM, respectively). This resulted in a peak velocity that was an average 0.5 ± 0.02 m·sec^{-1} greater during upright SJ at every load tested.

In summary, the findings associated with upright SJ in the present investigation agree with previous studies [3, 10, 27]. Additionally, a main purpose of the present investigation was to compare a traditional free-weight, upright SJ to horizontal SJ performed on a leg press. In this regard, the two SJ conditions demonstrated no significant differences in peak force, while upright SJ demonstrated significantly greater peak velocity at all intensities compared to horizontal SJ; and ultimately, peak power was significantly greater during upright SJ at every load tested. Lastly, with regards to muscle activity, no uniform differences were demonstrated between the SJ conditions, leading to the conclusion there was no difference in the neurological response between them. Because there were no significant differences in peak force between the two SJ conditions, peak power appears to have been most impacted by peak velocity. We recognize several limitations to the present investigation including using loads based purely on each condition's respective 1RM, and trying to make direct comparisons between the two; it may be that using the same load for both conditions (rather than a percentage of 1RM) would produce different results. Regarding muscle activity, despite our best effort to ensure sensor placement between test sessions 3 and 4, we acknowledge there may have been instances where this did not occur, and this may have impacted the muscle activity profiles; and perhaps a different method for ensuring sensor placement consistency would be more prudent. Based on these limitations, we recommend future studies examine these same test conditions using a three-dimensional motion capture system integrated with force plate and muscle activity technology to acquire more nuanced information including angular joint velocity, joint moment, joint power and muscle activity throughout the movements. We also recommend future studies be conducted with other horizontal leg press machines that can be used for SJ to determine if there is mechanical configuration that better optimizes peak power.

Practical Applications

Squat jumps are commonly used in sports performance training and injury rehabilitation. Previous research has focused on the traditional free-weight, upright SJ. In recent years, however, horizontal leg presses designed to accommodate SJ have become more popular, with safety and ease of use being reasons for doing so. The results of the present investigation reveal upright SJ leads to significantly greater peak power, a finding which appears most likely due to a significantly greater peak velocity achieved during the movement. If choosing to perform SJ using the traditional free-weight, upright approach, based on the present investigation a load equal to 20% of a 1RM back squat maximizes peak power. In contrast, if opting to perform horizontal SJ using the same horizontal leg press as the present investigation, our results indicate any intensity ranging 20%-60%1RM maximizes peak power. Anecdotally, however, the lowest load of 20%1RM often resulted in the sled hitting the rails' terminus; therefore, we recommend using a minimum intensity of 30%1RM. Prescribing sets and repetitions for either condition to develop peak power are beyond the scope of this investigation; and we recommend reviewing the available literature to arrive at an appropriate training load and volume.

Acknowledgements

The authors thank the participants for their effort, willingness and enthusiasm for participating in this study. They also great appreciate the assistance of the staff of Avera Sports and the support of Avera McKennan Hospital and University Health Center. The Principal Investigator also thanks John Frappier, who provided invaluable anecdotal findings and observations during his lifetime with respect to using a horizontal leg press as a testing and training tool for sports performance. This investigation was self-funded. The authors report there are no competing interests to declare.

Conflict of Interest

The authors declare no conflicts of interest.

Funding

None declared.

ORCID ID

Derek Ferley: https://orcid.org/0000-0003-1775-6798
Erik Hanson: https://orcid.org/0009-0003-0437-5985
Matthew Vukovich: https://orcid.org/0000-0001-6621-8588

REFERENCES

1. Ozbar N, Ates S, Agopyan A. The effect of 8-week plyometric training on leg power, jump and sprint performance in female soccer players. J Strength Cond Res. 2014;28(10):2888-94.
2. Baker D, Nance S, Moore M. The load that maximizes the average mechanical power output during jump squats in power-trained athletes. J Strength Cond Res. 2001;15(1):92-7.
3. Cormie P, McCaulley GO, Triplett NT, McBride JM. Optimal loading for maximal power output during lower-body resistance exercises. Med Sci Sports Exerc. 2007;39(2):340-9.
4. Cormie P, McCaulley GO, McBride JM. Power versus strength-power jump squat training: influence on the load-power relationship. Med Sci Sports Exerc. 2007;39(6):996-1003.
5. Harris NK, Cronin JB, Hopkins WG, Hansen KT. Squat jump training at maximal power loads vs. heavy loads: effect on sprint ability. J Strength Cond Res. 2008;22(6):1742-9.
6. McBride JM, Triplett-McBride T, Davie A, Newton RU. The effect of heavy- vs. light-load jump squats on the development of strength, power, and speed. J Strength Cond Res. 2002;16(1):75-82.
7. Hoffman JR, Ratamess NA, Cooper JJ, Kang J, Chilakos A, Faigenbaum AD. Comparison of loaded and unloaded jump squat training on strength/power performance in college football players. J Strength Cond Res. 2005;19(4):810-5.
8. Cormie P, McGuigan MR, Newton RU. Influence of strength on magnitude and mechanisms of adaptation to power training. Med Sci Sports Exerc. 2010;42(8):1566-81.
9. Folland JP, Williams AG. The adaptations to strength training : morphological and neurological contributions to increased strength. Sports Med. 2007;37(2):145-68.
10. Turner AP, Unholz CN, Potts N, Coleman SG. Peak power, force, and velocity during jump squats in professional rugby players. J Strength Cond Res. 2012;26(6):1594-600.
11. Bevan HR, Bunce PJ, Owen NJ, Bennett MA, Cook CJ, Cunningham DJ, et al. Optimal loading for the development of peak power output in professional rugby players. J Strength Cond Res. 2010;24(1):43-7.
12. Jiménez-Reyes P, Pareja-Blanco F, Balsalobre-Fernández C, Cuadrado-Peñafiel V, Ortega-Becerra MA, González-Badillo JJ. Jump-Squat Performance and Its Relationship With Relative Training Intensity in High-Level Athletes. Int J Sports Physiol Perform. 2015;10(8):1036-40.
13. Samozino P, Rivière JR, Rossi J, Morin JB, Jimenez-Reyes P. How Fast Is a Horizontal Squat Jump? Int J Sports Physiol Perform. 2018;13(7):910-6.
14. Padulo J, Migliaccio GM, Ardigò LP, Leban B, Cosso M, Samozino P. Lower Limb Force, Velocity, Power Capabilities during Leg Press and Squat Movements. Int J Sports Med. 2017;38(14):1083-9.
15. Ferley DD, Scholten S, Vukovich MD. Combined Sprint Interval, Plyometric, and Strength Training in Adolescent Soccer Players: Effects on Measures of Speed, Strength, Power, Change of Direction, and Anaerobic Capacity. J Strength Cond Res. 2020;34(4):957-68.
16. Haff G, Triplett N. National Strength and Conditioning Association: Essentials of Strength Training and Conditioning. Champaign, IL: Human Kinetics; 2016.
17. Staub JN, Kraemer WJ, Pandit AL, Haug WB, Comstock BA, Dunn-Lewis C, et al. Positive effects of augmented verbal feedback on power production in NCAA Division I collegiate athletes. J Strength Cond Res. 2013;27(8):2067-72.
18. Harrison AD, Ford KR, Myer GD, Hewett TE. Sex differences in force attenuation: a clinical assessment of single-leg hop performance on a portable force plate. Br J Sports Med. 2011;45(3):198-202.
19. Ferley DD, Vukovich MD. Assessing the Reliability of Using a Horizontal Leg Press Equipped With a Force Plate to Report on Measures of Positive and Negative Neuromuscular Characteristics. J Strength Cond Res. 2019;33(2):360-71.
20. Hermens HJ, Freriks B, Disselhorst-Klug C, Rau G. Development of recommendations for SEMG sensors and sensor placement procedures. J Electromyogr Kinesiol. 2000;10(5):361-74.
21. Kukić F, Mrdaković V, Stanković A, Ilić D. Effects of Knee Extension Joint Angle on Quadriceps Femoris Muscle Activation and Exerted Torque in Maximal Voluntary Isometric Contraction. Biology (Basel). 2022;11(10).
22. Saito A, Akima H. Knee joint angle affects EMG-force relationship in the vastus intermedius muscle. J Electromyogr Kinesiol. 2013;23(6):1406-12.
23. Hébert-Losier K, Schneiders AG, García JA, Sullivan SJ, Simoneau GG. Peak triceps surae muscle activity is not specific to knee flexion angles during MVIC. J Electromyogr Kinesiol. 2011;21(5):819-26.
24. Cochrane DJ, Gabriel E, Harnett MC. Evaluating gluteus maximus maximal voluntary isometric contractions for EMG normalization in male rugby players. J Phys Ther Sci. 2019;31(4):371-5.
25. Contreras B, Vigotsky AD, Schoenfeld BJ, Beardsley C, Cronin J. A comparison of two gluteus maximus EMG maximum voluntary isometric contraction positions. PeerJ. 2015;3:e1261.
26. Baum BS, Li L. Lower extremity muscle activities during cycling are influenced by load and frequency. J Electromyogr Kinesiol. 2003;13(2):181-90.
27. Dayne AM, McBride JM, Nuzzo JL, Triplett NT, Skinner J, Burr A. Power output in the jump squat in adolescent male athletes. J Strength Cond Res. 2011;25(3):585-9.
28. Sleivert G, Taingahue M. The relationship between maximal jump-squat power and sprint acceleration in athletes. Eur J Appl Physiol. 2004;91(1):46-52.
29. Stone MH, O'Bryant HS, McCoy L, Coglianese R, Lehmkuhl M, Schilling B. Power and maximum strength relationships during performance of dynamic and static weighted jumps. J Strength Cond Res. 2003;17(1):140-7.
30. Markovic G, Jaric S. Positive and negative loading and mechanical output in maximum vertical jumping. Med Sci Sports Exerc. 2007;39(10):1757-64.
31. Nuzzo JL, McBride JM, Dayne AM, Israetel MA, Dumke CL, Triplett NT. Testing of the maximal dynamic output hypothesis in trained and untrained subjects. J Strength Cond Res. 2010;24(5):1269-76.
32. Nuzzo JL, McBride JM. The effect of loading and unloading on muscle activity during the jump squat. J Strength Cond Res. 2013;27(7):1758-64.
33. Rossi FE, Schoenfeld BJ, Ocetnik S, Young J, Vigotsky A, Contreras B, et al. Strength, body composition, and functional outcomes in the squat versus leg press exercises. J Sports Med Phys Fitness. 2018;58(3):263-70.

Creative Commons (CC) License-
This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY 4.0) license. This license permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited. (http://creativecommons.org/licenses/by/4.0/).