



*Original Research*

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## Comparison of Countermovement and Squat Jumps Performance in Recreationally Trained Males

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### ABSTRACT

*International Journal of Exercise Science* 14(1): 462-472, 2021. The vertical jump has been shown to be an effective tool in assessing neuromuscular fatigue. The two most common iterations of the vertical jump are the countermovement and squat jumps. This investigation sought to identify if differences exist between the two jumping strategies with regard to electromyography (EMG) and kinetics in a group of recreationally trained males. Twenty-two participants completed one experimental session, where three countermovement (CMJ) and three squat jumps (SJ) were performed using a counterbalanced within-subject design. Jump performance was evaluated with data obtained using a force platform. Additionally, EMG was collected on the vastus lateralis (VL), vastus medialis (VM), semitendinosus (ST) and medial gastrocnemius (MG). Greater EMG values were seen in the CMJ for ST as well as percentage of activation in the MG ( $p < 0.05$ ). Increased values of mean force and mean power were observed in the SJ, while the CMJ showed greater peak and mean velocity. Greater jump heights in the CMJ were present as well ( $p < 0.05$ ). These findings suggest that the increase in CMJ jump height due to the increase in propulsive velocity is not due to increases in knee extensors muscle activation.

KEY WORDS: Vertical Jump, electromyography, kinetics

### INTRODUCTION

Monitoring and testing athletic performance has become a critical piece in the training of athletic populations across various levels of competition. An important aspect to both monitoring and testing athletes is to limit the amount of additional fatigue that can be induced by the testing measure itself. This has led to the use of the countermovement (CMJ) and squat (SJ) jumps, as both can be implemented with relative ease into training programs while limiting the amount of additional fatigue to the athlete. This is shown in a survey of high performance practitioners

in which jump testing was reported as the most popular assessment of fatigue in their athletes (22). Jump testing was reported in sports that both utilize similar ballistic movements during the sporting tasks (volleyball, soccer, and rugby), as well as those that do not (hockey, rowing, and cricket) (22). The use of jump testing across a multitude of sports with different demands points to the ease of implementation into a testing protocol to better understand where an athlete is at from a neuromuscular performance standpoint. While the goal of both movements is similar in that one tries to jump to a maximal height, the difference between the jumping techniques result in a reduced maximal jump height in the SJ. During the CMJ the athlete begins the task by starting in a standing position before descending into a semi squat, which is immediately followed by an upward motion that leads to takeoff from the ground. Conversely, the SJ begins from the same upright standing position and descent into a semi squat position, however this semi squat position is held for three to five seconds typically before performing an upward movement to achieve takeoff from the ground. When the same individual performs both movements, the CMJ will almost always outperform the SJ when time-dependent factors are excluded (2, 3, 12, 14). This can be seen by the greater jump heights in the CMJ over the SJ (2, 4, 8, 12).

Throughout the literature, several proposals have been made to the potential mechanism responsible for increased jump height in the CMJ. Traditional views suggest the greater performance in the CMJ is attributed to the performance-enhancing effect of the stretch-shortening cycle (12). The performance-enhancing effect of the stretch-shortening cycle, however, has been attributed to several different mechanisms. Several studies have shown that similar muscle activation is seen in both the CMJ and SJ with the use of electromyography (EMG) in the knee extensor musculature (4, 5, 11). Bosco et al. (5) suggested that with similar activation patterns the enhanced performance in the CMJ was primarily attributed to effective recoil of the elastic energy in the muscle during the stretch-shortening cycle. Similar results were seen by Bobbert et al. (4), in that no differences were seen in muscle activity of the lower body. Again, suggesting that the use of elastic energy produced through the countermovement phase of the task as the mechanism to increased jump height. However, the authors did see that greater values of force at the beginning of the propulsive phase and greater velocity of the center of mass at the point takeoff. These results showed that enhanced muscle activity again was not the primary mechanism for greater jump height in the CMJ and concluded that the amount of work a muscle could perform with the addition of a countermovement was greater than without the countermovement (4).

While force production is important to the vertical jumping task, it has been seen that peak values of forces can be similar between jumping techniques (10). This has led to the examination of other variables to explain differences between the CMJ and SJ. Peak velocity of the center of mass, is a variable that underpins an individual's jump height. The greater that the velocity is at takeoff, the longer it would take gravitational acceleration to bring you to a stop and return you to the ground. Additionally, it has been shown that a reduction in peak force can occur over the course of a competitive season, while maintaining jump height in the CMJ (21). Thus, differences in the SJ and CMJ jump height would not be attributed to force production but rather the velocity of the movement.

Previous investigations examining the differences in CMJ and SJ performance, have used samples that are familiar with ballistic lower body movements such as the CMJ (4, 11). This is important to note, as the SJ could potentially be a novel jumping technique that they would have less experience with causing a difference in performance even if controlling for other aspects (arm swing, depth of countermovement, etc.). Thus, using athletes and populations that have similar experience with the two tasks can provide better insight into the differences between the two jumping strategies. Thus, the primary purpose of this investigation was to examine differences in the electromyography, kinetics, and kinematics of the SJ and CMJ in a cohort of recreationally trained individuals. We hypothesize that differences in center of mass velocity will be present between jumping strategies.

## METHODS

### *Participants*

Twenty-two ( $n = 22$ ) recreationally trained males (height  $180.07 \pm 8.48$  cm, body mass  $84.51 \pm 12.63$  kg) between the age of 18 - 35 (age:  $23.61 \pm 2.64$  years) participated in this investigation. All subjects were physically active for the 6 months preceding data collection and were deemed free of injury and cleared for physical activity by the physical activity readiness questionnaire (PAR-Q). Informed consent approved from the University Institutional Review Board was obtained. This research was carried out fully in accordance to the ethical standards of the International Journal of Exercise Science (19). Sample size estimation was conducted based on previous investigations using a similar design to the present investigation (15). The use a conventional  $\alpha = 0.05$  and  $\beta = 0.80$  and moderate effect size of 0.5 were used in the calculation.

### *Protocol*

A counterbalanced within-subject design was used to identify differences in electromyography during the propulsive portion of both CMJ and SJ. Participants visited the laboratory for two sessions, one familiarization session and one experimental session that were separated by a minimum of 24 hours. During the first visit, participants were screened for exclusionary criteria and familiarized with test protocols for the CMJ and SJ as well as maximal voluntary contractions (MVC).

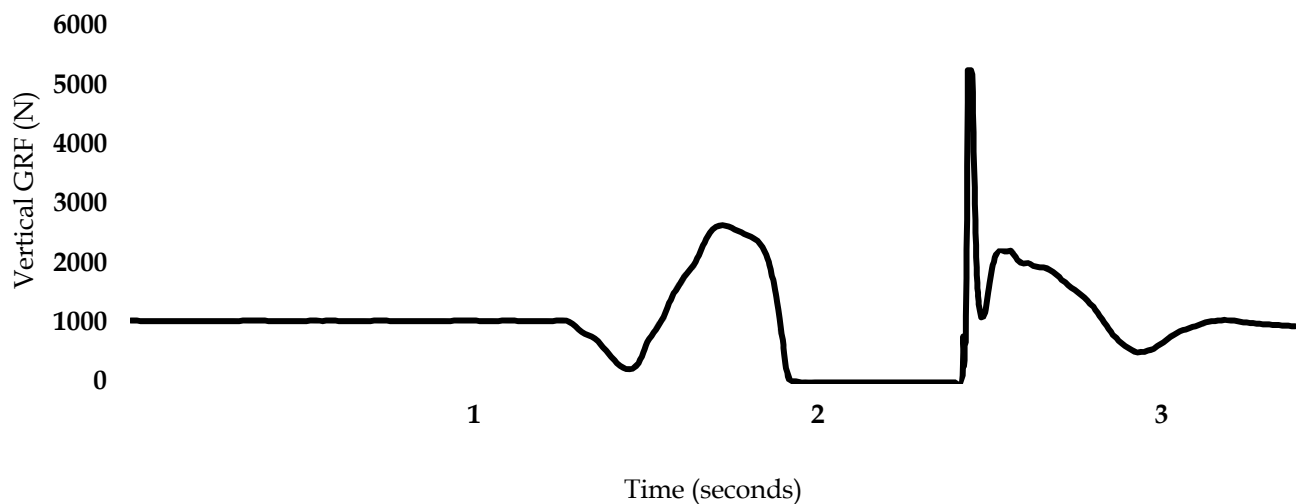
Upon arrival to the experimental session, subjects were prepped for MVCs. The skin over the muscle belly of the vastus lateralis (VL), vastus medialis (VM), semitendinosus (ST), and medial gastrocnemius (MG) in the dominant leg was abraded and cleaned prior to the application of bipolar silver/silver chloride surface electrodes with a ground electrode placed on the tibial tuberosity. Leg dominance was determined by asking subjects they would kick a ball with if rolled to them. Standardized warm up was then performed, consisting of jumping jacks, body weight squats, quadriceps and hamstring stretches, and five submaximal CMJ and SJ attempts each.

After completion of the warm-up, a five-minute rest period was given prior MVC being collected. EMG was collected at 1000Hz using Noraxon Telemetry DTS 900 system (Scottsdale, AZ) through Vicon Nexus (Oxford, UK) software. Three trials of MVCs for each of the four

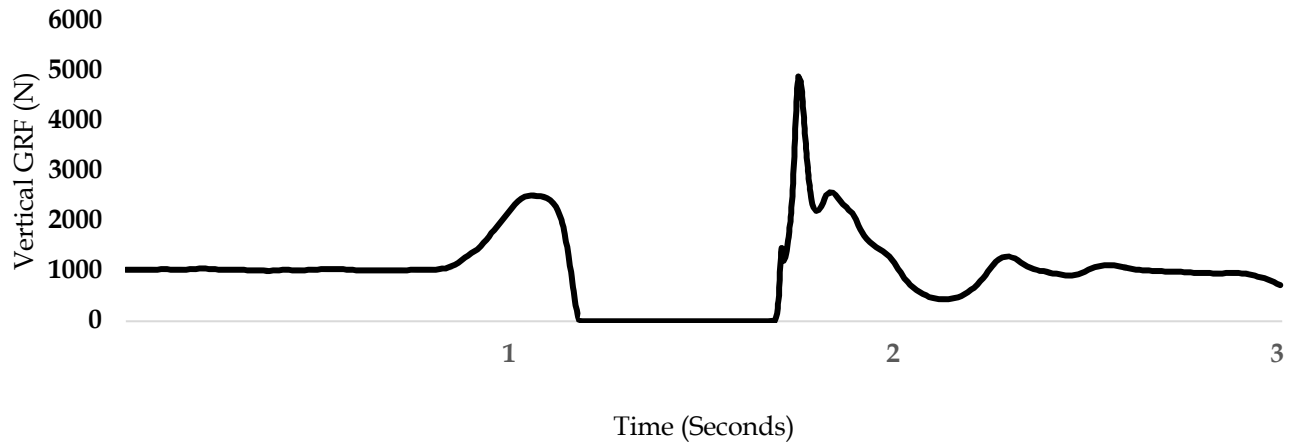
muscles of interest were collected. MVCs of the knee extension (VL and VM), knee flexion (ST), and plantarflexion (MG) movements were performed. Knee extension and flexion were performed on a padded weight bench with a leg extension attachment. Knee joint angle was set to ninety degrees. Subjects were instructed to kick into the pad on the attachment as hard as possible for five seconds followed by thirty seconds of recovery. This was then repeated for a total of three repetitions. Likewise, participants were instructed to pull their leg into the pad as hard as possible for five seconds followed by thirty seconds of recovery for three repetitions. Plantarflexion MVCs were obtained by asking the subjects to press their toes into the ground as hard as possible while in a standing position with minimal knee flexion for five seconds with thirty seconds of recovery between trials for a total of three trials (9, 23).

During both the CMJ and SJ, a wooden dowel (1.0 kg) was placed across the shoulders in a high bar squat position to remove the impact of arm movement (7, 9). Participants completed one set of three jumps at a self-selected foot position and to a self-selected depth. They were instructed to jump as explosively as possible to achieve maximal height (1). Participants were also instructed to maintain contact between the wooden dowel and the upper back at all times throughout the movement. The use of a "3, 2, 1" jump countdown was used for each trial. During the SJ, if a countermovement was visually detected the trial was repeated until three successful trials were recorded.

Ground reaction forces were also collected using a 600 x 400-mm force platform (Bertec Corp, Columbus, OH, USA). Force data was collected at 1000 Hz. Ground reaction data was used in the identification of the propulsive phase of the CMJ using methods recommended by Chavda et al. (6) and McMahon et al. (18). EMG and ground reaction force data were synchronized through the Vicon Nexus software. Similar analysis methods were adapted for the SJ regarding the phase identification (8). Only the propulsive phases of each jump technique were used in the analysis.



**Figure 1.** Sample force-time of the countermovement jump.



**Figure 2:** Sample force-time of the squat jump.

Raw EMG recordings were 4<sup>th</sup> order Butterworth band pass filtered (20-250 Hz) and full wave rectification was performed prior to the data analysis. Mean muscle activity from the MVC was calculated as the maximum mean amplitude across one second of the trial. Mean muscle activity during each jump was calculated as the mean rectified signal across the entire propulsive phase. Percentage of MVC was calculated as the propulsive mean muscle activity for each trial over the mean MVC muscle activity. Mean values across the three trials of the CMJ and SJ were then used in the analysis.

After determination of the end of the braking phase and takeoff point the peak and mean force, velocity, and power for the entire propulsive phase was calculated. Using double differentiation of ground reaction data, velocity was calculated for each time point. Power was then determined as the product of force and velocity. Additionally, jump height was then calculated using the impulse-momentum method.

### *Statistical Analysis*

Paired sample t-tests were used to analyze differences between CMJ and SJ for all variables of interest. Shapiro-Wilk tests of normality were conducted on each variable. All statistical analyses were performed in SPSS version 25 (IBM, Chicago, IL). An a priori alpha level of 0.05 was used in all analysis. Effect sizes are presented as Cohen's d and interpreted using the criteria of: trivial (0.0 - 0.2), small (0.2-0.6), moderate (0.6-1.2), large (1.2-2.0), very large (2.0), and nearly perfect (4.0 or greater) (13). Correlation coefficients are interpreted as trivial (0.00 - 0.1), small (0.1 - 0.3), moderate (0.3 - 0.5), large (0.5 - 0.7), very large (0.7 - 0.9), and nearly perfect (0.9 - 1.0) as suggested by Hopkins (13).

## **RESULTS**

Significant differences were found in mean muscle activity in the ST ( $t(21) = 2.051$ ,  $p = 0.02$ ,  $d = 0.54$ ) (Figure 3). No significant differences were seen in the VL, VM, and MG with regard to mean muscle activity (Figure 3). Significant differences were seen with respect to percentage of MVC between CMJ and SJ in the ST ( $t(21) = 2.89$ ,  $p = 0.009$ ,  $d = 0.62$ ), and MG ( $t(21) = 2.40$ ,  $p =$

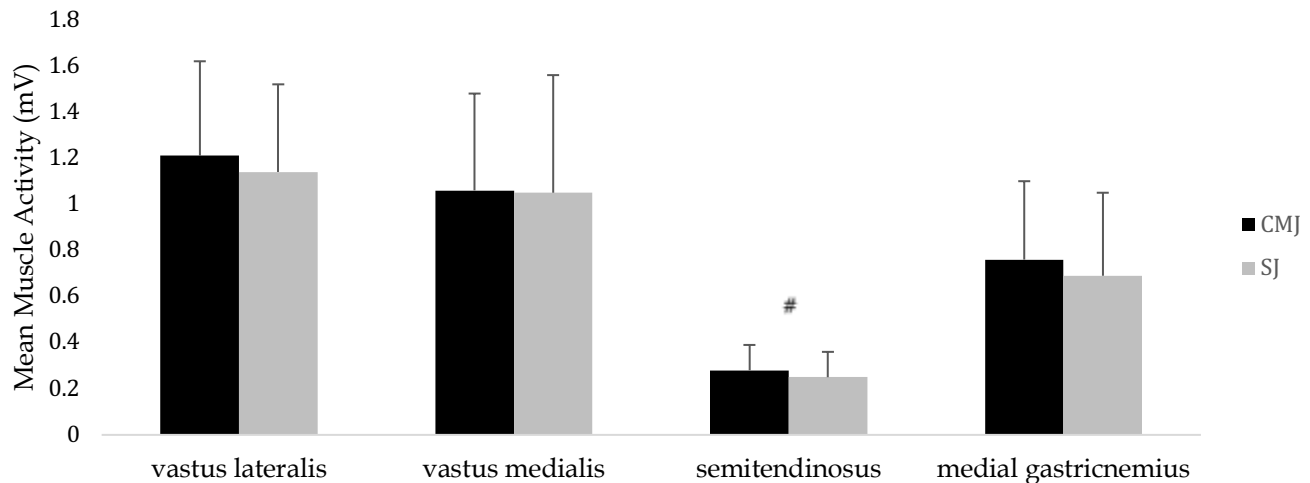
0.026,  $d = 0.51$ ) (Figure 4). No differences were seen in the VL and VM concerning percentage of MVC.

Significant differences were seen in jump height between CMJ and SJ ( $t(21) = 2.86$ ,  $p = 0.009$ ,  $d = 0.61$ ) (Table 1). Significantly greater values were seen in SJ over CMJ, in regards to mean force ( $t(21) = 9.75$ ,  $p < 0.001$ ,  $d = 2.08$ ) and mean power ( $t(21) = 4.73$ ,  $p < 0.001$ ,  $d = 1.01$ ) (Table 1). Conversely, significantly greater values were seen in peak and mean velocity in the CMJ over SJ ( $t(21) = 2.58$ ,  $p = 0.018$ ,  $d = 0.55$  and  $t(21) = 14.72$ ,  $p < 0.000$ ,  $d = 3.14$ , respectively) (Table 1). No significant differences were seen in peak force and peak power.

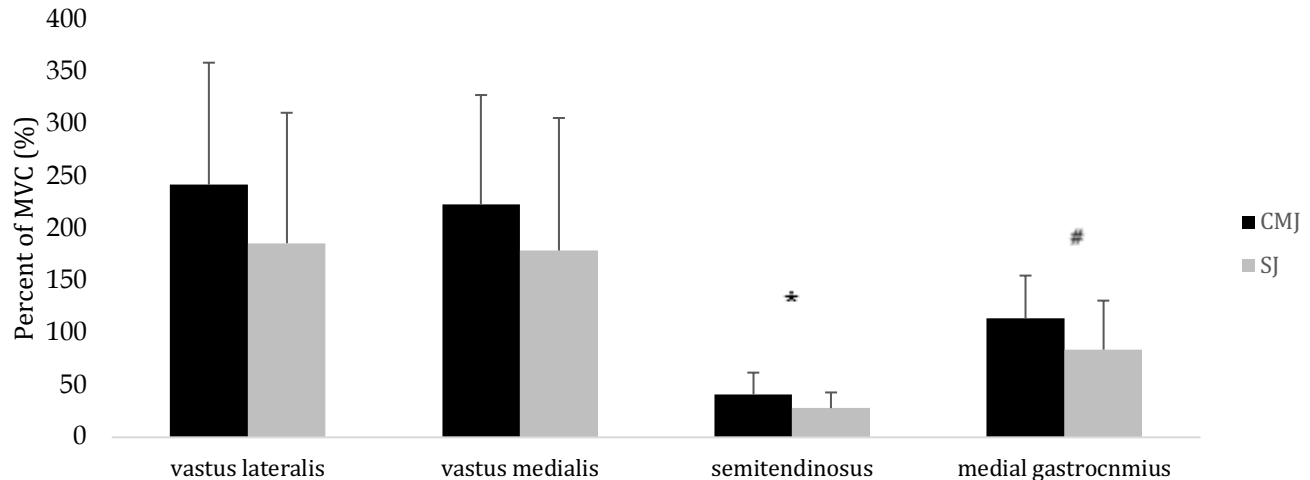
**Table 1.** Comparison of Squat and Countermovement Jumps (mean  $\pm$  SD).

	SJ	CMJ	<i>p</i>	<i>d</i>
Peak Force (N)	2103.19 $\pm$ 378.04	2069.82 $\pm$ 258.59	0.66	0.10
Mean Force (N)	1560.37 $\pm$ 210.18	1186.08 $\pm$ 132.69	< 0.001*	2.08
Peak Velocity (m/s)	2.70 $\pm$ 0.17	2.78 $\pm$ 0.23	0.018*	0.55
Mean Velocity (m/s)	1.25 $\pm$ 0.10	1.71 $\pm$ 0.18	< 0.001*	3.14
Peak Power (w)	4659.32 $\pm$ 673.96	4627.89 $\pm$ 657.25	0.76	0.07
Mean Power (w)	1973.31 $\pm$ 310.64	1705.39 $\pm$ 195.89	< 0.001*	1.01
Jump Height (cm)	33.51 $\pm$ 0.05	35.66 $\pm$ 0.06	0.009*	0.61

SJ = Squat jump, CMJ = Countermovement Jump; \* = Significant differences between jumps.



**Figure 3:** Mean muscle activity comparison during the propulsive phase of the countermovement and squat jump. # = Significant difference between jumps at the  $p < 0.05$  level.



**Figure 4:** Percentage of MVC during the propulsive phase of the countermovement and squat jump. # = Significant difference between jumps at  $p < 0.05$  level; \* = Significant difference between jumps at  $p < 0.01$  level.

## DISCUSSION

The main findings of this investigation include that the similar muscle activity occurs in the knee extensor musculature during both the SJ and CMJ and differences in peak and mean velocity during the propulsive phase. The results of this investigation also revealed that in recreationally trained males, no differences in peak force and peak power between the jumping strategies were present but mean force and power across the entire propulsive phase was greater during the SJ.

The findings that differences were not present in mean muscle activity of knee extensors in the propulsive phase of both jumps coincides with previous findings investigating muscle activity as a potential mechanism for the difference in jumping performance (4, 5, 11). Using similar musculature, Hakkinen et al (11) reported no differences between jumping strategies during the propulsive phase. However, they combined the readings of the VL and VM in their reporting. The current investigation expands on these previous findings by reporting the VL and VM separately. Though in the present study, VL mean muscle activity was not significantly different between jumps, ( $p = 0.076$ ) a small to moderate effect size was present. These results and the percentage of MVC in the VL show a similar pattern to previous investigations that examined muscle activity in that a non-significant increase knee extensor activity in the CMJ (11). The difference between the present study and that completed by Hakkinen et al (11) was that SJ was used as the normalization method rather than MVC.

In regard to muscle activity of the knee flexor musculature, there was a significant increase of the ST during the CMJ. This is in contrast to the previous findings that showed no difference in knee flexor muscle activity (4, 20). Each of the previous studies had contrasting findings as no differences were seen by Bobbert et al. (4) and greater amplitude were observed in the SJ over the CMJ by Padulo et al. (20). The differing results from the current investigation can come from observation of different musculature, as both of the previous investigations examined the biceps femoris. When comparing percentage of MVC to the results of Padulo et al. (20), similar levels

were seen in the SJ while large differences were seen in the CMJ (42% vs 25%). The greater muscle activity in the ST may be attributed to coordination differences between jumping techniques as well as antagonist activity to offset slightly higher agonist activity of the knee extensors. MG mean muscle activity through not significantly different showed a small to moderate effect size. This is similar to other investigations in which the muscle activity of the plantar flexors was measured in both CMJ and SJ (16). However, previous investigations have shown no differences in plantar flexor muscle activity (4, 10, 14). This can be explained by differences in the participant populations used. Bobbert et al. (4) used a sample of three volleyball athletes that were accustomed to jumping were the sample in this study had much less experience performing vertical jump tasks. The difference in percentage activation would coincide with the differences seen in mean muscle activity of the MG as both the SJ and CMJ normalized using the same MVC value. The percentage of activation was included in the investigation as a means to make comparisons to other literature as both mean and percentage are reported. The results in the current investigation in regard to percentage of MVC are different from those of Kawakami et al. were no difference was seen between jumping techniques (14). This in part may be due to methodological differences obtaining MVC values and jumping conditions. With regard to all muscle activity differences seen in the present study the impact on jump performance would to be small to negligible as no differences were seen in the knee extensors. The lack of consistency of muscle activity in both jumping techniques lends itself to having little impact. This is consist to other investigations conclusions on the role of muscle activity during the CMJ and SJ in explaining differences seen in jump height performance (4 , 5, 11, 12).

Ground reaction forces recording during both jumping techniques showed no differences in peak force during the propulsive phase of the jump. This is similar to the results that were reported by Finni et al. (10) where similar force was seen between jumps. The greater mean force during the propulsive phase of the SJ could be explained by the longer propulsive phase time in the SJ. If peak values were similar than a longer period of time of increasing force to reach that peak value could increase the mean value across the entire phase. The greater mean power would also be explained from a similar manner in that power was calculated as the product of force and velocity. Additionally, many of the subjects showed bimodal propulsive phase force-time curves in the CMJ. This reduction in force between the first and second peaks could have contributed to the lower mean force and power values in the CMJ. In some cases, the second peak was at a lower value than that of the first peak, thus a reduction in force was seen throughout the propulsive phase. The shape of the force-time curves during the propulsive phase may have been in part to the experience level the participants had with the jumping task where individuals were creating large forces to bring the countermovement to a stop before changing directions of the center of mass. This is important to the understanding of the results in the present investigation and the translation of the results to other populations where the jumping is not a critical part of success in the sport. As both the CMJ and SJ are commonly used as assessments of lower body power, translation to on-field performance can be limited. Donahue et al. (7) showed no significant relationship between pitching velocity in professional baseball pitchers and CMJ performance. This does not discredit the use of the CMJ as a measurement tool in populations where jumping performance is not a critical part to on-field



success, but demonstrates that the use of such tools should be done with caution. Thus, further investigations should examine the variables used with such populations in determining the translation to on-field success. This is important to acknowledge in the present study as many of the previous investigations into the differences in CMJ and SJ have used populations that rely on the stretch-shortening movements in their sporting event (4, 5, 11).

Significant differences in peak and mean velocity were seen between the CMJ and SJ. These findings show that simply the ability to accelerate one's own mass at a greater velocity can help in explaining the differences in jump height that was seen in the present investigation. The difference between peak velocity of the two jumps is similar to that of the Bobbert et al., where the CMJ had greater velocity than three separate SJ starting positions (4).

The data presented in this study shows similar levels of peak propulsive force and power were present in the CMJ and SJ with difference still existing in jump height and greater mean values in the SJ to that of the CMJ. While these findings are in contrast to other studies it may provide some insight to the importance to movement velocity in during jumping. Van Hooren and Zolotarjova (12) recently reviewed the underlying mechanisms to the difference in CMJ and SJ performance and proposed that a greater uptake of muscle slack and the buildup of high stimulation during the countermovement was the primary mechanism for greater performance. While it is important to have an understanding as to the mechanism to which greater jump height is achieved and it also important to note which variable is this mechanism impacting. It was seen in this investigation as well as others that muscle activity differences were not implicated in differences seen between CMJ and SJ performance. Additionally, peak levels of force and power were similar between jumps and that mean force and power was greater during the SJ. Based on the findings of this investigation it appears that any proposed mechanism as to the increased jump height in the CMJ over the SJ is centered on peak velocity of the movement. Peak velocity was the only variable assessed in which significantly higher values were seen in the CMJ over the SJ that coincided with the increase in CMJ jump height. The addition of a countermovement to the jumping task is similar to other sporting actions (i.e. overhand throwing) in which a countermovement is present, and a greater peak velocity is achieved. Therefore, further investigations should examine any proposed mechanism and the movement velocity concurrently during the CMJ and SJ to determine the impact on jump height. Future investigations should examine if populations were jumping ability plays a vital role in successful sport performance shows similar to the findings to those of the present.

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