

Squat Jump Movement Onset Thresholds Influence on Kinetics and Kinematics

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ABSTRACT

Background of Study: Differing movement onset thresholds have been used when analyzing the squat jump movement from force-time data obtained from a force platform. This makes comparisons difficult between investigations as this will impact the amount of the force-time curve that is analyzed. **Objective:** Thus, study examined the effect onset threshold had on kinetic and kinematic variables used in the assessment of the squat jump. **Methods:** Using a within-subject study design, fifteen recreational trained males performed three trials of squat jumps on a force platform. Each trial was analyzed using one of five different onset thresholds (2.5% SW, 5% SW, 10% SW, 20N, 5SD). Force, velocity, and power, as well as time to peak force, velocity, power and jump height were calculated using the vertical force data obtain from the force plate. Reliability was assessed using intraclass correlation coefficients and coefficients of variation. A one-way ANOVA was used to examine the impact of onset thresholds on all variables of interest. **Results:** The use of 10% SW and 5SD met minimum reliability criteria for all variables. Temporal related variables were impact to the greatest extent by differing thresholds with large ($d > 1.20$) significant differences. 10% SW showed the highest mean values of force, velocity, and power. **Conclusions:** The use of 5SD of the weighting phase is recommended as this showed high level of both absolute and relative reliability in addition to preserving a large portion of the force – time curve to be used in the analysis.

Key words: Movement, Sports, Vertical Jump, Kinematics, Kinetics, Data Analysis

INTRODUCTION

Vertical jump testing is commonly used in the assessment of lower body power in a wide range of populations as this is a fundamental motor skill (Eagles et al., 2015). The use of force plates in the analysis of vertical jumping ability is has become common and held as the criterion measure (Cronin et al., 2004; Linthorne, 2001). This is largely due to investigating the mechanics that underpin the performance of the jump itself, more so than examining jump height alone (Gathercole et al., 2015). Several variables derived from a force plate, are commonly assessed during vertical jump test include force, velocity, and power. Understanding of such variables allows for more targeted training interventions to improve performance (Dos'Santos et al., 2017; Meylan et al., 2011). With the use of vertical jump assessments from force plates increasing, it is important that attention is paid to the methodology surrounding the analysis of force – time data that is obtained.

The squat jump (SJ) is frequently used by practitioners working with athletic populations as an assessment of dynamic lower body power without the utilization of the stretch-shortening cy-

cle. The static starting position is similar to what is seen in several sporting events (García-Ramos, Padial, et al., 2016). Interestingly, the reliability of force-time variables has been shown to be different during the squat jump (SJ) using different movement onset thresholds (Pérez-Castilla et al., 2019). Force, velocity and power values have been shown to produce acceptable levels of reliability using different movement onset thresholds (Pérez-Castilla et al., 2019). The use of different movement onset thresholds have been shown to impact the reliability of measures that included an element of time such as rate of force development and time to peak to a greater extent (Pérez-Castilla et al., 2019). This holds true for other movements that use the analysis of force – time data such as the countermovement vertical jump (CMJ) and the isometric mid-thigh pull (IMTP).

Throughout the literature, a wide array of thresholds has been used to identify the onset of movement when analyzing force – time data. Onset of movement thresholds during jump analysis range from absolute values of 10 to 50 N above the value of an individual's mass, (García-Ramos, Stirn, et al., 2016; Janicijevic et al., 2020; Moir et al., 2005) to relative measures of 2.5 to 10 percent of system weight (García-Ra-

mos, Stirn, et al., 2016; Meylan et al., 2011). It has been proposed that the use of taking a value that is 5 times the standard deviation (*5SD*) of an individual's mass during one second of quiet standing can be used as the onset movement threshold (Owen et al., 2014). The use of the *5SD* threshold has been recommended in both the CMJ the IMTP (Chavda et al., 2018; Dos'Santos et al., 2017; McMahon et al., 2018), and been used in recent investigations using the SJ (Donahue et al., 2019, 2020). The impact of differing onset thresholds has been examined in the CMJ and the proposed *5SD* has been shown to provide the best reliability to the variables of interest and preserves a large portion of the force-time curve to be analysed (Owen et al., 2014). Similar investigations with reference to the SJ specifically are limited but results appear to be similar between the two vertical jump techniques (Pérez-Castilla et al., 2019).

As mentioned above, an advantage of the *5SD* threshold is that a large portion of the force signal is preserved leading to the largest amount of data to be used in the analysis. When using small absolute thresholds (10N), early detection may occur. Conversely large absolute thresholds (50N) may occur after the initiation of movement (Pérez-Castilla et al., 2019) Meylan et al (Meylan et al., 2011), used percentage of system weight (SW) (2.5, 5, and 10) thresholds in determining the impact on CMJ performance. Similar reliability was seen across thresholds, with the recommendation that the Smallest (2.5%) threshold be used as it provided the greatest amount of the signal to be analyzed. What makes the SJ different from the CMJ is the initial starting position as the CMJ begins in a standing position, while the SJ is initiated from a semi-squat position that is held isometrically prior to movement. As noted by Meylan et al (Meylan et al., 2011) the largest impact was to that of the eccentric (unweighting and braking) portion of the CMJ force – time curve as portions of the curve were removed from the analysis. The use of the isometric hold provides a separate challenge from that of the CMJ as the stability of the force signal during that time would be less than during the quiet standing in the CMJ. The isometric mid-thigh pull also utilizes a static position that can have noise in the signal during initial weighting periods due to posture and movements of the participants (Dos'Santos et al., 2017; Dotan et al., 2016; Maffioletti et al., 2016). When comparing the proposed method of *5SD*, thresholds of 2.5% and 5% of body mass showed acceptable levels of agreement and as well the lowest values of time-specific values (Dos'Santos et al., 2017). The greatest values of RFD and time – specific variables came from thresholds that occurred at later on the force - time curve (10% and 75N) (Dos'Santos et al., 2017). It has been shown that SW absolute (10N) and relative (1%) thresholds in the SJ have lower reliability for mean and time – specific variables than more conservative absolute (50N) and relative (10%) thresholds (Pérez-Castilla et al., 2019). This is attributed largely to the noise of the signal during the weighting phases, thus creating reliability issues. It should be noted that the use of the *5SD* has recommended for use in the SJ as it provided similar reliability to the greater thresholds (10% and 50N) with a larger portion of the signal being used in the analysis. (Pérez-Castilla et al., 2019)

Thus, the purpose of this investigation was first to determine the impact of the reliability of kinetic and kinematic

variables commonly used in SJ assessment using an absolute threshold (20N), relative thresholds (2.5%, 5%, and 10%), and the proposed *5SD* approach. It is hypothesised that the use of the proposed *5SD* approach will provide the highest levels of reliability of all variables of interest, additionally it is hypothesised that there will be differences in the magnitude of kinetic and kinematic variables as a result of differing onset thresholds.

METHODS

Participants and Study Design

Fifteen recreationally trained males (age: 23.73 ± 2.77 years, height 179.95 ± 6.46 cm, and mass 87.27 ± 11.13 kg) that had been physically active for the previous six months participated in this study. Additionally, participants were deemed to be free of injury and cleared for physical activity by the physical activity readiness questionnaire (PAR-Q) to be included in the study. Participants were instructed to avoid resistance training and to maintain normal dietary habits for the 24 hours prior to the testing. All participants provided written informed consent approved from the University Institutional Review Board prior to testing. A within subject repeated measures, design was employed where each trial was analysed using the different thresholds. Sample size estimation was conducted based on previous investigations using a repeated measures design similar to the present investigation (Pérez-Castilla et al., 2019). The use a conventional $\alpha = 0.05$ and $\beta = 0.80$ and moderate effect size of 0.5 were used in the calculation. Dependent variables of interest included jump height, peak, mean and time to peak values of force, velocity and power.

Testing Procedures

Participants were familiarized to the procedures prior to testing and given the opportunity to practice the SJ technique. This was done due to the novelty of the SJ to some of the participants. All participants prior to testing performed a dynamic lower body warm up consisting of (jumping jacks, body weight squats, straight leg marching, knee hugs) and 5 submaximal jumps. After warm ups were completed, a rest period of five-minutes was given prior to the first trial being performed.

Once the warm up was completed participants placed a dowel (1.0 kg) across their back, similar to a high bar back squat. Instructions were given to maintain contact between themselves and the wooden dowel throughout the movement and to jump as explosively as possible to get as high as possible. (Donahue et al., 2020). Three trials were then completed using a self-selected foot position and depth (Petronijevic et al., 2018). At the self-selected depth, participants were then instructed were given to hold the semi-squat position (Moir et al., 2005; Pérez-Castilla et al., 2019). Each trial begin with a countdown of “3, 2, 1, jump” once in the semi-squat position. Data collection began at “2” during each trial (McMahon et al., 2018). Each trial was separated by thirty seconds.

Data Analysis

Ground reaction force data was collected by way of a 600 x 400-mm force platform (Bertec Corp, Columbus, OH, USA).

Data was sampled at 1000 Hz. All dependant variables were calculated using the impulse-momentum method. Acceleration data was calculated as the net force divided by the mass of the system (participant and wooden dowel). SW was determined by taking the mean of one second of force data while in the semi-squat held position prior to the initiation of movement. Integration of the acceleration data with respect to time provided velocity data. The product of velocity and force were then used in the calculation of power at each sample. Peak and mean values of force, velocity, and power were calculated from the threshold of interest until the point of take-off. Onset of movement occurred at the instance when force exceeded the threshold of interest (2.5%, 5%, 10%, 20N and 5SD). Using the recommendation of Owen et al. (Owen et al., 2014) the starting point was moved to -30ms from the instance of which threshold was passed. The identification of the end of the propulsive phase and beginning of the flight phase was determined by methods described by Chavda et al (Chavda et al., 2018). Relative thresholds were determined as the given percentage (2.5%, 5%, and 10%) of this SW. All variables were calculated using a customized Excel spreadsheet (Donahue et al., 2019, 2020).

Statistical Analysis

Reliability of the variables of interest were assessed using coefficient of variation (CV) and interclass correlation coefficients (ICC). High reliability was determined as $CV \leq 5\%$ and an ICC of greater than ≥ 0.9 . Acceptable reliability was deemed to occur with a $CV \leq 10\%$ and an ICC of ≥ 0.8 (James et al., 2017).

To determine the impact of onset threshold with regard to kinematic and kinetic variables of interest, a one-way repeated measures analysis of variance (ANOVA) was performed for each variable. Mauchly's Test of sphericity was used to test the assumption of sphericity. If the assumption was violated, a Greenhouse – Geisser correction was used in the interpretation of findings. Post hoc analysis was completed using a least significant difference. An a priori alpha level of 0.05 was used. Effect sizes were first calculated as eta squared then converted and presented as Cohen's d and interpreted as trivial (<0.19), small ($0.20 - 0.59$), moderate ($0.60 - 1.19$), large ($1.20 - 1.99$) and very large ($2.0 - 4.00$). (Cohen, 1988; Hopkins, 2002) All statistical tests were performed using SPSS version 25 (IBM, Chicago, IL).

RESULTS

Both the 5SD and 10% SW thresholds yield results that all 11 variables of interest showed at least acceptable levels of reliability (Table 1). Additionally, 5SD and 10% SW thresholds resulted in at least 6 of 11 variables showing high reliability (Table 1). The 2.5% SW, 5% SW and 20N thresholds resulted in no reliable measures of time to peak force and mean velocity (Table 1). Mean power also displayed unacceptable reliability when using 2.5% and 20N thresholds (Table 1).

Significant differences were seen in force at threshold ($F_{1,16, 16,25} = 54.12, p \leq 0.001, d = 3.88$) (Table 2) Post-

hoc analysis found significant differences between 5SD vs 2.5% SW ($p = 0.003$), 5SD vs 10% SW ($p \leq 0.001$), 5SD vs 20N ($p \leq 0.001$). Differences were seen between 2.5% SW vs 5% SW ($p \leq 0.001$), 2.5% SW vs 10% SW ($p \leq 0.001$), 2.5% vs 20N ($p = 0.005$). Significant differences existed between 5% SW vs 10% SW ($p \leq 0.001$) and 5% SW vs 20N ($p \leq 0.001$). Significant differences were present between 10% SW and 20N ($p \leq 0.001$). No differences were seen between 5SD and 5% SW ($p = 0.35$) with force at threshold. Differences were seen between mean force ($F_{1,99, 27,95} = 11.79, p \leq 0.001, d = 1.85$). Post-hoc analysis found significant differences between 5SD vs 2.5% SW ($p = 0.028$), 5SD vs 10% SW ($p = 0.021$), 5SD vs 20N ($p = 0.024$) with no differences between 5SD vs 5% ($p = 0.451$). Differences were seen between 2.5% SW vs 5% SW ($p = 0.013$), 2.5% SW vs 10% SW ($p \leq 0.001$), with no differences 2.5% vs 20N ($p = 0.393$). Significant differences were present between 5% SW vs 10% SW ($p = 0.001$) and 5% SW vs 20N ($p = 0.012$). Significant differences were found amongst 10% SW and 20N ($p \leq 0.001$). Significant differences were found in mean velocity ($F_{1,54, 21,59} = 10.47, p = 0.001, d = 1.74$). Post-hoc analysis found a significant difference between 5SD vs 2.5% SW ($p = 0.028$), 5SD vs 10% SW ($p = 0.005$), 5SD vs 20N ($p = 0.044$) with no differences between 5SD vs 5% ($p = 0.261$). Differences were seen between 2.5% SW vs 5% SW ($p = 0.022$), 2.5% SW vs 10% SW ($p = 0.001$), with no differences 2.5% vs 20N ($p = 0.238$). Significant differences were found between 5% SW vs 10% SW ($p \leq 0.001$) and 5% SW vs 20N ($p = 0.044$). Significant differences were found between 10% SW and 20N ($p = 0.001$). Significant differences were found with mean power ($F_{1,51, 21,20} = 11.79, p \leq 0.001, d = 1.77$). Post-hoc analysis found a significant difference between 5SD vs 2.5% SW ($p = 0.038$), 5SD vs 10% SW ($p = 0.004$), 5SD vs 20N ($p = 0.033$) with no differences between 5SD vs 5% ($p = 0.382$). Differences were seen between 2.5% SW vs 5% SW ($p = 0.025$), 2.5% SW vs 10% SW ($p = 0.001$), with no differences 2.5% vs 20N ($p = 0.231$). Significant differences were found between 5% SW vs 10% SW ($p \leq 0.001$) and 5% SW vs 20N ($p = 0.023$). Significant differences were found between 10% SW and 20N ($p \leq 0.001$). Similar trends were seen across mean force, velocity and power, as the 10% SW was significantly greater than all other thresholds. Similar values of force, velocity and power were seen in the 5SD and 5% SW thresholds as well as similar values between 2.5% SW and 20N thresholds.

Measures of time to peak force ($F_{1,35, 18,86} = 5.35, p = 0.001, d = 1.25$) were found to have significant differences. Post-hoc analysis found significant differences between 5SD vs 10% SW ($p = 0.012$), with no differences between 5SD vs 2.5% SW ($p = 0.062$), 5SD vs 5% ($p = 0.284$), and 5SD vs 20N ($p = 0.059$). Differences were seen between 2.5% SW vs 10% SW ($p = 0.008$), with no differences 2.5% SW vs 5% SW ($p = 0.051$), 2.5% vs 20N ($p = 0.912$). Significant differences were found comparing 5% SW vs 10% SW ($p = 0.025$) while no differences present between 5% SW and 20N ($p = 0.054$). Significant differences were found between 10% SW and 20N ($p = 0.007$). Significant differences were found for time to peak velocity ($F_{1,45, 20,22} = 6.24,$

Table 1. Interclass correlation coefficients (ICC) (95% confidence interval) and coefficient of variation (cv %) (95% confidence interval) for each threshold

	20N		2.5% SW		5% SW	
	ICC	CV %	ICC	CV %	ICC	CV %
Force @ Threshold ^{a,c,e}	0.99 (0.99 - 0.99)	0.9 (0.3 - 1.5)	0.99 (0.99 - 0.99)	0.8 (0.2 - 1.5)	0.99 (0.99 - 0.99)	0.9 (0.3 - 1.5)
Peak Force ^{a,c,e}	0.99 (0.98 - 0.99)	2.0 (0.8 - 3.1)	0.99 (0.98 - 0.99)	2.1 (1.0 - 3.2)	0.99 (0.98 - 0.99)	2.0 (0.9 - 4.5)
Mean Force ^{a,c,e}	0.95 (0.88 - 0.98)	3.3 (1.5 - 5.1)	0.95 (0.88 - 0.98)	3.3 (1.5 - 5.1)	0.96 (0.91 - 0.99)	2.9 (1.4 - 4.5)
TTP Force	0.89 (0.68 - 0.95)	13.7 (7.2 - 20.2)	0.87 (0.69 - 0.95)	13.4 (7.1 - 19.7)	0.88 (0.73 - 0.96)	11.5 (5.5 - 17.5)
Peak Velocity ^{a,c,e}	0.91 (0.79 - 0.97)	2.7 (1.8 - 3.6)	0.91 (0.79 - 0.96)	2.7 (1.8 - 3.6)	0.91 (0.79 - 0.97)	2.8 (1.9 - 3.6)
Mean Velocity	0.66 (0.17 - 0.88)	8.2(3.1 - 13.3)	0.62 (0.07 - 0.86)	8.0 (2.8 - 13.1)	0.66 (0.17 - 0.88)	6.1 (1.8 - 10.3)
TTP Velocity ^{b,d,f}	0.86 (0.66 - 0.95)	9.0 (4.0 - 14.0)	0.85 (0.64 - 0.94)	8.8 (3.6 - 14.1)	0.88 (0.71 - 0.95)	6.7 (2.3 - 11.1)
Peak Power ^{a,c}	0.93 (0.83 - 0.97)	4.7 (2.9 - 6.4)	0.94 (0.86 - 0.98)	3.7 (2.2 - 5.3)	0.71 (0.31 - 0.90)	8.7 (1.0 - 18.3)
Mean Power ^f	0.78 (0.46 - 0.92)	9.3 (4.2 - 14.4)	0.79 (0.48 - 0.92)	9.2 (4.2 - 14.2)	0.84 (0.61 - 0.94)	7.6 (3.6 - 11.7)
TTP Power ^{b,d,f}	0.86 (0.66 - 0.95)	9.5 (4.1 - 14.9)	0.86 (0.66 - 0.95)	10.0 (4.4 - 15.7)	0.87 (0.69 - 0.95)	7.5 (2.6 - 12.4)
Jump Height ^{b,d,f}	0.89 (0.76 - 0.96)	8.0 (5.5 - 10.5)	0.91 (0.79 - 0.97)	7.2 (5.0 - 9.4)	0.91 (0.78 - 0.97)	7.3 (5.1 - 9.6)
		10% SW ICC	CV %		5SD ICC	CV %
Force @ Threshold ^{g,i}		0.99 (0.99 - 0.99)	0.9 (0.3 - 1.5)		0.99 (0.99 - 0.99)	1.6 (0.7 - 2.4)
Peak Force ^{g,i}		0.99 (0.98 - 0.99)	2.0 (0.8 - 3.1)		0.99 (0.98 - 0.99)	2.1 (1.0 - 3.2)
Mean Force ^{g,i}		0.98 (0.96 - 0.99)	2.2 (1.2 - 3.2)		0.97 (0.92 - 0.99)	2.4 (1.0 - 3.9)
TTP Force ^{h,j}		0.98 (0.94 - 0.99)	8.2 (4.4 - 12.0)		0.94 (0.87 - 0.98)	9.6 (4.2 - 14.9)
Peak Velocity ^{g,i}		0.91 (0.78 - 0.97)	2.8 (1.9 - 3.7)		0.91 (0.78 - 0.97)	2.7 (1.8 - 3.6)
Mean Velocity ^{h,i}		0.83 (0.62 - 0.94)	3.3 (1.7 - 4.9)		0.93 (0.82 - 0.97)	4.1 (1.2 - 6.9)
TTP Velocity ^{g,i}		0.98 (0.96 - 0.99)	3.8 (2.6 - 5.1)		0.94 (0.87 - 0.98)	5.6 (2.5 - 8.7)
Peak Power ^{g,i}		0.94 (0.86 - 0.98)	4.3 (2.5 - 6.1)		0.94 (0.87 - 0.98)	3.7 (2.2 - 5.3)
Mean Power ^{h,j}		0.91 (0.8 - 0.97)	5.1 (3.2 - 7.0)		0.87 (0.69 - 0.95)	5.3 (2.2 - 8.4)
TTP Power ^{h,j}		0.98 (0.95 - 0.99)	5.7 (3.1 - 8.4)		0.94 (0.87 - 0.95)	6.4 (2.7 - 10.1)
Jump Height ^{h,j}		0.91 (0.77 - 0.97)	7.4 (5.1 - 9.7)		0.91 (0.77 - 0.97)	6.5 (4.4 - 8.5)

SW = system weight; SD = standard deviation; ^a = highly reliable @ 20N; ^b = acceptable reliable @ 20N; ^c = highly reliable @ 2.5% SW; ^d = acceptable reliable @ 2.5% SW; ^e = highly reliable @ 5% SW; ^f = acceptable reliable @ 5% SW; ^g = highly reliable @ 10% SW; ^h = acceptable reliable @ 10% SW; ⁱ = highly reliable @ 5SD; ^j = acceptable reliable @ 5SD

$p = 0.013$, $d = 1.34$). Post-hoc analysis found significant differences concerning 5SD vs 2.5% SW ($p = 0.033$), with no differences between 5SD vs 5% SW ($p = 0.199$), 5SD vs 10% ($p = 0.072$), and 5SD vs 20N ($p = 0.053$). Differences were seen between 2.5% SW vs 10% SW ($p = 0.042$), 2.5% SW vs 5% SW ($p = 0.005$), 2.5% vs 20N ($p = 0.041$). Significant differences were found between 5% SW vs 10% SW ($p = 0.024$) and no differences between 5% SW and 20N ($p = 0.081$). Significant differences were present between 10% SW and 20N ($p = 0.009$). Finally time to peak power ($F_{1.48, 20.78} = 5.59$, $p = 0.018$, $d = 1.27$). Post-hoc analysis found a significant difference between 5SD vs 10% SW ($p = 0.008$), with no differences between 5SD vs 2.5% SW ($p = 0.056$), 5SD vs 5% SW ($p = 0.162$), and 5SD vs 20N ($p = 0.092$). Differences were seen between 2.5% SW vs 10% SW ($p = 0.005$), with no significant differences between 2.5% SW vs 5% SW ($p = 0.099$), and 2.5% vs 20N ($p = 0.106$). Significant differences existed between 5% SW vs 10% SW ($p = 0.009$) and no differences between 5% SW and 20N ($p = 0.21$). Significant differences were found between 10% SW and 20N ($p = 0.009$). Similar trends were seen in all three variables, as time to peak was the shortest using the 10% SW (Table 2). The longest time to peaks in all measures came from the 2.5% SW. No differences were seen between peak values of velocity ($F_{1.51, 21.21} = 2.239$, $p = 0.141$, $d = 0.81$) and power ($F_{1.13, 15.78} = 0.943$, $p = 0.358$, $d = 0.51$). Additionally, no significant differences were seen for jump height ($F_{1.59, 22.39} = 2.470$, $p = 0.116$, $d = 0.81$) using different onset thresholds (Table 2).

DISCUSSION

This investigation sought to examine the impact of movement onset threshold reliability during the SJ, as well as compare the differences in kinematics and kinetic variables associated with SJ performance based on the aforementioned thresholds. The primary finding was that the lowest level thresholds (2.5% SW and 20N) yielded the lowest number of reliable variables. In contrast the further along the force-time trace that a threshold was located (10% SW and 5SD), the greater the number of variables that were deemed reliable. Secondly, differences were present in the mean and time to peak values in force, velocity, and power. The 10% SW threshold resulted in the greatest values of mean force, velocity, and power, as well as the fastest time to peak across these variables.

The results of this investigation are similar to others that have examined onset threshold in the SJ and CMJ (Meylan et al., 2011; Owen et al., 2014; Pérez-Castilla et al., 2019). The lower the threshold, whether in terms of absolute (20N) or relative (2.5% SW) values, the lower level of reliability that may be present. When using the recommendation to go back 30ms in the force-time trace to find true movement onset, lower thresholds may have begun from a point during the weighing phase. This also will have an impact of the values of mean force, velocity and power by larger portions of the curves being included in the analysis. This same explanation can be used for the low levels of reliability seen in the 2.5% SW and 20N thresholds.

Time to peak force in the 2.5% SW, 5% SW, and 20N threshold all showed acceptable ICC values, with CV val-

Table 2. Mean \pm Sd for all thresholds

	20N	2.5% SW	5% SW	10% SW	5SD	d
Force @ Threshold (N)	925.81 \pm 140.46 ^{b,c,d,e}	928.36 \pm 123.07 ^{a,c,d,e}	950.78 \pm 126.25 ^{a,b,d}	996.29 \pm 132.08 ^{a,b,c,e}	958.81 \pm 140.46 ^{a,b,d}	3.88
Mean Force (N)	1560.49 \pm 217.70 ^{c,d,e}	1561.11 \pm 219.60 ^{c,d,e}	1582.81 \pm 222.37 ^{a,b,d}	1610.94 \pm 224.46 ^{a,b,c,e}	1588.49 \pm 215.50 ^{a,b,d}	1.85
TTP Force (s)	0.281 \pm 0.124 ^d	0.281 \pm 0.123 ^d	0.264 \pm 0.103 ^d	0.243 \pm 0.087 ^{a,b,c,e}	0.254 \pm 0.079 ^d	1.25
Peak Velocity (m/s)	2.71 \pm 0.19	2.71 \pm 0.19	2.71 \pm 0.20	2.71 \pm 0.20	2.71 \pm 0.19	0.81
Mean Velocity (m/s)	1.21 \pm 0.15 ^{c,d,e}	1.20 \pm 0.14 ^{c,d,e}	1.25 \pm 0.12 ^{a,b,d}	1.30 \pm 0.09 ^{a,b,c,e}	1.26 \pm 0.11 ^{a,b,d}	1.74
TTP Velocity (s)	0.359 \pm 0.115 ^d	0.361 \pm 0.115 ^{c,d,e}	0.341 \pm 0.093 ^{b,d}	0.321 \pm 0.079 ^{a,b,c}	0.329 \pm 0.072 ^b	1.34
Peak Power (W)	4759.94 \pm 608.27	4738.82 \pm 614.06	4657.78 \pm 771.38	4753.23 \pm 624.89	4750.37 \pm 623.85	0.51
Mean Power (W)	1919.68 \pm 322.69 ^{c,d,e}	1922.33 \pm 326.95 ^{c,d,e}	1997.86 \pm 319.35 ^{a,b,c}	2088.88 \pm 298.65 ^{a,b,c,e}	2018.89 \pm 292.87 ^{a,b,d}	1.77
TTP Power (s)	0.315 \pm 0.116 ^d	0.369 \pm 0.113 ^d	0.303 \pm 0.092 ^d	0.277 \pm 0.079 ^{a,b,c,e}	0.290 \pm 0.07 ^d	1.27
Jump Height (m)	0.333 \pm 0.056	0.335 \pm 0.054	0.338 \pm 0.055	0.337 \pm 0.055	0.337 \pm 0.055	0.81

SW = system weight; TTP = time to peak; ^a = significant different from 20N; ^b = significant difference from 2.5% SW; ^c = significantly different from 5% SW; ^d = significantly different from 10% SW; ^e = significantly different from 5SD

ues all greater than 10%. The opposite was seen in the mean velocity where acceptable levels of CV were present in the 2.5%, 5% and 20N thresholds yet low ICC values (0.62, 0.66, and 0.66 respectively). Both cases show that the lower thresholds are susceptible to issues with regard to relative and absolute measures of reliability. The use of two levels of reliability is different from criteria used by Pérez-Castillo et al. (Pérez-Castilla et al., 2019) in the evaluation of SJ variables using different onset thresholds. An ICC of greater than 0.70 and CV of less than 10% was used in their analysis. Similar results would have been seen using the criteria in mean velocity as ICC values fell below the 0.70 level. 5SD and 10% SW thresholds showed similar results to one another, as all variables showed at least minimum acceptable levels of reliability with 6 reaching high levels. Mean velocity was high in the 5SD and acceptable using 10% SW. This is a result of the lower ICC in the 10% SW. A possible explanation to this and to lower reliability when using relative and absolute thresholds accounting for noise in the signal. As discussed by Dos'Santos et al. (Dos'Santos et al., 2017) in the evaluation of isometric mid-thigh pull onset threshold the 5SD threshold accounts for noise associated in the weighting phase.

The results of this study agree with the only other investigation into the reliability and impact of onset threshold in the SJ that suggest the use of a threshold of 5 times the SD of the weighting phase during the SJ (Pérez-Castilla et al., 2019). This suggestion is based on similar reliability to threshold that are more conservative in nature (10%SW and 50N) while preserving a greater portion of the force-time curve to be used in the analysis. The use of 5SD threshold has been suggested when in the analysis of both the IMTP and countermovement jump for similar reasons as those mentioned above. Identifying movement onset is critical in the analysis of the movement using the force-time data. This is largely due to the integration of force data to calculate additional variables including velocity and power. Integration of force data begins at 30ms prior to force reaching the given threshold. This is important as moderate effect sizes were present in both peak velocity and jump height though no significant differences were seen. This is critically important in the calculation of power as it is comprised of the product of force and velocity. Thus, improper calculations of velocity are compounded during the power calculation. In addition to potential improper calculation of peak values, this could be used in the explanation of the large differences seen in mean values in conjunction with the length of time differences between thresholds. The practical implications for establishing a standardized analysis method of assessing squat jump performance from force-time data is of vital importance. This allows future research to be conducted in a manner where differences of results can longer be attributed to differences in analysis methods. The use of the 5SD threshold not only provides a high level of confidence in the results due the reliability across several variables, but allows for the greatest portion of the signal to be analyzed.

A limitation to this investigation is the population of recreational males that was used. Though each participant was

given a familiarization session to the squat jump movement and additional submaximal repetitions during the warm up period, the movement was still novel to most individuals. The results of this investigation however are similar to those of other investigations in which reliability of movement onset threshold have been examined (Dos'Santos et al., 2017; Pérez-Castilla et al., 2019). It should also be noted that several other onset thresholds have been used throughout the literature when evaluating vertical jump performance (10N, 50N) (Giroux et al., 2014; Moir et al., 2005). These specific thresholds were excluded from this investigation based on the findings of previous literature and current recommends.

CONCLUSION

Differences seen in the mean values of force, velocity and power are critical from the viewpoint of practitioners as mean values can provide a more robust understanding of the squat jump task. This is due to looking at a larger portion of the force – time curve rather than one sample of the curve (peak). Thus, the use of the 5SD threshold provides reliable data across multiple variables without sacrificing a large portion of the force-time curve. The use of the 5SD threshold additionally accounts for potential noise associated in the measure that absolute measures (20N) would not. This allows investigators and practitioners using the squat jump assessment to have a level of confidence that movement has occurred and that data obtained is reliable.

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