Reliability and Magnitude of Countermovement Jump Performance Variables: Influence of the Take-off Threshold

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Abstract

This study explored the influence of different take-off thresholds on the reliability and magnitude of countermovement jump (CMJ) performance variables. Twenty-three men were tested on two separate sessions. CMJ performance variables were obtained against three external loads (0.5-30-60 kg) using three take-off thresholds: 10N (arbitrary value of 10N), 5SD (mean value plus 5 standard deviations of the vertical force recorded during the flight phase), and PRF (peak difference between the vertical force trace and 0N during the flight phase). No significant differences in reliability were observed between the three thresholds (CV and ICC values of one threshold were within 95% CI of the other thresholds). The magnitude of the variables generally differed between the 10N threshold and the 5SD and PRF thresholds ($P<0.05$), but not between the 5SD and PRF thresholds ($P>0.05$). These results demonstrate that the take-off threshold influences the magnitude of CMJ performance variables but not their reliability.

Key words: force platform; kinematic; kinetic; vertical jump.

Word count: 3971

Introduction

The countermovement jump (CMJ) is a type of jump typically included in testing batteries because it provides valuable information about the lower-body neuromuscular function (Claudino et al., 2017; McMahon et al., 2018; Van Hooren & Zolotarjova, 2017). The force platform is the most commonly used to evaluate vertical jump performance within the research setting (Chavda et al., 2018; McMahon et al., 2018; Stanton et al., 2019). In addition, the use of force platforms has been recently extended to practical settings due to their higher affordability and portability (Chavda et al., 2018; Lake et al., 2018). Force-time data acquired through the force platform can be used to calculate a number of variables (e.g., mean force, power, velocity (Lombard et al., 2017; Meylan et al., 2012), impulse (Pérez-Castilla et al., 2019a), jump height (Chiu & Dæhlin, 2020; Perez-Castilla et al., 2018), or reactive strength index modified [RSI_{mod}] (Ebben & Petushek, 2010)) which are all indicators of CMJ performance (Chavda et al., 2018; Linthorne, 2001). The analysis of force-time data may also help to selectively assess the CMJ performance during the different phases of the jump (McMahon et al., 2018). In this regard, force platforms are needed for obtaining more comprehensive insight into CMJ performance. However, it is of critical importance to reduce the possible sources of error (both measurement and computational errors) before processing the force-time data and extracting the different CMJ performance variables (Kibele, 1998; Street et al., 2001; Vanrenterghem et al., 2001). Given that CMJ is used as a marker of performance, fatigue, and muscle damage (Dobbin et al., 2018; Watkins et al., 2017), this is an important issue. If errors are not minimized than researchers and practitioners are likely to be misinformed. Therefore, it is not surprising that a large number of studies have explored the influence of a variety of methodological factors (e.g., jump starting threshold, method of integration, or sample duration) on the reliability and magnitude of CMJ performance variables (Chavda et al., 2018; Eagles et al., 2015; Harry et al., 2020; Pérez-Castilla et al., 2019a).

Two potential sources of computation error are associated with the selection of the beginning and end points of the jump analysis (Street et al., 2001; Vanrenterghem et al., 2001). It is important that the jump-starting and take-off thresholds retain all of the true signal for the data analysis (Chavda et al., 2018; McMahon et al., 2018). Previous studies have shown that the jump-starting threshold influences both the reliability and magnitude of unloaded and loaded CMJ performance variables (Meylan et al., 2011; Pérez-Castilla et al., 2019a). For example, Pérez-Castilla et al. (2019a) recommended the jump-starting threshold proposed by Owen et al. (2014) (i.e., five standard deviations [SD] of system weight minus 30 ms) since it retained more signal for the analysis compared to more conservative thresholds (such as 50 N and 10% of system weight). Moreover, all these thresholds provided a comparable reliability. However, although it has been noted that the exact take-off instant is difficult to determine due to the high rate of change in force values at that moment (Kibele, 1998), there is no research concerning the influence of take-off thresholds on the reliability and magnitude of unloaded and loaded CMJ performance variables collected with a force platform.

There is no consensus in the scientific literature on what is the optimal take-off threshold for analysing CMJ performance (McMahon et al., 2017; Mizuguchi et al., 2015; Moir, 2008; Pérez-Castilla et al., 2019a). The most common take-off thresholds have included (I) five times the SD of the residual force (5SD) (Chavda et al., 2018; McMahon et al., 2017), (II) the peak residual force (PRF) (Moir, 2008) across a 300 ms period during the flight phase, and (III) an arbitrary force value (e.g., 10N) (Mundy et al., 2016; Pérez-Castilla et al., 2019a). The residual force is defined as the peak difference between the vertical force trace and 0 N during the flight phase of the jump with the force platform unloaded (Moir, 2008). Note that the identification of the take-off is important because many CMJ performance variables are sensitive to this event. For example, Kibele (1998) observed a ≈ 2% variation in velocity and displacement when the take-off instant was incorrectly identified for 2-3 ms. Similarly, Street et al. (2001) reported an overestimation in jump height of 1% and 1.5% when a take-off threshold of 6 N and 10 N, respectively, was used above the reference threshold determined by signal noise (0.7-2.0 N). In this regard, more conservative thresholds (e.g., 10 N) would result in early detection of take-of instant, while less conservative thresholds (e.g., 5SD and PRF) could lead to late identification of take-of instant (Street et al., 2001). Therefore, research is still required to achieve scientific consensus on which take-off threshold should be consistently used during CMJ testing routines to enable accurate data comparisons between different trials, sessions, athletes, or research centres (Harris et al., 2010).

To address the existing gaps in the literature, the present study attempted to identify the most appropriate take-off threshold for assessing the unloaded and loaded CMJ performance variables collected with a force platform. Specifically, the aim of this study was to compare the reliability and magnitude of CMJ performance variables between three commonly used take-off thresholds (5SD, PRF, and 10N). We hypothesised that i) the reliability of CMJ performance variables would be higher for the more conservative threshold (10N) compared to the less conservative thresholds (5SD and PRF), and ii) the magnitude of the CMJ performance variables would significantly differ using the 10N threshold compared to the 5SD and PRF thresholds. The results of this research should contribute to the refinement and standardization of the CMJ testing protocols via force platform analysis.

Materials and methods

Participants

Twenty-three men (mean ± SD; age = 23.1 ± 3.2 years [range: 20-31 years], body height = 1.77 ± 0.07 m, body mass = 74.7 ± 7.3 kg) volunteered to participate in this study. All participants were physically active sport science students with a minimum of two years of resistance training experience. Participants were free from health problems and musculoskeletal injuries that could compromise testing. Participants were informed of the study procedures and signed a written informed consent form prior to initiating the study. The study protocol adhered to the tenets of the Declaration of Helsinki and was approved by the Institutional Review Board.

Study design

A repeated-measured design was employed to examine the influence of the take-off threshold on the reliability and magnitude of different unloaded and loaded CMJ performance variables. Following one familiarization session, participants attended to the laboratory on two occasions separated by 48–72 h. The free-weight CMJ exercise was performed against six external loads (0.5, 17, 30, 45, 60, and 75 kg), in a randomized order, for both testing sessions. Participants were advised to avoid any strenuous physical activity over the course of the study. All testing sessions were conducted at the host University's research laboratory, at the same time of day for each participant (± 1 h), and under similar environmental conditions (≈ 22ºC and ≈ 60% humidity).

Procedures

The testing sessions began with a 10-min standardized warm-up consisting of jogging, joint mobility, dynamic stretching, followed by six unloaded CMJ and three loaded CMJ against an external load of 17 kg (i.e., the mass of the barbell used during the test). After warming-up, participants rested 3 min and then they performed two maximum CMJ trials with external loads of 0.5, 17, 30, 45, 60, and 75 kg. The unloaded CMJ was executed with a wooden barbell of 0.5 kg, while the loaded CMJ was performed with a free-weight barbell of 17 kg. The external loads were applied in a randomized order, but the same order was maintained for each participant during both testing sessions. Rest periods of 3-4 min were implemented between loading conditions.

The CMJ technique involved the participants standing on the centre of the force platform with the knees and hips fully extended, feet approximately shoulder-width apart, and the barbell resting across the back at the level of the acromion. Subsequently, participants were instructed to jump as high as possible after performing a countermovement to ≈ 90º of knee flexion (García-Ramos et al., 2018). Trained spotters were always present to verbally encourage the participants throughout the test and lifting belts were used.

Measurement equipment and data analysis

All CMJs were performed on a force platform (Dinascan/IBV, Biomechanics Institute of Valencia, Spain) that sampled the vertical ground reaction force (vGRF) data at 1000 Hz. During the weighing phase, participants were stationary on the centre of the force platform over 4 s. System weight (i.e., sum of body weight and external weight) and the SD of the weighing phase were determined during the last second preceding the onset of the movement (Moir et al., 2009). The countermovement phase started 30 ms before the instant in which the vGRF was lower than the system weight plus 5 SD of the weighing phase (Owen et al., 2014; Pérez-Castilla et al., 2019a) and finished when the velocity of the centre-of-mass was positive (Chavda et al., 2018). The propulsion phase was identified from this latter point until the selected take-off threshold (i.e., 5SD, PRF, and 10N) (**Figure 1**). The 5SD and PRF were calculated in three stages: (I) identification of the last time point with a force value greater than 10 N before the beginning of the flight phase, (II) selection of 300 ms for lighter loads (0 and 30 kg) or 100 ms for the heaviest load (60 kg) immediately after the point identified in stage I, and (III) calculation of the take-off thresholds (5SD = mean vGRF + 5 SD; PRF = peak difference between the vGRF and 0 N) considering the time frame identified in stage II. The take-off instant was identified as the first force value greater than the force threshold of 10N, 5SD and PRF. Only the external loads of 0.5, 30, and 60 kg were used for statistical analyses to simplify the results (Pérez-Castilla et al., 2019b). Specifically, the force threshold attained at 0.5, 30, and 60 kg were 3.9 ± 4.2 N, 5.0 ± 2.2 N, and 5.5 ± 2.1 N for the 5SD threshold, and 2.2 ± 4.2 N, 3.4 ± 2.2 N, and 3.7 ± 2.1 N for the PRF threshold, respectively. The impulse-momentum approach was used to calculate the dependent variables of the present study (Linthorne, 2001). Vertical acceleration was calculated as the net vGRF divided by system weight, while vertical velocity of the centre-of-mass was determined by integrating acceleration with respect to time. Finally, vertical power was calculated as the product of force and velocity at each time point. The following variables were calculated to assess the CMJ performance variables:

- Mean values: Force, velocity, and power values averaged throughout the propulsive phase of the jump (Meylan et al., 2012).
- Impulse: Area under the force–time curve during the propulsive phase of the jump (Pérez-Castilla et al., 2019a).
- Jump height: Jump height was estimated from the vertical velocity of the centre-of-mass at take-off (Linthorne, 2001; Perez-Castilla et al., 2018).
- RSI_{mod}: Jump height divided by the duration of the jump (time from the beginning of the countermovement phase until the take-off) (Ebben & Petushek, 2010).

The average value of the two trials performed with each load was considered for statistical analyses. Data of both sessions were used for reliability analyses, while only the data of the second testing session were used for the magnitude comparisons. Raw vGRF data were exported as text files and analysed using a customized 2019 Microsoft Excel® spreadsheet (version 16.32, Microsoft Corporations, Redmond, Washington, USA) for the subsequent determination of the variables described above (Chavda et al., 2018).

[Figure 1 near here]

Statistical analysis

Descriptive statistics are presented as means and SD. The normal distribution of the data was confirmed by the Shapiro-Wilk test ($P > 0.05$). Reliability was assessed by the coefficient of variation (CV) and the intraclass correlation coefficient (ICC; model 3,1) with the corresponding 95% confidence interval (CI). The following criteria were used to determine acceptable (CV ≤ 10%, ICC ≥ 0.80) and high (CV ≤ 5%, ICC ≥ 0.90) reliability (James et al., 2017). A higher reliability of one threshold was identified when the CV was below or the ICC above the 95% CI of another threshold (Pérez-Castilla et al., 2019b). A two-way repeated measures analysis of variance (ANOVA) (threshold [5SD, PRF, and 10N] × load [0.5, 30, and 60 kg]) was conducted to compare the magnitude of each dependent variable. The Greenhouse-Geisser correction was used when the Mauchly's sphericity test was violated and pairwise differences were identified using Bonferroni post-hoc corrections. The magnitude of the changes was also assessed through the Cohen *d* ES with the corresponding 95% CI. The criteria for interpreting the magnitude of the ES were as follows: *trivial* (< 0.20), *small* (0.20–0.59), *moderate* (0.60–1.19), *large* (1.20–2.00), and *extremely large* (> 2.00) (Hopkins et al., 2009). Reliability analyses were performed by means of a custom Excel spreadsheet (Hopkins, 2000a), while all other statistical analyses were performed using the software package SPSS (IBM SPSS version 25.0, Chicago, IL, USA). Alpha was set at a $P < 0.05$ level.

Results

Reliability of the CMJ performance variables

A total of 18 reliability outcomes were calculated for each take-off threshold (6 variables × 3 loads). An acceptable CV value (i.e., CV < 10%) was observed 14 times for the 5SD and PRF, and 15 times for the 10N. An acceptable ICC value (i.e., ICC > 0.80) was observed on 11, 12, and 13 times for 5SD, PRF, and 10N conditions, respectively. No significant differences in reliability were observed between the 5SD, PRF, and 10N thresholds (i.e., all CV and ICC values of one threshold were within 95% CI of the other thresholds) (**Table 1**).

[Table 1 near here]

Magnitude of the CMJ performance variables

The ANOVA revealed a significant main effect of 'threshold' ($F_{(2,44)} \geq 31.0$, $P < 0.001$) and 'load' ($F_{(2,44)} \geq 14.1$, $P < 0.001$) for all variables. The interaction 'threshold × load' reached statistical significance for the mean velocity ($F_{(4,88)} = 3.5$, $P = 0.044$) and impulse ($F_{(4,88)} = 9.8$, $P < 0.001$), but not for the remaining variables ($F_{(4,88)} \leq 2.1$, $P \geq 0.139$). The main effect of 'threshold' was caused by the higher (mean force, mean power, impulse, jump height, and RSI_{mod}) and lower (mean velocity) values observed for the 10N threshold compared to the 5SD and PRF thresholds. The main effect of 'load' was caused by the lower (mean power, mean velocity, impulse from 30 to 60 kg, jump height, and RSI_{mod}) and higher (mean force and impulse from 0.5 to 30 kg) values observed with the increment of the load. Finally, the significant 'threshold × load' interactions for the variables of mean velocity and impulse was caused by the higher mean velocity values observed for the PRF thresholds compared to the 5SD threshold and the higher impulse values observed for the 5SD thresholds compared to the PRF threshold only against the heaviest load (i.e., 60 kg). The pairwise comparisons are depicted in **Table 2**. It should be noted that, despite the significant differences observed between the take-off thresholds, the magnitude of the differences ranged from trivial to small (ES range = 0.01 to 0.22, %Δ range = 0.1% to 3.4%) (**Figure 2**).

[Table 2 near here]

[Figure 2 near here]

Discussion

This study explored the influence of the take-off threshold on the reliability and magnitude of different unloaded and loaded CMJ performance variables collected with a force platform. The main findings revealed that i) the reliability of the three take-off thresholds was comparable for all CMJ performance variables, and ii) the magnitude of the variables generally differed between the 10N threshold and the 5SD and PRF thresholds, but not between the 5SD and PRF thresholds. These results suggest that the magnitude of unloaded and loaded CMJ performance variables is influenced by the take-off threshold, but the reliability of the same variables is not affected by the take-off threshold.

One of main prerequisites of any physical test is to provide an acceptable reliability, which concerns the repeatability of the outcomes when the measurement is repeated (Hopkins, 2000b). Rejecting our first hypothesis, no meaningful differences in reliability were observed between the three take-off thresholds used in the present study (i.e., 5SD, PRF, and 10N). These results are not in line with previous studies which showed an influence of the jump-starting threshold on the reliability of CMJ performance variables (Meylan et al., 2011; Pérez-Castilla et al., 2019a). Meylan et al. (2011) reported a poorer absolute reliability (CV%) for all time-dependent variables collected during countermovement phase of unloaded CMJs (time to peak force, time to peak power, impulse, and phase duration) when the jump-starting threshold was decreased (2.5% > 5% > 10% of bodyweight). Similarly, when using more conservative jump-starting thresholds (50 N, 10%, and 5SD of system weight *vs.* 10 N and 1% of system weight), Pérez-Castilla et al. (2019a) observed better absolute reliability (lower CV values) for several variables collected during the countermovement phase of both unloaded and loaded CMJ (mean values of power and velocity, time to peak values of force, power, and velocity, and phase duration). In contrast, the most conservative take-off threshold (10N) did not show a higher reliability than less conservative take-off thresholds (5SD and PRF) which retained more force signal for the analysis. It is important to note that while the jump-starting threshold is mostly influenced by the variability of the vGRF during the weighing phase (i.e., “human” and signal noise) (McMahon et al., 2018; Pérez-Castilla et al., 2019a), the identification of the take-off threshold is mainly affected by the force platform’s slow response time to register rapid changes in force (Street et al., 2001). This is the first study to demonstrate that, unlike the jump-stating threshold, the take-off threshold does not affect the reliability of commonly used CMJ performance variables. These data suggest that researchers and practitioners can be confident in monitoring changes in certain CMJ performance with these three take-off thresholds.

Confirming our second hypothesis, the magnitude of the CMJ performance variables obtained by the 10N threshold significantly differed with respect to 5SD and PRF thresholds (higher values of mean force, mean power, impulse, jump height, and RSI_{mod} as well as lower values of mean velocity in the 10N condition). The greater magnitude of the CMJ performance variables when a more conservative threshold (i.e., 10N) was used was likely caused by an anticipated detection of the actual take-off (Street et al., 2001). Otherwise, it also plausible that the different CMJ performance variables obtained from less conservative thresholds (i.e., 5SD and PRF) could be underestimated by a later detection of the actual take-off. In this regard, our differences for the jump height performance (0.7-3.3%) between more and less conservative take-off thresholds are in similar to those observed previously. Street and colleagues (2001) reported differences of 0.3-1.5% when the take-off threshold was elevated above the signal noise (0.7-2.0 N) by 2-10 N. It is important to note that mean velocity was the only variable that showed greater values using less conservative thresholds. This is because the velocity of the centre-of-mass at time points close to the actual take-off is higher than the average velocity of the propulsive phase (McMahon et al., 2018). The current findings are also in agreement with previous research demonstrating that the magnitude of several variables collected during both phases of the loaded and unloaded CMJ significantly differed between more and less conservative jump-starting thresholds (Meylan et al., 2011; Pérez-Castilla et al., 2019a). Therefore, although it should be acknowledged that the take-off threshold has a small effect on the magnitude of the different CMJ performance variables (≤ 3.4%), researchers and practitioners should be encouraged to adopt a consistent take-off threshold for comparative purposes due to the diversity of take-off thresholds that have used in the scientific literature (McMahon et al., 2017; Mizuguchi et al., 2015; Moir, 2008; Pérez-Castilla et al., 2019a). Importantly, the available literature suggests that the jump-starting threshold has a larger influence on the reliability and magnitude of CMJ performance variables than the take-off threshold (Meylan et al., 2011; Pérez-Castilla et al., 2019a).

One of the primary goals of data processing is to, as much as possible, reduce the noise and to retain all the true signal for the analysis (Harry et al., 2020). In this regard, the 5SD and PRF thresholds should be a better choice that the 10N threshold because they consider more force signal for the analysis without compromising the reliability of the variables. It is important to note that the 5SD and PRF thresholds take into account the noise of the signal during a part of the flight phase (i.e., when the force platform is unloaded) (McMahon et al., 2017; Moir, 2008). Previous studies have used an arbitrary time frame of 300 ms from the expected take-off (vGRF below 10N) to calculate the 5SD (Chavda et al., 2018; Lake et al., 2018; McMahon et al., 2017) and PRF (Moir, 2008) thresholds during the unloaded CMJ exercise because most individuals can achieve this flight time. However, we reduced this arbitrary time frame from 300 ms to 100 ms for the heaviest load used in the present study (60 kg) because a time frame of 300 ms is likely to include the landing phase in our sample. Therefore, we propose that the time frame used to determine the 5SD and PRF thresholds is modified depending on the athlete's level and/or loading condition to include only the flight phase. A possible procedure could be to identify the time point in which the vGRF consistently exceed 10N after the flight phase and then to select a time frame before this point in which the vGRF is always lower than 10N. The duration of the time frame used to calculate the 5SD and PRF thresholds could be variable depending on the duration of the flight phase.

Although this is the first study that has comprehensively examined the influence of different take-off thresholds on the CMJ performance variables collected with a force platform, some caution should be taken when interpreting the current findings. For instance, the signal noise of the flight time needed to calculate the 5SD and PRF thresholds could differ between different force platforms or the characteristics of the recording environment (e.g., laboratory setting) (Harry et al., 2020). It should be noted that these errors cannot be isolated as it may be influenced by other sources of measurement error such as the sampling and integration frequency (McMahon et al., 2018; Vanrenterghem et al., 2001).

Conclusions

The novel findings of the present study are that the threshold used to identify the take-off instant with a force platform does not affect the reliability of the unloaded and loaded CMJ performance variables, but it may significantly affect the magnitude of the same variables. Therefore, to standardize the routine testing of CMJ performance variables with a force platform, the 5SD and PRF thresholds should be recommended because they include more force-time signal in the analysis than the 10N threshold. The use of a consistent take-off threshold is important to facilitate the comparison of the CMJ performance variables between different trials, sessions, athletes, or research centres. However, it is not mandatory to use the standard 300 ms time frame of the flight phase to calculate the 5SD and PRF thresholds. The duration of this time frame should be adapted to include most part of the flight phase but ensuring that the landing and contact phase prior to the take-off are not included. A possible procedure could be to identify the time point in which the vGRF consistently exceed 10 N after the flight phase and then to select a time frame before this point in which the vGRF is always stable and preferably lower than 10 N.

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Declaration of interests

The authors report no conflict of interest.

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Figure captions

Figure 1. Representative phases of the jump analysis during a countermovement jump performed by a participant (body mass = 75.3 kg) against an external load of 30 kg. The 0.3-second period used to calculate the five-standard deviation (5SD) and peak residual force (PRF) take-off thresholds is also depicted. Note that although represented by the same point the force threshold slightly differed between the three take-off thresholds (2.69 N in the PRF threshold, 4.69 N in the 5SD threshold and 10 N in the 10N threshold). SD, standard deviation.

Figure 2. Standardized differences (95% confidence intervals) for the countermovement jump performance variables between the five-standard deviation (5SD) and peak residual force (PRF) thresholds (upper panel), 5SD and 10 N (10N) thresholds (middle panel), and PRF and 10N thresholds (lower panel). RSI_{mod}, reactive strength index modified; %Δ, percent difference.

Table 1. Reliability of countermovement jump performance variables obtained separately for each take-off threshold.

Variable	**Threshold**	**0.5 kg**		**30 kg**		**60 kg**	
		CV (95% CI)	**ICC (95% CI)**	**CV (95% CI)**	**ICC (95% CI)**	**CV (95% CI)**	**ICC (95% CI)**
Mean force	5SD	3.56 (2.75, 5.04)	0.85 (0.68, 0.93)	1.86 (1.43, 2.63)	0.95 (0.89, 0.98)	3.09 (2.39, 4.38)	0.85 (0.69, 0.93)
	PRF	3.43 (2.65, 4.86)	0.86 (0.70, 0.94)	1.89 (1.46, 2.68)	0.95 (0.89, 0.98)	3.15 (2.44, 4.46)	0.85 (0.68, 0.93)
	10N	3.46 (2.68, 4.90)	0.86 (0.69, 0.94)	1.86 (1.44, 2.64)	0.95 (0.89, 0.98)	2.98 (2.31, 4.22)	0.86 (0.69, 0.94)
Mean power	5SD	8.02 (6.20, 11.4)	**0.68 (0.38, 0.85)**	4.10 (3.17, 5.81)	0.93 (0.85, 0.97)	8.59 (6.64, 12.2)	0.81 (0.61, 0.92)
	PRF	7.89 (6.10, 11.2)	**0.69 (0.39, 0.85)**	4.13 (3.19, 5.84)	0.93 (0.84, 0.97)	8.59 (6.64, 12.2)	0.82 (0.61, 0.92)
	10N	7.92 (6.12, 11.2)	**0.68 (0.39, 0.85)**	4.13 (3.20, 5.85)	0.93 (0.84, 0.97)	8.53 (6.60, 12.1)	0.81 (0.61, 0.92)
Mean velocity	5SD	6.55 (5.06, 9.27)	**0.57 (0.21, 0.79)**	3.01 (2.33, 4.27)	0.91 (0.80, 0.96)	7.02 (5.43, 9.94)	**0.77 (0.53, 0.90)**
	PRF	6.64 (5.14, 9.40)	**0.56 (0.20, 0.79)**	3.00 (2.32, 4.25)	0.91 (0.81, 0.96)	7.04 (5.44, 9.96)	**0.77 (0.53, 0.90)**
	10N	6.68 (5.17, 9.46)	**0.55 (0.19, 0.78)**	3.00 (2.32, 4.25)	0.91 (0.81, 0.96	7.03 (5.44, 9.95)	**0.77 (0.53, 0.90)**
Impulse	5SD	4.88 (3.77, 6.90)	0.90 (0.78, 0.96)	3.13 (2.42, 4.44)	0.94 (0.86, 0.97)	**10.0 (7.76, 14.2)**	**0.75 (0.49, 0.88)**
	PRF	4.88 (3.77, 6.90)	0.90 (0.78, 0.96)	3.18 (2.46, 4.50)	0.94 (0.86, 0.97)	**10.6 (8.18, 15.0)**	**0.74 (0.48, 0.88)**
	10N	4.88 (3.77, 6.90)	0.90 (0.78, 0.96)	3.05 (2.36. 4.32)	0.94 (0.86, 0.97)	9.26 (7.17, 17.1)	**0.76 (0.51, 0.89)**
Jump height	5SD	6.33 (4.89, 8.96)	0.88 (0.73, 0.95)	4.53 (3.51, 6.42)	0.94 (0.87, 0.98)	**15.8 (12.2, 22.3)**	**0.79 (0.56, 0.90)**
	PRF	6.04 (4.67, 8.55)	0.89 (0.75, 0.95)	4.57 (3.53, 6.46)	0.94 (0.87, 0.98)	**16.2 (12.5, 22.9)**	**0.79 (0.57, 0.90)**
	10N	6.15 (4.76, 8.70)	0.88 (0.73, 0.95)	4.32 (3.34, 6.11)	0.95 (0.88, 0.98)	**14.6 (11.3, 20.7)**	0.80 (0.58, 0.91)
RSI$_{mod}$	5SD	**11.0 (8.53, 15.6)**	**0.79 (0.56, 0.90)**	5.96 (4.61, 8.43)	0.93 (0.85, 0.97)	**19.9 (15.4, 28.2)**	**0.73 (0.46, 0.88)**
	PRF	**10.4 (8.06, 14.7)**	0.80 (0.59, 0.91)	5.90 (4.57, 8.36)	0.94 (0.85, 0.97)	**20.5 (15.8, 29.0)**	**0.73 (0.46, 0.88)**
	10N	**10.5 (8.12, 15.0)**	0.80 (0.58, 0.91)	6.23 (4.82, 8.82)	0.93 (0.84, 0.97)	**19.2 (14.8, 27.1)**	**0.73 (0.46, 0.88)**

RSI$_{mod}$, reactive strength index modified; SD, standard deviation; PRF, peak residual force; CV, coefficient of variation; ICC, intraclass correlation coefficient; 95% CI, 95% confidence interval. Bold numbers indicate an unacceptable reliability (CV > 10% or ICC < 0.80).

Table 2. Magnitude of countermovement jump performance variables obtained separately for each take-off threshold.

Variable	**Threshold**	**0.5 kg**		**30 kg**		**60 kg**	
		Mean ± SD	**Range**	**Mean ± SD**	**Range**	**Mean ± SD**	**Range**
Mean force (N)	5SD	1423 ± 128	1181-1661	1606 ± 119	1405-1809	1788 ± 119†	1538-1973
	PRF	1420 ± 127	1177-1658	1604 ± 119	1405-1806	1785 ± 119	1538-1969
	10N	1427 ± 127*,†	1187-1663	1610 ± 119*,†	1409-1816	1794 ± 117*,†	1559-1973
Mean power (W)	5SD	1921 ± 230	1376-2403	1753 ± 231	1303-2225	1488 ± 244†	982-1924
	PRF	1917 ± 229	1371-2399	1751 ± 231	1303-2222	1485 ± 244	982-1924
	10N	1927 ± 230*,†	1383-2408	1757 ± 232*,†	1305-2234	1492 ± 243*,†	985-1928
Mean velocity ($m \cdot s^{-1}$)	5SD	1.480 ± 0.106$^{\#}$	1.284-1.651	1.170 ± 0.104$^{\#}$	0.977-1.320	0.877 ± 0.106$^{\#}$	0.601-1.050
	PRF	1.482 ± 0.106$^{\#}$	1.287-1.653	1.170 ± 0.104$^{\#}$	0.979-1.320	0.878 ± 0.105$^{*,\#}$	0.601-1.050
	10N	1.477 ± 0.106	1.281-1.651	1.168 ± 0.104	0.977-1.319	0.875 ± 0.106	0.601-1.049
Impulse ($N \cdot s$)	5SD	192.8 ± 22.5	142.6-245.4	208.8 ± 26.0	153.5-262.6	189.0 ± 34.4†	122.3-246.3
	PRF	192.3 ± 22.4	141.9-245.0	208.4 ± 26.1	153.5-262.6	187.9 ± 34.7	122.3-246.3
	10N	193.5 ± 22.4*,†	143.7-245.9	209.7 ± 25.9*,†	154.0-262.6	191.3 ± 33.5*,†	125.3-247.8
Jump height (cm)	5SD	30.7 ± 4.2	19.9-40.6	18.9 ± 3.2	11.6-25.5	9.1 ± 2.9†	3.2-14.5
	PRF	30.5 ± 4.3	19.8-40.4	18.8 ± 3.2	11.6-25.5	9.0 ± 2.9	3.2-14.5
	10N	30.9 ± 4.2*,†	20.2-40.6	19.1 ± 3.2*,†	11.6-25.5	9.4 ± 2.9*,†	3.4-14.7
RSI_{mod} (ratio)	5SD	0.385 ± 0.063	0.249-0.479	0.209 ± 0.042	0.135-0.274	0.083 ± 0.028†	0.022-0.136
	PRF	0.385 ± 0.064	0.246-0.479	0.208 ± 0.042	0.135-0.274	0.082 ± 0.028	0.022-0.136
	10N	0.390 ± 0.063*,†	0.253-0.492	0.212 ± 0.042*,†	0.136-0.277	0.085 ± 0.028*,†	0.023-0.138

RSI_{mod}, reactive strength index modified; SD, standard deviation; PRF, peak residual force. *, significantly higher than 5SD; †, significantly higher than PRF; $^{\#}$, significantly higher than 10N ($P < 0.05$; ANOVA with Bonferroni Correction).

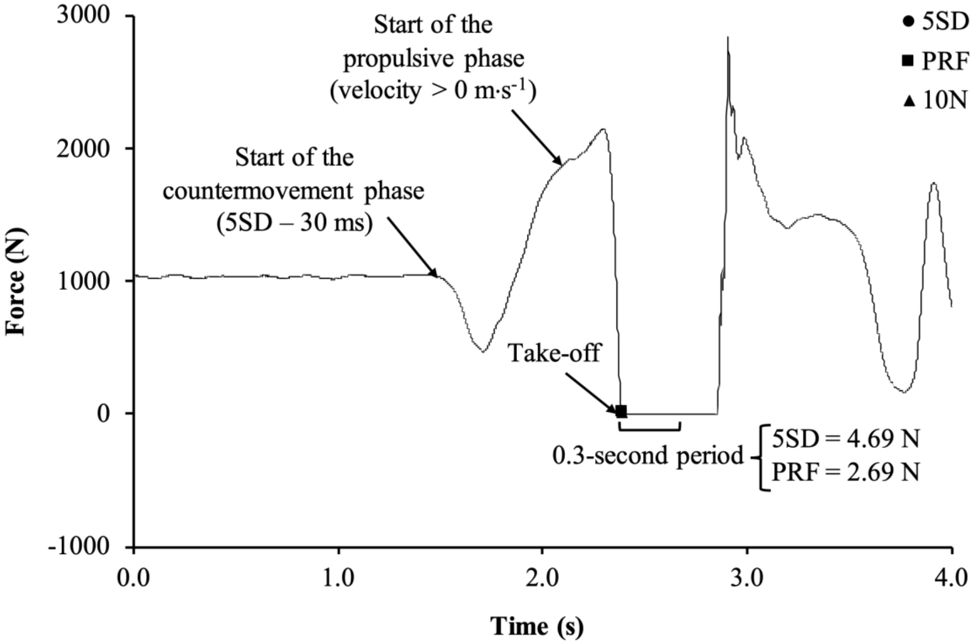

Figure 1. Representative phases of the jump analysis during a countermovement jump performed by a participant (body mass = 75.3 kg) against an external load of 30 kg. The 0.3-second period used to calculate the five-standard deviation (5SD) and peak residual force (PRF) take-off thresholds is also depicted. Note that although represented by the same point the force threshold slightly differed between the three take-off thresholds (2.69 N in the PRF threshold, 4.69 N in the 5SD threshold and 10 N in the 10N threshold). SD, standard deviation.

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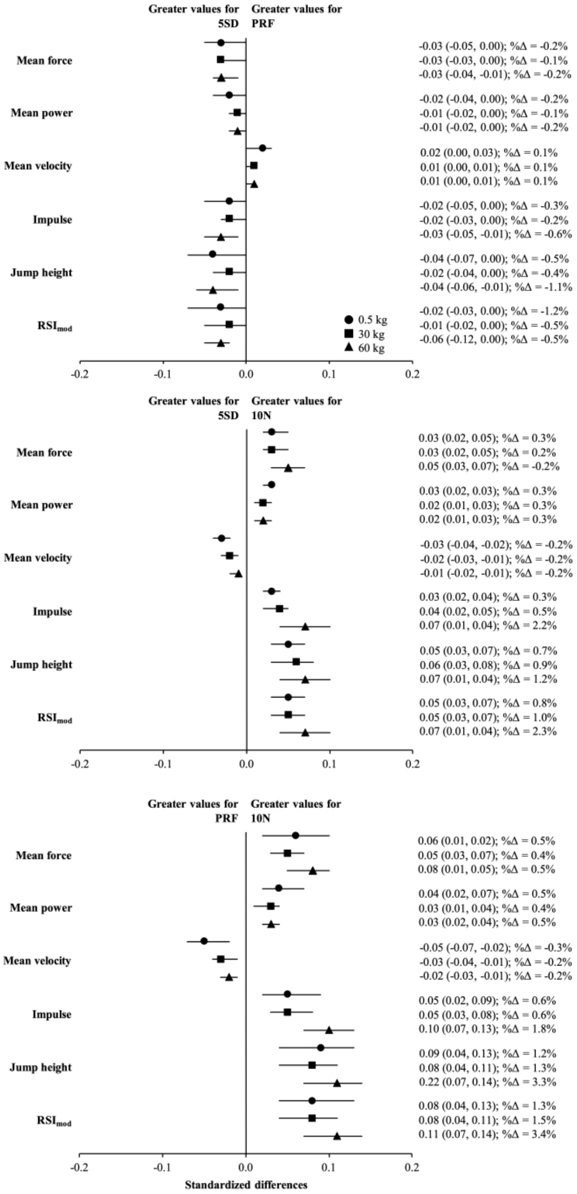

Figure 2. Standardized differences (95% confidence intervals) for the countermovement jump performance variables between the five-standard deviation (5SD) and peak residual force (PRF) thresholds (upper panel), 5SD and 10 N (10N) thresholds (middle panel), and PRF and 10N thresholds (lower panel). RSImod, reactive strength index modified; %Δ, percent difference.

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