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Comparison of Different Take-off Thresholds When Assessing Vertical Jump Performance

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ABSTRACT

International Journal of Exercise Science 17(1): 660-669, 2024. Reliably determining vertical jump (VJ) take-off on a force plate is crucial when identifying performance-related biomechanical factors. Therefore, the purpose of this study was to compare several take-off thresholds (20 N, 10 N, 5 N, 1 N, five standard deviations above an unloaded force plate (5SD), and peak residual force (PkRes) produced when the force plate was unloaded) in terms of jump height (JH), movement time (MT), reactive strength index modified (RSImod), net impulse (netIMP), and propulsive impulse (prIMP). Twenty-one participants performed five countermovement VJs on a force plate. All thresholds were reliable with intraclass correlations ≥ 0.835 and coefficient of variation < 10%. Our results show significant differences across the different take-off thresholds for JH, MT, RSImod, netIMP, and prIMP. However, these differences were considered trivial based on effect sizes. While differences in these thresholds may not be practically meaningful, practitioners are encouraged to consider the noise in the force-time signal and select an appropriate threshold that matches PkRes within their given environment.

KEY WORDS: Kinetics, kinematics, force plate, athlete monitoring

INTRODUCTION

For the strength and conditioning professional, routine athletic testing and monitoring are necessary in order to aid the practitioner with managing the athlete's neuromuscular fatigue as it pertains to their training program. Vertical jump height is a simple measure that can be used to evaluate neuromuscular readiness for resistance training (26). Performance and other biomechanical variables relating to performance can be assessed when vertical jump testing is conducted on a force plate (6, 12, 13, 24, 25).

Being able to reliably identify when the jumping motion begins and when take-off occurs are two methodological concerns that could influence several metrics used to assess jump performance conducted on a force plate. While several studies have evaluated different methods for identifying movement initiation (2, 19, 22, 23), there has been no direct comparison in jump performance when using different methods for identifying take-off from the force-time curve.

Methods for identifying take-off include when the vertical ground reaction force (VGRF) initially drops below 20 N (7, 12, 18), 10 N (2, 16), 5 N (9), when the VGRF equals 0 N (10, 17), when the VGRF drops within five standard deviations of the first 300 ms of the flight phase (3, 14, 15), and when the VGRF drops below the peak residual force that occurs during the flight phase (20). Therefore, the purpose of this investigation was to compare several different kinetic and kinematic variables using these different take-off thresholds.

METHODS

Participants

Twenty-one participants (mean ± SD, female, n = 9, age, 21.4 ± 1.2 yrs; height, 165.4 ± 4.8 cm; body mass, 68.3 ± 19.5 kg; male, n = 12, age, 22.5 ± 3.3 yrs; height, 179.1 ± 5.5 cm, body mass, 84.7 ± 10.9 kg) volunteered to participate in this study. Seventeen participants were currently physically active, which we defined as participating in resistance training and/or aerobic training at least twice per week. The remaining four participants were defined as sedentary. We did not perform a power analysis or use effect size to determine the total number of participants needed for this investigation. However, previous studies evaluating different movement thresholds used sample sizes ranging from 10 to 17 participants (4, 19, 22, 23). To be eligible for participation, participants had to be free from any neurological or musculoskeletal condition or injury that would prohibit them from performing a maximal effort vertical jump. This research was carried out fully in accordance to the ethical standards of the International Journal of Exercise Science (21). All procedures and protocols were approved by the University's Institutional Review Board. All participants were informed of the risks and benefits of participation prior to providing their written informed consent.

Protocol

For this study, we used data from previously published work in our lab (2). Using a within-subjects design, all participants completed two sessions, a familiarization session and an experimental session. Both sessions were scheduled at least 48 h apart and no more than two weeks apart with both sessions being completed at the same time of day. The familiarization session was completed first followed by the experimental session. During the familiarization session all procedures were explained to the participants, all paperwork (informed consent and health history questionnaire) was completed, and each participant was familiarized with the jump procedure. The experimental session consisted of a five-minute warm-up followed by a standardized dynamic warm-up, then two submaximal effort vertical jumps, and five countermovement vertical jumps.

For the familiarization session, participants first completed paperwork (informed consent and health history questionnaire) followed by their height and body mass measured. At the conclusion of the treadmill warm-up, participants became familiarized with the jumping protocol by performing several practice jumps with their hands on their hips on a portable force plate (Kistler Type 9260AA6; Kistler Instruments AG, Winterthur, Switzerland). Countermovement depth for each jump was self-selected by the participant. Participants performed several countermovement vertical jumps on the force plate until they were able to jump and land without losing their balance and were able to report feeling comfortable with the jumping procedure.

Participants started the experimental session with a five-minute warm-up on a motorized treadmill. At the conclusion of the treadmill warm-up, participants performed a standardized dynamic warm-up (i.e., forward gate swings, high knees, and walking lunges) (1) over a distance of 14 m. Next, participants performed two submaximal effort vertical jumps on the force plate. Participants were instructed to jump at 50% effort followed by 75% effort for these jumps. These jumps were not included in the data analysis and were meant to serve as a more specific warm-up. There was 30 s of rest between these jumps and after the last submaximal effort jump. Following this last 30 s of rest, participants performed five, maximal effort vertical jumps. Participants were allowed to rest one minute between each jump.

Data were obtained from the force plate during these five maximal effort jumps using the force plate software (BioWare, Version 5.4.8, Kistler Instruments AG). The sampling rate was set to 1000 Hz. Unfiltered time and VGRF data were exported from BioWare as a text file to be analyzed by a custom software program. The dependent variables analyzed were jump height (JH), movement time (MT), reactive strength index modified (RSImod), net impulse (netIMP), and propulsive impulse (prIMP) using each of the take-off thresholds.

Participants' body weight was obtained during a quiet stance on the force plate prior to performing each jump. Body weight was determined as the mean VGRF during this one second period of quiet stance. The threshold for determining the beginning of the jumping movement was set to five standard deviations below the jumper's body weight. Take-off was determined using the following thresholds: when the VGRF initially went below 50 N, below 20 N, below 10 N, below 1 N, when the VGRF dropped within five standard deviations of the VGRF during the flight phase (5SD), and when the VGRF dropped below the peak residual force that occurred during the flight phase (PkRes). For the PkRes threshold, the beginning of the flight phase was identified as 30 ms after the VGRF went below 10 N and the end of the flight phase was identified as 30 ms prior to VGRF exceeding 10 N. The net force produced during each jump was calculated by subtracting the participant's body weight from the VGRF. To determine NetIMP, we integrated net force and time using the trapezoid rule. This integration started 30 ms before the start of the jumping motion (20) and ended with take-off. Acceleration-time curve was calculated by dividing the net force by the participant's body mass. Velocity-time curve was calculated from the integral of acceleration and time. Take-off velocity was determined by using the impulse-momentum method**.** JH was determined by dividing the square of the velocity at take-off by 19.62. MT was the time elapsed between movement initiation and take-off. We calculated RSImod by dividing JH by MT (5). The propulsive phase of each jump began at the end of the braking phase, when the jumper's velocity was closest to zero (3), and ended with take-off. The product of the average net force produced during the propulsive phase and the duration of this phase were used to calculate PrIMP.

Statistical Analysis

Separate one-way repeated measures ANOVA were used to analyze differences in the JH, MT, netIMP, RSImod, and prIMP across the six different take-off thresholds. Coefficient of variation (CV%) was calculated for each participant for each metric using each take-off threshold. CV% was determined for each participant by using the equation below:

$$\text{CV\%} = \frac{Standard\ Deviation}{Mean} \text{ X } 100$$

The threshold for acceptable CV% was set to 10% (5). Relative reliability was determined for each metric and threshold using intraclass correlation coefficients (ICCs) using a two-way mixed effects model for single measures. The following scale was used to interpret ICCs and their 95% CI: < 0.5, poor; between 0.5 and 0.75, moderate; between 0.75 and 0.9, good; > 0.90, excellent reliability (11). SPSS (Version 28.0; IBM Corp., Armonk, NY, USA) was used to perform all statistical analyses. Greenhouse-Geisser correction was used in subsequent analyses if sphericity was violated during the repeated measures ANOVA tests. If the repeated measures ANOVA detected statistical significance, pairwise comparisons using a Bonferroni adjustment were used as the post hoc test. Hedges' g was calculated by hand to determine effect sizes and were interpreted using the following scale: 0.0 to 0.2, trivial; 0.2 to 0.6, small; 0.6 to 1.2, moderate; 1.2 to 2.0, large; 2.0 to 4.0, very large; 4.0+, nearly perfect (8). The alpha level was set to $p < 0.05$.

RESULTS

There was a consistent pattern in terms of ranking the take-off thresholds based on time of occurrence. From earliest to latest, the order of occurrence was 5SD, 20 N, PkRes, 10 N, 5 N, and < 1 N. Sometimes more than one threshold was achieved simultaneously. The 20 N and PkRes thresholds were achieved simultaneously for ~58% of the jumps. The 10 N and 5 N thresholds were achieved simultaneously for ~13% of the jumps. The 5SD, 20 N, and PkRes thresholds were achieved simultaneously for ~13% of the jumps. The 10 N, 5 N, and < 1 N thresholds were achieved simultaneously for ~13% of the jumps. The 5SD and 20 N thresholds were achieved simultaneously for ~19% of the jumps. The 5 N and < 1 N thresholds were achieved simultaneously for ~26% of the jumps. Figure 1 shows a typical force-time graph that identifies each take-off threshold.

Table 1 shows the means and standard deviations for JH, MT, RSImod, netIMP, and prIMP for each of the different take-off thresholds. There was a significant difference in JH among the different take-off thresholds ($F = 86.938$, $p < 0.001$, $\eta_p^2 = 0.813$, $1 - \beta = 1.000$). The 20 N threshold resulted in a larger JH compared to the 10 N ($g = 0.05$, $p < 0.001$), 5 N ($g = 0.08$, $p < 0.001$), < 1N ($g = 0.11$, $p < 0.001$) thresholds. The 20 N threshold had a smaller JH compared to the 5SD ($g = 0.05$, $p < 0.001$) and PkRes ($g = 0.01$, $p = 0.001$) thresholds. JH for the 10 N threshold ($g = 0.02$, $p < 0.001$) was larger compared to the 5 N ($g = 0.02$, $p < 0.001$) and < 1 N ($g = 0.06$, $p < 0.001$) thresholds, and smaller compared to the 5SD ($g = 0.13$, $p < 0.001$) and PkRes ($g = 0.04$, $p < 0.001$) thresholds. The 5 N threshold had a larger JH compared to the < 1 N threshold ($g = 0.03$, $p = 0.002$), and a smaller JH compared to the 5SD ($g = 0.16$, $p < 0.001$) and PkRes ($g = 0.07$, $p < 0.001$)

thresholds. The < 1 N threshold had a smaller JH compared to the 5SD (g = 0.20, p < 0.001) and PkRes (g = 0.10, p < 0.001) thresholds. The 5SD threshold had a larger JH compared to the PkRes threshold (g = 0.06, p < 0.001). Table 2 shows the CV% and ICCs for each metric and take-off threshold.

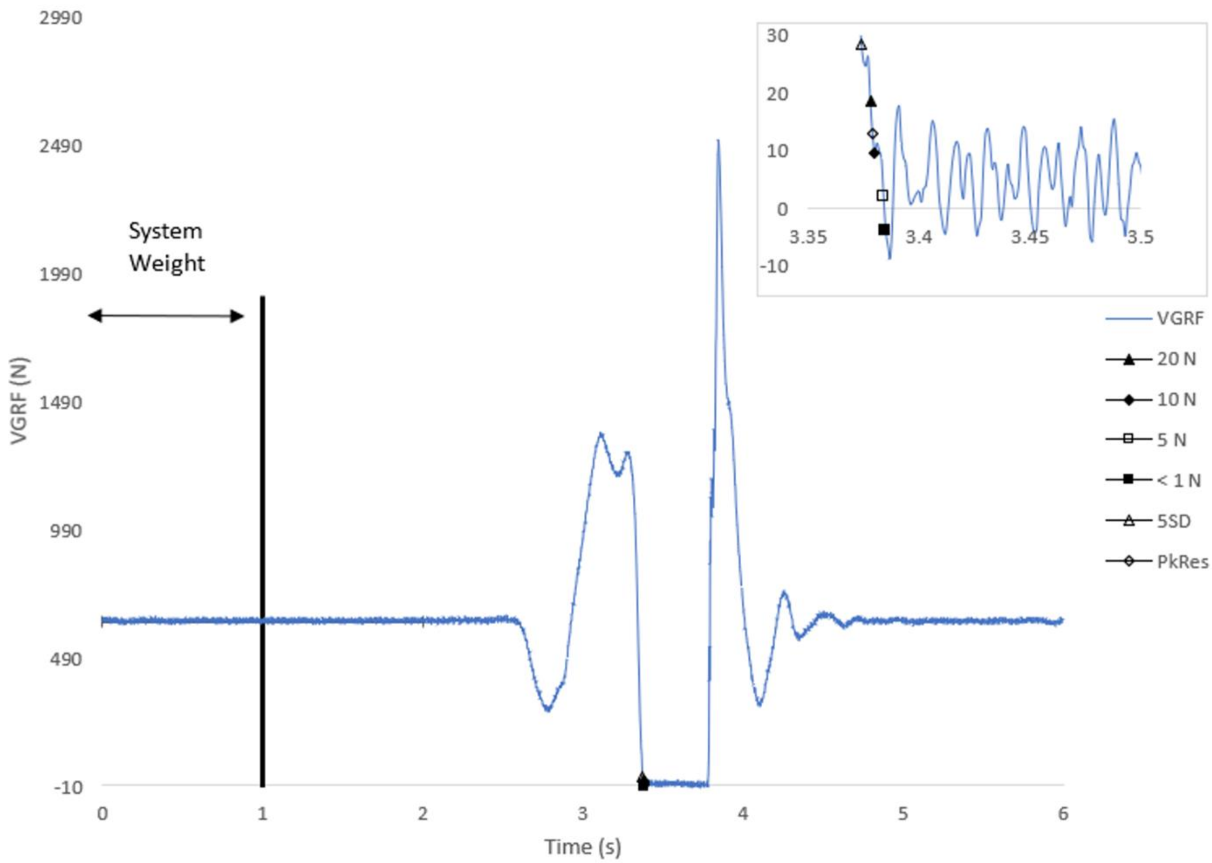

Figure 1. Force-time graph of a 65.5 kg subject showing system weight assessment as well as the six take-off thresholds. The inset shows the location of each take-off threshold as well as the signal noise when the force plate is unloaded.

Table 1. Means (SD) of various VJ metrics for each take-off threshold.

	20N	10N	5N	< 1N	5SD	PkRes
JH (cm)	29.8 (10.0)[1]	29.2 (10.0)[1]	29.0 (10.1)[1]	28.7 (10.2)[1]	30.1 (10.0)[1]	29.7 (10.0)[1]
MT (s)	1.148 (0.230)[5]	1.149 (0.230)	1.151 (0.229)	1.151 (0.229)	1.146 (0.228)[4,5]	1.148 (0.230)
RSImod	0.27 (0.10)	0.26 (0.10)[2]	0.26 (0.10)[2]	0.26 (0.10)[2,3]	0.27 (0.10)[3,4,5]	0.27 (0.10)[3,4,5]
netIMP (Ns)	186.98 (57.47)[1]	185.29 (57.32)[1]	184.50 (57.54)[1]	183.32 (57.94)[1]	188.10 (57.40)[1]	186.73 (57.46)[1]
prIMP (Ns)	187.48 (57.85)[1]	185.78 (57.71)[1]	185.00 (57.93)[1]	183.82 (58.33)[1]	188.59 (57.78)[1]	187.23 (57.84)[1]

[1]significantly different from all other thresholds ($p \leq 0.002$) [2]significantly different from 20N ($p < 0.001$) [3]significantly different from 10N ($p \leq 0.002$) [4]significantly different from 5N ($p \leq 0.014$) [5]significantly different from < 1N ($p \leq 0.033$)

Table 2. ICC and CV% for several metrics for each take-off threshold.

		20 N	10 N	5 N	< 1 N	5SD	PkRes
JH	ICC [95% CI]	0.975 [0.953, 0.989]	0.972 [0.947, 0.988]	0.972 [0.947, 0.988]	0.965 [0.933, 0.984]	0.976 [0.954, 0.989	0.976 [0.954, 0.989]
	CV%	4.9	5.1	5.2	6.0	4.6	4.8
MT	ICC [95% CI]	0.837 [0.718, 0.924]	0.839 [0.720, 0.924]	0.838 [0.719, 0.924]	0.835 [0.715, 0.922]	0.836 [0.716, 0.923]	0.835 [0.715, 0.923]
	CV%	6.4	6.4	6.4	6.4	6.4	6.4
RSImod	ICC [95% CI]	0.916 [0.847, 0.962]	0.920 [0.854, 0.964]	0.919 [0.852, 0.964]	0.911 [0.840, 0.959]	0.917 [0.848, 0.962]	0.917 [0.847, 0.962]
	CV%	8.5	8.5	8.8	9.7	8.4	8.5
netIMP	ICC [95% CI]	0.992 [0.984, 0.996]	0.991 [0.982, 0.996]	0.990 [0.981, 0.996]	0.988 [0.976, 0.955]	0.992 [0.985, 0.997]	0.992 [0.984, 0.996]
	CV%	2.4	2.5	2.6	3.0	2.2	2.3
prIMP	ICC [95% CI]	0.992 [0.984, 0.996]	0.991 [0.983, 0.996]	0.991 [0.982, 0.996]	0.988 [0.977, 0.955]	0.992 [0.985, 0.997]	0.992 [0.985, 0.997]
	CV%	2.3	2.4	2.5	2.9	2.2	2.3

The repeated measures ANOVA for MT also revealed significant difference among the different take-off thresholds ($F = 9.006$, $p < 0.001$, $\eta_p^2 = 0.310$, $1 - \beta = 0.994$). MT using the 20 N threshold was less than the < 1 N threshold ($g = 0.02$, $p = 0.033$). MT using the 5 N threshold was significantly longer than the 5SD threshold ($g = 0.02$, $p = 0.014$). MT for the < 1 N threshold was significantly longer than the 5SD threshold ($g = 0.02$, $p = 0.002$).

There was a significant difference in RSImod among the different take-off thresholds ($F = 47.603$, $p < 0.001$, $\eta_p^2 = 0.704$, $1 - \beta = 1.000$). The 20 N threshold resulted in larger RSImod compared to the 10 N, 5 N, and < 1 N thresholds ($g = 0.06 – 0.14$, $p < 0.001$). RSImod for the 10 N threshold was greater than the < 1 N threshold ($g = 0.08$, $p = 0.001$) but smaller than the 5SD ($g = 0.08$, $p < 0.001$) and PkRes ($g = 0.05$, $p = 0.002$) thresholds. The 5 N threshold resulted in a lower RSImod compared to the 5SD ($g = 0.12$, $p < 0.001$) and PkRes ($g = 0.09$, $p < 0.001$) thresholds. The < 1 N threshold resulted in a lower RSImod compared to the 5SD ($g = 0.16$, $p < 0.001$) and PkRes ($g = 0.13$, $p < 0.001$) thresholds.

There was a significant difference in netIMP among the different take-off thresholds ($F = 79.553$, $p < 0.001$, $\eta_p^2 = 0.799$, $1 - \beta = 1.000$). The 20 N threshold resulted in a larger netIMP compared to the 10 N ($g = 0.03$, $p < 0.001$), 5 N ($g = 0.04$, $p < 0.001$), and < 1 N thresholds ($g = 0.04$, $p < 0.001$). The netIMP for the 20 N threshold was smaller compared to the 5SD ($g = 0.02$, $p < 0.001$) and PkRes ($g = 0.00$, $p = 0.001$) thresholds. NetImp for the 10 N threshold was larger compared to the < 1 N threshold ($g = 0.03$, $p < 0.001$) and smaller compared to the 5SD ($g = 0.05$, $p < 0.001$) and PkRes ($g = 0.03$, $p < 0.001$) thresholds. The 5 N threshold had a larger netIMP compared to the < 1 N threshold ($g = 0.02$, $p = 0.001$), but a smaller netIMP compared to the 5SD ($g = 0.06$, $p < 0.001$) and PkRes ($g = 0.04$, $p < 0.001$) thresholds. NetImp for the < 1 N threshold was smaller than the 5SD ($g = 0.08$, $p < 0.001$) and PkRes ($g = 0.06$, $p < 0.001$) thresholds. The 5SD threshold had a larger netIMP compared to the PkRes threshold ($g = 0.02$, $p < 0.001$).

The repeated measures ANOVA for prIMP also revealed significant difference among the different take-off thresholds ($F = 79.511$, $p < 0.001$, $\eta_p^2 = 0.799$, $1 - \beta = 1.000$). The 20 N threshold had a larger prIMP compared to the 10 N ($g = 0.03$, $p < 0.001$), 5 N ($g = 0.04$, $p < 0.001$), and < 1 N ($g = 0.06$, $p < 0.001$) thresholds. The netIMP for the 20 N threshold was smaller compared to the 5SD ($g = 0.02$, $p < 0.001$) and PkRes ($g = 0.02$, $p = 0.001$) thresholds. The 10 N thresholds had a larger netIMP compared to the 5 N ($g = 0.01$, $p < 0.001$) and < 1 N ($g = 0.03$, $p < 0.001$) thresholds. The 5 N threshold had a larger netIMP compared to the < 1 N threshold ($g = 0.02$, $p = 0.001$), but a smaller netIMP compared to the 5SD ($g = 0.06$, $p < 0.001$) and PkRes ($g = 0.04$, $p < 0.001$) thresholds. The netIMP for the < 1 N threshold was smaller compared to the 5SD ($g = 0.08$, $p < 0.001$) and PkRes ($g = 0.06$, $p < 0.001$) thresholds. The 5SD threshold had a larger netIMP compared to the PkRes threshold ($g = 0.02$, $p < 0.001$).

DISCUSSION

The purpose of this study was to evaluate the effect of using different take-off thresholds when determining JH, MT, RSImod, netIMP, and prIMP from vertical jumps performed on a force plate. While there were several statistically significant differences across these thresholds for all metrics evaluated, all of these differences were trivial based on Hedge's *g*. Therefore, these differences may not be practically meaningful. Furthermore, all thresholds demonstrated acceptable absolute reliability as measured by CV% and good-to-excellent relative reliability as measured by ICCs.

In all participants, the 5SD threshold was achieved first and the < 1N threshold was achieved last. Due to the close proximity of these thresholds, multiple thresholds were achieved at the same time in some participants. Because JH was based on the impulse-momentum method, differences in JH were a result of differences in the integration of VGRF and time with greater JHs being achieved with higher take-off thresholds. As a result, the differences across take-off thresholds for netIMP and prIMP were the same as the differences in take-off thresholds for JH. As expected, the lower thresholds resulted in longer MTs. Since the thresholds that were achieved earlier in the force-time curve resulted in greater JHs, it would appear that the VGRF was a more important factor than MT when determining take-off velocity. RSImod for the 20 N, 5SD, and PkRes thresholds were statistically greater than the 5 N and < 1 N thresholds. RSImod is determined by JH and MT. So, a vertical jump that achieved a greater JH in a shorter MT would result in a greater RSImod. Therefore, using a take-off threshold that occurs earlier in the force-time curve could result in a greater RSImod.

Relative reliability as measured by ICCs was excellent (> 0.90) for JH, RSImod, netIMP, and prIMP and good (between 0.75 and 0.90) for MT. For all measures, the CV% was less than 10% for each of the take-off thresholds used in this study. All take-off thresholds demonstrated similar CV% for each metric analyzed. NetIMP and prIMP had the greatest absolute reliability with CV% $\leq$ 3.0%. While still within the acceptable range (< 10%), RSImod was the least reliable variable with a CV% of 8.4 – 9.7% with the < 1 N threshold being the least reliable. As can be seen in the inset of Figure 1, this threshold occurred below the mean of the VGRF signal when the force plate was unloaded, which raises questions concerning the validity of using this threshold for our lab conditions and force plate.

Practitioners should consider the noise in the signal when determining the appropriate threshold. In the present study, the peak residual force was 17 ± 2.4 N (mean ± SD), which explains why the 20 N and PkRes thresholds were achieved simultaneously in ~58% of the trials analyzed. In 3 of the jumps analyzed, the peak residual force was above 20 N. The inset in Figure 1 illustrates the relationship between the different take-off thresholds and the peak residual force. Using a take-off threshold that falls within the range of the noise in the signal may lead to inaccuracies in terms of JH, MT, RSImod, netIMP, and prIMP. In the present study, it would appear that using a threshold of 10 N, 5 N, or < 1 N occurred within the range of the signal noise since the peak residual force for all jumps occurred ~17 N or higher. Arbitrary assignment of an absolute threshold (e.g., 5 N) without considering the noise in the VGRF signal may lead to less accurate results. In addition, filtering the data to remove this noise and use one of the absolute thresholds may also adversely impact determining the beginning of the jumping movement, which could also adverse impact on many of the metrics calculated in this study.

To a lesser extent, a similar problem can occur with the determination of the 5SD and PkRes thresholds. These two methods were based on the VGRF signal 30 ms after the force level fell below 10 N. While the 5SD method uses the mean signal to determine the threshold, using a cutoff of 10 N that occurs below the peak residual force removes higher force values from the 5SD calculation that could stem from noise. Therefore, we would expect the true 5SD threshold to be slightly higher than what was used in our study. Similarly, the true peak residual force may have occurred either before the 10 N threshold was achieved or within the 30 ms window after the 10 N threshold was achieved, which would influence JH, MT, RSImod, netIMP, and prIMP. Therefore, we recommend evaluating the noise in the VGRF signal for each trial before determining the appropriate threshold to be used.

REFERENCES

1. Avila BJ, Brown LE, Coburn JW, Statler TA. Effects of imagery on force production and jump performance. JEPonline 18(4): 42–8, 2015.

2. Barefoot M, Lamont H, Smith JC. Comparison of the reliability of four different movement thresholds when evaluating vertical jump performance. Sports (Basel) 10(12): 193, 2022.

3. Chavda S, Bromley T, Jarvis P, Williams S, Bishop C, Turner AN, et al. Force-time characteristics of the countermovement jump: analyzing the curve in Excel. Strength Cond J 40(2): 67–77, 2018.

4. Cormack SJ, Newton RU, McGuigan MR, Doyle TLA. Reliability of measures obtained during single and repeated countermovement jumps. Int J Sports Physiol Perform 3(2): 131–44, 2008.

5. Ebben WP, Petushek EJ. Using the reactive strength index modified to evaluate plyometric performance. J Strength Cond Res 24(8): 1983–7, 2010.

6. Gathercole R, Sporer B, Stellingwerff T, Sleivert G. Alternative countermovement-jump analysis to quantify acute neuromuscular fatigue. Int J Sports Physiol Perform 10(1): 84–92, 2015.

7. Harry JR, Paquette MR, Schilling BK, Barker LA, James CR, Dufek JS. Kinetic and electromyographic subphase characteristics with relation to countermovement vertical jump performance. J Appl Biomech 34(4): 291–7, 2018.

8. Hopkins WG, Marshall SW, Batterham AM, Hanin J. Progressive statistics for studies in sports medicine and exercise science. Med Sci Sports Exerc 41(1): 3–12, 2009.

9. Kibele A. Possibilities and limitations in the biomechanical analysis of countermovement jumps: A methodological study. J Appl Biomech 14: 105–17, 1998.

10. Kipp K, Kiely MT, Geiser CF. Reactive strength index modified is a valid measure of explosiveness in collegiate female volleyball players. J Strength Cond Res 30(5): 1341–7, 2016.

11. Koo TK, Li MY. A guideline of selecting and reporting intraclass correlation coefficients for reliability research. J Chiropr Med 15(2): 155–63, 2016.

12. Krzyszkowski J, Chowning LD, Harry JR. Phase-specific predictors of countermovement jump performance that distinguish good from poor jumpers. J Strength Cond Res 36(5): 1257–63, 2022.

13. Laffaye G, Wagner PP, Tombleson TIL. Countermovement jump height: gender and sport-specific differences in the force-time variables. J Strength Cond Res 28(4): 1096–105, 2014.

14. Lake J, Mundy P, Comfort P, McMahon JJ, Suchomel TJ, Carden P. Concurrent validity of a portable force plate using vertical jump force–time characteristics. J Appl Biomech 34(5): 410–3, 2018.

15. Lake JP, Mundy PD, Comfort P, McMahon JJ, Suchomel TJ, Carden P. Effect of barbell load on vertical jump landing force-time characteristics. J Strength Cond Res 35(1): 25–32, 2021.

16. Lindberg K, Solberg P, Bjørnsen T, Helland C, Rønnestad B, Thorsen Frank M, et al. Force-velocity profiling in athletes: Reliability and agreement across methods. PLoS One 16(2): e0245791, 2021.

17. Linthorne NP. Analysis of standing vertical jumps using a force platform. Am J Physics 69(11): 1198-204, 2001.

18. McMahon JJ, Ripley NJ, Comfort P. Force plate-derived countermovement jump normative data and benchmarks for professional rugby league players. Sensors (Basel) 22(22): 8669, 2022.

19. Meylan CMP, Nosaka K, Green J, Cronin JB. The effect of three different start thresholds on the kinematics and kinetics of a countermovement jump. J Strength Cond Res 25(4): 1164–7, 2011.

20. Moir GL. Three different methods of calculating vertical jump height from force platform data in men and women. Meas Phys Educ Exerc Sci 12(4): 207–18, 2008.

21. Navalta JW, Stone WJ, Lyons TS. Ethical issues relating to scientific discovery in exercise science. Int J Exerc Sci 12(1): 1-8, 2019.

22. Owen NJ, Watkins J, Kilduff LP, Bevan HR, Bennett MA. Development of a criterion method to determine peak mechanical power output in a countermovement jump. J Strength Cond Res 28(6): 1552–8, 2014.

23. Pérez-Castilla A, Rojas FJ, García-Ramos A. Reliability and magnitude of loaded countermovement jump performance variables: A technical examination of the jump threshold initiation. Sports Biomech 21(5): 622-36, 2022.

24. Rice PE, Goodman CL, Capps CR, Triplett NT, Erickson TM, McBride JM. Force- and power-time curve comparison during jumping between strength-matched male and female basketball players. Eur J Sport Sci 17(3): 286–93, 2017.

25. Thomas C, Jones PA, Dos'Santos T. Countermovement jump force-time curve analysis between strength-matched male and female soccer players. Int J Environ Res Public Health 19(6): 3352, 2022.

26. Watkins CM, Barillas SR, Wong MA, Archer DC, Dobbs IJ, Lockie RG, et al. Determination of vertical jump as a measure of neuromuscular readiness and fatigue. J Strength Cond Res 31(12): 3305–10, 2017.