Title: Do the peak and mean force methods of assessing vertical jump force asymmetry agree?

Preferred running title head: Vertical jump force asymmetry method agreement

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Abstract

The aim of this study was to assess agreement between peak and mean force methods of quantifying force asymmetry during the countermovement jump (CMJ). Forty-five men performed four CMJ with each foot on one of two force plates recording at 1000 Hz. Peak and mean were obtained from both sides during the braking and propulsion phases. The dominant side was obtained for the braking and propulsion phase as the side with the largest peak or mean force and agreement was assessed using percentage agreement and the kappa coefficient. Braking phase peak and mean force methods demonstrated a percentage agreement of 84% and a kappa value of 0.67 (95% confidence limits: 0.45 to 0.90), indicating substantial agreement. Propulsion phase peak and mean force methods demonstrated a percentage agreement of 87% and a kappa value of 0.72 (95% confidence limits: 0.51 to 0.93), indicating substantial agreement. While agreement was substantial, side-to-side differences were not reflected equally when peak and mean force methods of assessing CMJ asymmetry were used. These methods should not be used interchangeably, but rather a combined approach should be used where practitioners consider both peak and mean force to obtain the fullest picture of athlete asymmetry.

Keywords: Countermovement jump, movement symmetry, kinetics, method comparison

Introduction

The vertical jump provides practitioners with a way of assessing their athletes' capacity to accelerate their body mass within a relatively controllable methodological framework (Aragon, 2000; Balsalobre-Fernandez, Glaister, & Lockey, 2015; Bosco, Luhtanen, & Komi, 1983; Hatze, 1998; Impellizzeri, Rampinini, Maffiuletti, & Marcora, 2007; Mundy, Smith, Lauder, & Lake, 2017). Jumping on a force plate can provide practitioners with information regarding the forces that accelerate their whole body centre of gravity (CoG) and how long these forces are applied for (Hatze, 1998; Lake, Mundy, & Comfort, 2014; Mundy et al., 2017; Street, McMillan, Board, Rasmussen, & Heneghan, 2001). Multiplying the average force applied over the propulsion phase of vertical jumping by the duration of this phase yields impulse, and, if determined accurately, this impulse is proportional to take-off velocity (Hatze, 1998). This in turn dictates jump height. However, the last decade has seen an increase in research interest in using the vertical jump to assess lower-body asymmetry by studying the distribution of forces between the left and right sides (Bailey, Sato, Burnett, & Stone, 2015; Bell, Sanfilippo, Binkley, & Heiderscheit, 2014; Impellizzeri et al., 2007; Jordan, Aagaard, & Herzog, 2014; Newton et al., 2006; Patterson, Raschner, & Platzer, 2009).

The increased interest in assessing force distribution between the left and right sides appears to be based on its potential to reflect previous injury, the positional demands of sport, and leg length discrepancies (Newton et al., 2006). Further, force asymmetries may lead to athletes routinely applying a larger mechanical demand to the favoured side, which may increase the potential for injury, especially if the strength and conditioning process is continued. Therefore, quantifying force asymmetry has the potential to become a critical part of athlete assessment. However, there are different ways of assessing force asymmetry and currently no data exist to inform practitioners about whether the different methods agree.

A frequently used method of assessing force asymmetry is based upon performance in a bilateral vertical jump, with each foot positioned on a separate force plate (Bailey et al., 2015; Bell et al., 2014; Jordan et al., 2014; Newton et al., 2006; Patterson et al., 2009). Typically asymmetry is then quantified by identifying the side that applies the largest peak (Bailey et al., 2015; Bell et al., 2014; Benjanuvatra, Lay, Alderson, & Blanksby, 2013; Impellizzeri et al., 2007; Newton et al., 2006; Patterson et al., 2009) or mean force (Benjanuvatra et al., 2013; Iwanska et al., 2016; Jordan et al., 2014; Lawson, Stephens, Devoe, & Reiser, 2006; Newton et al., 2006) before either categorising that as the dominant limb or by calculating some form of symmetry index (Bishop, Read, Chavda, & Turner, 2016). However, there are no data to inform practitioners about agreement between these two methods. Therefore, there is currently a need to undertake research to assess whether the peak and mean force methods agree. The results of this research would provide practitioners with important information about whether these two methods can be used interchangeably. The aim of this study was to assess the agreement between the peak and mean force methods of quantifying force asymmetry during vertical jumping. It was hypothesised that the peak and mean force methods of assessing asymmetry during vertical jumping would agree.

Method

Participants

Forty-five men (age: 20.83 ± 0.84 years, body mass: 84.41 ± 6.87 kg, height: 1.80 ± 0.57 m) who regularly participated in a variety of university level sports (e.g. soccer, rugby (both codes), basketball and volleyball), volunteered to participate in this study and provided written informed consent. The study was approved in accordance with the University of Chichester's Ethical Policy Framework for research involving the use of human participants.

Procedures

Before jump testing, participants performed a standardised dynamic warm-up. This began with 5 minutes of easy stationary cycling, and was followed by 2-3 minutes of upper- and lower-body dynamic stretching. Specifically, participants performed two circuits of 10 repetitions each of 'arm swings', 'lunge walk', 'walking knee lift', and 'heel to toe lift'. Participants then performed four bilateral countermovement jumps (CMJ), interspersed by 30 s of rest. They were instructed to perform a rapid countermovement, to approximately quarter squat depth, following this with a rapid propulsion phase with the intention of jumping as high as possible. Jump performances were watched to ensure that participants kept their hands on their hips throughout each jump. Each CMJ was performed on two parallel Kistler force platforms (Type 9851B; Kistler Instruments Ltd., Hook, UK) embedded in the floor of the laboratory, each sampling at 1000 Hz. The vertical component of the ground reaction force (VGRF) from both force platforms were synchronously acquired in VICON Nexus (Version 1.7.1; Vicon Motion Systems Ltd., Oxford, UK); left and right side vertical forces were summed for the initial part of data analysis.

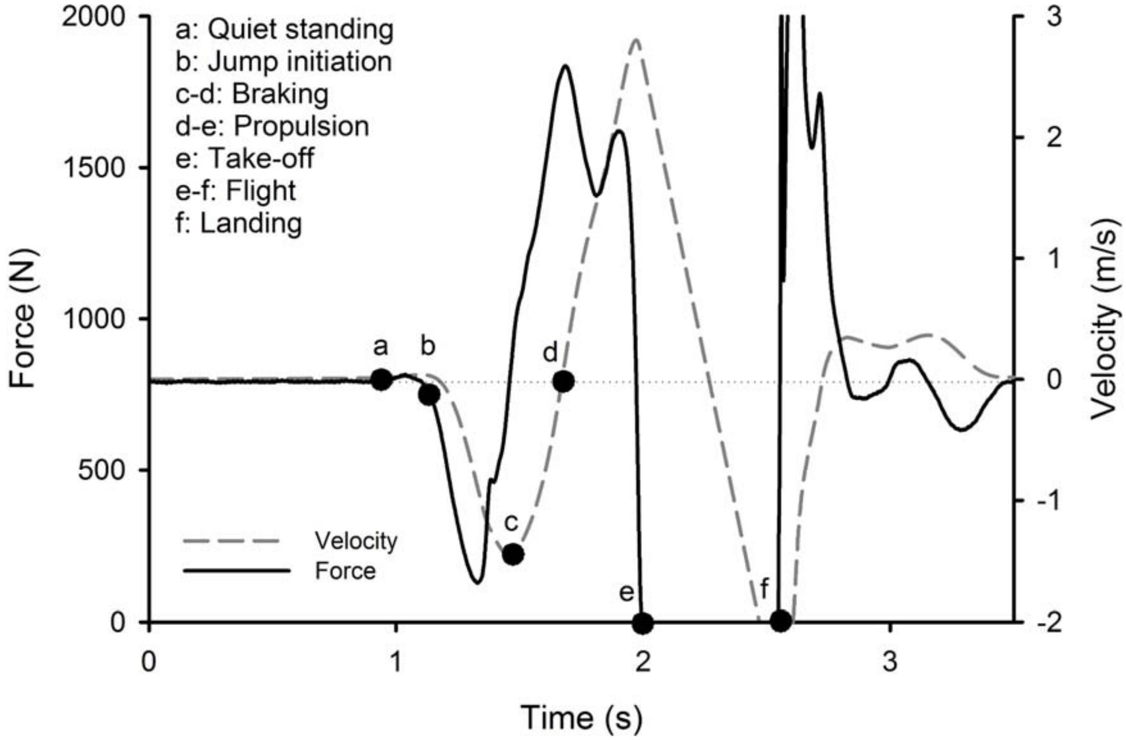

Figure 1. Identification of the braking and propulsion phases of countermovement vertical jumping.

Data Analysis

The start point of the analysis of the force-time data was standardised by identifying the start using the methods described by Owen, Watkins, Kilduff, Bevan, and Bennett (2014). Briefly, body weight was obtained by averaging 1 s of force-time data as the participants stood still while awaiting the word of command to jump (Figure 1, up to ‘a’). This was recorded during each trial and the participant was instructed to stand perfectly still. The standard deviation (SD) of this force-time data during the ‘quiet standing’ phase was also calculated and the first force value that was either less or greater than 5 SD represented jump initiation (Figure 1, point ‘b’). The final part of this process was to then go back through the force-time data by 30 ms. This is because it has been shown that this positions the start of force-time data integration at a point when the participant is still motionless so that the assumption of zero velocity is not compromised negatively impacting the calculation of subsequent kinetic and kinematic data (Owen et al., 2014). Calculation of CoG velocity started from this point. First, body weight (obtained from quiet standing) was subtracted from force, which was then divided by body mass to provide CoG acceleration. Then CoG acceleration was then integrated with respect to time using the trapezoid rule to provide CoG velocity.

The eccentric braking phase began one sample after the lowest countermovement CoG velocity occurred (Figure 1, point ‘c’) and ended one sample after the first occurrence of a CoG velocity of 0 m/s (Figure 1, point ‘d’) (McMahon, Jones, Suchomel, Lake, & Comfort, 2017); one sample after this also marked the beginning of the concentric propulsion phase, which ended at take-off (Figure 1, point ‘e’) (McMahon et al., 2017).

Take-off was determined in three stages (see Figure 1). First, the first force value less than 10 N (Figure 1, around point ‘e’) and the next force value greater than 10 N (Figure 1, after point ‘e’) were identified; second, points 30 ms after and before these points, respectively were identified to identify the centre ‘flight phase’ array; third, mean and SD ‘flight phase’ force was calculated, and mean ‘flight phase’ force plus 5 SD was used to identify take-off.

Statistical Analysis

Asymmetry was quantified using two methods: peak and mean force. Left and right side peak forces were identified as the highest forces applied by each side respectively during the eccentric braking phase and the concentric propulsion phase of each CMJ. Left and right side mean forces were then obtained by averaging left and right side force over the eccentric braking phase and concentric propulsion phase. The dominant side was identified as the side with the largest peak and mean force respectively on a phase-by-phase basis. To assess agreement between the peak and mean force methods of assessing asymmetry, these data were first coded on a participant-by-participant basis. Where the side that was favoured agreed across the peak and mean force methods a '1' was assigned; where they disagreed a '0' was assigned. The percentage agreement between the peak and mean force methods of assessing asymmetry were calculated. However, a certain amount of this agreement is likely to have occurred by chance. Therefore, the kappa coefficient, and its 95% confidence limits, were then calculated in a spreadsheet using methods published in the literature (Cohen, 1960; O'Donoghue, 2010; Viera & Garrett, 2005). The kappa coefficient describes the proportion of agreement between the two methods after any agreement by chance has been removed (Cohen, 1960). The agreement scale presented by Viera and Garrett (2005), where kappa values of 0.01-0.20, 0.21-0.40, 0.41-0.60, 0.61-0.80, and 0.81-0.99 represented slight, fair, moderate, substantial, and almost perfect agreement, respectively, was used to quantify agreement. Finally, relative reliability of peak and mean force from the braking and propulsion phase was assessed using intraclass correlation coefficients (two-way random effects model (ICC)), while the absolute reliability was assessed using percentage coefficient of variation (CV) (Banyard, Nosaka, & Haff, 2016). The magnitude of the ICC was determined using the criteria set out by Cortina (1993), where $r \geq 0.80$ is considered highly reliable. The magnitude of the CV was determined using the criteria set out by Banyard et al. (2016), where >10% is considered poor, 5-10% is considered moderate, and <5% is considered good.

Results

Table 1 shows that the peak and mean forces applied during the braking and propulsion phases demonstrated high relative reliability and good absolute reliability. Regarding the agreement between the peak and mean force methods of assessing asymmetry, during the eccentric braking phase the peak and mean force methods demonstrated a percentage agreement of 84% and a kappa value of 0.67 (95% confidence limits: 0.45 to 0.90), indicating substantial agreement. During the concentric propulsion phase the peak and mean force methods demonstrated a percentage agreement of 87% and a kappa value of 0.72 (95% confidence limits: 0.51 to 0.93), indicating substantial agreement.

Table 1. Results of the within-session reliability analysis.

	ICC (95% confidence intervals)	% CV (95% confidence intervals)
Eccentric braking peak force left	0.971 (0.952-0.983)	5.5 (4.7-6.2)
Eccentric braking peak force right	0.952 (0.921-0.972)	6.1 (5.2-7.1)
Eccentric braking mean force left	0.979 (0.965-0.988)	5.0 (4.3-5.8)
Eccentric braking mean force right	0.964 (0.941-0.979)	5.4 (4.4-6.4)
Concentric propulsion peak force left	0.980 (0.967-0.988)	3.2 (2.6-3.9)
Concentric propulsion peak force right	0.974 (0.957-0.985)	3.2 (2.5-3.9)
Concentric propulsion mean force left	0.988 (0.980-0.993)	2.6 (2.2-3.0)
Concentric propulsion mean force right	0.976 (0.960-0.986)	3.0 (2.4-3.5)

Discussion and implications

The aim of this study was to assess the agreement between the peak and mean force methods of quantifying force asymmetry during vertical jumping. It was hypothesised that the peak and mean force methods of assessing force asymmetry during vertical jumping would agree perfectly. The results of this study showed substantial agreement between the two methods of assessing force asymmetry during vertical jumping.

However, while substantial agreement suggests a positive outcome, the hypothesis must be rejected because these methods did not agree perfectly.

While the results of this study show that there was substantial agreement between the peak and mean force methods of assessing force asymmetry during vertical jumping, it is important to note that this means that 28-33% of the cases in the present study did not agree. From an applied perspective, this means that if practitioners use these methods interchangeably significant confusion could surround the assessment of force asymmetry in around one third of their athletes. This could have serious implications for the athlete physical preparation and rehabilitation process. Therefore, we strongly recommend that these methods are not used interchangeably. Instead practitioners should decide on which approach they use based on the relative merits of each.

To the authors' knowledge, none of the researchers that have used peak force to quantify force asymmetry during vertical jumping have explained why they have done so (Bailey et al., 2015; Bell et al., 2014; Benjanuvatra et al., 2013; Ceroni, Martin, Delhumeau, & Farpour-Lambert, 2012; Hoffman, Ratamess, Klatt, Faigenbaum, & Kang, 2007; Impellizzeri et al., 2007; Menzel et al., 2013; Newton et al., 2006; Patterson et al., 2009; Suchomel, Sato, DeWeese, Ebben, & Stone, 2016). In the present study, peak force represented the highest force recorded over one sample during the phase of interest. It is important to note that because we used a sampling frequency of 1000 Hz peak force represents the highest force applied over 1 ms. Therefore, the practitioner should decide whether differences in the forces applied by the left and right side over 1 ms provide enough information to quantify force asymmetry. The literature awaits a rationale for the use of this approach. However, it should be noted that the peak force method provides insight into the symmetry strategy that an athlete uses to maximise their force application during CMJ.

In the present study mean force represented force averaged over the phase of interest. It has been suggested that this sort of approach might provide a more robust approach of assessing force asymmetry because it considers the entire phase of interest (Flanagan & Salem, 2007). Therefore, it could be argued that the mean force approach provides a more complete picture of force asymmetry. However, it should also be reiterated that only one study has suggested averaging variable(s) of interest over the phase(s) of interest (Flanagan & Salem, 2007). While the peak force approach might misrepresent force asymmetry by not considering enough of the phase of interest, it is entirely possible that the mean force approach could also misrepresent force asymmetry because it cannot consider the magnitude of differences across various sub-phases. Therefore, we recommend that practitioners and researchers should use a combined approach, studying both peak and mean force asymmetries over phases (and sub-phases) of interest. This will provide a far fuller picture about athlete force asymmetries.

While the results of this study provide some important information regarding the issues with agreement between the peak and mean force methods of assessing force asymmetry during vertical jumping, it is not without its limitations. For example, while both approaches are routinely used in the literature, force asymmetry cannot provide a complete picture of lower-body asymmetry. Recent work has shown that additional methods should be employed to gain a fuller understanding of athlete lower-body asymmetries (considering athlete strength [Bailey et al., 2015], and different calculation methods [Bishop et al., 2016; Impellizzeri et al., 2007]). However, it should also be noted that while additional methods have been employed there is still considerable work to be done. For example, we currently know nothing about force asymmetry driven changes in movement strategy and so this remains an important area of research that must be undertaken, in addition to the methods mentioned above, to obtain a thorough understanding of movement asymmetry. Finally, use of the terms 'dominant' and 'non-dominant' merits discussion. In the present study 'dominant' was applied to the side that was able to apply the largest peak and mean force. However, it should be noted that this term has also been used to describe the side that research participants favour, whether during day-to-day tasks, sport, or exercise, and that this does not always agree with the side that applies the largest forces (Bishop et al., 2016).

Conclusion

In conclusion, side-to-side differences are not reflected equally when the peak and mean force methods of assessing CMJ asymmetry are used. Therefore, the hypothesis was rejected. These methods should not be used interchangeably. Instead we recommend that practitioners use a combined approach, considering both peak and mean force, depending on the performance characteristics of concern. This will enable practitioners to more fully assess side-to-side difference in CMJ force-time curves.

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Figure and Table Captions

Figure 1. Identification of the braking and propulsion phases of countermovement vertical jumping.

Table 1. Results of the within-session reliability analysis.