Agreement between the force platform method and the combined method measurements of power output during the loaded countermovement jump

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Abstract

There are two perceived criterion methods for measuring power output during the loaded countermovement jump (CMJ): the force platform method and the combined method (force platform + optoelectronic motion capture system). Therefore, the primary aim of the present study was to assess agreement between the force platform method and the combined method measurements of peak power and mean power output during the CMJ across a spectrum of loads. Forty resistance-trained team sport athletes performed maximal effort CMJ with additional loads of 0 (body mass only), 25, 50, 75 and 100% of body mass (BM). Bias was present for peak velocity, mean velocity, peak power and mean power at all loads investigated, and present for mean force up to 75% of BM. Peak velocity, mean velocity, peak power and mean power 95% ratio limits of agreement were clinically unacceptable at all loads investigated. The 95% ratio limits of agreement were widest at 0% of BM and decreased linearly as load increased. Therefore, the force platform method and the combined method cannot be used interchangeably for measuring power output during the loaded CMJ. As such, if power output is to be meaningfully investigated, a standardised method must be adopted.

Introduction

The triple extension of the hips, knees and ankles is integral to the successful execution of a multitude of dynamic athletic tasks (e.g. jumping, sprinting and tackling). During such tasks, the lower extremities are inevitably loaded by the body's own mass, and often by the mass of an opponent. As such, training with external loads is an essential part of physical preparation for many athletes. Barbell-loaded jumping is one of the most commonly used forms of externally loaded jump training. It is postulated that ballistic movements such as barbell-loaded jumping allow the athlete to accelerate the system (body + external load) centre of mass (CM) throughout the entire push off phase producing greater velocity and power outputs than traditional non-ballistic movements (Frost, Cronin, & Newton, 2010). Therefore, the effects of barbell loading on system CM mechanics during countermovement jumping (CMJ) have been extensively investigated.

In particular, there has been a focus on the effects of barbell loading on the maximal production of power output (Cormie, McGuigan, & Newton, 2011; Jaric & Markovic, 2013). Such studies are typically based on the hypothesis that power output is a performance determining factor in a multitude of dynamic athletic tasks; however, it is important to note that the use of power output during jumping has also been heavily criticised (Knudson, 2009; Winter & Fowler, 2009; Winter & Knudson, 2011). To date, the results of such studies have been used for optimising resistance training programmes (Cormie et al., 2011; Kawamori & Haff, 2004), assessing and monitoring athletes (Sheppard, Cormack, Taylor, McGuigan, & Newton, 2008), discriminating between levels of competitive playing ability (Baker, 2002; Hansen, Cronin, Pickering, & Douglas, 2011) and understanding the design and function of the locomotor system (Jaric & Markovic, 2009, 2013). However, measuring power output during the loaded CMJ remains a contentious issue, with no criterion (‘gold standard’) method currently accepted within the literature (Cormie, Deane, & McBride, 2007; Cormie, McBride, & McCaulley, 2007; Dugan, Doyle, Humphries, Hasson, & Newton, 2004; Hori et al., 2007; Li, Olson, & Winchester, 2008). Therefore, if the theoretical and practical importance of measuring power output is to be investigated, it must be done so within a theoretically valid framework.

The force platform method (Hori et al., 2007; Li et al., 2008) and the combined method (Cormie, Deane, et al., 2007; Cormie, McBride, et al., 2007; Dugan et al., 2004) are the two most commonly used methods within the literature (Jaric & Markovic, 2013), with both argued to be the criterion method for calcualting power output. In brief, both methods ostensibly calculate the power output as the product of the force applied to the system CM and the velocity of the system CM. Both methods use force platform vertical ground reaction force (VGRF) data to represent the force applied to the system CM (Newton’s third law); however, the velocity used to represent the system CM is different within each method (Cormie, Deane, et al., 2007; Cormie, McBride, et al., 2007; Dugan et al., 2004; Hori et al., 2007; Li et al., 2008). Within the force platform method, the velocity of the system CM is calculated by the integration of force platform acceleration data (derived from Newton’s second law) (Cormie, McBride, et al., 2007; Dugan et al., 2004; Hori et al., 2007; Li et al., 2008). Conversely, within the combined method, the velocity of the system CM is calculated by the differentiation of displacement data of an Olympic barbell (or an aluminium, plastic or wooden bar alternative during the unloaded CMJ), which is collected using various motion capture equipment (e.g. a high-speed digital camera system (Li et al., 2008), a linear position transducer (Cormie, Deane, et al., 2007; Cormie, McBride, et al., 2007; Hori et al., 2007), two linear position transducers (Cormie, Deane, et al., 2007; Cormie, McBride, et al., 2007) or an optoelectronic motion capture system (Moir, Gollie, Davis, Guers, & Witmer, 2012).

The combined method is underpinned by the assumption that the velocity of the barbell is equivalent to the velocity of the system CM (Cormie, McBride, et al., 2007). When this assumption is violated, the combined method is not valid as it results in the calculation of erroneous power output values due to a mismatch of mechanical parameters (Hori et al., 2007; Lake, Lauder, & Smith, 2012; Li et al., 2008). Upon comparison, power output calculated by the combined method is often significantly greater than that of the force platform method (Cormie, McBride, et al., 2007; Hori et al., 2007; Li et al., 2008), suggesting that the combined method is not theoretically sound. However, statistical tests designed to test for significant differences (t-tests, ANOVA models and effect size) are not appropriate for determining whether two measurement methods are in agreement (McLaughlin, 2013). In context, agreement refers to how much the combined method is likely to differ from the force platform method: if this difference does not cause problems in clinical interpretation, then the two methods can be used interchangeably (Altman & Bland, 1983; Bland & Altman, 1986, 1999). To the authors’ knowledge, agreement between the force platform method and the combined method is yet to be assessed. Further, the influence that load may have on agreement is also yet to be assessed. Therefore, previous studies investigating the effects of loading on power output during the CMJ may be confounded by fundamental methodological issues.

The primary aim of the present study was to assess agreement between the force platform method and the combined method measurements of peak power and mean power output during the CMJ across a spectrum of loads. The secondary aim of this study was to assess agreement between measurements of the peak and mean force applied to the system CM and the peak and mean velocity of the system CM. It was hypothesised that the agreement between the force platform method and the combined method measurements of peak power, mean power, peak velocity and mean velocity would not be clinically acceptable at any load investigated. Conversely, it was hypothesised that the agreement between the force platform method and the combined method measurements of peak force and mean force would be clinically acceptable at all loads. Further, to enable comparisons with previous studies, it was hypothesised that peak power, mean power, peak velocity and mean velocity would be significantly different at all loads investigated. Conversely, it was hypothesised that peak force and mean force would not be significantly different at any load investigated.

Method

Participants

Forty male team sport athletes (M ± SD: age 22.5 ± 2.8 years, height 1.81 ± 0.05 m, BM 89.1 ± 12.4 kg) volunteered to participate in this study at the beginning of their respective preseason training period. All participants had at least two years of structured resistance training experience and were deemed technically proficient in the loaded CMJ during a familiarisation session. Following a verbal and written explanation of the procedures and potential risks, the participants provided their written, informed consent. This study was approved in accordance with the University of Chichester's Ethical Policy Framework for research involving the use of human participants.

Testing procedures Participants were instructed to report to the laboratory in a fully hydrated state, a minimum of two and a maximum of four hours postprandial, and having abstained from caffeine consumption. Further, participants were instructed to refrain from alcohol consumption and vigorous exercise for at least 48 h prior to data collection. Following a standardised warm-up (submaximal cycling, dynamic stretching and submaximal CMJ), participants performed two single maximal effort CMJ with additional loads of 0, 25, 50, 75 and 100% of BM. Additional loads of 25, 50, 75 and 100% of BM were applied by positioning an Olympic barbell across the posterior aspect of the shoulders. To allow the combined method to be used during the 0% of BM condition, a wooden bar of equal length yet negligible mass (0.7 kg) was placed across the posterior aspect of the shoulders (Cormie, McBride, et al., 2007). Participants were instructed to keep constant downward pressure on the Olympic barbell/wooden bar throughout each CMJ (Cormie, Deane, et al., 2007). All CMJ were performed utilising a standard technique (Cormie, Deane, et al., 2007; Hori et al., 2007), but no attempts were made to control the depth of the countermovement (Argus, Gill, Keogh, & Hopkins, 2011). One-minute rest was provided between each CMJ, with four-minute rest provided between each load (Nibali, Chapman, Robergs, & Drinkwater, 2013).

Equipment

All CMJ were performed on two parallel force platforms (Type 9851B, Kistler Instruments Ltd., Hook, UK) embedded in the laboratory floor, each capturing VGRF at 1000 Hz. A retro-reflective marker (14 mm) was placed on each end of the Olympic barbell/wooden bar. Three-dimensional (3D) retro-reflective marker position data were synchronously captured with VGRF at 250 Hz in VICON Nexus (Version 1.7.1; Vicon Motion Systems Ltd., Oxford, UK) using a 10-camera optoelectronic motion capture system (VICON MX T-Series (T40-S), Vicon Motion Systems Ltd., Oxford, UK).

Force platform method calculations

Instantaneous power was calculated as the product of the VGRF and the vertical velocity of the system CM. The vertical velocity of the system CM was obtained by the integration of acceleration data (derived from Newton's second law) using the trapezoidal rule (Owen, Watkins, Kilduff, Bevan, & Bennett, 2014). A quiet standing period of 1 s was recorded prior to the initiation of each respective CMJ to ensure an initial velocity of zero. System weight, from which system mass was calculated, was determined by averaging the summed VGRF over the 1 s quiet standing period (Owen et al., 2014; Street, McMillan, Board, Rasmussen, & Heneghan, 2001). The push off phase (commonly referred to as the concentric phase, the propulsion phase) was identified as beginning at the transition from negative (downward) to positive (upward) vertical velocity of the system CM and ending at take off (identified using a 10 N threshold).

Combined method calculations

As the combined method relies on the assumption that the vertical velocity of the Olympic barbell/wooden bar is equivalent to the vertical velocity of the system CM (Cormie, Deane, et al., 2007; Cormie, McBride, et al., 2007; Dugan et al., 2004; Hori et al., 2007), instantaneous power was calculated as the product of the VGRF and the vertical velocity of the Olympic barbell/wooden bar. It is important to note that VGRF was down sampled to 250 Hz to match position data, and is therefore different to the VGRF used within the force platform method. To reduce error associated with asymmetric lifting technique, the geometric centre of the Olympic barbell/wooden bar was calculated from the respective end points. Vertical velocity was then calculated by differentiating Olympic barbell/wooden bar displacement using the finite difference method. The push off phase was identified as beginning at the transition from negative (downward) to positive (upward) velocity of the Olympic barbell/wooden bar and ending at take off. Based on a residual analysis, position data were filtered using a fourth-order zero-lag Butterworth filter with a cut-off frequency of 5 Hz (Winter, 2009).

For each method, peak force, peak velocity and peak power were identified as the greatest instantaneous value of the respective signal within the push off phase, whereas mean force mean velocity, and mean power were determined by averaging the respective signal over the push off phase. Both peak and mean values were investigated as they are commonly reported within the literature (Jaric & Markovic, 2013). Further, only vertical components were considered as approximately 97% of the total power output during the push off phase of an unloaded CMJ is used for vertical propulsion (Hatze, 1998). The trial with the greatest mean power output calculated by the force platform method was selected from each additional load for further analysis.

Statistical analyses

Separate analyses were conducted for each dependent variable at each load. Following checks for normality and uniform distribution, the mean of the differences, the standard deviation of the differences and the 95% limits of agreement (LOA: M of the differences ± 1.96 SD) were calculated on base 10 logarithmically transformed data using methods described by Bland and Altman (Altman & Bland, 1983; Bland & Altman, 1986, 1999). Clinically unacceptable LOA were determined a priori as a ratio of greater than 0.05, which equates to ± 5% (Hansen, Cronin, & Newton, 2011). It was inferred that bias was present if the 95% confidence interval (CI) of the mean of the differences did not include the ratio 1.00. To enable comparisons with previous studies, paired t-tests were also used to examine bias (Altman & Bland, 1983). Alpha was set a priori at $\alpha = 0.05$.

Results

The combined method calculations of mean force, peak velocity, mean velocity, peak power and mean power were significantly ($p < 0.0001$) greater than the force platform method calculations at all loads. Conversely, at all loads, there were no significant differences between calculations of peak force.

Bias was present for peak velocity, mean velocity, peak power and mean power at all loads investigated (Tables 1 and 2). Further, bias was also present for mean force at loads of 0, 25, 50 and 75% of BM (Table 3). In contrast, bias was absent for mean force calculations at 100% of BM, and at all loads for peak force calculations (Table 3). Peak velocity, mean velocity, peak power and mean power LOA were clinically unacceptable at all loads (Tables 1 and 2), whereas peak force and mean force LOA were clinically acceptable at all loads investigated (Table 3).

Discussion and implications

To the best of the authors' knowledge, no criterion method for measuring power output during the loaded CMJ has been accepted within the literature (Cormie, Deane, et al., 2007; Cormie, McBride, et al., 2007; Dugan et al., 2004; Hori et al., 2007; Li et al., 2008). Therefore, the primary aim of the present study was to assess agreement between the two most commonly reported criterion methods: the force platform method (Hori et al., 2007; Li et al., 2008) and the combined method (Cormie, Deane, et al., 2007; Cormie, McBride, et al., 2007; Dugan et al., 2004). It was hypothesised that the agreement between the force platform method and the combined method measurements of peak power and mean power would not be clinically acceptable at any load investigated. It was found that peak power and mean power were limited by the presence of bias and clinically unacceptable LOA at all loads investigated. Therefore, depending on which method is deemed to be the criterion method, previous studies must be interpreted with caution, as fundamental methodological issues may confound the results. Consequently, standardisation within the literature is of paramount importance if power output is to be meaningfully investigated (Cronin & Sleivert, 2005; Li et al., 2008).

There is a strong argument for the force platform method to be considered the criterion method for measuring power output during the loaded CMJ. The force platform method is derived from Newton's second law, whereby the motion of the CM is fully determined by the system's mass, the forces applied to the system CM and the initial velocity of the system CM (Cavagna, 1975). Therefore, the possible sources of error originate from the force platform electronics, the analog-to-digital conversion and the data processing (Kibele, 1998). Recently, Owen et al. (2014) presented excellent guidelines for calculating peak power output during the unloaded CMJ, which produced errors of less than 1% ($p < 0.05$). Further, the possible sources of error when integrating force platform data have been extensively documented, and necessary precautions for minimising error within VGRF and velocity data presented (Kibele, 1998; Street et al., 2001; Vanrenterghem, De Clercq, & Cleven, 2001). In spite of this, the combined method is the most commonly reported method within the literature (Jaric & Markovic, 2013).

It has been suggested that the combined method overcomes the disadvantages of the force platform method: it uses accurate force platform VGRF data to represent the force applied to the system CM, but ostensibly requires less 'data manipulation' to calculate the velocity of the system CM, thus decreasing the risk of accumulating error (Cormie, McBride, et al., 2007; Dugan et al., 2004). In terms of 'data manipulation' the force platform method requires acceleration to be integrated with respect to time, whereas the combined method requires displacement to be differentiated with respect to time. Upon comparison, these two types of 'data manipulation' yield a different outcome with regards to noise: integration suppresses noise in the velocity signal, whereas differentiation amplifies noise in the velocity signal. As such, the combined method requires a further 'data manipulation' known as filtering, which introduces potential error due to over smoothing or under smoothing of the true signal (Winter, 2009). Conversely, filtering of CMJ VGRF data is not require (Street et al., 2001), meaning the combined method in fact appears to increase the risk of accumulating error. Moreover, there appears to be no consensus on the equipment used to collect displacement data, with various motion capture equipment reported within the literature (e.g. a high-speed digital camera system (Li et al., 2008), a linear position transducer (Cormie, Deane, et al., 2007; Cormie, McBride, et al., 2007; Hori et al., 2007), two linear position transducers (Cormie, Deane, et al., 2007; Cormie, McBride, et al., 2007) or an optoelectronic motion capture system (Moir et al., 2012). Therefore, paradoxically, not only is the combined method less accessible to sport scientists and strength and conditioning coaches, but the combined method does not logically improve the measurement of power output during the unloaded or loaded CMJ.

For the calculation of power output to be meaningful, the calculation must be made using the correct theoretical framework (Lake et al., 2012; Li et al., 2008); that is, power output must be calculated as the product of the force applied to the system CM and the velocity of the system CM. Therefore, the secondary aim of this study was to assess agreement between measurements of the force applied to the system CM and the velocity of the system CM. It was hypothesised that the agreement between the force platform method and the combined method measurements of peak force and mean force would be clinically acceptable at all loads investigated. Further, to enable comparisons with previous studies, it was hypothesised that peak force and mean force would not be significantly different at any load investigated. In line with previous studies (Cormie, McBride, et al., 2007; Hori et al., 2007), the present study found no significant differences between calculations of peak force. Conversely, the combined method measurements of mean force were significantly greater than the force platform method measurements at all loads. This may be explained by the different sampling frequencies and phase identification methods used between the force platform method and the combined method, which were kept constant by Cormie et al. (2007). However, despite the statistical significance, mean force LOA were clinically acceptable at all loads investigated. As such, the methods could be used interchangeably within practice for calculating mean force despite the methodological differences. At the 0% of BM condition where the mean force LOA were widest, 95% of the combined method observations were between 0% and 3% greater than the force platform method. Practically speaking, using the present studies group mean as an example, this equates to 0 and 47 N, respectively. Therefore, it is unlikely that the differences in VGRF used within each method explains the presence of bias and clinically unacceptable LOA reported for peak power and mean power. Further, these findings highlight the limitation of using statistical tests designed to test for significant differences when determining agreement (McLaughlin, 2013).

The clinically unacceptable peak power and mean power LOA are likely explained by the velocity used to represent the system CM in each method. A concern with the combined method is the underpinning assumption that the velocity of the Olympic barbell/wooden bar is equivalent to the velocity of the system CM (Hori et al., 2007; Lake et al., 2012; Li et al., 2008). When this assumption is violated, it results in the calculation of erroneous power output values due to a mismatch of mechanical parameters (Lake et al., 2012; Li et al., 2008). In the present study, as hypothesised, comparison of the theoretically sound force platform method peak velocity and mean velocity to the combined method peak velocity and mean velocity revealed the presence of bias and clinically unacceptable LOA at all loads. Therefore, the presence of bias and clinically unacceptable LOA reported for peak power and mean power are most likely explained by the erroneous assumption that the velocity of Olympic barbell/wooden bar is equivalent to the velocity of the system CM

(Hori et al., 2007; Lake et al., 2012; Li et al., 2008).

It is important to note that although still clinically unacceptable, the peak power and mean power LOA improved as load increased. At the 0% of BM condition where the mean power LOA were widest, 95% of the combined method observations were between 28 and 63% greater than the force platform method. Practically speaking, using the present studies group mean as an example, this equates to 615 and 1384 W, respectively. Conversely, at the 100% of BM condition where the LOA were narrowest, 95% of the combined method observations were between −5% and 38% of the force platform method, which equates to −86 and 655 W. This suggests that the assumption underpinning the combined method depends on the loads investigated. A possible explanation is that as load increases, the position of the system CM moves upwards to the superior position of the Olympic barbell, making the Olympic barbell a better representation of the system CM. Further considerations are the depth of the countermovement (Argus et al., 2011; Bobbert, 2014) and the forward inclination of the trunk (Lees, Vanrenterghem, & De Clercq, 2004; Swinton, Stewart, Lloyd, Agouris, & Keogh, 2012), both of which may decrease as load increases. With a decrease in either, the Olympic barbell may become more likely to move in a vertical and linear path with the system CM (Chiu, Schilling, Fry, & Weiss, 2004), consequently improving agreement. However, controlling the depth of the countermovement (Argus et al., 2011) or the forward inclination of the trunk (Lees et al., 2004) may limit the work done during the unloaded and loaded CMJ. Thus, in line with previous studies (Cormie, McBride, et al., 2007; Hori et al., 2007; Li et al., 2008), the present study did not stringently control for either to ensure ecological validity. Therefore, further investigation of both system and segmental kinematic data may be warranted to explain the true aetiology of this clinically unacceptable agreement (Lake et al., 2012).

Conclusions

The force platform method and the combined method cannot be used interchangeably within practice for measuring peak and mean power output during the loaded CMJ between loads of 0 and 100% of BM. A growing body of research, the present study included, suggests that this may be because the velocity of the Olympic barbell is not equivalent to the velocity of the system CM (Hori et al., 2007; Lake et al., 2012; Li et al., 2008), which is a key assumption underpinning the combined method (Cormie, Deane, et al., 2007; Cormie, McBride, et al., 2007; Dugan et al., 2004). Therefore, previous studies using the combined method should be interpreted with caution, particularly when comparisons are made between loads. Further, as agreement was influenced by load, comparisons between previous studies using the force platform method and the combined method should also be made with caution. As such, the authors discourage researchers and practitioners against using the combined method for measuring power output during the unloaded and loaded CMJ. However, it is important to note that the aim of the present study was not to discredit the work of previous authors by pointing out methodological flaws. The intention was to provide steps towards a standardised method of measuring power output. Therefore, it is proposed that the force platform method be used as the criterion method for measuring power output during the unloaded and loaded CMJ.

Disclosure statement

No potential conflict of interest was reported by the authors.

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Table 1. Group descriptive statistics and 95% ratio limits of agreement for peak power and mean power.

		Force platform method		Combined method		Ratio 95% limits of agreement‡						
						Differences						
		M	*SD*	*M*	*SD*	*M*	[95% CI]	*SD*	Lower limit	[95% CI]	Upper limit	[95% CI]
Peak power (W)	+0% BM	4,132	600	5,432	773	1.31*	[1.29–1.34]**	0.06	1.17	[1.13–1.21]	1.48	[1.43–1.53]
	+25% BM	4,026	565	4,993	705	1.24*	[1.22–1.26]**	0.04	1.14	[1.12–1.17]	1.34	[1.31–1.38]
	+50% BM	4,044	573	4,759	646	1.18*	[1.16–1.19]**	0.05	1.08	[1.05–1.10]	1.29	[1.26–1.32]
	+75% BM	3,967	588	4,487	660	1.13*	[1.11–1.15]**	0.06	1.00	[0.97–1.04]	1.27	[1.23–1.32]
	+100% BM	3,752	595	4,197	648	1.12*	[1.09–1.15]**	0.09	0.94	[0.90–0.99]	1.33	[1.27–1.39]
Mean power (W)	+0% BM	2,198	346	3,177	514	1.44*	[1.42–1.47]**	0.06	1.28	[1.23–1.32]	1.63	[1.58–1.69]
	+25% BM	2,085	320	2,705	395	1.30*	[1.28–1.32]**	0.04	1.20	[1.17–1.23]	1.41	[1.38–1.44]
	+50% BM	2,005	297	2,446	361	1.22*	[1.20–1.24]**	0.05	1.11	[1.08–1.14]	1.34	[1.30–1.37]
	+75% BM	1,900	296	2,213	349	1.16*	[1.14–1.19]**	0.06	1.03	[0.99–1.07]	1.32	[1.27–1.36]
	+100% BM	1,726	311	1,977	377	1.14*	[1.11–1.18]**	0.10	0.95	[0.90–1.00]	1.38	[1.31–1.45]

Notes: *SD* = Standard deviation; CI = Confidence interval; BM = Body mass.

*Indicates a significant difference ($p < 0.0001$) between the means.

**Indicates the presence of bias.

‡A ratio of >1.00 indicates that the combined method gave a higher estimate than the force platform method.

Table 2. Group descriptive statistics and 95% ratio limits of agreement for peak velocity and mean velocity.

		Force platform method		Combined method		Ratio 95% limits of agreement‡						
						Differences						
		M	*SD*	*M*	*SD*	*M*	[95% CI]	*SD*	Lower limit	[95% CI]	Upper limit	[95% CI]
Peak velocity (m/s)	+0% BM	2.63	0.22	3.09	0.38	1.17*	[1.15–1.20]**	0.07	1.02	[0.99–1.06]	1.34	[1.29–1.39]
	+25% BM	2.30	0.20	2.66	0.27	1.15*	[1.14–1.17]**	0.05	1.06	[1.03–1.08]	1.26	[1.23–1.29]
	+50% BM	2.06	0.20	2.30	0.23	1.12*	[1.10–1.13]**	0.05	1.02	[1.00–1.05]	1.22	[1.19–1.25]
	+75% BM	1.85	0.22	2.02	0.21	1.09*	[1.07–1.11]**	0.06	0.98	[0.95–1.01]	1.22	[1.19–1.26]
	+100% BM	1.61	0.21	1.77	0.20	1.10*	[1.07–1.13]**	0.09	0.94	[0.90–0.98]	1.30	[1.24–1.36]
Mean velocity (m/s)	+0% BM	1.50	0.13	2.07	0.25	1.37*	[1.34–1.40]**	0.07	1.20	[1.16–1.25]	1.56	[1.51–1.62]
	+25% BM	1.31	0.12	1.65	0.17	1.26*	[1.24–1.28]**	0.04	1.16	[1.14–1.19]	1.37	[1.34–1.40]
	+50% BM	1.14	0.11	1.36	0.14	1.19*	[1.17–1.21]**	0.05	1.09	[1.06–1.12]	1.31	[1.27–1.34]
	+75% BM	1.00	0.12	1.14	0.13	1.14*	[1.12–1.16]**	0.06	1.02	[0.99–1.05]	1.28	[1.24–1.32]
	+100% BM	0.84	0.11	0.95	0.12	1.13*	[1.10–1.16]**	0.09	0.95	[0.90–1.00]	1.34	[1.28–1.41]

Notes: *SD* = Standard deviation; CI = Confidence interval; BM = Body mass.
*Indicates a significant difference ($p < 0.0001$) between the means.
**Indicates the presence of bias.
‡A ratio of >1.00 indicates that the Combined Method gave a higher estimate than the Force Platform Method.

Table 3. Group descriptive statistics and 95% ratio limits of agreement for peak force and mean force.

		Force platform method		Combined method		Ratio 95% Limits of Agreement‡						
						Differences						
		M	*SD*	*M*	*SD*	*M*	[95% CI]	*SD*	Lower limit	[95% CI]	Upper limit	[95% CI]
Peak force (N)	+0% BM	2,000	330	1,999	330	1.00	[1.00–1.00]	0.00	1.00	[1.00–1.00]	1.00	[1.00–1.00]
	+25% BM	2,122	308	2,124	309	1.00	[1.00–1.00]	0.00	1.00	[1.00–1.00]	1.00	[1.00–1.01]
	+50% BM	2,292	294	2,292	293	1.00	[1.00–1.00]	0.00	1.00	[0.99–1.00]	1.00	[1.00–1.01]
	+75% BM	2,467	326	2,464	327	1.00	[1.00–1.00]	0.00	0.99	[0.99–0.99]	1.01	[1.01–1.01]
	+100% BM	2,650	374	2,649	374	1.00	[1.00–1.00]	0.00	1.00	[1.00–1.00]	1.00	[1.00–1.00]
Mean force (N)	+0% BM	1,593	252	1,616	258	1.01*	[1.01–1.02]**	0.01	1.00	[1.00–1.01]	1.03	[1.02–1.03]
	+25% BM	1,721	259	1,738	261	1.01*	[1.01–1.01]**	0.00	1.00	[1.00–1.00]	1.02	[1.02–1.02]
	+50% BM	1,878	264	1,891	267	1.01*	[1.01–1.01]**	0.00	1.00	[1.00–1.00]	1.01	[1.01–1.02]
	+75% BM	2,016	290	2,029	295	1.01*	[1.01–1.01]**	0.00	1.00	[0.99–1.00]	1.02	[1.01–1.02]
	+100% BM	2,152	314	2,168	322	1.01*	[1.00–1.01]	0.01	0.99	[0.99–1.00]	1.02	[1.02–1.02]

Notes: *SD* = Standard deviation; CI = Confidence interval; BM = Body mass.
*Indicates a significant difference ($p < 0.0001$) between the means.
**Indicates the presence of bias.
‡A ratio of >1.00 indicates that the combined method gave a higher estimate than the force platform method.