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Validity of a Jump Mat for assessing Countermovement Jump Performance in Elite Rugby Players

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Abstract

This study determined the validity of the Just Jump System® (JJS) for measuring flight time, jump height and peak power output (PPO) in elite rugby league players. 37 elite rugby league players performed 6 countermovement jumps (CMJ; 3 *with* and 3 *without* arms) on a jump mat and force platform. A sub-sample (n = 28) was used to cross-validate the equations for flight time, jump height and PPO. The JJS systematically overestimated flight time and jump height compared to the force platform ($P < 0.05$), but demonstrated strong associations for flight time (*with* $R^2 = 0.938$; *without* $R^2 = 0.972$) and jump height (*with* $R^2 = 0.945$; *without* $R^2 = 0.987$). Our equations revealed no systematic difference between corrected and force platform scores and an improved the agreement for flight time (Ratio limits of agreement: *with* 1.00 vs. 1.36; *without* 1.00 vs. 1.16) and jump height (*with* 1.01 vs. 1.34; *without* 1.01 vs. 1.15), meaning that our equations can be used to correct JJS scores for elite rugby players. While our equation improved the estimation of PPO (*with* 1.02; *without* 1.01) compared to existing equations (Harman: 1.20; Sayers: 1.04), this only accounted for 64 and 69% of PPO.

Introduction

Rugby league is a multiple sprint collision sport that requires highly developed physical qualities [5, 15, 23, 33]. Of these, lower-body power has been identified as an essential quality for rugby league players [5, 10–14], showing strong associations with successful skill execution (i.e., tackling proficiency) [11, 12, 33, 38] and reducing post-match fatigue [20, 21]. Countermovement jump (CMJ) performance differentiates between starters and non-starters [12], playing standard (club cf. international) [35] and playing position [13, 22]. Therefore, CMJ is regularly employed by practitioners to assess the effectiveness of a conditioning programme [29, 34, 26, 39], to profile players and identify talent [35] and to monitor recovery status [21, 27, 36, 37].

Whereas video analysis and force platforms are recognised as criterion methods for measuring jump height, flight time and muscle power, these are expensive and not easily accessible for most rugby league clubs [18, 25, 31]. Flight time and jump height during the CMJ are routinely measured by rugby league practitioners using commercially available equipment such as the Just Jump System® (JJS), to provide estimates of jump performance [28, 30, 39]. However, the ability of the JJS to accurately measure flight time and jump height has recently been questioned [28, 39]. The authors reported that flight time and jump height measured on the JJS and force platform are highly related but that flight time is on average 105 ms longer on the JJS resulting in an overestimation of jump height [28, 39]. Whilst both studies provided a correction equation for the measurement of jump height, neither provided a correction equation for the measurement of flight time, which has been reported to be a more reliable determinant of jump performance [6]. Also, the equations provided were not cross-validated using a sub-sample and therefore their agreement with the criterion method is unknown. Although the authors [28, 39] reported a strong correlation between methods, the random error associated with these measurements was not assessed and therefore the application of these corrected equations in the applied environment also remains unknown.

As jump mats are unable to measure muscle power, several prediction equations have been developed that allow practitioners to calculate

muscle power using jump height and body mass [4,7,16,32]. Whilst some prediction equations demonstrate no systematic difference to power recorded on a force platform [16], the accuracy of the equation is highly dependent upon the population it is derived from [25]. For example, the use of previously established prediction equations [16,32] for estimating muscle power in specifically trained team sport athletes are known to underestimate true PPO by 3.3–19.4% [8,18].

In professional rugby league, where the accurate assessment of CMJ performance using a jump mat seems important, recently developed prediction equations [28,39] are not suitable given that they were developed using non-elite populations. Moreover, where the assessment of muscle power is of interest [38] the application of established prediction equations might result in an underestimation of the player's actual PPO. Therefore, the aims of this study were to: a) quantify the difference in jump height and flight time between the JJS and force platform and, if required, develop and cross-validate a correction equation for elite rugby league players; and b) develop and cross-validate a prediction equation for PPO in elite rugby league players.

Material & Methods

Participants and design

With institutional ethics approval and informed consent, 37 elite senior rugby league players from 2 professional Super League teams (age = 23.3 ± 4.0 y, stature = 182.0 ± 5.5 cm, body mass = 96.8 ± 9.0 kg) participated in this study. A sub-sample of 28 elite senior players from one professional Super League club (age = 23.4 ± 4.3 y, stature = 181.9 ± 5.5 cm, body mass = 96.1 ± 9.0 kg) was later recruited to cross-validate the equations for jump height, flight time and PPO. All testing procedures were conducted in accordance with the ethical standards of the International Journal of Sports Medicine [17].

In one visit, participants completed one practice jump followed by 6 CMJs, 3 using their arms (*with* arms; $n = 111$) and 3 with their hands on their hips (*without* arms; $n = 108$), interspersed by 60 s recovery between jumps. All participants were familiar with the procedures as this was part of their weekly monitoring processes. To cross-validate the data, the sub-sample of participants attended a second session 5 days after the first at a similar time of day (± 2 h) and completed 2 CMJs, one *with* ($n = 28$) and one *without* arms ($n = 28$), interspersed by 60 s recovery.

Procedures

For the CMJ, participants maintained a stance with feet positioned shoulder width apart before flexing their knees in a rapid downward motion and extending into the jump. To standardise the jumps participants had to have been judged to reach approximately 90° knee flexion [37] and keep their legs straight throughout the jump (i.e., not lifting knees or bringing their heels towards their buttocks). Those jumps ($n = 3$ *without* arms) that did not meet these criteria were excluded from the analysis. Each jump was performed on a timing mat (Just Jump System, Probotics, Huntsville, Alabama, USA) that was positioned on top of a 600 × 600 mm uni-axial calibrated force platform (HUR Labs, FP4, Tampere, Finland) sampling at 1 200 Hz. The jump mat was positioned on the force platform before calibration and allowed both apparatus to record measurements simultaneously [25]. Both flight time and jump height derived from the JJS and force platform were displayed on a hand held computer and on custom software (HUR Labs Force Platform Software Suite), with jump height calculated using the following equation [24]:

$$\text{Jump height} = (\text{flight time}^2 \times g)\ 8^{-1}$$

In this equation, g denotes the acceleration of gravity ($9.81\ \text{m} \times \text{s}^{-2}$). For the JJS, flight time was measured as the time the participant was in the air and was detected by the micro switches embedded within the mat sampling at 100 Hz [39]. For the force platform, flight time was also determined as the time the participant was in the air with < 5 N being used to detect take-off and > 50 N for landing. To ascertain PPO the force platform used the following in-built equations:

$$\text{Force} = \text{average force at point of take-off and landing}$$

$$\text{Momentum} = (\text{momentum} + \text{average force}) \times (1/1200)$$

$$\text{Impulse} = (\text{momentum} \times \text{impulse} / \text{weight} \times 1) \times (1/1200)$$

$$\text{PPO} = (\text{force} \times \text{impulse} / \text{mass})$$

The within-session coefficient of variation for flight time during the first session was 4.8 and 5.0% for *with* and *without* arms, respectively.

Statistical analyses

Data were initially checked for normality via the Kolmogorov-Smirnov statistic before using Pearson product-moment correlation (r-value) to check for heteroscedastic errors. Data that demonstrated heteroscadascity was log-transformed to reduce the error [2]. Paired sample t-tests were used to calculate differences (biases) between means of measurement methods. In order to make comparisons, the coefficient of variation (CV: SD/Mean × 100) was also used to assess validity and was quantified in accordance with previous research [2]. Linear and multiple regression analysis was used to determine a correction equation for flight time and jump height and to develop a new prediction equation for PPO. Collinearity was assessed before the multiple regression and indicated that there was a high collinearity between jump height and flight time (*with* $r = 0.992$; *without* $r = 0.996$), hence jump height was excluded. Weak collinearity (*with* $r = -0.366$; *without* $r = -0.292$) existed between flight time and body mass, with both variables contributing significantly to predictive model. Data are reported as mean and standard deviation(s) throughout and analysed using SPSS for Windows (Version 22.0, 2013).

Results

There was a positive relationship between CMJ flight time derived from the JJS and force platform *with* ($r = 0.969$, $P < 0.001$) and *without* ($r = 0.986$, $P < 0.001$) arms, which resulted in adjusted coefficient of determinations (R^2) of 0.938 and 0.972, respectively (**Fig. 1**). A positive relationship was also present between jump height derived from the JJS and force platform *with* ($r = 0.972$, $P < 0.001$) and *without* arms ($r = 0.994$, $P < 0.001$), resulting in adjusted R^2 values of 0.945 and 0.988, respectively. Despite the strong relationship between methods, ratio LoA indicated that there was a systematic ($P < 0.05$) overestimation of

flight time and jump height, *with* and *without* arms using the JJS compared to the force platform (**Table 1**). Given the near perfect R^2 between the 2 systems, linear regression analysis was used to establish 4 correction equations, allowing practitioners within the field of rugby league to accurately measure jump height and/or flight time *with* and *without* arms from the JJS (**Fig. 1**).

The adjusted R^2 between criterion and corrected flight time and jump height *with* and *without* arms were strong (**Fig. 1**) and demonstrated a reduced systematic bias ($P>0.05$) compared to the uncorrected scores (**Table 2**). Cross-validation analyses for flight time and jump height revealed an adjusted R^2 (flight time: *with* 0.924; *without* 0.966; jump height: *with* 0.914; *without* 0.937) that represented a shrinkage of 2.22, 2.23, 2.56 and 3.60%, respectively.

Stepwise regression analysis was used to predict PPO (W) from flight time (s) and body mass (kg). The 2 predictor variables accounted for a significant proportion of variability in PPO, *with* (adjusted $R^2=0.642$, $F=96.52$, $P<0.001$) and *without* arms (adjusted $R^2=0.691$, $F=111.34$, $P<0.001$). However, the regression model for PPO *with* ($PP_{est}=12\,413.90\times$(flight time)$+58.77\times$(body mass)$-7\,383.05$) and *without* arms ($PP_{est}=8\,167.97\times$(flight time)$+49.13\times$(body mass)$-4\,390.76$) showed a large degree of random error (**Table 3**). Cross-validation analysis revealed an adjusted R^2 (*with* 0.613; *without* 0.654) that represented shrinkage of 4.52 and 5.36% relative to the cross-validation model (*with* 64.2%; *without* 69.1%).

Discussion

The primary aim of this study was to establish the criterion validity of the JJS against a force platform for measuring flight time and jump height during a CMJ in elite rugby league players. In accordance with previous studies [28, 39], we report a systematic overestimation of flight time and jump height derived from the JJS. On average, flight time was 85 ms longer using the JJS compared to the force platform, which resulted in an overestimated jump height of ~13 cm. The ratio LoA indicated that for a player with a flight time of 0.50 s using the force platform, they could, in the worst case scenario, achieve a value between 0.56 and 0.59 s *with* and 0.56 and 0.60 s *without* arms when using the JJS. Furthermore, the ratio LoA for jump height indicated that a player who jumped 30 cm using the force platform, could jump between 37.9 and 42.6 cm and 38.9 and 42.8 cm *with* and *without* arms, respectively, when measured using the JJS. Our findings reaffirm previous work [28, 39] that the JJS does not provide a valid measure of flight time or jump height during a CMJ.

Several reasons might explain the observed differences between measurement systems. McMahon et al. [28] suggested that jump height might have been overestimated due to the JJS requiring a large minimal force for the microswitches within the mat to detect the take-off and landing during the CMJ. Whilst this might explain some of the difference, it is important to note that the JJS does not directly measure jump height but calculates this from fight time. Therefore, any delay in the microswitches to detect the landing is likely to results in a large overestimation in flight time. Whitmere et al. [39] proposed that due to the consistent differences between methods, approximately 100 ms have been added

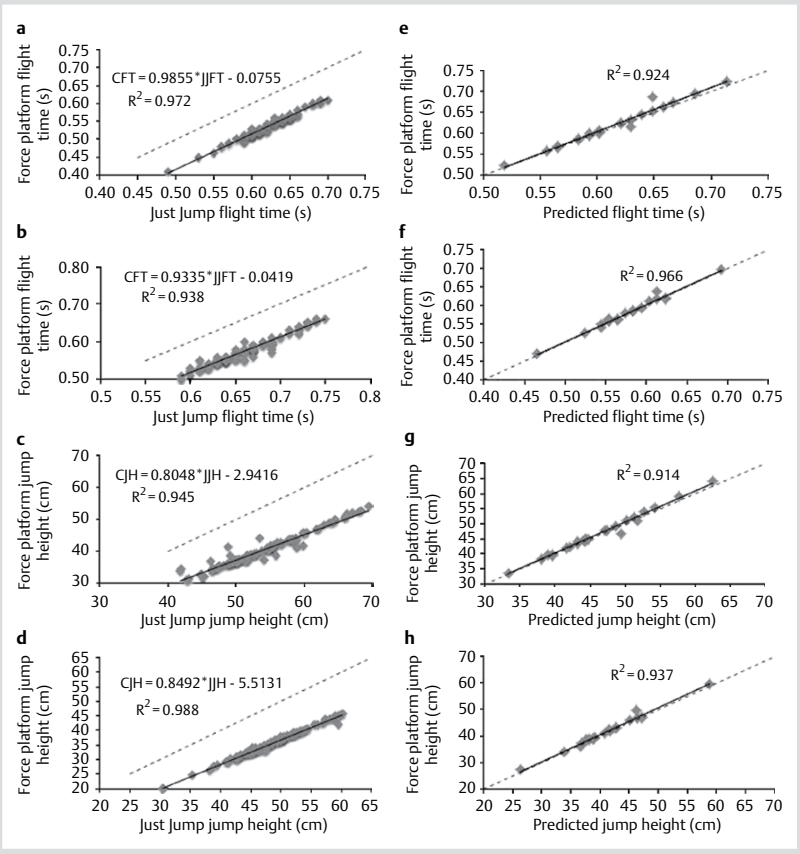

Fig. 1 Relationship between JJS and force platform for flight time *with* (**a** $n=111$) and *without* (**b** $n=108$) arms and jump height *with* (**c** $n=111$) and *without* (**d** $n=108$) arms and the relationship between the correction equation and force platform for flight time *with* (**e** $n=28$) and *without* (**f** $n=28$) arms and jump height *with* (**g** $n=28$) and *without* (**h** $n=28$) arms. R^2 = adjusted coefficient of determination. CFT = criterion flight time, JJFT = Just Jump flight time, CJH = criterion jump height and JJH = Just Jump height). The dashed line represents the line of identity (force platform = Just Jump System).

	Just Jump®	Force platform	Ratio 95% LoA	CV%	Adjusted R^2
Jump height (cm)					
With arms	53.69 ± 6.14 *	40.28 ± 5.10	1.34 × / ÷ 1.06	18.68	0.938
Without arms	48.62 ± 5.51 *	35.81 ± 4.72	1.15 × / ÷ 1.03	19.48	0.972
Flight time (s)					
With arms	0.66 ± 0.04 *	0.57 ± 0.04	1.36 × / ÷ 1.05	9.15	0.945
Without arms	0.62 ± 0.03 *	0.54 ± 0.03	1.16 × / ÷ 1.03	9.40	0.988

LoA = limits of agreement. CV% = coefficient of variation. * Significantly higher than criterion ($P < 0.05$)

Table 1 Validity of Just Jump® against force platform to measure jump height and flight time.

	Corrected	Force platform	95% Ratio LoA	CV%	Adjusted R^2
Jump height (cm)					
With arms	45.99 ± 5.69	46.36 ± 6.06	1.01 × / ÷ 1.17	14.35	0.924
Without arms	41.00 ± 4.87	41.36 ± 5.70	1.01 × / ÷ 1.19	14.43	0.966
Flight time (s)					
With Arms	0.61 ± 0.04	0.62 ± 0.05	1.00 × / ÷ 1.13	7.34	0.914
Without arms	0.58 ± 0.03	0.58 ± 0.41	1.00 × / ÷ 1.11	7.20	0.937

LoA = limits of agreement. CV% = coefficient of variation. * Significantly higher than criterion ($P < 0.05$). Shrinkage = 2.22 and 2.23% for jump height and 2.56 and 3.60 for flight time *with* and *without* arms, respectively

Table 2 Validity of correction equations against measured jump height and flight time using cross-validation sample.

	Peak power output (W)	SEE	Ratio 95% LoA	CV%	Adjusted R^2
Measured					
With arms	5 846.9 ± 651.6	–	–		–
Without arms	5 048.2 ± 589.0	–	–		–
Predicted					
With arms	5 930.0 ± 603.2	410.6	1.02 × / ÷ 1.17	10.69	0.613
Without arms	5 060.4 ± 479.0	310.0	1.01 × / ÷ 1.15	10.91	0.654
Harman et al. (1991)					
Without arms	4 205.6 ± 417.3 *	–	1.20 × / ÷ 1.16	14.55	0.77
Sayers et al. (1999)					
Without arms	4 837.7 ± 458.3 *	–	1.04 × / ÷ 1.16	11.18	0.78

SEE = standard error of estimate. LoA = limits of agreement. CV% = coefficient of variation. * Significantly different to actual peak power ($P < 0.05$). Shrinkage = 4.52 and 5.36% for *with* and *without* arms, respectively

Table 3 Validity of prediction equations for peak power.

to the algorithm used to calculate flight time. However, as the algorithms used are unknown, it is difficult to conclude that this is the case, despite our results showing a similar trend. The observed difference might also be explained by the higher sampling frequency of the force platform (1 200 Hz) compared to the JJS (100 Hz). Such large differences are likely to result in different detection rates during the take-off and landing, influencing the accuracy of flight time and subsequently jump height.

Using the correction equations, results revealed that the accuracy of flight time and jump height were improved (**Table 2**) and could, therefore, be used by practitioners to accurately measure jump performance. The results indicate that the correction equations removed the over-estimation created by the JJS and reduced the mean bias. As a result, the potential range of scores achieved now encompasses the measured score and therefore, one can be 95% confident that the same participant who scored 30 cm on their first trial (*with arms*), could score between 25.8 and 35.4 cm during their second trial. Based on these calculations, it appears that the JJS and the correction equation are, in some cases, not sensitive enough to detect small, but potentially meaningful changes in jump performance. For example, Gabbett [14] reported a 4.2 cm increase in CMJ performance in junior rugby league players after a 14-week training intervention. Based on our analysis, it is possible, in some cases, this improvement would not be detected using the JJS or the correction equation due to the large random error associated with this method.

The second aim of this study was to develop an equation for predicting PPO in elite rugby league players. Whereas previous work has used jump height [28, 39], our analysis indicated that flight time was a better predictor of PPO. The use of flight time is somewhat understandable since it is measured directly by the JJS and is a more reliable performance indicator of jump performance [6]. The results support previous observations [8, 18] that PPO estimated using equations derived from non-elite populations underestimates true PPO in well-trained athletes [16, 32]. The ratio LoA indicated that there was a systematic under-estimation of PPO when using the Harman et al. [16] and Sayers et al. [32] equations, but not systematically different when using our equations. This finding suggests that when applied to elite rugby league players, these equations are an improvement on those of Harman et al. [16] and Sayers et al. [32]. However, the results indicate that a player who achieved a PPO of 5 000 W on their first visit (*with arms*), could, in the worst case scenario, score as low as 4 359 W or as a high as 5 967 W during a second visit. It is likely this degree of random error is too large to detect small but meaningful changes in lower-body power [1]. For example, Speranza et al. [33] reported an improvement in CMJ PPO of ~205 W in senior rugby league players after a 15-week preseason training period. Based on our analysis, it is possible, in some cases, that this improvement in PPO would not be detected using our prediction equation due to the large random error associated with this measure.

Our results support the notion that generalised equations to estimate PPO developed using non-elite populations are unsuitable for elite rugby league players. This might, in part, be explained by the strong emphasis placed on strength and power development in rugby league players [3] that leads to improved neuromuscular characteristics when compared to non-elite populations. Indeed, those athletes requiring highly developed speed, strength and power, have a higher proportion of fast twitch muscle fibres [19] and are capable of producing large ground reaction forces through increased muscle mass, muscle fibre recruitment, co-ordination and firing frequency [9] compared to non-elite populations. These enhanced neuromuscular characteristics mean that elite rugby league players are likely to have an enhanced ability to produce greater force and power during explosive movements such as the CMJ compared to non-elite athletes. This might explain the systematic underestimation of PPO when using equations based on non-elite athletes, suggesting that a more homogenous equation is required. As flight time and body mass only accounted for 64 and 69 % of PPO, it is possible that differences in neuromuscular characteristics between players, due different training experiences and genetic differences, could have contributed to the variation in PPO.

Limitations

Whilst our equations for correcting flight time and jump height removed the systematic over-estimation, the large random error associated with these equations could limit their usefulness for detecting small, but potentially meaningful changes in CMJ performance. The PPO prediction equation was an improvement on those previously reported when working with elite rugby league players, but also demonstrated a large random error, which too could limit its application in the applied environment. It is important to note that the correction equations for flight time and jump height, as well as the prediction equation for PPO are specific to the JJS and caution should be taken when applying these equations to other jump mats.

Conclusion

Although attempts have been made to create correction equations for the JJS [28, 39], these authors did not cross-validate their equations or assess the agreement between the equations and force platform. In contrast, the present study established and cross-validated 4 equations that can be used by applied practitioners to accurately measure jump height and/or flight time when using the JJS. Furthermore, this is the first study to use flight time within the PPO equation. As flight time is measured rather than predicted, this is likely to provide a more accurate and reliable measure of jump performance and therefore should be used for predicting PPO. The results indicate that the prediction equations to estimate PPO of elite rugby league players are an improvement on those reported previously using non-elite participants. However, as the R^2 between the force platform and prediction equations *with* and *without* arms only accounted for 64 and 69 % of PPO, it is reasonable to suggest that PPO cannot be estimated accurately using a JJS and that practitioners requiring measures of PPO should use a force platform.

Conflict of interest: The author have no conflict of interrest to declare.

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