Manuscript Title: Validity of a portable jump mat for assessing countermovement jump performance in elite rugby league players.

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Abstract

The purpose of this study was: 1) to determine the validity of the Just Jump® system for determining flight time and jump height in elite rugby league players, 2) to examine the validity of a new and established equations to estimate peak power in this group of athletes. Thirty-seven elite rugby league players performed six (3 *with* and 3 *without* arms) countermovement jumps (CMJ) on a Just Jump mat positioned on a force platform. A sub-sample of 28 elite rugby league players were then used to cross-validate the correction equations for flight time, jump height and power output. The Just Jump® System significantly over estimated flight time and jump height compared to the force platform ($P < 0.05$). However, there were strong associations between both systems for flight time *with* ($R^2 = 0.938$) and *without* ($R^2 = 0.972$) arms, and jump height *with* ($R^2 = 0.945$) and *without* arms ($R^2 = 0.987$). Four correction equations were produced, with cross-validation revealing no systematic differences between the force platform and corrected scores ($P > 0.05$) and an improvement in the agreement for jump height *with* (1.01 vs. 1.34) and *without* (1.01 vs. 1.15) arms, and flight time *with* (1.00 vs. 1.36) and *without* (1.00 vs. 1.16) arms. Power output equations based on sub-elite populations are not suitable for elite rugby league players and the equations produced in this study were an improvement on those previously used. It is recommended that our equations are used to correct flight time and jump height when using the Just Jump® System with elite rugby league players. Our results indicate that whilst our equation for peak power output is more accurate in elite rugby league players, due to the large random error, peak power output cannot be accurately determined.

Key Words: Jump mat system, countermovement jump, force platform, rugby league

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, 14, 10], showing strong associations with successful skill execution (i.e. tackling proficiency) [12, 33, 38] and reducing post-match fatigue [20, 21]. CMJ performance differentiates between starters and non-starters [12], playing standard (club cf. international) [35], and playing position [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, to provide estimates of jump performance [28, 30, 39]. However, the ability of the Just Jump® system 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 Just Jump® mat and force platform are highly related but that flight time is on average 105 ms longer on the Just Jump® mat 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 dependant 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 peak power 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 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 peak power output. Therefore, the aims of this study were to: a) quantify the difference in jump height and flight time between the Just Jump® System 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 peak power output in elite rugby league players.

Material & Methods

Participants and design

With institutional ethics approval and informed consent, 37 elite senior rugby league players from two 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 power output. 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 six CMJs; three using their arms (*with* arms; *n* = 111) and three with their hands on their hips (*without* arms, *n* = 108), interspersed by 60 s recovery. 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 and completed two 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). Each jump was

performed on a timing mat (Just Jump System, Probotics, Huntsville, Alabama, USA) that was positioned on top of a calibrated force platform (HUR Labs, FP4, Tampere, Finland) to allow both apparatus to record measurements simultaneously [25]. Both flight time and jump height derived from the Just Jump ® System 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 $m \times s^{-2}$). For the Just Jump® System, 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 using a 1200 Hz sampling frequency. Peak power output was measured using the force platform.

Statistical Analyses

All data were checked for normality via the Kolmogorov-Smirnov statistic before descriptive statistics (mean ± *SD*) were generated. The validity of the Just Jump® System measured against the portable force platform was examined using correlation analyses (Pearson r) and ratio limits of agreement (LoA) [2], owing to the presence of heteroscedasticity. This was assessed via a correlation between measurement error and the grand mean, and subsequently reduced with log transformation [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 peak power output, respectively, which was then cross-validated using a

sub-sample of data and analysed using the ratio LoA. Ratio LoA were also used to assess the agreement between the measured and predicted peak power output using the equations of Harman et al. [16] and Sayers et al. [32]. Alpha was set at $P < 0.05$, and all statistical analyses were conducted using SPSS for Windows (Version 22.0, 2013).

Results

There was a positive relationship between CMJ flight time derived from the Just Jump® System and force platform *with* ($r = 0.969$, $P < 0.001$) and *without* ($r = 0.986$, $P < 0.001$) arms, which resulted in coefficient of determinations (R^2) of 0.94 and 0.97, respectively (Figure 1). A positive relationship was also present between jump height derived from the Just Jump® System and force platform *with* ($r = 0.972$, $P < 0.001$) and *without* arms ($r = 0.994$, $P < 0.001$), resulting in R^2 values of 0.95 and 0.99, 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 Just Jump® system compared to the force platform (Table 1). Given the near perfect R^2 between the two systems, linear regression analysis was used to establish four 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 Just Jump® System (Figure 1).

*** Insert Table 1 here ***

*** Insert Table 2 here ***

The R^2 between criterion and corrected flight time and jump height *with* and *without* arms were strong (Figure 1) and demonstrated a reduced systematic bias ($P > 0.05$) compared to the uncorrected scores (Table 2).

*** Insert Figure 1 here ***

Stepwise regression analysis was used to predict peak power output (W) from flight time (s) and body mass (kg). The two predictor variables accounted for a significant proportion of variability in peak power output, *with* ($R^2 = 0.64$, $F = 96.52$, $P < 0.001$) and *without* arms ($R^2 = 0.69$, $F = 111.34$, $P < 0.001$). However, the regression model for peak power *with* (PP_{est} = 12413.90 x (flight time) + 58.77 x (body mass) – 7383.05) and *without* arms (PP_{est} = 8167.97 x (flight time) + 49.13 x (body mass) – 4390.76) showed a large degree random error (Table 3).

*** Insert Table 3 here ***

Discussion

The primary aim of this study was to establish the criterion validity of the Just Jump® system 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 Just Jump® System. On average, flight time was 85 ms longer using the Just Jump® System compared to the force platform, which resulted in an overestimation of 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 Just Jump® system. Furthermore, the ratio LoA for jump height

indicate 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 Just Jump® System. Our findings reaffirm previous work [28, 39] that the Just Jump® System 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 Just Jump® System 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 Just Jump® System 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 to the algorithm used to calculate flight time. However, as the algorithms used are unknown, it is difficult to conclude 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 (1200 Hz) compared to the Just Jump® System (100 Hz). Such large differences are likely to result in different rates of detection 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 Just Jump® system

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 Just Jump® System and the correction equation are, in some cases, not sensitive enough to 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 Just Jump® System 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 peak power output 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 peak power output. The use of flight time is somewhat understandable since it is measured directly by the Just Jump® system and is a more reliable performance indicator of jump performance [6]. The results support previous observations [8, 18] that peak power output estimated using equations derived from non-elite populations underestimates true peak power output in well-trained athletes [16, 32]. The ratio LoA indicated that there was a systematic under-estimation of peak power output 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 peak power output of 5000 W on their first visit (*with arms*),

could, in the worst case scenario, score as low as 4359 W or as a high as 5967 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 peak power output 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 peak power output 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 peak power output 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 peak power output 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 peak power output, it is possible that differences in neuromuscular characteristics between

players, due different training experiences and genetic differences, could have contributed to the variation in peak power output.

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 peak power output 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.

Conclusion

Although attempts have been made to create correction equations for the Just Jump® System [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 four equations that can be used by applied practitioners to accurately measure jump height and/or flight time from the Just Jump® system. Furthermore, this is the first study to use flight time within the peak power output equation. As flight time is measured rather than predicted, it is likely this is a more accurate and reliable of measure of jump performance and therefore should be used for predicting peak power output. The results indicate that the prediction equations to estimate peak power output 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 peak power output, it is reasonable

to suggest that peak power output cannot be estimated accurately using a Just Jump® system and that practitioners requiring measures of peak power output should use a force platform.

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

	Just Jump®	Force platform	Ratio 95% LoA	R^2
Jump height (cm)				
With arms	53.69 ± 6.14*	40.28 ± 5.10	1.34 x/÷ 1.06	0.94
Without arms	48.62 ± 5.51*	35.81 ± 4.72	1.15 x/÷ 1.03	0.97
Flight time (s)				
With arms	0.66 ± 0.04*	0.57 ± 0.04	1.36 x/÷ 1.05	0.95
Without arms	0.62 ± 0.03*	0.54 ± 0.03	1.16 x/÷ 1.03	0.99

LoA = limits of agreement. *Significantly higher than criterion.

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

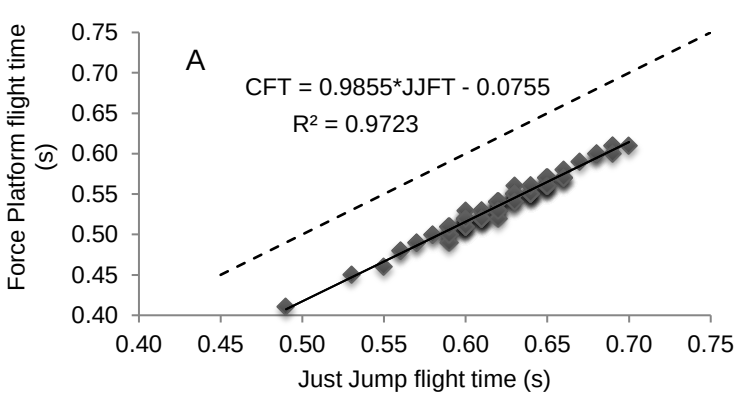
	Corrected	Force platform	95% Ratio LoA	R^2
Jump height (cm)				
With arms	45.99 ± 5.69	46.36 ± 6.06	1.01 x/÷ 1.17	0.99
Without arms	41.00 ± 4.87	41.36 ± 5.70	1.01 x/÷ 1.19	0.98
Flight time (s)				
With Arms	0.61 ± 0.04	0.62 ± 0.05	1.00 x/÷1.13	0.98
Without arms	0.58 ± 0.03	0.58 ± 0.41	1.00 x/÷ 1.11	0.98

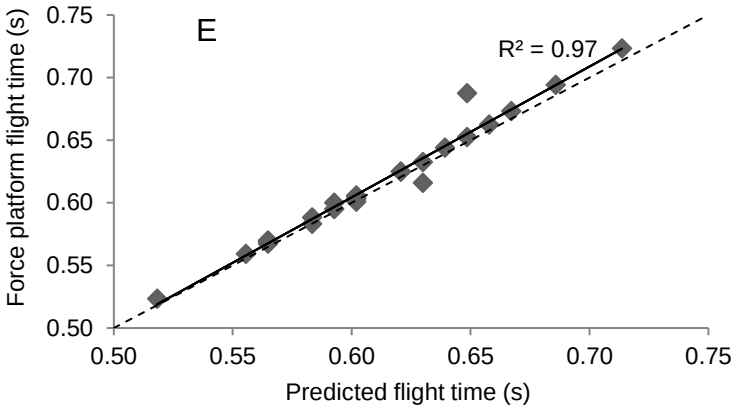
LoA = limits of agreement. *Significantly higher than criterion.

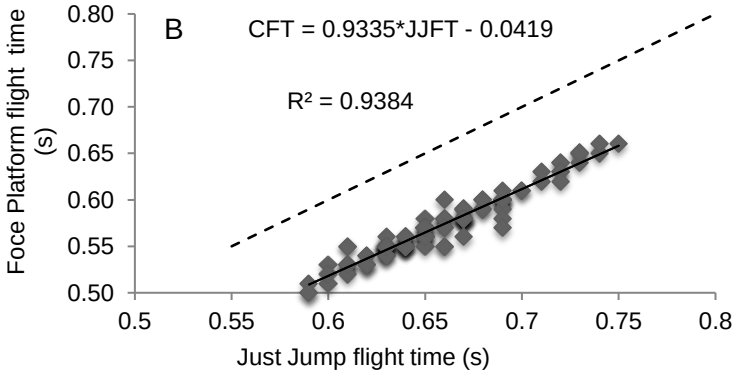
Table 3. Validity of prediction equations for peak power

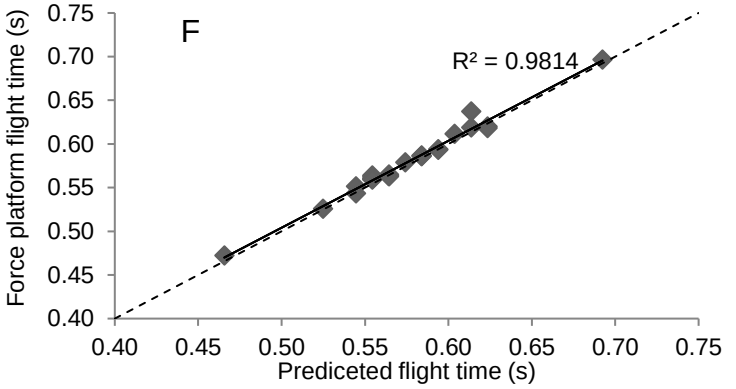
	Peak power output (W)	SEE	Ratio 95% LoA	R^2
Measured				
With arms	5846.9 ± 651.6	-	-	-
Without arms	5048.2 ± 589.0	-	-	-
Predicted				
With arms	5930.0 ± 603.2	410.6	1.02 x/÷ 1.17	0.64
Without arms	5060.4 ± 479.0	310.0	1.01 x/÷ 1.15	0.69
Harman et al. (1991)				
Without arms	4205.6 ± 417.3*	-	1.20 x/÷ 1.16	0.77
Sayers et al. (1999)				
Without arms	4837.7 ± 458.3*	-	1.04 x/÷ 1.16	0.79

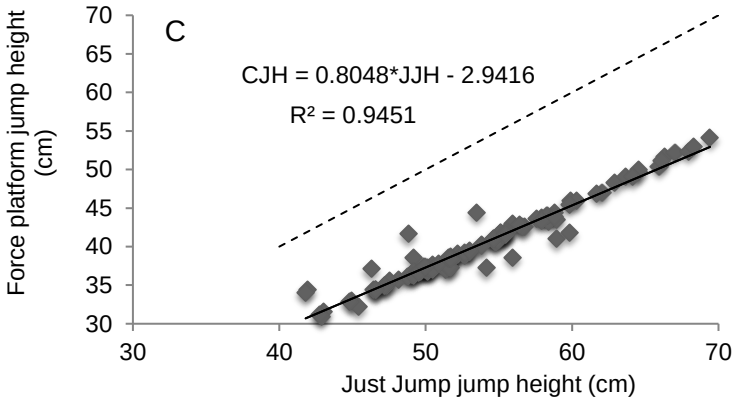
LoA = limits of agreement. SEE = standard error of estimate. *Significantly difference to actual peak power.

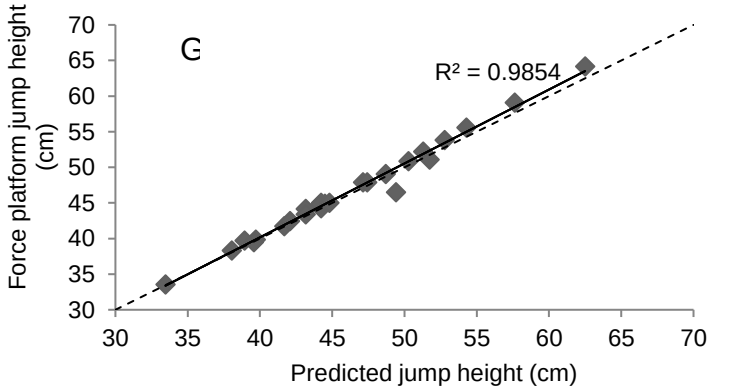


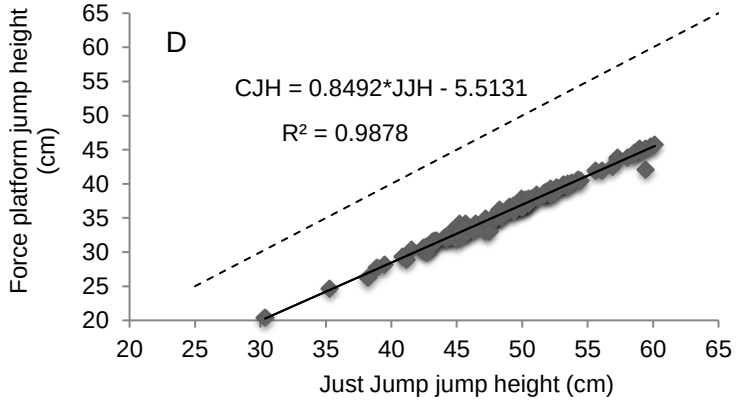












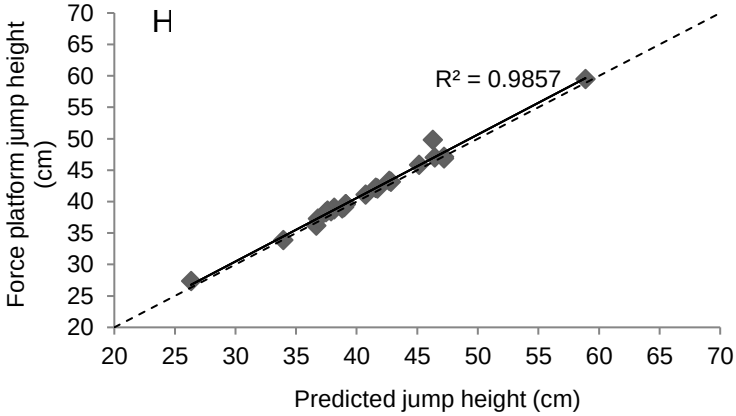


Figure 1. Relationship between JJS and force platform for flight time *with* (A) and *without* (B) arms and jump height *with* (C) and *without* (D) arms and the relationship between the correction equation and force platform for flight time *with* (E) and *without* (F) arms and jump height *with* (G) and *without* (H) arms. CFT = criterion flight time, JJFT = Just Jump flight time, CJH = criterion jump height and JJH = Just Jump jump height).