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Test Re-Test Reliability of Countermovement Jump Testing in Academy Rugby League Environments: Establishing Thresholds for Minimum Detectable Change to Guide Longitudinal Development

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ABSTRACT

League wide profiling is well established in rugby league academy pathways, however the understanding of between-session reliability of assessments completed in applied settings is unknown. This study aimed to determine the between-session reliability of force-time characteristics of the countermovement jump (CMJ) in academy rugby league players. Forty-one academy rugby league players performed three separate CMJ trials on two occasions, separated by 48 hours prior to their resistance training session. Between session reliability was determined by calculating the intraclass correlation coefficient (ICC) and coefficient of variation (CV) with 95% confidence intervals, standard error of measurement (SEM) and minimal detectable change (MDC) from the mean of three trials. Analysis reported moderate to excellent reliability ($ICC_{-95} \geq 0.5$) for 33 out of 37 variables for profiling lower body ballistic force capabilities. Jump height and jump momentum reported good to excellent reliability (ICC_{-95} = 0.78, CV = 6.64% and ICC_{-95} = 0.90, CV = 3.58% respectively). League wide profiling assessments undertaken within club environments result in reliable insights of CMJ performance and associated force-time characteristics. Although reliable, future improvements to league wide profiling protocols should remove the club environment as a factor with centralised testing at a singular time in the season to improve data quality of large sample normative datasets.

Keywords: Countermovement jump, Applied practice, Physical profiling

INTRODUCTION

The countermovement jump (CMJ) assessment for determining lower body neuromuscular performance is well established in rugby league populations to quantify performance benchmarks [1], monitor fatigue status [2] and measure associations with key physical determinants of performance [3,4]. In addition, vertical jump testing to quantify lower body neuromuscular performance has been shown to discriminate between levels of performance in men's and women's Super League as well as youth rugby league players [5–7].

Reliability is defined as the expected repeatability of a measure or variable, used to determine whether an observed value differs from the true value [5]. Repeatability of such measures within the specific context of an applied populations' environment is an important consideration that is underrepresented within sports science reliability research [8]. Measures that are used to inform practice and/or rank physical performance should accurately represent the intended underpinning physical quality whilst reducing any associated measurement error influenced by the environment. Especially where external factors such as variable training loads and timing of the day may influence results [9]. Despite the prevalent application of the CMJ assessment in academy rugby league cohorts [10], there is a requirement to understand the between session variance of CMJ performance and underpinning force-time characteristics. This would determine meaningful thresholds to guide performance enhancement as well as establishing how reliable force-time characteristics within the context of ranking a players' performance.

The CMJ is recognised as the most common assessment of ballistic force production and slow (>250ms) stretch shortening cycle (SSC) function [11]. The increase in commercially available force plates [12] gives practitioners in applied environments detailed insights into neuromuscular function through analysis of the force-time curve and phase specific variables compared to CMJ jump height (JH) alone [13]. In applied youth environments where training loads vary and can impact neuromuscular performance [9], it is important to establish which force-time variables can be used reliably to profile and detect meaningful changes in neuromuscular function.

Assessment of CMJ test-retest reliability has demonstrated acceptable between trial and between-day reliability (coefficient of variation [CV] <10%) for force-time characteristic variables [14] as well as commonly used strategy ratio metrics such as contact:flight time ratio and modified reactive strength index (mRSI) determined by dividing JH by time to take-off (TTTO)[15]. The most frequently reported metric of CMJ performance in academy rugby league physical profiling is JH [4], which demonstrates excellent between session reliability in adolescent athletes (ICC = 0.94, CV = 2.63%) [16]. Large sample, league wide physical profiling allows for the standardised assessment and comparison of how physical attributes differ between age group, position and playing standard in academy rugby league players [3,7,17]. To date, league wide investigations in rugby league have only reported JH as a single measure of lower body neuromuscular performance which has been reported to be less sensitive to change [18,19]. In collision sports such as rugby league, where increases in body mass are a desirable adaptation of developing rugby league players [4], relying solely on JH as a performance outcome metric may disadvantage heavier athletes in profiling contexts [20]. Including temporal, displacement and force variables in CMJ analysis will inform subsequent programme design to target improvements in movement outcome . Therefore, further investigation into the underpinning lower body force-time characteristics and establishing thresholds for meaningful change is required to more accurately profile neuromuscular performance in male academy rugby league players.

Previous research demonstrates that the analysis of CMJ force-time characteristics differentiates between collision sport positional groups, as well as being sensitive to longitudinal change following resistance training periods [21,22]. Therefore, to better inform longitudinal physical development, further research is required to determine the expected between session reliability of CMJ force-time characteristics. Furthermore, where analysis is cross sectional, metrics that describe the outcome and underpinning kinetics of a CMJ may provide insight into the slow SSC capabilities of athletic populations. This will enable practitioners to determine the sensitivity of force-time metrics in an applied academy environment and based on mechanical underpinnings, identify which metrics can be used for tracking changes over time.

In applied populations, good to excellent relative between-day reliability of the CMJ has been demonstrated in youth footballers [23] and Division 1 Collegiate American Footballers [24].

However, the testing conditions are not reflective of youth sport environments where multiple factors (e.g., school stress, variable training loads and training time of day) can influence neuromuscular performance [9]. Youth rugby union environments have been described as "chaotic" [25] and the expected measurement error in these environments must be established. Reliability research in jump assessments has focused on the test-retest reliability in laboratory-controlled environments and/or non-sporting specific populations. Whilst such studies have focused on test measurement error to better interpret data, league wide projects [3,7] face challenges in implementation, such as embedding within the applied environments discussed. In addition, recent research has demonstrated that floor surface has a direct impact on resultant ground reaction forces [26] which will vary between environments. Therefore, the ecological reliability of data obtained in such environments must be assessed to determine how test-retest reliability impacts the observed value from the athletes' true value [8]. As such, this study aimed to determine the between session reliability of CMJ force-time characteristics in male academy rugby league players across different environments. The findings of this study will inform the efficacy of league wide profiling to effectively physically profile players in applied environments. It was hypothesized that for the purposes of ranking physical performance between session relative reliability of CMJ force time variables would be acceptable. However, due to the variable environment of youth sport, absolute reliability would report poorer reliability than previously reported findings in senior applied populations resulting in larger MDC thresholds.

MATERIALS AND METHODS

Participants

Players from two male English rugby league academy pathways (n = 41; age: 17.7 ± 0.9 years, stature: 179.2 ± 6.1 cm, body mass: 84.8 ± 11.9 kg) participated in a repeated measures design study. Testing was completed over 2 sessions separated by 48hrs as part of their regular training schedule. Informed consent and parental assent was provided, and the study was pre-approved by the Institutional Ethics Committee (122273).

Test Protocols

Hawkin Dynamics (HD) force plate systems (5th Generation, Westbrook, Maine, USA) were used for all jump assessments. Two portable adjacent force plates were placed onto a flat and stable floor as per recommended guidelines [27], with accompanying foam surround to minimise injury risk in the regular training location. Ground reaction forces (GRF) were sampled through each leg independently and simultaneously at 1000Hz with a low pass filter at 50Hz using HD proprietary software (version 16.1.3) in accordance with previous recommendations [28]. Systems were zeroed before data acquisition initiated and between participants. In all test conditions, participants were required to stand still and upright for the first second of data collection [29,30] to calculate body weight (mean force over 1s). Participants were required to perform 3 maximal separate CMJ assessments, ensuring that participants returned to the desired start position following landing for subsequent repetitions.

Following a standardised warm up comprising of dynamic stretching and submaximal jumping (3 x 1 repetitions of single effort CMJs). Participants were instructed to perform the CMJ to their preferred countermovement depth [31] with arms akimbo and cued to "jump as fast and as high as possible" to enable participants to perform the countermovement and propulsive phase of the CMJ as quickly as possible [32]. All cues were standardized across all testers.

For each CMJ trial, ground reaction forces were analysed via the HD cloud software, previously validated against custom analysis of the force-time curve [33]. Then phase specific characteristics were identified as per recommendation [13] Jump height was calculated using the criterion, take-off velocity method by applying the impulse momentum theorem to the ground contact phase of the jump [34,35]. Participants all had previous experience of performing the CMJ as part of a league wide physical profiling battery [3].

Statistical Analysis

The average of three CMJ trials were used for statistical analysis which has previously demonstrated to be more reliable than a single trial [8,36]. Variables obtained from subsequent force-time curve analysis for the CMJ were selected as per recommendations of previous research and categorised into the phases of the movement of which they represent [37]. All variables were calculated automatically by HD proprietary software and are defined in supporting information materials

(S1 Data).

Relative (i.e., how individuals maintain their position in a sample of repeated measurements) and absolute (i.e., how repeated measurements vary for each athlete) reliability were assessed through intraclass correlation coefficient (ICC) and coefficient of variation (CV), respectively [5].

A two-way mixed-effects model intraclass correlation coefficient (ICC, model 3,1) with upper and lower 95% confidence intervals (95%CI) was used to determine the relative between-session reliability of each variable. Thresholds for ICC magnitude were values based on the lower 95%CI (ICC_{-95}), with values less than 0.5, between 0.5 and 0.75, between 0.75 and 0.9 and greater than 0.9 indicating poor, moderate, good and excellent reliability respectively [38]. Standard error of measurement (SEM) was calculated as pooled standard deviation (SD) multiplied by the square root of one minus the ICC [39]. Absolute between-session reliability was interpreted from the upper 95% confidence interval of the CV (CV_{+95}), with values described as: poor (≥ 15%), moderate (10-15%), good (5-10%) and excellent (≤5%), respectively. Minimal detectable change (MDC) was calculated as SEM multiplied by 1.96 and the square root of SEM ^2 and then expressed as a percentage (MDC %) by dividing MDC by the pooled mean and multiplying by 100.
All statistical analysis was performed in Rstudio statistical software [41]

RESULTS

Mean values (± SD) for CMJ are presented in Table 1. Between-session reliability data of CMJ, force-time data are presented in Table 2.

The between-session CV+95 for CMJ variables ranged from 3.58% to 31.88%, with 26 out of 37 variables meeting acceptable thresholds of reliability (Table 2). The least reliable metrics with regard to intra-individual variance were stiffness and braking rate of force development (RFD) (CV_{+95} 26.14 and 31.88% respectively). Relative reliability between-sessions was moderate to excellent for 33 out of 37 variables. For ranking and profiling, the most reliable variable was the propulsive net impulse, which is equivalent to the output variable, jump momentum (ICC_{-95} 0.90). The least reliable variable in terms of ranking was TTTO, which then reduced the reliability of the outcome measure mRSI (ICC_{-95} 0.44 and 0.47 respectively).

DISCUSSION

The aim of this study was to investigate the ecological reliability of force time characteristics quantified via CMJ in male academy rugby league players. For ranking and monitoring purposes, 23 out of 37 force-time variables demonstrated moderate to excellent relative reliability and acceptable absolute reliability. These findings suggest that specific CMJ metrics related to lower body neuromuscular performance are reliable for profiling and monitoring physical adaptations in varied, applied sports environments.

Historically, CMJ performance in this population is reported using the trial with the highest JH [4,42]. However, the present study demonstrates that the mean of 3 trials yields good relative reliability (ICC_{-95} = 0.78) and acceptable absolute reliability (CV_{+95} = 6.64%), supporting its use for monitoring physical development. Notably, the MDC of JH was 0.05m, requiring a 15.2% increase in performance to confirm a meaningful improvement. Previous investigations have reported annual JH improvements of only 5.5% in players aged 17 – 18 years [43], which would not exceed the MDC established in this study. Using the mean of three trials has previously demonstrated improved test-retest reliability [8,36], however results of the current study report less reliable findings (ICC_{-95} 0.5 ≤ 0.95) than previous investigations that have used the best trial determined by JH [8,23,24,44]. Consequently, practitioners must account for test error and context specific MDC thresholds derived from the mean of three trials when interpreting CMJ data to quantify performance changes. In applied youth environments, relying on a single "best" trial may reduce measurement reliability and potentially lead to misinformed training interventions. Furthermore, as increasing body mass is a development priority in academy rugby league pathways [45], proportionate development of propulsive force-time characteristics are required to maintain JH. Increasing body mass, whilst maintaining JH may also be interpreted as a positive adaptation, demonstrated by an increase in CMJ momentum.

In the present study, CMJ momentum was the most reliable variable of CMJ performance (ICC_{-95} 0.90, CV_{+95} 3.58%) and is directly proportional to the propulsion net impulse applied to the centre of mass [20]. Practitioners are therefore advised to longitudinally monitor CMJ momentum as a profiling metric as it directly represents the lower body force-time characteristics against the players' mass. In

Table 1. Mean (SD) of CMJ force-time characteristics

Category	Variable	Session 1 Mean (SD)	Session 2 Mean (SD)
Output	Jump Height (m)	0.33 (0.06)	0.34 (0.06)
	Jump Momentum (kg·m·s^{-1})	217.75 (30.84)	221.58 (29.84)
	mRSI (AU)	0.48 (0.08)	0.50 (0.09)
	Peak Velocity (m·s^{-1})	2.65 (0.21)	2.69 (0.20)
	Positive Net Impulse (N·s)	323.61 (43.12)	330.98 (41.35)
Strategy	Countermovement Depth (m)	-0.28 (0.06)	-0.28 (0.06)
	Stiffness (N·m^{-1})	-8423.75 (4086.66)	-8395.3 (3659.41)
	Time to Take-off (s)	0.69 (0.10)	0.69 (0.10)
Braking	Average Braking Force (N)	1564.25 (251.07)	1605.59 (256.84)
	Avg. Braking Power (W)	-1114.21 (243.93)	-1172.31 (210.46)
	Avg. Braking Velocity (m·s^{-1})	-0.79 (0.12)	-0.82 (0.10)
	Avg. Relative Braking Force (%)	184.77 (22.65)	189.73 (22.98)
	Avg. Relative Braking Power (W·kg^{-1})	-13.01 (3.00)	-13.67 (2.53)
	Braking Net Impulse (N·s)	104.4 (18.07)	107.98 (15.92)
	Braking Phase (s)	0.16 (0.04)	0.15 (0.03)
	Braking RFD (N·s^{-1})	9039.37 (4576.8)	9584.9 (5045.38)
	Peak Braking Force (N)	2107.67 (349.22)	2155.47 (373.47)
	Peak Braking Power (W)	-1534.36 (407.67)	-1588.97 (324.49)
	Peak Braking Velocity (m·s^{-1})	-1.22 (0.21)	-1.26 (0.17)
	Peak Relative Braking Force (%)	248.7 (29.15)	254.58 (32.91)
	Peak Relative Braking Power (W·kg^{-1})	-17.92 (4.99)	-18.54 (4.03)
Transfer	Force at MD (N)	2106.94 (350.41)	2149.92 (370.08)
	Relative Force at MD (N·kg^{-1})	248.59 (29.05)	253.85 (31.56)
	Impulse Ratio	2.15 (0.35)	2.09 (0.27)
Propulsive	Avg. Propulsive Force (N)	1781.19 (269.68)	1802.51 (274.5)
	Avg. Propulsive Power (W)	2510.32 (395.78)	2584.2 (400.91)
	Avg. Propulsive Velocity (m·s^{-1})	1.57 (0.11)	1.60 (0.11)
	Avg. Relative Propulsive Force (%)	210.04 (17.31)	212.8 (20.18)
	Avg. Relative Propulsive Power (W·kg^{-1})	29.13 (3.58)	30.04 (3.95)
	Peak Propulsive Force (N)	2209.34 (369.91)	2245.42 (386.43)
	Peak Propulsive Power (W)	4334.65 (643.62)	4487.53 (676.03)
	Peak Relative Propulsive Force (%)	260.55 (29.00)	265.07 (32.54)
	Peak Relative Propulsive Power (W·kg^{-1})	50.34 (5.88)	52.16 (6.42)
	Propulsive Net Impulse (N·s)	219.21 (31.00)	222.99 (29.97)
	Propulsive Phase (s)	0.24 (0.04)	0.24 (0.04)
Landing	Peak Landing Force (N)	5292.05 (1650.4)	5329.92 (1466.4)
	Relative Peak Landing Force (%)	626.11 (192.37)	633.67 (180.19)

Avg = Average; mRSI = Modified Reactive Strength Index; RFD = Rate of Force Development; MD = Minimum Displacement

Table 2. Between session reliability for CMJ force-time characteristics

Category	Variable	ICC [95% CI]	SEM	CV% [95% CI]	MDC95	MDC%
Output	Jump Height (m)	0.90 [0.78,0.95]	0.02	5.49 [4.35 to 6.64]	0.05	15.23
	Jump Momentum (kg·m·s^{-1})	0.95 [0.90, 0.98]	6.50	2.96 [2.34 to 3.58]	18.03	8.21
	mRSI (AU)	0.69 [0.47,0.82]	0.05	10.01 [7.92 to 12.1]	0.14	27.75
	Peak Velocity (m·s^{-1})	0.89 [0.74,0.95]	0.07	2.63 [2.08 to 3.18]	0.19	7.29
	Positive Net Impulse (N·s)	0.91 [0.82,0.96]	12.31	3.76 [2.97 to 4.55]	34.11	10.42
Strategy	Countermovement Depth (m)	0.83 [0.70,0.91]	0.03	9.27 [7.33 to 11.2]	0.07	-25.68
	Stiffness (N·m^{-1})	0.78 [0.62,0.88]	1818.57	21.63 [17.11 to 26.14]	5040.82	-59.94
	Time to Take-off (s)	0.66 [0.44,0.80]	0.06	8.16 [6.46 to 9.87]	0.16	22.62
Braking	Average Braking Force (N)	0.85 [0.73,0.92]	98.55	6.22 [4.92 to 7.52]	273.17	17.24
	Avg. Braking Power (W)	0.77 [0.59,0.87]	109.81	9.60 [7.6 to 11.61]	304.37	-26.62
	Avg. Braking Velocity (m·s^{-1})	0.81 [0.65,0.90]	0.05	5.96 [4.71 to 7.2]	0.13	-16.52
	Avg. Relative Braking Force (%)	0.71 [0.52,0.84]	12.23	6.53 [5.17 to 7.9]	33.91	18.11
	Avg. Relative Braking Power (W·kg^{-1})	0.78 [0.61,0.88]	1.29	9.68 [7.66 to 11.7]	3.58	-26.83
	Braking Net Impulse (N·s)	0.81 [0.67,0.90]	7.35	6.92 [5.48 to 8.37]	20.38	19.19
	Braking Phase (s)	0.81 [0.67,0.89]	0.02	9.76 [7.72 to 11.8]	0.04	27.05
	Braking RFD (N·s^{-1})	0.74 [0.56 0.85]	2455.37	26.37 [20.86 to 31.88]	6805.94	73.09
	Peak Braking Force (N)	0.85 [0.73,0.91]	141.23	6.63 [5.24 to 8.01]	391.47	18.37
	Peak Braking Power (W)	0.75 [0.57,0.86]	185.27	11.86 [9.38 to 14.34]	513.53	-32.88
	Peak Braking Velocity (m·s^{-1})	0.81 [0.66,0.89]	0.08	6.78 [5.37 to 8.2]	0.23	-18.81
	Peak Relative Braking Force (%)	0.69 [0.49,0.82]	17.20	6.83 [5.41 to 8.26]	47.66	18.94
	Peak Relative Braking Power (W·kg^{-1})	0.76 [0.60,0.87]	2.19	12.02 [9.51 to 14.53]	6.08	-33.32
Transfer	Force at MD (N)	0.86 [0.75,0.92]	134.51	6.32 [5 to 7.64]	372.84	17.52
	Relative Force at MD (%)	0.71 [0.52,0.83]	16.23	6.46 [5.11 to 7.81]	45.00	17.91
	Impulse Ratio (AU)	0.79 [0.63,0.88]	0.14	6.79 [5.37 to 8.2]	0.40	18.81
Propulsive	Avg. Propulsive Force (N)	0.91 [0.84,0.95]	80.58	4.50 [3.56 to 5.44]	223.36	12.47
	Avg. Propulsive Power (W)	0.87 [0.76,0.93]	141.88	5.57 [4.41 to 6.73]	393.26	15.44
	Avg. Propulsive Velocity (m·s^{-1})	0.84 [0.66,0.92]	0.04	2.78 [2.2 to 3.36]	0.12	7.70
	Avg. Relative Propulsive Force (%)	0.74 [0.56 0.85]	9.61	4.55 [3.6 to 5.5]	26.65	12.60
	Avg. Relative Propulsive Power (W·kg^{-1})	0.80 [0.64,0.89]	1.68	5.69 [4.5 to 6.88]	4.67	15.78
	Peak Propulsive Force (N)	0.86 [0.76,0.93]	140.56	6.31 [4.99 to 7.63]	389.62	17.49
	Peak Propulsive Power (W)	0.91 [0.76,0.96]	196.47	4.45 [3.52 to 5.38]	544.58	12.35
	Peak Relative Propulsive Force (%)	0.69 [0.49,0.82]	17.11	6.51 [5.15 to 7.87]	47.44	18.05
	Peak Relative Propulsive Power (W·kg^{-1})	0.86 [0.63,0.94]	2.33	4.55 [3.6 to 5.5]	6.46	12.61
	Propulsive Net Impulse (N·s)	0.95 [0.90,0.98]	6.53	2.95 [2.34 to 3.57]	18.10	8.19
	Propulsive Phase (s)	0.78 [0.62,0.88]	0.02	7.64 [6.05 to 9.24]	0.05	21.18
Landing	Peak Landing Force (N)	0.84 [0.73,0.91]	614.50	11.57 [9.15 to 13.99]	1703.30	32.07
	Peak Relative Landing Force (%)	0.84 (0.72, 0.91)	74.15	11.77 (9.31 to 14.23)	205.53	32.63

Avg = Average; mRSI = Modified Reactive Strength Index; RFD = Rate of Force Development; MD = Minimum Displacement; MDC95 = Minimum detectable change at 95%; MDC% = Minimum detectable change at 95% as percentage addition, CMJ momentum is positively correlated with linear sprint momentum [20] which has been identified as predictor of collision dominance in the tackle [46]. Monitoring JH in isolation may therefore mask meaningful improvements in force-generating capacity based on the current findings. Interpreting changes in body mass, and the underpinning force production qualities in relation to expected MDC thresholds (Table 2) will determine whether changes in CMJ momentum are due to neuromuscular adaptation and/or increased body mass.

Consistent with previous research in applied environments [24,40], TTTO was one of the least reliable metrics (ICC_{-95} = 0.47) and unsuitable for profiling purposes. Conversely, absolute reliability demonstrated comparable acceptable thresholds (CV_{+95} <10%) for most variables except for mRSI, average braking power, average relative braking power, braking phase duration, peak braking power, peak relative braking power, peak landing force and relative peak landing force (CV_{+95} 11.61 - 14.53%). Furthermore, stiffness and braking RFD were the least reliable metrics, which were not reported by previous studies [24,44] but are significantly higher than braking RFD values reported by Howarth et al. (2022) in senior rugby union athletes (CV_{+95} = 14%). Therefore, practitioners assessing braking force-time characteristics would be advised to monitor force and temporal metrics e.g. braking net impulse (ICC_{-95} = 0.67, CV_{+95} = 8.37%) to determine braking capabilities.

The underpinning impulses produced during the CMJ in the current study demonstrate better reliability than outcome variables and directly represent the neuromuscular ability to produce force minus body mass throughout the whole movement (positive net impulse; ICC_{-95} = 0.82, CV_{+95} = 4.6%) and propulsive phase (propulsive net impulse (ICC_{-95} = 0.90, CV_{+95} = 3.6%). In combination with assessing changes in JH, practitioners are advised to monitor development in underpinning kinetic qualities that produce the CMJ outcome to determine whether significant change has occurred because of training adaptation or fatigue.

Whilst this study is the first to assess the ecological reliability of CMJ testing in male academy rugby league players, it is not without limitations. The training history of participants or training methodology of each club was not considered. Subsequently, some participants may have had greater exposure to training activities (e.g., plyometrics) which may have better prepared them for a CMJ test. Due to the limited testing frequency (3-4 times per year) and club training time available with participants [47], the CMJ testing may present as a novel activity which is not a part of the everyday training prescription. In the context of league wide profiling which shares the same limitations and is typical in this population [3], future profiling are encouraged use the mean of three trials to quantify CMJ performance.

PRACTICAL APPLICATIONS

The data presented provides practitioners with a guideline for between-session reliability and expected SEM and MDC values for CMJ force-time characteristics in male academy rugby league players. For determining change of neuromuscular performance via CMJ testing, outcome and force variables can be reliably used. Practitioners can use the MDC and MDC95% values presented (Table 2) to determine whether observed changes in CMJ outcome and force-time variables exceed the threshold for meaningful change. Based on these findings, practitioners within applied environments can reliably assess CMJ performance derived from the mean of three trials to profile and monitor changes in physical qualities over time using force plate technologies. Additionally, reporting the underpinning force-time characteristics would enhance the physical development process with clear benchmarks for academy rugby league players based on force, temporal and displacement characteristics.

CONFLICTS OF INTEREST

This work forms part of the lead author's PhD studentship which is funded by Hawkin Dynamics, whose force plate technology was used in this study. Dr Peter Mundy and Dr John McMahon are employees of Hawkin Dynamics as the Chief Scientific Officer and Chief Product Officer respectively. This affiliation is disclosed in the interest of transparency. No financial incentives were received in relation to this publication. The authors affirm that the integrity of the research and its findings has not been compromised by any commercial interests.

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ETHICAL APPROVAL

Informed consent and parental assent was provided, and the study was pre-approved by the Institutional Ethics Committee (122273).

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