Factors influencing optimum countermovement jump performance and movement strategy in Championship professional football players: Implications for player profiling.

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Abstract

Single leg countermovement jump (CMJ) is a common profiling test influenced by sport, age, sex and playing level. Controlling for these confounding variables, outfield players from an English Championship squad (n=36) were retrospectively categorised as best (n=10) or worst (n=10), based on mean single leg CMJ height and flight time:contraction time ratio. Movement strategy was quantified as force-time history metrics differentiating eccentric and concentric phases. Jump height revealed that best performers elicited greater rate of force development in both phases ($P \leq 0.033$), with concentric impulse the strongest predictor of performance. Time ratio also differentiated best performers as utilising a shallower ($P = 0.002$) countermovement, with concentric rate of force development the strongest predictor of good performance. Successful jump height performance can mask ineffectual eccentric and stretch shortening cycle neuromuscular characteristics. Time ratio is therefore advocated as the key performance indicator, with movement strategy prioritised over gross outcome measures.

Keywords: neuromuscular performance, soccer, rehabilitation, profiling, optimum performance

Introduction

Within our professional football club, we systematically employ player profiling to inform practice regarding player readiness and injury risk across a multi-disciplinary team including coaching, sports science and sports medicine. In this context test selection is critical. The countermovement jump (CMJ) is commonly used within the player monitoring process, providing a test that is submaximal with regards testing demands on the player, easy to administer, sensitive to change (Ryan et al., 2019) and reliable (Cormack et al., 2008; Heishman et al., 2018). The CMJ has also been shown to be sensitive to fatigue (Edwards et al., 2018) and to previous injury (Hart et al., 2019), with practical implications in the context of a professional football club (Ekstrand et al., 2016). The influence of previous injury has been observed as inter-limb asymmetries during the double legged CMJ (Cohen et al., 2014; Hart et al., 2019) and anecdotally we have observed greater sensitivity to previous injury in the single leg CMJ. The single leg CMJ negates the opportunity for movement compensation strategies that might reflect previous injury, or the strength asymmetries observed in professional football players (Croisier et al., 2003; Rahnama et al., 2005; Fousekis et al., 2010).

CMJ performance has also been shown to be sensitive to age (McMahon et al., 2017a), sex (Laffaye et al., 2017) and playing level (Stahl et al. 2020; McMahon et al., 2018). Stahl et al. highlighted differences in CMJ performance between American collegiate athletes from different competition levels. Within a single professional club, McMahon et al. (2018) highlighted differences in CMJ performance between senior and academy rugby league players. However, this differential might reflect the greater training history and subsequent adaptation of the senior players, with +7 years differentiating the mean age of the senior players. Therefore, within the senior squad of a professional football team one might expect a greater degree of homogeneity in performance, given the standardised playing level, training status and training history.

The aim of the current study was to investigate the factors influencing single leg CMJ performance within a professional, male football team. Retrospective classification of players based on performance was used to differentiate the best and worst performers, with between group differences then investigated in movement strategy. Performance was defined as single leg CMJ height as a measure of movement output, and as the flight time:contraction time (FT:CT) ratio as a measure of movement strategy (Martinez et al., 2016). Heishman et al. (2019) suggested that changes in movement strategy might be more insightful than gross outcome measures in the profiling of athletes. In the current study it was hypothesised that the performance-based classification of players would highlight differences in single leg CMJ movement strategy. Identifying the movement strategy variables that elicit optimum performance would have practical implications for training and rehabilitation.

Methods

Participants

Thirty-six professional footballers from the same Championship football club completed the study (age 23.3 ± 5.6 yrs, weight 78.1 ± 1.9kg, body fat 6.8 ± 1.9%, professional playing history 6.8 ± 4.8 yrs). All participants were full time professional outfield players with a minimum of 6 years as a professional footballer and participating in full time daily training at the time of testing. Primary outcome measures of single leg CMJ performance were defined as jump height and flight time:contraction time ratio. These measures were chosen to differentiate between jump outcome and jump strategy respectively (Martinez et al., 2016; Heishman et al., 2019). The mean jump height and mean time ratio across five trials of the dominant limb was calculated for each player (n = 36) and a rank ordering of performance subsequently used to create two groups, differentiating the 'Best' players (n = 10) and the 'Worst' players (n = 10) within the squad. This group stratification was developed independently for CMJ jump height and flight time:contraction time ratio.

All players provided written consent and were made aware that data would remain anonymised and would not affect their standing within the team. Ethical consent was provided by the Research Development Committee at Blackburn Rovers Football Club, in accord with the Helsinki declaration.

Procedures

All players were weighed on a Seca performance scale (model 799) and had their body fats recorded with a 7-point calibre testing procedure using Harpenden skinfold callipers (Gabbett et al., 2007). All testing took place between 9.30 – 10.30am, +5 days since the previous match and following a scheduled rest day. Footwear, nutritional status and a 15-minute warm-up was standardised between trials, with the warm-up including three familiarisation trials performed at 50%, 75% and 100% of perceived maximal performance (Byrne et al., 2017; Sole et al., 2017).

The CMJ testing procedure consisted of each player performing a series of 10 jumps with 10 seconds rest between each jump. Successive trials were alternated between limbs, with 5 trials completed on each limb. The mean score for the five trials performed on the players dominant limb was calculated for subsequent analysis. Players performed a countermovement to a self-selected depth with self-selected arm swing (Laffaye et al., 2014; McLellan et al., 2011) and were instructed to jump as fast and as high as possible. The players were given a simple count into each jump of “3-2-1 jump” by the tester to promote reliability between trials and between participants (McMahon et al., 2018). The non-jumping leg remained slightly flexed at the hip and knee so that the non-jumping foot hovered at a height approximating to the mid-shin of the jumping leg, with no swinging of the non-jumping leg permitted (Bromley et al., 2018).

Data Collection & Analysis

All experimental trials were completed on a dual force plate system (PASPORT force plate, Model No: PS 2141; Pasco Roseville, CA, USA) and integrated ForceDecks customised software package (NMP ForceDecks). Heishman et al. (2018) reported intersession and intrasession reliability intraclass coefficient correlation values of > 0. 0.700 and coefficient of variation values < 10% across a range of performance and movement strategy variables using this methodological approach. Each force platform measured 0.35 x 0.35m and vertical ground reaction force was sampled at 1000Hz.

CMJ phases were defined as described by Heishman et al., (2019) with initiation of the jump defined by a 20N change relative to passive bodyweight (Hart et al., 2019; Heishman et al., 2018). The eccentric deceleration phase was defined from peak negative velocity to zero velocity of the mass centre, and the concentric phase from zero velocity to takeoff. The time of takeoff was defined as the timepoint at which total vertical force fell below a predetermined threshold of 20N below bodyweight (Heishman et al., 2018, 2019). Performance variables were defined as: jump height (calculated using flight time); and the ratio of flight time-to-contraction time as described by Heishman et al. (2018, 2019). Contraction time was calculated as the time interval between the onset of movement and take-off, with flight time calculated as the interval between take-off and touchdown (Heishman et al., 2019). Vertical force values were standardised for bodyweight of each player, and movement strategy variables were defined as the peak force (BW), duration (s), impulse (BW·s) and rate of force development ($BW \cdot s^{-1}$) in the eccentric and concentric phases, the force at zero velocity (BW) and the depth of the CMJ (cm), as provided by the ForceDecks software analysis output.

Statistical Analysis

A univariate general linear model was defined to investigate main effects for group (Best vs. Worst) in each of the CMJ performance and movement strategy variables. Group classification was developed for jump height and time ratio performance discretely, acknowledging these as independent outcome measures of CMJ performance. Prior to completion of the parametric analysis, the assumptions of normality of the residual values were assessed using a Shapiro-Wilk test. Statistical significance was predetermined at $P \leq 0.05$ and was supported by eta squared as a measure of effect size (0.01 = small, 0.06 = medium, 0.13 = large).

Linear regression analysis was applied to quantify the strength of the association between each movement strategy variable and both jump height and flight time:contraction time ratio. The strength of the correlation was quantified as the correlation coefficient (r), with a value greater than 0.6 considered a strong correlation.

Results

Figure 1 summarises the influence of group classification on single leg CMJ performance and FT:CT ratio. Jump height was significantly higher ($P < 0.001$; $\eta^2 = 0.968$) in the Best performers (36.24 ± 1.53cm) compared with the Worst (20.15 ± 1.56cm). FT:CT ratio was also significantly higher ($P < 0.001$; $\eta^2 = 0.880$) in the Best performers (1.04 ± 0.17) than in the Worst (0.35 ± 0.09).

** Insert Figure 1 near here **

Table 1 summarises the influence of group classification on movement strategy variables. When differentiated by jump height, the Best performers elicited significantly higher EccRFD ($P = 0.006$; $\eta^2 = 0.352$), and significantly higher Impulse, PkForce and

RFD in the concentric phase ($P \leq 0.034$; $\eta^2 \geq 0.226$). When differentiated by FT:CT ratio, the Best performers elicited significantly higher PkForce and RFD in the eccentric phase ($P \leq 0.002$; $\eta^2 \geq 0.417$), in addition to a shorter phase duration ($P = 0.003$; $\eta^2 = 0.412$). Best performers utilised a shallower CMJ depth ($P = 0.002$; $\eta^2 = 0.451$), prior to eliciting significantly greater PkForce and RFD in the concentric phase ($P < 0.001$; $\eta^2 \geq 0.599$), which was of a shorter duration ($P < 0.001$; $\eta^2 = 0.771$).

** Insert Table 1 near here **

Table 2 summarises the magnitude (r) and direction of the linear correlation coefficient quantifying the strength of the association between each movement strategy variable and jump height for the Best and Worst performers, and similarly with flight time:contraction time ratio. A negative correlation is annotated with "-" to denote the direction of the association, and strong correlations ($r > 0.6$) are highlighted in bold font.

Jump height was most strongly correlated with greater concentric phase impulse in the Best performers, with the Worst performers exhibiting no strong correlations between movement strategy variables and jump height.

Time ratio was most strongly associated with greater concentric phase rate of force development, and lower eccentric phase impulse in the Best performers. Conversely, the Worst performers were strongly associated with greater magnitude of peak force, rate of peak force, duration and impulse in the eccentric phase, along with greater force at zero velocity. The Worst performers also exhibited a strong negative correlation with CMJ depth and concentric rate of force development.

** Insert Table 2 near here **

Discussion

The aim of the current study was to investigate the movement strategy variables influencing single leg CMJ performance within a professional, male football team. CMJ performance has previously been shown to be sensitive to sex (Laffaye et al., 2017), age (McMahon et al., 2017a), sport (Stahl et al. 2020) and playing level (McMahon et al., 2018). Despite standardising all these confounding variables by using a professional male football squad, a lack of homogeneity was highlighted by a range of 17.3 to 39.3cm in single leg CMJ height. This range might be attributed to differences in playing position, and whilst we only used outfield players, Harry et al. (2018) reported no influence of playing position on double leg CMJ performance in collegiate football players. Retrospective classification of players based on performance was used to differentiate the best and worst performers, with between group differences then investigated in movement strategy. Identifying deficits in movement strategy arguably has greater practical implication than deficits in performance capacity, enabling the practitioner to develop specific neuromuscular intervention strategies. For example, Hart et al. (2019) recently identified CMJ movement strategy differences in professional players with previous injury, despite no performance deficits. Differences in movement strategy might therefore be more insightful than gross outcome measures in the profiling of athletes (Heishman et al., 2019).

The group stratification approach used in the current study elicited significant ($P < 0.001$) between group differences in single leg CMJ height (36.24 ± 1.53cm vs. 20.15 ± 1.56cm). Players producing the greatest jump height performance were characterised by generating greater rate of force development during the eccentric phase, and greater concentric phase impulse, peak force and rate of force development. Group stratification by flight time-to-contraction time ratio also elicited significant ($P < 0.001$) differences between groups (1.04 ± 0.17 vs. 0.35 ± 0.09). Players eliciting the highest time ratios were characterised by greater peak force and shorter duration of the eccentric and concentric phases, leading to greater rate of eccentric and concentric force development, and a shallower countermovement depth. These findings are consistent with recent previous studies in highlighting the contribution of both phases to CMJ performance. McMahon et al. (2017b) used the modified reactive-strength index defined as the ratio of jump height and time to take-off (as opposed to the flight time:contraction time ratio used in the present study), observing that better performance was associated with greater peak force, peak power, and peak velocity in the eccentric and concentric phases of double-legged CMJ. Krzyszkowski et al. (2020) used the same outcome measure and employed a similar group stratification technique as used in the present study, differentiating good and poor jumpers from a sample of collegiate basketball players. Greater rate of force development in a braking phase, differentiated from the unloading phase and demonstrating greater deconstruction of the downward phase than employed in the current study, and a shorter time to takeoff were key to good performance. Similarly, Harry et al. (2018) observed that better jumpers displayed a more rapid unloading phase prior to a greater propulsive impulse. This highlights the contribution of eccentric rate of force development to subsequent concentric force production (Laffaye et al., 2013). In the present study, concentric phase impulse was the strongest predictor of jump height in the best performers. This should not be misinterpreted as better jump height performance being solely derived from the concentric phase of the jump which would negate the neuromuscular objective of the CMJ task. An intervention aimed solely at increasing concentric impulse would be counterproductive to the CMJ jump strategy, and the physical demands of football more broadly. An increase in concentric impulse will produce an increase in jump height as the primary mechanical determinant, but this would be an ineffectual intervention considered in isolation. Furthermore, the variation in concentric impulse was only able to account for 37% of the variability in jump height in the best group, and jump height was not strongly associated with any movement strategy variables in the worst performers. The relatively small magnitude of explained variance might be attributed to the calculation of jump height from flight time, which is susceptible to alterations in body position at touchdown relative to takeoff. The lack of power in the movement strategy variables being able to predict jump height performance highlights the diversity in movement strategy when completing the single leg CMJ. Different movement strategies may elicit the same level of performance, as observed by Hart et al. (2019) in previously injured players, with the potential for misinterpretation of an athlete’s neuromuscular capacity. Movement strategy rather than gross performance measures should therefore be considered when profiling players to inform decisions regarding return to injury, or readiness to play.

Similarly, greater concentric rate of force development and lower eccentric impulse were the strongest predictors of flight time ratio in the best performers. Concentric or propulsive impulse was able to account for 77% of the variation in time ratio, whilst the lower eccentric phase impulse can be attributed to a shorter phase duration and resulted in significantly greater rate of eccentric force development. In contrast, the worst performers were strongly correlated with greater eccentric phase metrics (duration, magnitude of force, and impulse), a deeper countermovement and greater force at zero velocity, and a lower rate of force development in the concentric phase. These poor jumpers were characterised by significantly lower eccentric peak force and rate of force development, a significantly longer eccentric phase duration, a deeper countermovement, and subsequently significantly lower propulsive force production. The longer concentric phase also created a significantly lower rate of propulsive force production in these lesser performers. This highlights that an ineffectual eccentric phase will inhibit performance, supporting previous research (Laffaye et al., 2013; McMahon et al., 2017b; Harry et al., 2018). Interpretation of a deeper countermovement should be treated with caution in the absence of the countermovement phase duration. A deep countermovement does not presume a slow action, and in fact a deep, fast countermovement would be advantageous given the impact of eccentric force on subsequent concentric output. Greater analysis of the downward phase and differentiating unloading from braking as employed by Krzyszkowski et al. (2020), highlights the importance of an efficient amortisation phase. The authors highlight that in terms of rapid force production, increased rate of force development during unloading and braking are critical to success.

A lack of eccentric phase contribution to jump height suggests that players might compensate for an ineffective eccentric phase or amortisation, essentially replicating a 'rocket jump' performed from an isometric position. This negates the neuromuscular interpretation of the task and might mask movement compensations that have clinical relevance in considering poor utilisation of the stretch-shortening cycle and impaired eccentric rate of force development. Further analysis and greater temporal deconstruction of the downward phase used in the current study would inform an investigation of such changes in movement compensations, for example by differentiating the unloading phase and braking phase of the CMJ (Harry et al., 2020; Krzyszkowski et al., 2020) CMJ height might be recovered to preinjury levels in rehabilitation which might satisfy return to play criteria for example, but this gross outcome measure can mask latent deficiencies in movement strategy. Movement compensations have been identified in players with injury history (Cohen et al., 2014; Hart et al., 2019; Jordan et al., 2015; Baumgart et al., 2017), and thus it is possible that a player might mask eccentric strength deficiencies with a concentric jump strategy. The potential to generate CMJ height without effective utilisation of the eccentric phase of the jump might also highlight eccentric strength deficiencies, widely acknowledged as a primary and modifiable risk factor for hamstring strain, knee and ankle joint injuries which are all common in football (Ekstrand et al., 2016). Furthermore, eccentric muscular actions are fundamental in the primary mechanism of injury in ballistic locomotor tasks including high speed running and jumping (La Stayo et al., 2003; Thelen et al., 2006). Misinterpretation of readiness to play might have implications for the re-injury rate in football, where recurrent injury is often associated with greater severity defined as time lost (Hagglund et al., 2006; Ekstrand et al., 2020). This has implications in the context of our professional football club where the purpose of profiling is to inform decisions regarding personalised training needs. Appropriate and effective clinical interpretation demands informative data, beyond gross performance outcome measures. Practitioners without access to instrumented force platforms might therefore also consider a countermovement:rocket jump height ratio, which would quickly establish the efficacy of the stretch shortening cycle and inform personalised training interventions.

Care should be taken when generalising beyond the specific research design elements of the present study, for example when considering how this study might inform the assessment of female athletes, young athletes, or athletes from different sports including those with a greater bilateral emphasis. The group stratification approach identified the top ten and bottom ten performers from a squad of thirty-six, but it should be acknowledged that the 'worst' CMJ performers are professional football players. In the current study we investigated the performance of single leg CMJ performance, and future research might consider the double leg CMJ. The single CMJ is considered more challenging to perform (Benjanuvatra et al., 2013), but in elite athletes we advocate this test as being more valid of the physical challenge and injury risk of our sport. We have also identified, anecdotally, that single CMJ is more sensitive to the influence of previous injury, with inter-limb asymmetries providing a movement compensation strategy to maintain double CMJ performance. Such masking strategies are problematic for the practitioner, and we advocate an assessment of movement strategy as opposed to task outcome. We utilise CMJ testing frequently within the players' schedule, and this familiarity has been shown to reduce the magnitude of inter-limb asymmetries (Bishop et al., 2018). The use of 'normative' data should consider the context and athletes represented, however, in considering the lack of homogeneity within a single elite football squad, the current study does present a range of performance data metrics. Alternative analytical approaches might also be considered, such as a single-subject approach where each player is compared against themselves, for example within and between seasons. Consideration should also be given to the movement strategy variables and CMJ temporal phases defined in the present study and recent literature (Jordan et al., 2015; Heishman et al., 2019) which reflect the ForceDecks analysis software and are therefore accessible to practitioners. Greater analysis of the force-time curve including further deconstruction of the CMJ to differentiate the unloading and braking phases would further an understanding of movement strategy (Harry et al., 2020; Krzyszkowski et al., 2020). Furthermore, jump height might be better considered as a function of takeoff velocity rather than flight time, which is prone to altered body position at landing relative to takeoff.

In summary, despite standardising for confounding variables in sex, age, sport and playing level, there was still a relative lack of homogeneity in single leg CMJ performance within a professional football club. Jump height, selected as a measure of performance, was most strongly correlated with greater concentric impulse, although better performers elicited significantly greater rate of force development in the eccentric and concentric phases. Flight time-to-contraction time ratio, selected as a measure of movement strategy, also differentiated the best performers as eliciting greater rate of force development in both phases, along with a shallower countermovement. Greater concentric rate of force development and lower eccentric impulse (attributed to shorter phase duration) were the strongest predictors of good performance. Assessing movement strategy within a submaximal, logistically easy task like the single CMJ has the potential to inform personalised exercise prescription and rehabilitation from injury.

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Figure 1. Categorisation of players based on CMJ jump height and flight time:contraction time ratio. * denotes significant difference between groups (P < 0.001).

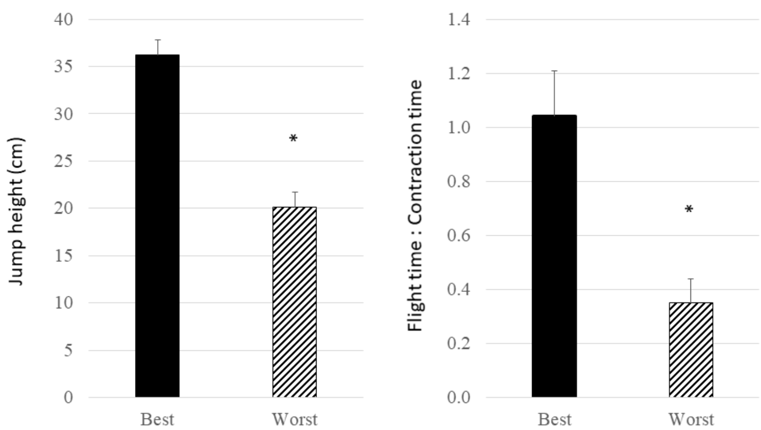

Table 1. The influence of performance level on CMJ movement strategy.

	Jump Height				FT:CT Ratio			
	Best	Worst	P	η^2	Best	Worst	P	η^2
Ecc Impulse	58.74 ± 21.13	55.40 ± 25.17	0.752	0.006	41.59 ± 12.34	59.65 ± 28.23	0.095	0.155
Ecc PkForce	17.13 ± 2.82	15.27 ± 2.18	0.116	0.131	17.87 ± 2.85	14.15 ± 1.62	**0.002**	0.417
Ecc RFD	62.80 ± 32.36	28.20 ± 13.31	**0.006**	0.352	102.80 ± 37.66	17.00 ± 6.43	< **0.001**	0.737
Ecc Duration	0.18 ± 0.09	0.18 ± 0.04	0.975	< 0.001	0.13 ± 0.02	0.21 ± 0.07	**0.003**	0.412
Force @ 0vel	1.83 ± 0.31	1.61 ± 0.22	0.091	0.151	1.85 ± 0.34	1.59 ± 0.22	0.059	0.185
CMJ Depth	16.93 ± 8.96	12.06 ± 14.12	0.369	0.045	10.08 ± 2.69	25.41 ± 12.00	**0.002**	0.451
Con Impulse	176.61 ± 41.93	130.43 ± 47.85	**0.034**	0.226	167.68 ± 27.63	149.96 ± 28.52	0.175	0.100
Con PkForce	23.98 ± 5.07	19.71 ± 1.28	**0.019**	0.270	26.74 ± 3.57	18.89 ± 2.24	< **0.001**	0.658
Con RFD	61.61 ± 50.07	24.20 ± 11.55	**0.033**	0.227	98.84 ± 44.97	21.03 ± 15.09	< **0.001**	0.599
Con Duration	0.29 ± 0.07	0.32 ± 0.05	0.207	0.087	0.23 ± 0.04	0.39 ± 0.05	< **0.001**	0.771

Table 2. Movement strategy variables as predictors of CMJ performance.

	Jump Height		FT:CT Ratio	
	Best	Worst	Best	Worst
Ecc Impulse	0.44	- 0.14	**- 0.66**	**0.85**
Ecc PkForce	- 0.02	0.25	- 0.59	**0.80**
Ecc RFD	- 0.23	0.39	0.40	**0.71**
Ecc Duration	0.31	- 0.24	0.56	**0.89**
Force @ 0 vel	0.07	0.10	0.53	**0.84**
CMJ Depth	- 0.45	0.44	0.18	**- 0.87**
Con Impulse	**0.61**	0.07	0.48	- 0.27
Cone PkForce	0.07	- 0.40	0.40	- 0.45
Con RFD	- 0.09	- 0.35	**0.88**	**- 0.64**
Con Duration	0.38	- 0.33	0.12	0.17