Countermovement Jump Phase Characteristics of Senior and Academy Rugby League Players

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Abstract

Purpose: Gross measures of countermovement jump (CMJ) performance are commonly used to track maturational changes in neuromuscular function within rugby league (RL). The purpose of this study was to conduct both a gross and a more detailed temporal phase analysis of the CMJ performances of senior and academy RL players, to provide greater insight into how neuromuscular function differs between these groups.

Methods: Twenty senior and fourteen academy (under-19) male RL players performed three maximal effort CMJs on a force platform with forward dynamics subsequently employed to allow gross performance measures and entire kinetic and kinematic-time curves to be compared between groups.

Results: Jump height (JH), reactive strength index modified, concentric displacement, and relative concentric impulse (C-IMP) were the only gross measures that were greater for senior players (d = 0.58-0.91) compared to academy RL players. The relative force- and displacement-time curves were similar between groups, but the relative power- and velocity-time curves were greater (d = 0.59-0.97) for the senior players at 94-96% and 89-100% of the total movement time, respectively.

Conclusions: The CMJ distinguished between senior and academy RL players, with seniors demonstrating greater JH through applying a larger C-IMP and thus achieving greater velocity throughout the majority of the concentric phase and at take-off. Therefore, academy RL players should train to improve ~~movement velocity during~~ triple (i.e. ankle, knee and hip) extension velocity during the CMJ in order to bring their jump height scores in line with those attained by senior players.

Keywords: Force-Time, Power-Time, Temporal Phase Analysis, Neuromuscular Function, Maturation

Introduction

The countermovement jump (CMJ) ~~test~~ is commonly used as part of the athlete monitoring process within rugby league (RL), as it is simple to perform and it provides insight into players' seasonal variations in neuromuscular function and fatigue.[1-7] The CMJ ~~test~~ has also been used within RL to discriminate between playing positions and selection levels across the junior age groups.[8-11] The research conducted within RL, and indeed in most ~~other~~ sports, has typically reported gross measures of CMJ performance (e.g. mean and peak values) including flight time,[3, 5] jump height~~,~~[1, 6, 8-11] and peak force,[4, 5] ~~peak~~ power,[4, 5, 7] and ~~peak~~ rate of force development (RFD) [5].

Whilst these ~~above-mentioned~~ gross ~~CMJ related variables~~performance measures have provided useful information pertaining to player monitoring and maturation in RL, they only describe changes (e.g. across the season) or differences (e.g. between age groups) during a specific phase of the CMJ rather than comparing performance data sampled throughout the entire movement. Indeed, the latter approach has been recently shown to provide more detailed information about neuromuscular function and fatigue when compared to the aforementioned 'typical' CMJ analysis methods.[12] This method, first published by Cormie at al.[13], involves re-sampling all CMJ performance data to an equal number of samples and then conducting a temporal phase analysis (TPA). The TPA approach allows for changes[14] and/or differences[13] in a range of kinetic (e.g. force and power) and kinematic (e.g. velocity and displacement) variables calculated throughout the entire CMJ performance to be determined, rather than just at solitary phases within the jump.

Of the gross measures of CMJ performance described earlier, jump height derived from a jump mat (using the flight time method) has been the sole CMJ metric used to distinguish between the junior age groups in RL. [8-11] Whilst the jump mat used in these studies (i.e. the Just Jump System) demonstrated that CMJ height increased with age, it could not provide insight into *how* the increased CMJ height seen with maturation in RL players was achieved. Additionally, the Just Jump System has been recently shown to overestimate CMJ height,[15] albeit consistently, which does not affect the CMJ height comparisons made across academy squads but does ~~invalidate~~ compromise the CMJ height values reported. Furthermore, to the authors' knowledge, no studies have compared CMJ performances between the oldest academy age group (i.e. the under 19 (u19) age category) and senior players in RL which may provide further understanding of the neuromuscular development required for the transition from academy to senior squads.

Collecting both u19 academy and senior squad CMJ data on a force platform (i.e. the criterion method) and subsequently conducting a TPA, in line with previous work[12-14], would deliver a more comprehensive insight into how the CMJ can be used to differentiate between these levels of play in RL and may help to guide the neuromuscular training focus of academy squads. Furthermore, comparing the typically reported gross measures of CMJ performance between these cohorts, in addition to alternative gross measures of CMJ performance such as the reactive strength index modified (RSImod),[16] would lend insight into which of these more basic measures may also be useful to include as part of the ongoing athlete monitoring process within RL. The purpose of this study was, therefore, to compare both gross measures of CMJ performance and the entire CMJ force-, velocity-, power- and displacement-time curves between high-level senior and u19 academy RL players. It was hypothesized that senior players would outperform academy players on all gross measures of

CMJ performance and display ~~superior~~ greater force~~-~~, velocity~~-~~ and power~~-~~ throughout key phases of the CMJ~~curves~~.

Methods

Subjects and Design

Senior (n = 20, age 26 ± 3.2 years, height 181 ± 5.0 cm, body mass 98 ± 11.9 kg) and academy (n = 14, age 19 ± 1.3 years, height 182 ± 4.3 cm, body mass 88 ± 8.8 kg) male RL players, comprised of an equal mix of forwards and backs, were recruited from an English Championship club. Each squad attended a single, but separate, testing session in a laboratory setting at the same time of day during the first week of pre-season training. Written informed consent, or parental assent where appropriate, was provided prior to testing and the study was pre-approved by the institutional ethics committee.

Methodology

Following a brief warm-up consisting of dynamic stretching and sub-maximal jumping, participants performed three CMJs ~~trials~~ (interspersed with approximately one minute of rest) to a self-selected depth. Participants were instructed to perform the CMJ as fast as possible with the aim of maximising jump height, whilst keeping their arms akimbo ~~at all times~~throughout. Any CMJs ~~trials~~ that were inadvertently performed with the inclusion of arm swing or tucking of the legs during the flight phase of the jumps were omitted and, in such cases, additional CMJs ~~trials~~ were performed after a one-minute rest period.

~~All recorded~~Successful CMJs ~~trials~~ were recorded at 1000 Hz using a Kistler type 9286AA force platform ~~performed on a portable force platform sampling at 1000 Hz (type: 9286AA, dimensions 600 mm x 400 mm, Kistler Instruments Inc., Amherst, NY, USA) via~~and Bioware 5.11 software (~~version 5.11,~~ Kistler Instruments Inc., Amherst, NY, USA). Participants were instructed to stand still for the initial one second of the data collection period ~~(known as the silent period)~~[17, 18] to allow for the subsequent determination of body weight ~~(see later in this section)~~. The raw vertical force-time data for each jump trial were exported as text files and analysed using a customised Microsoft Excel spreadsheet (version 2016, Microsoft Corp., Redmond, WA, USA).

Centre of mass (COM) velocity ~~throughout the sampling period~~ was determined by dividing vertical force data (minus body weight) by body mass and then integrating the product using the trapezoid rule. Instantaneous power was determined by integrating COM velocity and ~~then calculated by multiplying vertical force and velocity data at each time point~~ and ~~centre of mass~~COM displacement was determined by double integration of the vertical force data.[18]

The onset of movement for each CMJ trial was considered to have occurred 30 milliseconds prior to the instant when vertical force had ~~reduced~~ decreased by five times the standard deviation of body weight, as derived during the silent period.[17] The unweighting phase of the CMJ was considered to have occurred between the onset of movement and the instant of peak negative ~~centre of mass~~COM velocity (which occurs when the vertical force equals body weight again). The eccentric phase of the CMJ was defined as occurring between the instants of peak negative ~~centre of mass~~COM velocity and zero ~~centre of mass~~COM velocity. The concentric phase of the CMJ was deemed to have occurred between the instant that ~~centre of mass~~COM velocity exceeded 0.01 $m \cdot s^{-1}$ and the instant of take-off. The instants of take-off and touchdown were defined as the instants that vertical force had fallen below and above, respectively, a threshold equal to five times the standard deviation of the residual force which was calculated during the first 300 milliseconds of flight phase of the jump (i.e. when the force platform was unloaded). The 300 millisecond time frame of this residual force threshold calculation was in line with previous suggestions.[18] The interpretation of the CMJ force-time curves attained in this study can be seen in Figure 1.

INSERT FIGURE 1 ABOUT HERE

Eccentric and concentric peak force and power were defined as the maximum vertical force and power values, respectively, attained during the eccentric and concentric phases of the jump.

Impulse was calculated during both the eccentric and concentric phases of the jump as the area under the net force-time curve (minus body weight) using the trapezoid rule.[19] Area under the force-velocity curve was calculated to provide a measure of total power, from the onset of movement to the instant of take-off in line with previous work[13] using the Simpson's rule, as this method of integration was most effective for these data. Mean RFD was calculated as eccentric peak force divided by the time taken to reach this peak value from the onset of the eccentric phase. All kinetic data were also divided by body mass to allow for a normalised comparison of these data between groups. Jump height was derived from vertical velocity at take-off. Reactive strength index modified was calculated as jump height divided by movement time.[16]

The TPA of the three CMJ trials ~~were~~ was conducted by modifying each individual's force-, velocity-, power- and displacement-time curves from the onset of movement to the instant of take-off so that they each equalled 500 samples.[13] This was achieved by changing the time delta between the original samples (e.g. original number of samples/500) and subsequently re-sampling the data.[13] This resulted in an average sample frequency of 618 ± 61 and 620 ± 63 for the senior and academy squad players' data, respectively, and allowed the averaged curve of each variable to be expressed over a percentage of time (e.g. 0-100% of movement time).

Statistical Analysis

For each gross measure and the TPA, the mean output of the three CMJ trials was taken forward for statistical analysis. All data satisfied parametric assumptions except eccentric phase time. Mean differences in each parametric variable (including differences in the normalised kinetic and kinematic time curves) derived for senior and academy players were; therefore, compared using independent t-tests whereas eccentric phase time was compared between squads via the Mann-Whitney U test. A two-way random-effects model intraclass correlation coefficient (ICC) was used to determine the relative between-trial reliability of each variable. The ICC values were interpreted according to previous work[20] where a value of ≥ 0.80 is considered highly reliable. Independent t-tests, the Mann-Whitney U test and ICCs were performed using SPSS software (version 20; SPSS Inc., Chicago, IL, USA) with the alpha level set at $P \leq 0.05$. Absolute between-trial variability of each variable was calculated using the coefficient of variation expressed as a percentage (%CV). Effect sizes were calculated using the Cohen *d* method to provide a measure of the magnitude of the differences in each variable noted between squads and they were interpreted in line with previous recommendations which defined values of < 0.35, 0.35-0.80, 0.80-1.5 and > 1.5 as trivial, small, moderate, and large, respectively.[21]

Results

Reliability and Variability of Data

Each variable, excluding movement time (ICC = 0.68), demonstrated high between-trial reliability with ICCs of ≥ 0.82 (Table 1). Only eccentric peak power and mean RFD showed large between-trial variability (CV ≥ 10%) with the remaining variables demonstrating low-moderate variability (CV 1.9-7.5%). The majority of the data presented in this study can, therefore, be considered to have yielded acceptable between-trial reliability and variability.

Kinematic and Temporal Comparison

Senior players jumped significantly ($P = 0.005$) higher than the academy players, by achieving a significantly ($P = 0.004$) greater vertical take-off velocity; they also demonstrated significantly ($P = 0.027$) greater reactive strength capacity (Table 1). ~~The o~~Overall movement time (from the onset of movement to take-off) and ~~the ~~eccentric and concentric phase times were comparable between squads (Table 1). ~~Centre of mass~~COM displacement during the eccentric phase of the jump was almost significantly larger for the senior players ($P = 0.05$) with a small effect noted, whereas concentric ~~centre of mass~~COM displacement was significantly ($P = 0.013$) larger for the senior players (Table 1).

INSERT TABLE 1 ABOUT HERE

Absolute and Relative Kinetic Comparison

Each kinetic variable, expressed in absolute terms, was significantly greater for the senior players with mostly moderate to large effects noted (Table 1). Contrastingly, relative kinetic data was similar between squads for all variables apart from concentric impulse which was significantly ($P = 0.004$) larger for the senior players (Table 1).

Temporal Phase Analysis Comparison

Senior players produced significantly larger absolute vertical force at 0-3% (P = 0.022-0.046, d = 0.77-0.89), 52-72% (P = 0.004-0.048, d = 0.74-1.15) and 87-100% (P = 0.001-0.037, d = 0.56-1.03) of the total movement time (Figure 2), however, there were no significant temporal differences in relative ~~vertical~~ force noted between senior and academy players (Figure 3). Senior players also produced greater absolute vertical power at 50-55% (P = 0.021-0.025, d = 0.81-0.87) and 71-100% (P = 0.001-0.046, d = 0.71-1.37) of the total movement time (Figure 2), but differences were only noted between 94% and 96% of the total movement time with small effects noted (P = 0.044-0.048, d = 0.59-0.61) when relative vertical power was compared between squads (Figure 3).

Senior players achieved significantly greater vertical ~~centre of mass~~COM velocity (Figure 2) during the final 19% of the movement with small-moderate effects seen (d = 0.70-0.97). Vertical ~~centre of mass~~COM displacement was not significantly different between squads throughout the jumping movement (Figure 3), although it approached statistical significance between 61% and 69% of the movement (P = 0.052-0.058, d = 0.63-0.65), which corresponded to the transition from the eccentric to the concentric phase of the jump (i.e. the bottom of the countermovement).

A comparison of the absolute and relative force-velocity curves attained by senior and academy players is shown in Figure 4. These graphs show that although the total area under the mean absolute force-velocity curve was significantly greater for senior players (Table 1), the total area under the mean relative force-velocity curve was not, despite the velocity attained by the senior players being significantly higher throughout the majority of the concentric phase of the jump (Figure 2).

INSERT FIGURE 2 ABOUT HERE

INSERT FIGURE 3 ABOUT HERE

INSERT FIGURE 4 ABOUT HERE

Discussion

To the authors' knowledge, this is the first study to include TPA, alongside reporting typically reported gross measures, of the CMJ in RL players and compare results between levels of play. The main findings of this study were that senior RL players produced a significantly greater CMJ height (P = 0.005, d = 0.91) than academy RL players by applying a significantly larger (P = 0.004, d = 0.86) relative concentric impulse (Table 1). A larger relative concentric impulse allowed senior players to achieve a greater vertical velocity of their ~~centre of mass~~COM throughout the majority of the concentric phase of the jump (Figure 2) and, importantly, at take-off (P = 0.004, d = 0.87). A larger relative concentric impulse was achieved by senior players despite this group demonstrating similar relative concentric peak force and concentric phase time to academy players (Table 1). Nevertheless, a small between-squad effect size was observed for concentric phase time (d = 0.39) with senior players demonstrating a marginally longer concentric phase duration, suggesting that this cohort achieved a larger relative concentric impulse by subtly increasing the duration of concentric force application. Despite the slightly increased concentric phase duration seen in senior players, their concentric ~~centre of mass~~COM displacement was significantly greater (*P* = 0.013, *d* = 0.89) than academy players (Table 1) which led to the aforementioned higher ~~centre of mass~~COM velocity noted throughout most of the concentric phase of the jump (Figure 2).

Combining the novel TPA approach with the typical reporting of important gross variables has ~~allowed for~~enabled a more detailed description of the kinetic and kinematic aspects of the CMJ that differentiate between senior and academy levels of play in RL and where these differences occur within the entire CMJ~~ movement~~. Based on the results of the TPA, velocity was the best discriminator between senior and academy players' performances due to higher values being shown for senior players in the final 19% of the CMJ movement (which corresponded to ≥ 50% of the concentric portion of the jump), due to the reasons discussed earlier in this section. Relative power was greater for senior players for a small part of the concentric phase of the CMJ recorded immediately after the attainment of peak power (94-96% of the total movement time), which must have been due to the greater vertical velocity of centre mass noted for the senior squad during this time frame given that the time-associated relative force was similar between squads (Figure 3).

Of the gross measures of CMJ performance reported in this study (excluding the absolute kinetic variables which were all larger for senior players due to their greater body mass), only jump height, RSImod and relative concentric impulse differentiated ~~between~~ academy and senior squads (Table 1). Jump height has also previously been reported to differentiate between the junior age groups in RL,[8-11] thus warranting the continued use of this basic measure to monitor performance changes across maturation groups within this sport. Furthermore, in terms of performance in the sport, jump height is arguably the most important of the gross variables reported here. Although force platforms are considered to yield the criterion measure of jump height (preferably when calculated from take-off velocity), a recent stud~~ies~~y ~~have validated CMJ height values derived from an iPhone app~~~~[22]~~ ~~and~~ provided a correction equation[15] for CMJ height values calculated from the jump mat used in the aforementioned work,[8-11] which makes CMJ height an easily attainable metric to be included in the ongoing athlete monitoring process in RL.

The RSImod has not been previously reported for RL players but this metric does offer more insight into the explosive nature of the CMJ performance than jump height alone, by also accounting for movement time.[16, 22] Indeed, RSImod has been shown to differentiate between the reactive strength qualities of several collegiate sports teams[23]~~[24]~~ which further justifies its use within the ongoing athlete monitoring process. The only potential difficulty in this metric being utilised within RL is that the calculation currently requires a force platform to determine movement time,[16, 22]~~[16, 23]~~ which may be unaffordable for many RL clubs. Future research should, therefore, aim to develop more affordable technology that can be used to derive valid RSImod measurements in a RL setting given its apparent usefulness in distinguishing between the senior and academy levels of play in this sport (Table 1).

To the authors' knowledge, relative concentric impulse produced in the CMJ has not been previously reported in the RL related research, however, it has been shown to differentiate between u19 academy and senior RL players in this study. The reason for relative concentric impulse not being included in previous work that has monitored the CMJ in RL players might be due to it being ~~directly~~ almost perfectly related to jump height.[19] With this in mind, and due to a direct measurement of relative concentric impulse requiring the use of a force platform, it may be sufficient for researchers and applied practitioners to monitor CMJ height alone going forward given that this is a more easily attainable and relatable metric. However, where possible, the calculation of concentric impulse should be considered as it can provide valuable information pertaining to how much net force is applied in the CMJ and for how long.

It has been previously advised that peak force should not be used to assess CMJ performance due to it being inversely related to CMJ height[19] and although relative peak power attained in the CMJ has been shown to positively correlate with resultant jump height,[2425] neither of these variables distinguished between u19 academy and senior level RL squads in the present study. Additionally, although peak RFD has been used in previous studies to provide insight into the neuromuscular function of RL players,[5] the mean RFD values reported in this study did not discriminate between senior and academy players and showed high variability. These findings suggest that peak force, peak power and mean RFD may not be a useful variable for monitoring maturational changes in CMJ performance in this sport.

Field Code Changed

A limitation of this study is that the different playing positions (e.g. forwards and backs) within each squad were not compared, therefore, future studies with a larger sample of forwards and backs from each level of play should consider making this comparison to help further understanding of how TPA of the CMJ can be used to differentiate between playing position. Furthermore, it could be argued that centre of massCOM displacement during the countermovement phase of CMJs (i.e. squat depth) should be equated to allow for fairer group comparisons, given that centre of massCOM displacement during this phase significantly affects CMJ height,[19] however, manipulating centre of massCOM displacement may also be viewed as being less ecologically valid (as this would alter the participants' natural jump strategy) which is why both squads were instructed to perform the countermovement to their preferred depth in the present study. Finally, not assessing other factors that may have also influenced the between-squad differences seen in CMJ height, such as trunk and hip angular velocity,[2526] was also a limitation of the present study and thus warrants future exploration.

Field Code Changed

Field Code Changed

Practical applications

Based on the results of the TPA, u19 academy RL players should strive to increase the velocity of the CMJ in order to bridge the gap between their CMJ height scores and those attained by senior squad players. Specifically, owing to the fact that senior RL players performed the CMJ with greater eccentric and concentric displacement within a similar movement time (Table 1), academy players should train to improve triple (i.e. ankle, knee and hip) flexion and extension velocity in the CMJ without compromising force production.

Conclusions

The CMJ distinguished between senior and u19 academy RL competing at the English Championship level. Specifically, senior players demonstrated greater CMJ height by applying a larger relative concentric impulse which enabled them to achieve greater velocity throughout the majority of the concentric phase of the jump and, importantly, at take-off. The results of this study illustrate the benefit of conducting a TPA alongside reporting typical gross measures of CMJ performance, as this combined approach has provided a greater insight into the differences in neuromuscular function between senior and academy RL players. This being said, if access to a force platform is unachievable, although cheaper force platforms are now available,[26] then simply monitoring CMJ height alone via more affordable meansusing equipment such as (e.g. jump mats or iPhone apps) would still be beneficial to the ongoing athlete monitoring process in this sport.

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Figure Captions

Figure 1 – Countermovement jump force-time curve (black solid line) interpretation based on velocity-time curve (grey dashed line) data (data represents the pooled mean senior players' force- and velocity-time curve).

Figure 2 – A comparison of the countermovement jump absolute force-time (top), absolute power-time (second from top), velocity-time (second from bottom), and displacement-time (bottom) curves between senior and academy rugby league players (grey shaded area highlights significant ($P < 0.05$) differences between groups).

Figure 3 – A comparison of the countermovement jump relative force-time (top) and relative power-time (bottom) curves between senior and academy rugby league players (grey shaded area highlights significant ($P < 0.05$) differences between groups).

Figure 4 – A comparison of the countermovement jump absolute (top) and relative (bottom) force-velocity curves between senior and academy rugby league players.

Table

Table 1: A comparison of kinetic and kinematic jump variables between senior (*n* = 20) and academy (*n* = 14) rugby league players.

	Senior		Academy					
Jump Variables	**Mean**	**SD**	**Mean**	**SD**	***P***	***d***	**ICC**	**%CV**
Absolute Data								
Jump Height (m)	0.36	0.04	0.32	0.05	0.005	0.91	0.92	3.8
Velocity at Take-off ($m.s^{-1}$)	2.67	0.16	2.50	0.20	0.004	0.87	0.93	1.9
RSImod	0.45	0.07	0.40	0.10	0.027	0.58	0.87	6.5
Movement Time (s)	0.818	0.084	0.815	0.077	0.910	0.04	0.68	5.4
Eccentric Phase Time (s)	0.174	0.036	0.181	0.034	0.319	0.21	0.82	7.5
Concentric Phase Time (s)	0.272	0.031	0.259	0.037	0.258	0.39	0.88	3.7
Eccentric COM Displacement (m)	0.35	0.04	0.31	0.06	0.050	0.70	0.85	5.4
Concentric COM Displacement (m)	0.47	0.04	0.42	0.06	0.013	0.89	0.88	3.6
Peak Eccentric Force (N)	2345	354	2005	299	0.009	1.04	0.94	3.9
Peak Concentric Force (N)	2421	326	2129	309	0.016	0.92	0.96	2.7
Peak Eccentric Power (W)	1969	694	1431	415	0.023	0.94	0.83	10.0
Peak Concentric Power (W)	5245	601	4421	603	0.001	1.37	0.96	2.7
Area Under F-v Curve (W)	8321	1480	6754	1304	0.003	1.12	0.94	4.2
Eccentric Impulse (N.s)	134	27	107	24	0.007	1.05	0.93	5.8
Concentric Impulse (N.s)	254	28	213	24	0.000	1.56	0.98	1.9
Rate of Force Development ($N.s^{-1}$)	8569	3279	6681	2461	0.005	0.68	0.88	13.1
Relative Data								
Peak Eccentric Force ($N.kg^{-1}$)	24.0	3.3	22.7	2.5	0.220	0.42	0.89	3.9
Peak Concentric Force ($N.kg^{-1}$)	24.7	2.6	24.1	2.6	0.354	0.08	0.92	2.6
Peak Eccentric Power ($W.kg^{-1}$)	20.1	6.8	16.2	4.0	0.115	0.71	0.88	10.0
Peak Concentric Power ($W.kg^{-1}$)	53.6	5.1	50.3	6.6	0.067	0.56	0.94	2.7
Area Under F-v Curve ($W.kg.^{-1}$)	85.2	15.5	76.7	13.4	0.086	0.59	0.93	4.2
Eccentric Impulse ($N.kg^{-1}.s$)	1.4	0.2	1.2	0.2	0.065	0.58	0.88	5.8
Concentric Impulse ($N.kg^{-1}.s$)	2.6	0.2	2.4	0.2	0.004	0.86	0.93	1.9
Rate of Force Development ($N.kg.s^{-1}$)	88.3	34.2	75.9	27.7	0.271	0.40	0.87	13.1

SD = Standard Deviation; ICC = Intraclass Correlation Coefficient; %CV = Percentage Coefficient of Variation; RSI_{mod} = Reactive Strength Index Modified; COM = Centre of Mass

Figure 1

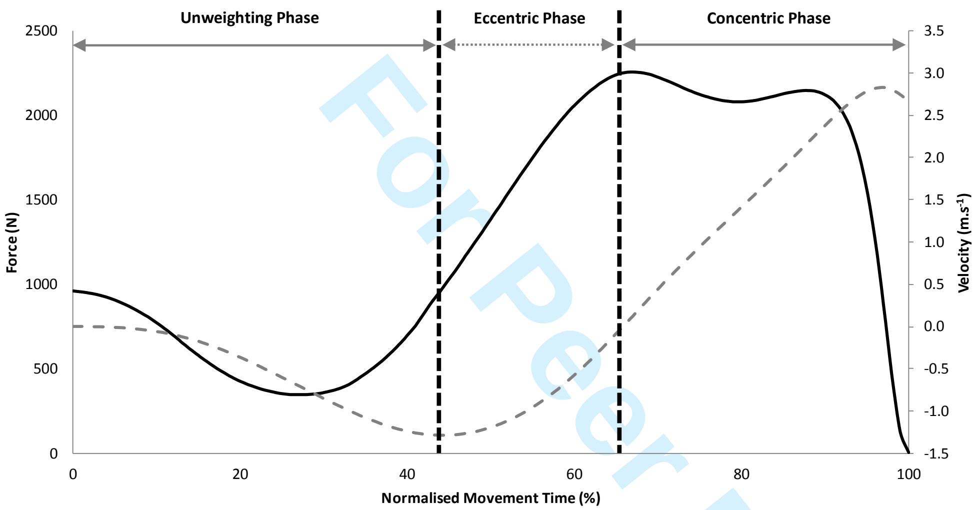
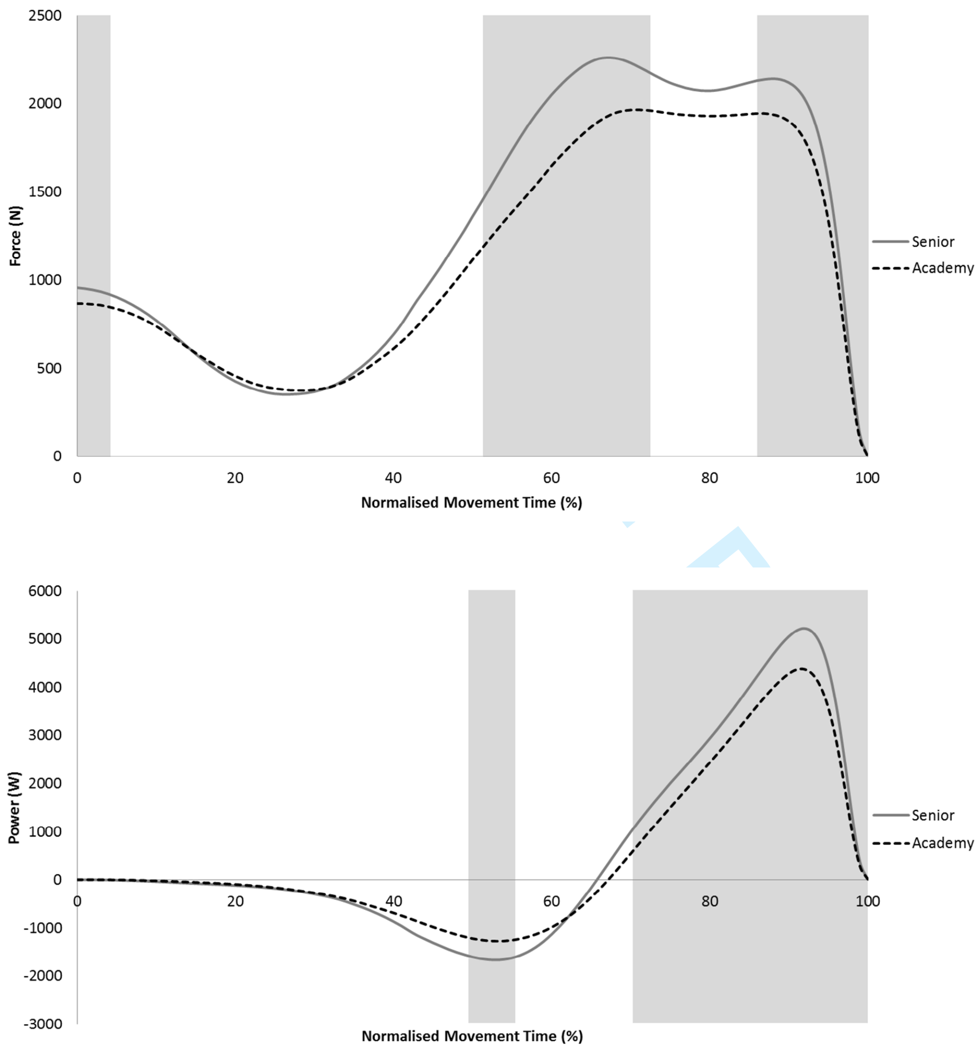
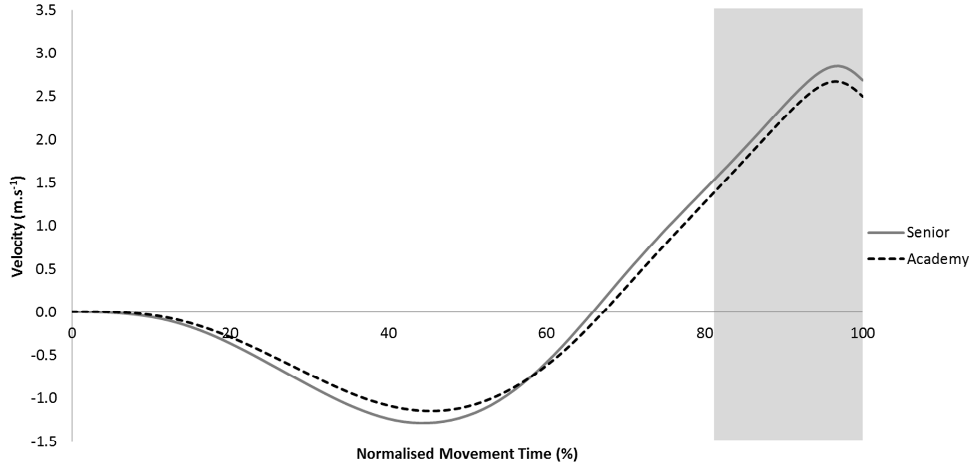

Unweighting Phase
Eccentric Phase
Concentric Phase
2500
2000
1500
1000
500
0
Force (N)
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
Velocity (m.s-1)
0
20
40
60
80
100
Normalised Movement Time (%)

Figure 2


2500
2000
1500
1000
500
0
Force (N)
0
20
40
60
80
100
Normalised Movement Time (%)
Senior
Academy
6000
5000
4000
3000
2000
1000
0
-1000
-2000
-3000
Power (W)
Normalised Movement Time (%)


3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
Velocity (m.s⁻¹)
0
20
40
60
80
100
Normalised Movement Time (%)
Senior
Academy

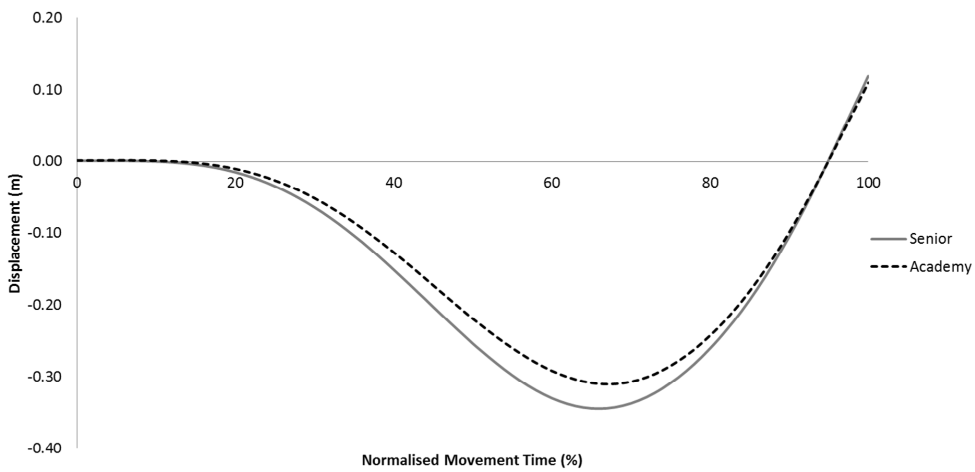

0.20
0.10
0.00
-0.10
-0.20
-0.30
-0.40
Displacement (m)
0
20
40
60
80
100
Normalised Movement Time (%)
Senior
Academy

Figure 3

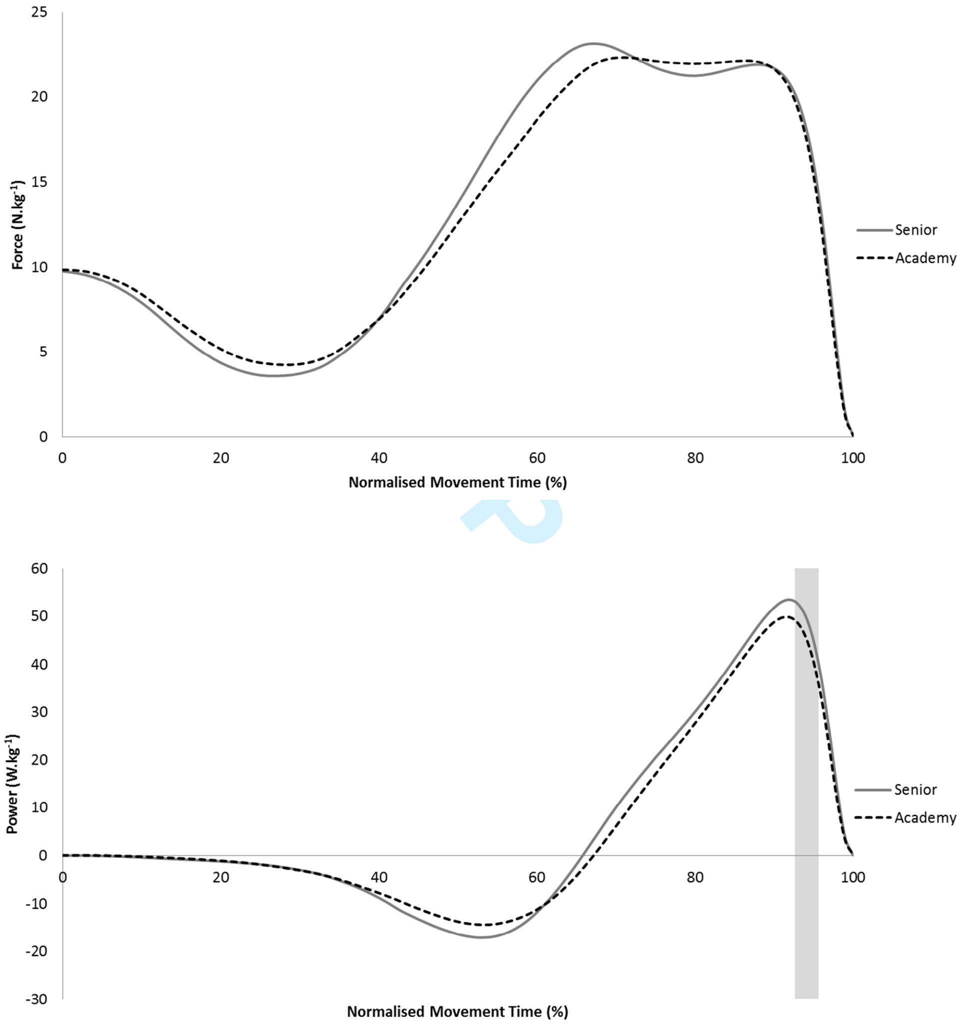
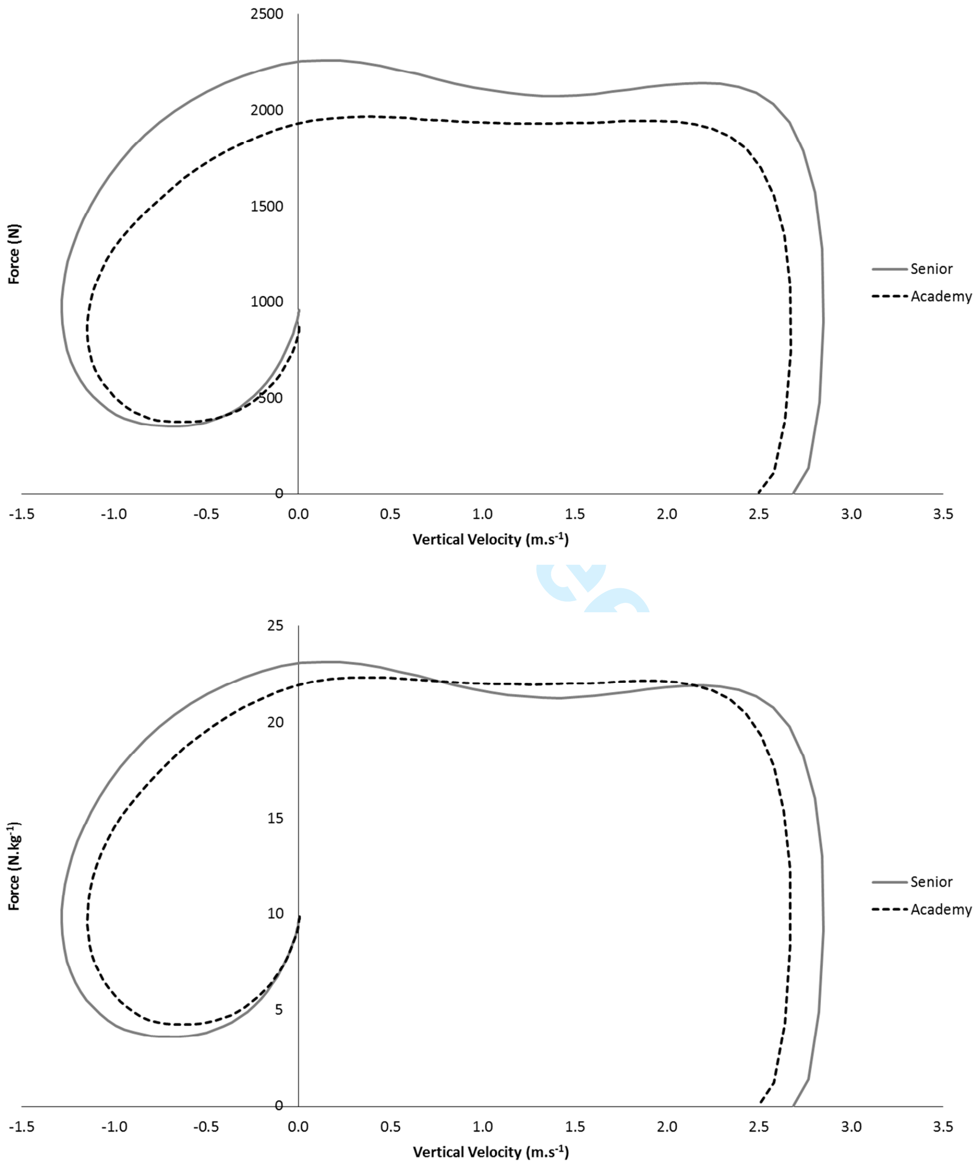

Force (N.kg-1)
25
20
15
10
5
0
0
20
40
60
80
100
Normalised Movement Time (%)
Senior
Academy
Power (W.kg-1)
60
50
40
30
20
10
0
-10
-20
-30
0
20
40
60
80
100
Normalised Movement Time (%)
Senior
Academy

Figure 4


Force (N)
2500
2000
1500
1000
500
0
-1.5
-1.0
-0.5
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
Vertical Velocity (m.s-1)
Senior
Academy
Force (N.kg-1)
25
20
15
10
5
0
-1.5
-1.0
-0.5
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
Vertical Velocity (m.s-1)
Senior
Academy