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A comparison of countermovement jump performance and kinetics at the start and end of an international Rugby Sevens season

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ABSTRACT

The countermovement jump (CMJ) is used to profile and monitor lower body neuromuscular performance in a variety of sports. While jump height, peak power and peak force are commonly reported CMJ variables (CMJ-TYP), several temporal and rate-limited kinetic "alternative" (CMJ-ALT) variables have shown greater response to acute and chronic load, but this has not been examined in male Rugby Sevens (7s) athletes. We evaluated changes in CMJ-ALT and CMJ-TYP variables at the start and end of a World 7s Series season. We compared mean values for CMJ-ALT and CMJ-TYP variables in three CMJs performed by elite male rugby 7s players (n = 12) close to the start and at the end of the season. Potential differences were determined with repeated measures t-tests and magnitude of change quantified using effect sizes. Comparing the start and the end of the season, there were significant differences with very large and large effect sizes in concentric peak force and in a number of CMJ-ALT variables such as concentric duration, countermovement depth, concentric impulse-100ms, concentric rate of power development, eccentric deceleration rate of force development, RSI-modified and FT:CT, with effect sizes ranging between d = 0.98 to 1.39 and p values ranging between p < 0.001 to 0.04. There was no significant change in jump height or concentric peak power. Season-long exposure to matches and training blocks led to improvements in specific CMJ kinetic variables, the majority which were temporal or rate-limited kinetic or CMJ-ALT variables, but not in jump height and peak power or eccentric deceleration impulse. When aiming to quantify chronic response to loading using the CMJ, monitoring of a limited number of 'typical' variables may lead to misleading null conclusions about the response of these athletes to long-term/season long loading. In contrast, a more comprehensive kinetic analysis may reveal improvements in aspects of neuromuscular performance.

1. Introduction

Rugby Sevens (7s) is an Olympic sport with a competitive season that lasts seven months, comprised of 10 tournaments of 2-3 days each. Rugby 7s competitions impose large running-based demands during a 14-minute game period with large high-speed running (HSR) distances per minute e.g., 21.9 m/min, distances covered per minute e.g., 112.1 m.min (Suarez-Arrones et al., 2016) and maximum speed outputs e.g., 8.4m/s (Ross, Gill, & Cronin, 2015), higher than that of the 15s game. Positional differences are reported in distance covered (66.8 m.min in forwards and 73.3

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m.min in backs) and HSR per minute (3.1 m.min in forwards and 7.2 m.min in backs) (Cunningham et al., 2016).

Due to the high physical demands of the sport, competition density during tournaments, and small squad sizes, superior physical qualities may increase a team's chances of success via the potential ability to tolerate greater match outputs, faster recovery (Johnston, Gabbett, Jenkins, & Hulin, 2015), and potentially reduced injury risk (Thorpe, Atkinson, Drust, & Gregson, 2017). Due to the structure of the 7s calendar, training loads can be adapted across the season to induce specific physiological adaptations, minimising effects of travel, or emphasise recovery post-tournament (Marrier et al., 2019). In high performance settings, monitoring neuromuscular responses to load and recovery is often achieved using the countermovement jump (CMJ) (Gibson, Boyd, & Murray, 2016). The CMJ provides both commonly reported performance variables such as jump height and peak power that can be measured or estimated with a number of technologies and a range of other kinetic variables that can be derived from the analysis of force, velocity, power and displacement-time curves following force platform testing (Cormie, Mcbride, & McCaulley, 2009). Gathercole, Stellingwerff, and Sporer (2015) defined these commonly reported variables as typical (CMJ-TYP) and introduced the use of a number of other variables, mainly phase durations, and defined these as 'alternative' (CMJ-ALT). Gathercole and colleagues work extended the observations of Cormack, Newton, McGuigan, and Cormie (2008), which demonstrated that the ratio of flight time to contraction time (FT:CT) was a more sensitive indicator of neuromuscular status and marker of the response to competition, residual fatigue and recovery in elite populations (Cormack et al., 2008; Cormack, Mooney, Morgan, & McGuigan, 2013). FT:CT significantly decreased in response to match play while jump height remained stable (Cormack et al., 2008), and decreases in FT:CT during the season were associated with reduced HSR performance and altered movement strategy (Cormack et al., 2013). In addition, evidence suggests that FT:CT and other rate- or time-limited CMJ-ALT variables that have since been described often provide a deeper insight into neuromuscular responses and alterations in movement strategy not expressed in CMJ-TYP outputs. For example, CMJ-ALT variables have indicated adaptations to short term training programs (Kijowski et al., 2015), long term changes in performance qualities (Heishman, Daub, Miller, Freitas, & Bemben, 2020), residual deficits following injury (Hart et al., 2019) and deconditioning following COVID-19-induced home training (Cohen et al., 2020) while CMJ-TYP were stable following these alterations in loading.

In 7s athletes, West et al. (2013) evaluated changes in CMJ performance across a two-tournament period and reported decreases in jump height of 26% at 12 hours post-tournament one which remained reduced five days later by 8% at the start of tournament two. However, CMJ-ALT variables were not examined. This study, and others (Claudino et al., 2017), indicate that jump height can be a useful marker, but neither of these investigations included CMJ-ALT variables which may provide greater sensitivity. Nonetheless, in 7s a comprehensive and wider array of CMJ kinetic variables has not been investigated throughout the course of the season. Such an analysis may reveal neuromuscular changes that are not be expressed in CMJ-TYP variables and so could provide additional insights on team and individual training, competition and recovery responses. This study aims to quantify potential changes in CMJ-TYP and ALT variables across the World 7s series season, by comparing performance at start versus the end of a season, in male elite Rugby 7s athletes. We also examined whether the CMJ kinetic profile at the start of the season differed between forwards and backs. Finally, for descriptive purposes we compare CMJ kinetics in athletes from other sports for comparable variables, to contrast with that of the present 7s players.

2. Methods

This is a retrospective cohort analysis of CMJ assessments performed across the World Rugby 7s 2018-2019 Series. Nine testing sessions were implemented by sports science support staff during a six-month period, as part of routine athlete monitoring. The first testing session was completed one week after the first pairings of World 7s Series stages (Dubai), with the last testing session completed one week post the last World 7s Series competition (Paris). The remainder of the testing sessions were conducted as part of a normal monitoring process, one-week pre-tournament travel and during the first week back in training post-tournament completion, typically one week after returning to the UK. For the purposes of the present analysis, to examine changes across the whole season, we compared CMJ performance in test session 1 and test session 9. These tests were performed under similar conditions, 1-week post competition.

Table 1**:** Player characteristics (mean (SD)).

	Testing Point 1			Testing Point 9	
	Age (y)	**Height (cm)**	**Body Mass (kg)**	**Height (cm)**	**Body Mass (kg)**
Forwards (n = 5)	26.8 (6.0)	185.8 (7.8)	94.0 (9.7)	185.9 (7.9)	94.5 (8.0)
Backs (n = 9)	24.2 (4.7)	181.6 (6.4)	89.2 (7.6)	181.8 (6.6)	89.3 (7.1)

2.1. Participants

The team consisted of 19 male international rugby 7s players, however the present analysis only includes data from 14 players in testing session 1 and 12 players in testing session 9 (Table 1) who: 1) were with the 7s programme for at least six months, 2) had competed in a World 7s series, 3) had no current or prior (in the preceding two months) training or game time-loss lower limb injuries, and 5) performed a minimum of four CMJ assessments during the season assessed. All players had at least 2 years of training experience. Ethical approval for this study was granted by the St Mary's University, Twickenham ethics committee in line with the principles of the Declaration of Helsinki.

2.2. Procedure

All testing was conducted on the first day of the testing week at the same time in the morning before the scheduled gym-based session. Players were instructed to wear the same footwear for each testing session. The bilateral CMJ was part of a series of jump tests performed by each athlete and was always performed first after a standardised five-minute warm-up of self-selected dynamic stretches, 10 bodyweight squats, 10 lunges and 10 pogo jumps followed by three practice jumps at 60%, 80% and 100% of perceived maximal effort. Two minutes rest was then allowed before the first of three measured jumps performed on dual force platforms (Model No: PS 2141; Pasco Roseville, CA, USA) sampled at 1000 Hz using proprietary software (ForceDecks v1.2.6109, Vald Performance). All players were familiar with the CMJ testing procedures as part of pre-season physical assessments.

2.2.1. Countermovement Jump

After stepping onto the force platforms, players remained still for three seconds to measure body mass (Hart et al., 2019) Athletes performed three bilateral CMJ to a self-selected depth with hands on hips throughout and 30 seconds of rest between each jump. Athletes were instructed to "dip as quick as possible and jump as high as possible" with verbal encouragement provided to encourage maximal effort. A jump was ruled invalid during the jump, exhibited excessive knee flexion once airborne, or not autodetected by the software as a CMJ. For example, jumps in this population are not autodetected correctly (i.e., as a CMJ) if countermovement velocity is insufficient or players do not land on the force plates.

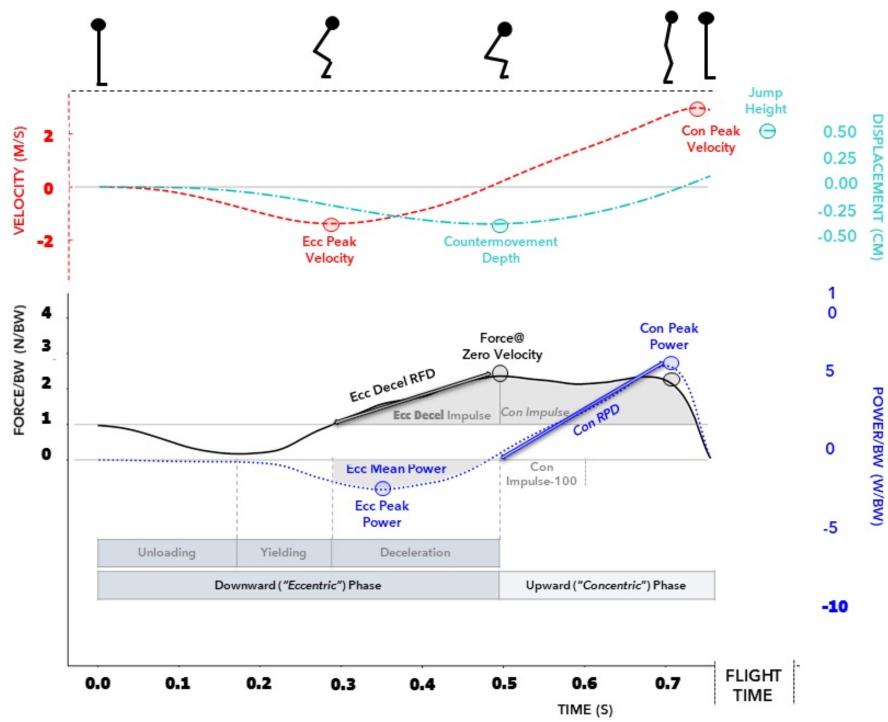

Figure 1: Countermovement jump downward and upward phase vertical ground reaction Force, Velocity, Power, and (Centre of Mass) Displacement-time curves with selected bilateral variables highlighted Force (N-Newtons) Power (W-Watts) are expressed relative to bodyweight (BW): /kg. Con = Concentric, Ecc = Eccentric; RFD = Rate of force development; RPD = Rate of power development; COM = Centre of Mass; Con Imp100 = Concentric impulse during the first 100ms following the start of the upward (concentric) phase. "Depth" refers to COM displacement. Concentric peak force not shown as due to variations in the shape of the force-time curve it occurs at different time points across the phase. As eccentric peak force typically aligns with force at zero velocity, it is not shown. Adapted from Cohen et al. (2020) The initiation of the jump (start of movement) was determined by a 20N change from body-mass quantified before the jump. The eccentric phase was defined from the start of movement to zero velocity and concentric phase from zero velocity to take-off (Kijowski et al., 2015)

2.3. Statistical Approach

Variables and phases included in the analysis are defined in Table 2 (Heishman et al., 2020) and visualised in Figure 1. We dichotomised variables reported as either typical (CMJ-TYP), i.e., CMJ output variables and those most commonly reported, or alternative (CMJ-ALT), including: FT:CT, Reactive Strength Index Modified (RSImod) and component phase durations, time-constrained or rate-related kinetics, and eccentric variables such as mean and peak power. These alternative variables are used by practitioners and have been referred to in the literature but do not appear to be commonly reported.

SPSS statistical analysis software (SPSS, version 24, Chicago, IL) was used for statistical analyses with alpha level set at 0.05. To determine if there were positional differences within the current playing group, independent t-tests were used to compare CMJ variables in the forwards (n = 5) and backs (n = 9) assessed at testing session 1. To determine if there were changes in CMJ variables between testing session 1 and testing session 9, a paired t-test was used to compare players assessed at both these testing points (n = 12); players missing a CMJ assessment at either timepoint were omitted from this analysis.

Table 2: Definition of variables (see Figure 1 for phases and positions of variables).

Variable	Definition
Overall performance	
Jump Height (Imp-Mom) [cm]^{TYP}	Jump Height calculated from take-off velocity
RSI-modified [m/s]^{ALT}	Jump Height (Flight Time) divided by Contraction time (eccentric + concentric duration)
Flight Time:Contraction Time ^{ALT}	Flight Time divided by Contraction Time
Upward (Concentric) phase: Zero velocity / maximum negative displacement to take-off (20N)	
Concentric Impulse [Ns] ^{TYP}	Net impulse across phase
Concentric Peak Force [N/kg] ^{TYP}	Maximum force within phase
Concentric Peak Velocity [m/s] ^{TYP}	Maximum velocity within phase
Peak Power [W/kg] ^{TYP}	Maximum power within phase
Concentric Impulse-100ms [Ns] ^{ALT}	Net impulse during the first 100-ms of phase
Concentric Duration [ms] ^{ALT}	Time from start of phase to take-off
Concentric RPD [W/s/kg] ^{ALT}	Average rate of power development (Δpower / Δtime) between start of phase to peak power
Downward (Eccentric) phase: start of movement (20N offset from body-mass) to end zero velocity / maximum negative displacement	
Eccentric Deceleration Impulse [Ns] ^{TYP}	Net Impulse during the eccentric deceleration subphase (maximum negative velocity to zero velocity)
Eccentric Duration [ms] ^{ALT}	Time from start of movement to end of the phase
Force at Zero Velocity [N] ^{ALT}	Force at the time point of zero velocity (maximum negative displacement)
Countermovement Depth [cm] ^{ALT}	Maximum negative displacement
Eccentric Peak Velocity [m/s] ^{ALT}	Maximum negative velocity during phase
Eccentric Mean Power [W/kg] ^{ALT}	Average power within phase
Eccentric Peak Power [W/kg] ^{ALT}	Maximum negative power within phase
Eccentric Deceleration RFD [N/s/kg] ^{ALT}	Average RFD (Δforce / Δtime) between start of deceleration phase to end of the phase

Note: cm = centimetres; /kg = refers to adjusted for body weight (kilograms); m = metres; ms = milliseconds; N = Newtons; RFD = rate of force development; RPD = rate of power development; s = seconds; W = Watts

Standardised effect sizes (Cohen's *d*) were determined to assess the magnitude of differences in CMJ variables between testing session 1 (start of season) and 9 (end of season). The magnitude of the effect sizes was classified as small (0.2-0.49), medium (0.5-0.79), large (0.8-1.2) and very large (>1.2).

We also calculated coefficient of variation for the variables assessed using two tests performed by the same players under similar conditions, early in the season; this analysis included 12 players who were assessed at both testing session 1 and a second testing session 4 weeks later. Evaluation of inter-day reliability would typically involve comparison of two tests closer together – separated by days or a week. Therefore, while these CVs may not qualify as a reliability analysis, they do provide some population-specific information related to the magnitude of variability (or "noise") in the metrics reported. This data, which uses the two earliest assessments, those *least* contaminated by repeated competition and training cycles, puts into context the percentage changes ("signal") determined between the start to end of season.

3. Results

In the start of season test, there were no statistical differences between forwards and backs for any variable (Table 3), therefore in the subsequent start versus end of season analysis, we included all players. Table 4 shows t-test and effect size for all variables in start versus end of season tests. In comparison to the start of season test, there were significant decreases in concentric duration ($p = 0.01$; $d = 1.39$), and countermovement depth ($p = 0.02$; $d = 1.29$) in the end of season test. There were significant increases in concentric impulse-100ms ($p = 0.04$, $d = 0.98$), concentric RPD ($p < 0.001$; $d = 1.14$), concentric peak force ($p < 0.001$; $d = 1.08$), eccentric deceleration RFD ($p = 0.01$; $d = 1.03$), RSI-modified ($p < 0.001$; $d = 1.14$), and FT:CT ($p < 0.001$; $d = 1.28$).

Table 3: Descriptive data and (mean (SD)) and comparison between forwards (n = 9) and backs (n = 5) for countermovement jump typical (CMJ-TYP) and alternative (CMJ-ALT) variables.

Variable	Forward	Backs	ES	*p*-value
CMJ-TYP				
Jump Height (Imp-Mom) [cm]	44.8 (4.8)	45.5 (4.8)	0.12	0.86
Concentric Peak Force [N/kg]	29.7 (1.9)	29.6 (3.2)	0.06	0.92
Concentric Impulse [Ns]	261.6 (18.5)	265.8 (27.2)	0.19	0.71
Concentric Peak Velocity [m/s]	2.93 (0.2)	3.03 (0.2)	0.50	0.43
Concentric Peak Power [W/kg]	58.8 (7.0)	62.4 (7.4)	0.50	0.43
Eccentric Deceleration Impulse [Ns]	137.4 (7.3)	136.5 (18.4)	0.07	0.91
CMJ-ALT				
RSI-modified [m/s]	0.72 (0.1)	0.70 (0.1)	0.14	0.82
Flight Time:Contraction Time	1.0 (0.1)	0.94 (0.1)	0.24	0.70
Concentric Duration [ms]	220.5 (22.4)	225.6 (33.7)	0.18	0.77
Eccentric Duration [ms]	406.7 (52.7)	435.6 (70.4)	0.47	0.46
Force at Zero Velocity [N]	2755.4 (217.2)	2636.4 (116.0)	0.71	0.31
Concentric Impulse-100ms [Ns]	168.3 (23.2)	163.55 (17.0)	0.24	0.71
Concentric RPD [W/s/kg]	386.0 (88.7)	410.7 (132.1)	0.22	0.89
Eccentric Mean Power [W/kg]	7.3 (0.6)	6.9 (0.8)	0.54	0.39
Eccentric Deceleration RFD [N/s/kg]	163.1 (36.6)	169.0 (67.2)	0.11	0.86
Eccentric Peak Velocity [m/s]	-1.5 (0.1)	-1.5 (0.2)	0.14	0.83
Eccentric Peak Power [W/kg]	25.3 (4.2)	30.2 (12.2)	0.59	0.32
Countermovement Depth [cm]	-30.4 (5.7)	-30.9 (5.6)	0.09	0.89

Note: cm = centimetres; ES = effect size; Imp-Mom = Impulse-Momentum calculation; /kg= variable expressed relative to bodyweight; ms = milliseconds; m = metres; N = Newtons; RFD = rate of force development; RPD = rate of power development; RSI = reactive strength index; s = seconds; W = Watts.

Table 4: Comparison of countermovement jump typical (CMJ-TYP) and alternative (CMJ-ALT) variables in start versus end of season tests.

Variable	Start of Season Mean (SD)	End of season Mean (SD)	ES (95% CI)	*p*-value	% Change	CV (95% CI)
CMJ-TYP						
Jump Height (Imp Mom) [cm]	45.18 (5.86)	45.48 (3.69)	0.06 (-0.80, 0.92)	1.0	1%	3.5 (3.1, 5.5)
Concentric Peak Force [N/kg]	29.63 (2.57)	33.24 (4.14)	1.05 (0.13, 1.96)	0.007*	12%	3.3 (2.9, 5.2)
Concentric Impulse [Ns]	263.89 (22.62)	250.95 (24.25)	-0.55 (0.32, -1.42)	0.454	-5%	2.1 (1.9, 3.4)
Concentric Peak Velocity [m/s]	2.99 (0.19)	2.90 (0.17)	-0.46 (0.44, -1.37)	0.845	-3%	1.6 (1.5, 2.6)
Concentric Peak Power [W/kg]	60.77 (7.12)	63.59 (5.24)	0.46 (-0.42, 1.32)	1.0	5%	1.9 (1.7, 3.1)
Eccentric Deceleration Impulse [Ns]	136.95 (13.80)	130.43 (11.44)	-0.52 (-1.38, 0.36)	1.0	-5%	5.7 (5.1, 9)
CMJ-ALT						
RSI-modified [m/s]	0.71 (0.11)	0.83 (0.11)	1.14 (0.17, 2.01)	0.009*	17%	3.2 (2.9, 5.1)
Flight Time:Contraction Time	0.95 (0.12)	1.11 (0.13)	1.28 (0.34, 2.22)	0.002*	17%	2.7 (2.4, 4.3)
Concentric Duration [ms]	223.30 (27.87)	185.72 (26.10)	-1.39 (-2.35, -0.44)	0.01*	-17%	3.4 (3.1, 5.4)
Eccentric Duration [ms]	422.44 (61.79)	373.25 (63.24)	-0.79 (-1.68, 0.10)	0.138	-12%	3.5 (3.1, 5.6)
Force at Zero Velocity [N]	2690.48 (171.64)	2928.35 (410.26)	0.82 (-0.13, 1.64)	0.97	9%	3.8 (3.4, 6)
Concentric Impulse-100ms [Ns]	165.72 (19.14)	189.33 (29.18)	0.98 (0.05, 1.86)	0.042*	14%	4.6 (4.1, 7.3)
Concentric RPD [W/s/kg]	399.47 (109.73)	545.60 (146.60)	1.14 (0.21, 2.05)	0.002*	37%	7.1 (6.4, 11.3)
Eccentric Mean Power [W/kg]	7.11 (0.68)	6.59 (0.91)	-0.65 (-1.53, 0.23)	0.503	-7%	4.4 (3.9, 6.9)
Eccentric Deceleration RFD [N/s/kg]	166.30 (52.93)	242.50 (94.98)	1.03 (0.08, 1.90)	0.01*	46%	11.0 (9.9, 17.5)
Eccentric Peak Velocity [m/s]	-1.49 (0.18)	-1.45 (0.13)	0.26 (-0.61, 1.11)	1.0	-3%	4.7 (4.2, 7.4)
Eccentric Peak Power W/kg]	27.97 (9.36)	28.99 (4.34)	0.15 (-0.72, 1.00)	1.0	4%	9.9 (8.9, 15.7)
Countermovement Depth [cm]	-30.63 (5.37)	-24.97 (3.42)	1.29 (0.32, 2.19)	0.02*	-18%	4.0 (3.6, 6.3)

Note: * = significant difference ($p < 0.05$) between start of season test and end of season test (in the 12 players who performed both assessments); cm = centimetres; CV = coefficient of variation calculated using data from 12 players who performed both the start of season test and a second test 4 weeks later under the same conditions (1 week post competition); ES = effect size; Imp-Mom = Impulse-Momentum calculation; /kg= variable expressed relative to bodyweight ms = milliseconds; N = Newtons; s = seconds; RFD = rate of force development; RPD = rate of power development; RSI = reactive strength index; s = seconds; W = Watts

4. Discussion

To our knowledge the present retrospective study conducted in elite rugby 7s is the first analysis to examine potential changes in both CMJ-TYP and CMJ-ALT variables between the start and end of a season and to describe a detailed kinetic profile of these athletes. Comparing CMJ performance at the beginning versus the end of season, We, found that while CMJ-TYP variables jump height and peak power were stable, over this period there were significant changes of a large magnitude in CMJ-ALT variables including concentric impulse 100ms, concentric rate of power development, concentric duration, eccentric deceleration rate of force development and RSI-modified, and in the CMJ-TYP variable concentric peak force. The finding that CMJ-ALT variables show larger magnitude and statistically significant changes while CMJ-TYP are stable aligns with the conclusions of previous studies regarding the greater sensitivity in detecting acute, residual and chronic responses to load. In these studies, CMJ-ALT variables such as phase durations, and time-limited or rate, force, power or impulse variables, were more sensitive markers of the neuromuscular response to the input of intense exercise or competition (i.e., neuromuscular fatigue (Gathercole et al., 2015; Cormack et al., 2008)) or of training (i.e., positive adaptations) (Kijowski et al., 2015). In the present analysis, this implies that by monitoring only CMJ-TYP variables practitioners might have incorrectly concluded that CMJ performance and neuromuscular status was stable across a season, whereas CMJ-ALT variables revealed team-level seemingly favorable neuromuscular responses to competition and conditioning between the start and end of the season.

As well as a tool for monitoring responses to training and competition load and adaptations to targeted training, CMJ kinetics have also been used to "profile" elite athlete populations. They have also been used to determine their underlying neuromuscular characteristics and strategies that may contribute to performance (Laffaye, Wagner, & Tombleson, 2014). CMJ-TYP variables such as jump height and concentric peak power and peak force are frequently reported due to associations with key physical qualities such as acceleration (Loturco et al., 2019; Morris, Weber, & Netto, 2020) and maximum velocity performance (Loturco et al., 2015). CMJ-ALT variables provide additional information by describing and quantifying the underlying neuromuscular qualities, temporal variables and strategies with which performance outputs are generated.

To provide context for the present data, Table 5 shows selected CMJ kinetic variables of other elite athletes, including sprinters (Tawiah-Dodoo & Graham-Smith, 2020), rugby league players (McMahon, Jones, & Comfort, 2019; McMahon et al., 2020) and elite footballers (Cohen et al., 2020) alongside the current cohort. RSI-modified for rugby 7s athletes is comparable to that of elite sprinters, with lower values for concentric peak power and eccentric peak power respectively (Laffaye et al., 2014) but larger values than elite rugby league and professional football for the variables presented. In our start of season analysis, there were no significant differences between forwards and backs in any CMJ variables. In our start of season analysis, there were no significant differences between forwards and backs in any CMJ variables. However, backs did show moderately higher concentric peak velocity and concentric peak power, eccentric peak power while eccentric mean power and force at zero velocity was moderately higher in forwards. As there were only five backs within the sample, our study may have been underpowered for such a comparison. This conclusion is supported by the findings of McMahon et al. (2020) who noted significantly higher (moderate to large effect size) jump height, RSImod, concentric peak and mean power in rugby league backs than forwards.

In the present analysis, concentric peak force was the only CMJ-TYP variable to display a significant change between start of season and end of season tests, with small non-significant improvements in jump height and peak power also observed. Gathercole et al. (2015) also reported that amongst CMJ-TYP, concentric peak force showed the greatest sensitivity to a 19-week training block in elite snowboard cross athletes. Corresponding to this study and in contrast to the minimal changes observed in CMJ-TYP variables, we observed significant increases of a large magnitude in a range of time related CMJ-ALT variables such as FT:CT, concentric rate of power development and eccentric deceleration rate of force development, of 17%, 37% and 46% respectively (Table 3).

While no other studies have examined changes in these alternative variables across a 7s season, Mitchell, Pumpa, Williams, and Pyne (2016) (season-long testing period) and Gibson et al. (2016) (three weeks testing period) found no change in jump height in 7s athletes. Mitchell et al. (2016) observed a significant decline in peak power in forwards, but due to the use of a linear transducer to determine power in this study rather than force platforms this data may not be directly comparable. However, a study involving a comprehensive kinetic analysis of force platform CMJ variables across a five-week pre-season training block in elite university basketball players reported a similar pattern observed here in the current study (Heishman et al., 2020). Significant increases in RSI-modified (0.71 to 0.83) and FT:CT (0.95 to 1.11) were reported, but no significant change in jump height (45.2 cm versus 45.5 cm). The present study therefore adds to the literature showing that the temporal, kinetic or strategy CMJ-ALT variables may provide greater sensitivity to the positive neuromuscular responses to periods of competition and training compared to 'CMJ-TYP' variables.

RSI-modified or its equivalent, FT:CT, is considered an indicator of lower limb explosiveness (rapid force development), stretch shortening cycle function and reactive qualities (Mitchell et al., 2016). Improvements in RSI-modified/FT:CT alongside stable jump height represents improved neuromuscular efficiency whereby the same performance output (jump height) is produced in a shorter time. This is driven by reductions in the contraction time components (eccentric and concentric duration). Interestingly, the concentric phase showed a significant and large magnitude decrease while the eccentric duration decrease was of moderate magnitude but not significant. Our analysis provides clues as to possible kinetic changes underpinning the improved neuromuscular efficiency globally represented by RSI mod/FT:CT.

The lack of change in peak velocity in this cohort, alongside large significant improvements in concentric peak force, RFD and time limited impulse variables supports the suggestion that RSI-modified is more strongly associated with strength than speed capabilities (Mitchell et al., 2016). We observed a clear pattern whereby time-constrained impulse, force, and power variables showed large changes, whereas their equivalent that represents a peak or overall, for the same phase or kinetic characteristic was stable, or declined.

Overall concentric impulse and eccentric deceleration impulse both showed non-significant moderate magnitude declines while there were large magnitude significant increases in concentric impulse 100ms (impulse in the first 100ms of the concentric phase) and eccentric deceleration rate of force development. Kijowski et al. (2015), reported similar patterns in response to a four-week plyometric/strength program following jump height and concentric peak power were relatively stable whereas there were significant increases in concentric rate of power development and eccentric deceleration rate of force development (Kijowski et al., 2015).

Concentric impulse 100ms has not been specifically examined longitudinally or part of group studies examining responses, but in a rehabilitation case report Taberner et al. (2020) highlighted its greater sensitivity to neuromuscular fatigue relative to overall concentric impulse. The value of characterising not only the magnitude of concentric impulse but also its “shape” has been previously highlighted by Mizuguchi, Sands, Wassinger, Lamont, and Stone (2015). The significant increase in concentric impulse 100ms we observed, represents an increase in early concentric phase force production and change in impulse shape that was not reflected in impulse across the concentric phase.

As impulse is determined by the magnitude of force and the time over which it is applied, increased values would be limited by the reduction in the time and range over which force was applied, demonstrated by the reduced countermovement depth (center of mass displacement). This would also explain the divergent response also observed in the two variables used to quantify the kinetics during this phase (Kijowski et al, 2015; McMahon et al., 2019; West et al., 2013). Eccentric deceleration rate of force development and eccentric deceleration impulse displayed a significant large magnitude increase and a moderate magnitude, non-significant decrease, respectively.

Interestingly, while there was a significant, large magnitude decrease in concentric duration and countermovement depth, eccentric duration only showed a moderate magnitude but non-significant decrease. This is perhaps counterintuitive; however, eccentric and concentric duration are not entirely equivalent in terms of the range or displacement over which they are calculated: concentric duration ends at toe-off (in plantar flexion) whereby center of mass displacement is higher than in the starting position (flat footed). Furthermore, from an adaptation perspective, eccentric duration comprises 3 subphases, which have been shown to respond differently to load (Cohen et al., 2020; Taberner et al., 2020). We suggest future work should report the duration of these subphases, to better define neuromuscular load-response.

It is worth noting that while eccentric deceleration impulse is recognised as a more reliable variable than eccentric deceleration RFD,[31] eccentric deceleration RFD asymmetries (Hart et al., 2019) and total eccentric deceleration RFD have been shown to be more sensitive markers of prior lower limb injury (Taberner et al., 2020). The present sample were well familiarised with the test and have a substantial training age, factors associated with better reliability, particularly in CMJ-ALT eccentric variables such as eccentric deceleration RFD (Howarth, Cohen, McLean, & Coutts, 2021). Furthermore, as highlighted by Howarth et al. (2021) determining the value of a variable in monitoring, requires consideration, not only of its the reliability (noise) but also its responsiveness to load (signal). The coefficient of variation’s we determined between the start of season and a test 4 weeks later (Table 4) are comparable with that of Howarth et al. (2021) in an inter-day reliability analysis in 36 elite Rugby (15’s) players across the first two days of preseason. This study also showed that the more sensitive rate-limited and phase duration CMJ-ALT variables have higher coefficient of variations than CMJ-TYP variables and whole phase impulses. Nonetheless, the magnitude of change observed in these variables far exceeded their coefficients of variation and SDs, suggesting these are meaningful changes in these variables. It is important to note that towards the latter part of the season (and prior to the end of season test) in preparation for Olympic qualifications players were exposed to an increase in plyometrics and change of direction training was programmed to ensure peaking during regional qualification. As such, the changes observed may not reflect a typical 7s end of season loading profile.

Table 5: Comparison of selected CMJ variables across different sports.

	Jump Height (m)	RSI-modified	Concentric Peak Power (W/kg)	Eccentric Peak Power (W/kg)
Rugby 7s (Current Study)	0.45 ± 3.69	0.83 ± 0.11	63.59 ± 5.24	-28.99 ± 4.34
Elite Sprinters (Cohen et al., 2020)	0.57 ± 0.03	0.83 ± 0.07	75.00 ± 2.60	-33.36 ± 7.20
Rugby League (Claudino et al., 2017; West et al., 2013)	0.37 ± 3.99	0.52 ± 0.05	55.02 ± 4.91	-14.64 ± 11.90
Professional Football (McMahon et al., 2020)	0.40 ± 5.12	0.49 ± 0.07	56.41 ± 6.23	-20.04 ± 4.78

Nonetheless, positive adaptations related to the season as a whole and this final competition and training block were expressed in the time-constrained and rate variables, with concentric impulse 100ms, concentric rate of power development and eccentric deceleration rate of force development, suggested to be indicators of better stretch-shortening cycle function (Cormie et al., 2009; Kijowski et al., 2012).

While we cannot define the precise mechanisms underlying the alterations in CMJ-ALT variables observed, previous work suggests that strength and plyometric-specific training increases in eccentric deceleration rate of force development might be attributed to changes in muscle-tendon length, stiffness, muscle calcium sensitivity, and muscle pre-activity (Bohm, Mersmann, & Arampatzis, 2015; Kijowski et al., 2012). Consistent exposure to targeted resistance training is shown to produce changes in lower limb tendon properties such as increased stiffness (Bohm et al., 2015), and potentially an improved stretch-reflex sensitivity and increased muscle tendon stiffness during the eccentric phase, thereby increasing elastic energy utilization (Avela, Kyröläinen, Komi, & Rama, 1999). Irrespective of the mechanism, the large reduction in countermovement depth (d = 1.29, -18%) suggesting reduced knee flexion and time spent developing eccentric and subsequently concentric impulse indicates a more mechanically efficient triple extension, but only a trivial or small improvement in "output", i.e., jump height.

This study should be interpreted considering a few limitations. First, no "true" baseline measure was taken prior to the first tournament and although our defined start of season test was a week post-first tournament after a de-load period, neuromuscular changes could have already occurred with training and game exposure. Furthermore, logistics prevented us from obtaining an ideal reliability measure early in the season separated by several days or 1 week rather than four weeks that we were able to implement. Due to this and the small sample size of the main analysis, these findings should be confirmed in larger samples and using an inter-day reliability assessment implemented earlier in the season. Future research should also investigate the association between changes in specific CMJ variables and external workload over shorter time periods. We recommend that these types of analysis should be conducted within other elite sports, in order to confidently identify the variables that best quantify positive and negative adaptations to sports and position-specific loading patterns, as our results may be specific to the competition and training demands of Rugby 7s.

In summary, the comparison between the beginning and end of the season, Rugby 7s athletes showed stability in typically reported "performance" CMJ variables such as jump height and peak power, but large improvements in "alternative" kinetic and temporal variables (concentric impulse 100ms, reactive strength index modified, FT:CT, concentric peak force, concentric rate of power development, concentric duration, eccentric deceleration rate of force development and CMJ depth). This appears to show a positive neuromuscular change in athletes across the season, with an increased ability to express reactive and explosive qualities via improvements in rate- or time-limited measures of force, impulse and power, potentially driven by shorter phase durations manifesting in large improvements in RSI-modified and FT:CT. Use of these variables suggested that, at least within the 7s schedule, specific conditioning can produce ongoing enhancement of underlying neuromuscular performance characteristics. Therefore, as previously described in the context of short-term fatigue and recovery cycles, a comprehensive kinetic analysis which includes CMJ-ALT variables also enhances the detection of positive responses to the input of training and match loads over longer periods, whereas if only typical outputs are considered practitioners may not identify specific neuromuscular changes and may falsely conclude that their conditioning prescription has been ineffective.

Conflict of Interest

Daniel D. Cohen has been a consultant to Vald Performance, the suppliers of the force platform system used in the study.

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