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## The acute effects of intracomplex rest intervals on rate of force development and ballistic performance responses following strength-power complex training in talent-identified adolescent rugby players

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**Abstract:** This study investigated the effects of a strength-power complex on subsequent ballistic activity (BA) performance responses across a profile of jumps in adolescent talent-identified rugby players. Rate of force development (RFD) and BA performance responses was recorded in 22 participants over four intracomplex rest intervals (ICRI) (15s, 30s, 45s, 60s) following a complex of 3 repetitions of back squat @80% 1RM and 7 countermovement jumps (CMJs) in a randomised, counterbalanced design. Within subjects, repeated measures ANOVAs were conducted on peak rate of force development (PRFD), time to peak rate of force development (TPRFD), peak force (PF), and time to a peak force (TPF). Confidence limits were set at  $\pm 90\%$  and effect size across the sample (partial  $\eta^2$ ) was calculated across P1-P4 for all jump profiles. No significant effects were observed across jump profiles or ICRI. The research confirms RFD and BA performance responses were maintained across all jump profiles and each ICRI. In contrast to previous research, the use of minimal ICRI of 15s, 30s, 45s and 60s following strength-power complex training is a practical time-efficient means of maintaining RFD and BA performance responses across jump profiles of seven jumps, which has important implications in practical coaching environments.

**Key Words:** Complex training, Adolescent, Rugby Union, Intracomplex rest interval (ICRI), Rate of force development (RFD), Countermovement jump (CMJ)



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## 1. Introduction

Rugby union is characterised by high-intensity dynamic efforts and collisions interspersed with incomplete rest periods, which dictates that players develop well rounded strength-power profiles including ballistic capabilities such as force-velocity-power, critical for competing at the highest level [1-3]. Strength and power output discriminates between levels, therefore developing enhanced strength-power abilities are of critical importance to talent identified adolescent rugby players so they progress to the next level of competition [1, 4]. In academy environments like these it is important to

emphasise physical development to realise maximal gains as research suggests the greatest improvements in strength and power are realised within the first one to two years of commencing structured training [1, 2]. The peak force (PF) a player can generate is a critical determinant of sports performance [5]. However, as player performance progresses, speeds at which limb movements are performed, quickens and the greater the role rate of force development (RFD) plays in assisting efficient completion of motor skills and techniques [6, 7]. The first 1-200 milliseconds of an action are of paramount importance, where success or failure may be determined, and where maximal muscular force may not be realised. Therefore, the ability to increase the rate of contractile muscular force can provide adolescent rugby players with distinct advantages within the game [8, 9]. Arguably, training for the RFD factor should be the most important consideration when the training objective is increasing power or explosive strength [9, 10].

Complex training is proposed as an effective method to elicit acute short-term explosive power output and rate of force development (RFD) improvements in performance [11, 12]. These methods are highly appropriate within rugby-specific environments as they prompt efforts at different points along the force-velocity curve. This can prove valuable for developing and advanced athletes in enhancing subsequent performance through building capacity and resilience across the speed-strength spectrum [5]. As peak power and rate of force development measures have been used to predict 'levels' of potential performance within the sport, early identification of responders to these types of strength-power potentiating complexes may prove extremely significant and valuable to performance staff across professional academies worldwide as adolescent academy aged rugby players can take advantage of the "trainability of youth" [3, 11, 13, 14]. Due to increased physiological demands in the modern-day game and proposed acute and chronic performance benefits of complex training, research into the effects of complex training in elite, non-elite and amateur rugby union players is much more prevalent [15, 12]. Complex training essentially involves performance of

'complex pairs' comprised of a near maximal or high-intensity dynamic exercise or preload (PL) followed by a biomechanically similar lightly-loaded ballistic activity (BA) [10, 16, 18]. Empirical evidence supports acute enhancement of RFD and explosive power following near maximal preload stimulus (PL), commonly using loads between 80-100% 1RM [18, 19]. Since the load is high, movement velocity may be relatively short. Bursts of muscle action are performed as fast as possible with maximum intent, for both PL and subsequent BA. These exercises should be performed in a rested state, immediately after a warm up [20, 21].

Although the exact physiological mechanism that govern responses seen in complex training are still not fully understood, empirical evidence suggests acute performance enhancements occur harnessing a condition referred to commonly as post activation potentiation (PAP) when muscle force output is enhanced because of contractile history [12, 16, 18]. An individual performing a 'complex pair' augments more power on BA following PL by eliciting properties of the neuromuscular and/or psychomotor systems. Complex training theoretically induces increases in RFD, stimulating and increasing motor unit synchronisation, increasing pennation angle and phosphorylation of myosin regulatory light chains [16, 19]. These increases are thought to be associated with intended BA and the high order frequency motor unit-firing pattern, which augments neural activity by enhancing rate coding and timing of force production [22]. In an ideal scenario, athletes 'tune in' to newly acquired capabilities using intermuscular coordination whilst maximising physical development opportunities ensuring that the effects are tolerable in an adolescent population [8, 23-25]. In response to high-intensity exercise seen in PL activities, type II muscle fibres exhibit greater neural excitation [15]. Exercises designed to elicit PAP during training or before competition have been shown to influence neuromuscular characteristics, including peak force or strength, joint range of movement (ROM), velocity and muscle activity during the exercise [26]. Motor-neuron excitability increases at the spinal level in muscle is in a potentiated or 'active state' as

seen in changes in the H-reflex. This reflexive neural signal increases the electrical impulse strength, which activates more motor units when superimposed on a voluntarily activated muscle. Increased recruitment of high threshold motor units within localised muscle and phosphorylation of myosin regulatory chains affects myofilament  $Ca^{2+}$  sensitivity and may also decrease presynaptic inhibition [16, 26, 27]. The increased sensitivity of actin and myosin to  $Ca^{2+}$  released from the sarcoplasmic reticulum during high intensity exercise results in a faster rate of muscular contraction (higher force production) due the increased rate of myosin cross bridge activity [18, 28]. Power production is improved owing to more ATP production as the level of cellular levels of  $Ca^{2+}$  increase [16, 18, 29-30]. Individuals with greater maximal strength display more elevated levels of myosin light chain phosphorylation and possess larger and stronger type II muscle fibres, meaning elite athletes possess higher type II muscle fibres have increased subsequent performance [15]. When examining the research on post-activation potentiation (PAP) and complex training it is important to note methodological differences in the literature that relate to studies conducted on rugby players [4, 13, 16, 17, 26]. Due to inter-subject variability (percentage of fast-twitch muscle fibres, relative strength, recovery time), it is highly unlikely that any one PAP protocol will prove effective for every player tested [31]. Rationale dictates that even though not all players will respond and elicit PAP, some will as a direct result of a well-planned pre-game PAP protocol perform at a higher level than previously due to enhanced potentiation [11, 12, 32].

There is also empirical literature reporting minimal or no improvements in performance following complex training protocols [12, 15, 25, 33]. It should be noted however that in most of these instances where no significant potentiation of performance indicators was realised, the complex training protocol was not counterproductive. This indicates that complex training can be employed to create more efficient workouts and is an effective method of combining strength and dynamic BA [16]. The apparent disparity in reported findings

following complex training can be partially attributed to inconsistent use of variables which include: the PL stimulus (magnitude and mode); the ICRI employed between PL and BA; the number of repetitions of either exercise; the number of sets; the rest intervals employed between BAs and recovery periods between 'complex pair' sets [31]. Additional variables for consideration include training age, gender, training status, strength and competency of participants [11, 12, 34].

Of primary interest in the present paper is the potentiation-fatigue relationship and the interplay between these two factors affecting performance intra-complex. Near maximal or intense dynamic exercises, elicit both potentiating and fatiguing effects prior to performance of BA performance in a complex pair. The balance between these two variables determines the performance outcome of this athletic movement. Positive performance effects have been observed following PL activities in subsequent BA and have in many cases been attributed to acute potentiation, although due to inconsistent use of experimental variables, eliciting enhanced BA or athletic performance may as easily be attributed to an appropriate warm up or many other physical or psychological factors [11, 12]. As fatigue dissipates, identifying an ideal, or optimal ICRI where the muscle has partially recovered from fatigue and is in an 'active state' has become something of a holy grail in the literature due in part to the previously noted inconsistencies in study design and other variables [10, 19, 35–40]. Reported recovery intervals ranging from 10 seconds to 20 minutes have been discussed as 'optimal' without there ever being consensus and shorter recovery intervals have been suggested of between three and four minutes to aid practical application for strength and conditioning coaches [16, 17].

The search for 'optimal' intra-complex rest intervals (ICRI) are widespread in the literature, this limiting approach fails to reflect the individual nature of physiological responses to exercise of any classification. Most of the complex training and PAP literature discussed in this paper has dealt with ICRI of  $\geq 3$  minutes which have positively enhanced

subsequent performances [16–17, 29]. Several studies have looked at ICRI of  $\leq 3$  minutes where some non-significant decrements in power output were reported [11, 12, 17, 30, 34]. Although no positive performance enhancements were realised in these instances following complex training, no adverse effects were reported, the potential benefits to BA performance warrants further investigation especially within a more highly trained elite youth rugby population [1–2, 13, 15]. Unpublished pilot study data corroborates empirical evidence that indicates children and adolescents are more resistant to fatigue and resynthesise and replenish PCr substrate metabolites much faster than adults [34, 41] replenish replenish. This alone forms a convincing argument for further investigation in this field of study [34, 41]. There is additional evidence emerging that inter-set and inter-repetition rest periods accelerate the rate of energy substrate replenishment, maintaining availability of ATP and PCr that in turn acutely maintains or improves expression of force, velocity and power. In contrast to traditional sets of exercises, these 'clusters' draw on work outlined in the literature that blunt declines in performance whilst maintaining speed-strength capabilities at high levels for long periods without deterioration using rest intervals of between thirty and sixty seconds inter repetition, or in this case intracomplex [5–7, 37–39]. These shorter, more frequent rest periods than postulated in more traditional training paradigms promote an improved kinetic and kinematic profile especially later in the set and may be key determinants of training RFD [40]. Whilst metabolic fatigue has been identified as an absolute necessity for developing cross sectional area of muscles (hypertrophy) and strength training, generating force and peak velocity does not necessarily involve fatigue or metabolic stress [22, 36, 39]. The potentially increased rate of force development (RFD) in the affected muscle groups are of interest to the researchers in the present paper as potentiated muscle may express acute and potentially chronic increases in acceleration and velocity [12, 18]. Force generating capabilities are largely dependent on increases in 'active state' of muscle at the onset of the muscle contraction rather than on speed-related properties



of the muscle [23]. Anecdotal evidence suggests minimal rest intervals following PL utilises heightened neural stimulation to perform the BA and in theory in trained individuals potentiating effects will be realised much sooner than in untrained individuals.

The primary purpose of the present paper is to ascertain if there is a positive, negative or maintained response across the profile of seven CMJs (BA) following PL, and if there is a change to identify, where it occurs. Further, the researcher aims to ascertain if the above question changes when the time before subsequent efforts changes from 15, 30, 45 and 60 seconds.

## 2. Method

### 2.1 Experimental approach to the problem

Participants attended a familiarisation session and subsequent experimental session where RFD and BA performance responses were observed following a PL set of 3 repetitions @ 80% of participant 1RM followed by a jump profile of countermovement jumps (CMJs) following an assigned, random ICRI, with 10 seconds' recovery between CMJs. After a rest period of 12 minutes this process was repeated until all four ICRI had been performed in a randomised, counterbalanced study design.

During the familiarisation session, participants' anthropometric characteristics and 1RM back squat were established [13]. Participants were measured for stature using a stadiometer (SECA 216, Birmingham, UK) and weight using professional grade weighing scales (SECA 813, Birmingham, UK). Following this, participants familiarised themselves with countermovement jump (CMJ) protocol to be employed in the study [42]. All participants had experience of and technical competency in both the back squat and CMJ, which are regularly performed in most strength and conditioning environments.

### 2.2 Participants

Twenty-two healthy, adolescent-academy aged male rugby union players took part in this study (*age*  $17.1 \pm 0.5$  years, *height*  $178.4 \text{ cm} \pm 8.3 \text{ cm}$ , *mass*  $85.9 \text{ kg} \pm 12.0 \text{ kg}$ ). All participants were either regional age grade players or Welsh Rugby Union (WRU) tracked players in the Performance Pathway participating in further education rugby academies. Participants supervised resistance training experience varied from between 12 months to 30 months, all were competent in all necessary techniques and were aware of potential risks involved having given informed assent and parents/guardians providing informed consent. Additionally, physical activity readiness questionnaires (PARQ) were completed in line with recommendations received from the Ethics Committee of Cardiff Metropolitan University, Cardiff, Wales, United Kingdom [43]. All participants reserved the right to withdraw from the process at any time and all aspects of the study were conducted under the strictest of confidence. All testing procedures were conducted in an organised manner with health and safety of participants in mind by dedicated, trained researchers and support staff [42].

### 2.3 One Repetition Maximum Back Squat Testing

The approved back squat 1RM protocol used in this study has been used extensively in the literature [44] and was performed on a squat rack using a 20kg Olympic bar and weight plates (Eleiko, Chicago, IL, USA). As subjects were in pre-season, maximal testing was appropriate and only 2-3 attempts were required to determine their 1RM following their warm up. To ensure appropriate technique and squat depth was attained, an additional assessor manually filmed 1RM attempts in the frontal plane using a hand-held camera (iPhone 5s, Apple Inc., Cupertino, CA USA). This process ensured participants had a 1RM back squat established ( $126.7 \text{ kg} \pm 29.2 \text{ kg}$ ) from which a load of 80% of 1RM could be calculated for the testing procedures ( $101.4 \text{ kg} \pm 23.4 \text{ kg}$ ).

### 2.4 Countermovement Jump (CMJ)

Participants stood on the middle of the force plate (PASCO systems dual axis force plates PS-2142 Roseville, CA, USA - sampling at 1000hz) in an upright position with feet hip width apart and parallel. Participants were instructed to keep hands on hips throughout movement and to keep the trunk as upright as possible. Participants were told to self-select depth of the CMJ and the researcher cued participants to jump as high as they could.

## 2.5 Experimental Procedures

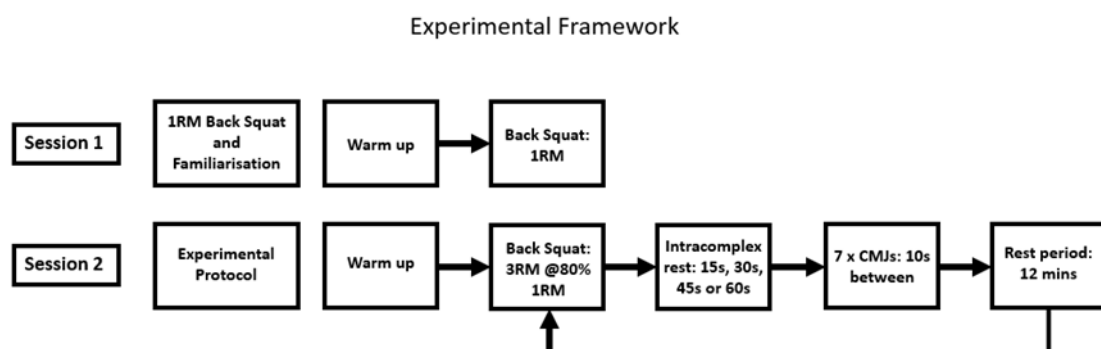
A unique numeric identifier was assigned to participants at the end of the familiarisation session to randomise conditions in subsequent sessions and to assist in data protection. Researchers performed randomisation which identified ICRI order for each participant prior to the session commencing so timings could be configured for maximum reliability.

A pilot study previously established that a period of 12 minutes' rest was sufficient for fatigue to dissipate in agreement with Bogdanis et. Al [45] who proposed periods of this length where PCr metabolites returned to 95% of original levels in adults and therefore the subject being able to replicate maximal explosive abilities following this timescale [45]. Participants attended one main test session. The warm up employed full body dynamic movements designed to: elevate core body temperature, enhance motor unit excitability, neuromuscular activity, improve kinaesthetic awareness, utilising specific biomechanical movements, maximising the ranges of motion used in a game and reducing the risk of injury.

The main test session was 48 hrs post the familiarisation session under identical conditions to minimise residual fatigue and ensure maximum reliability [43]. Following the warm up, participants stepped into the rack to perform the first set of 80% 1RM back squat (3 repetitions calculated to the nearest 1.25kg). On completion of the set, each participant had a randomly assigned ICRI (P1 = 15 seconds, P2 = 30 seconds, P3 = 45 seconds, P4 = 60 seconds) prior to stepping onto the force platform when directed. On the researcher's command, each subject performed a maximal CMJ before resetting their feet and remaining still for a duration of 10 seconds [46]. This process repeated a further six times. On completion of the complex pair, each participant rested for 12 minutes before repeating the same process using another randomly assigned ICRI and continued to do so until all four had been completed.

## 2.6 Statistical Analysis

Following data collection, descriptive statistics for peak rate of force development (PRFD), time to PRFD (TPRFD), peak force (PF) and time to peak force (TPF) were calculated (data are mean  $\pm$  standard deviation).



**Figure 1** Experimental Framework

**Table 1** Descriptive statistics for each intra-complex rest interval (ICRI) condition across each profile of countermovement jumps (CMJs). Mean and standard deviation values for peak rate of force development (PRFD), time to peak rate of development (TPRFD), peak force (PF) and time to peak force (TPF) across each CMJ profile for each ICRI (P1-P4).

<b>P1 (15 seconds)</b>							
<b>Variable</b>	<b>Jump1</b>	<b>Jump 2</b>	<b>Jump3</b>	<b>Jump4</b>	<b>Jump5</b>	<b>Jump6</b>	<b>Jump7</b>
<b>PRFD (N.s<sup>1</sup>)</b>	12968 ± 5035	11162 ± 5560	13262 ± 6637	13524 ± 5092	12808 ± 5162	11866 ± 4778	13202 ± 4801
<b>TPRFD (Ms)</b>	0.456 ± 0.218	0.407 ± 0.146	0.369 ± 0.126	0.382 ± 0.145	0.419 ± 0.188	0.367 ± 0.170	0.357 ± 0.113
<b>PF (N)</b>	1991 ± 538	1975 ± 454	2024 ± 406	2047 ± 431	2007 ± 539	2047 ± 442	2084 ± 435
<b>TPF (Ms)</b>	0.623 ± 0.187	0.606 ± 0.154	0.548 ± 0.098	0.539 ± 0.129	0.585 ± 0.216	0.551 ± 0.162	0.526 ± 0.108
<b>P2 (30 seconds)</b>							
<b>PRFD (N.s<sup>1</sup>)</b>	10293 ± 4895	12303 ± 5970	10945 ± 3203	11404 ± 3549	11208 ± 4738	12272 ± 5595	12350 ± 4837
<b>TPRFD (Ms)</b>	0.404 ± 0.172	0.379 ± 0.136	0.397 ± 0.137	0.332 ± 0.191	0.382 ± 0.118	0.419 ± 0.175	0.414 ± 0.147
<b>PF (N)</b>	1811 ± 581	1902 ± 582	1977 ± 442	2043 ± 382	2040 ± 384	2012 ± 354	1991 ± 417
<b>TPF (s)</b>	0.621 ± 0.141	0.583 ± 0.101	0.575 ± 0.106	0.554 ± 0.101	0.562 ± 0.093	0.602 ± 0.161	0.586 ± 0.144
<b>P3 (45 seconds)</b>							
<b>PRFD (N.s<sup>1</sup>)</b>	10574 ± 3514	11622 ± 4738	13270 ± 7316	12081 ± 3078	14537 ± 8638	13519 ± 6671	13649 ± 7956
<b>TPRFD (Ms)</b>	0.386 ± 0.125	0.392 ± 0.147	0.358 ± 0.121	0.359 ± 0.123	0.366 ± 0.190	0.392 ± 0.151	0.356 ± 0.105
<b>PF (N)</b>	2006 ± 305	2042 ± 265	2057 ± 296	2027 ± 373	1971 ± 497	2051 ± 324	2030 ± 303
<b>TPF (s)</b>	0.606 ± 0.120	0.592 ± 0.129	0.563 ± 0.117	0.553 ± 0.121	0.576 ± 0.177	0.570 ± 0.129	0.596 ± 0.172
<b>P4 (60 seconds)</b>							
<b>PRFD (N.s<sup>1</sup>)</b>	9901 ± 2748	12311 ± 4797	15604 ± 4148	12829 ± 7767	13131 ± 9518	12466 ± 3746.222	12245 ± 4982
<b>TPRFD (Ms)</b>	0.427 ± 0.139	0.391 ± 0.164	0.386 ± 0.150	0.405 ± 0.135	0.388 ± 0.152	0.402 ± 0.182	0.399 ± 0.154
<b>PF (N)</b>	2020 ± 303	2079 ± 326	2069 ± 356	2065 ± 306	2132 ± 464	1995 ± 361.875	2039 ± 294
<b>TPF (s)</b>	0.600 ± 0.101	0.567 ± 0.120	0.558 ± 0.573	0.573 ± 0.139	0.608 ± 0.176	0.591 ± 0.141	0.594 ± 0.125

**Table 2** Summary of within-subjects analysis of variance conducted across RFD, TPRFD, PF and TPF. Mauchly's test of sphericity and effect size across all variables are also reported. Abbreviations DF = degrees of freedom,  $\alpha$  = alpha level (statistical significance), partial  $\eta^2$  (eta<sup>2</sup>) = effect size, CL = confidence limits,  $\chi^2$  = chi<sup>2</sup>.

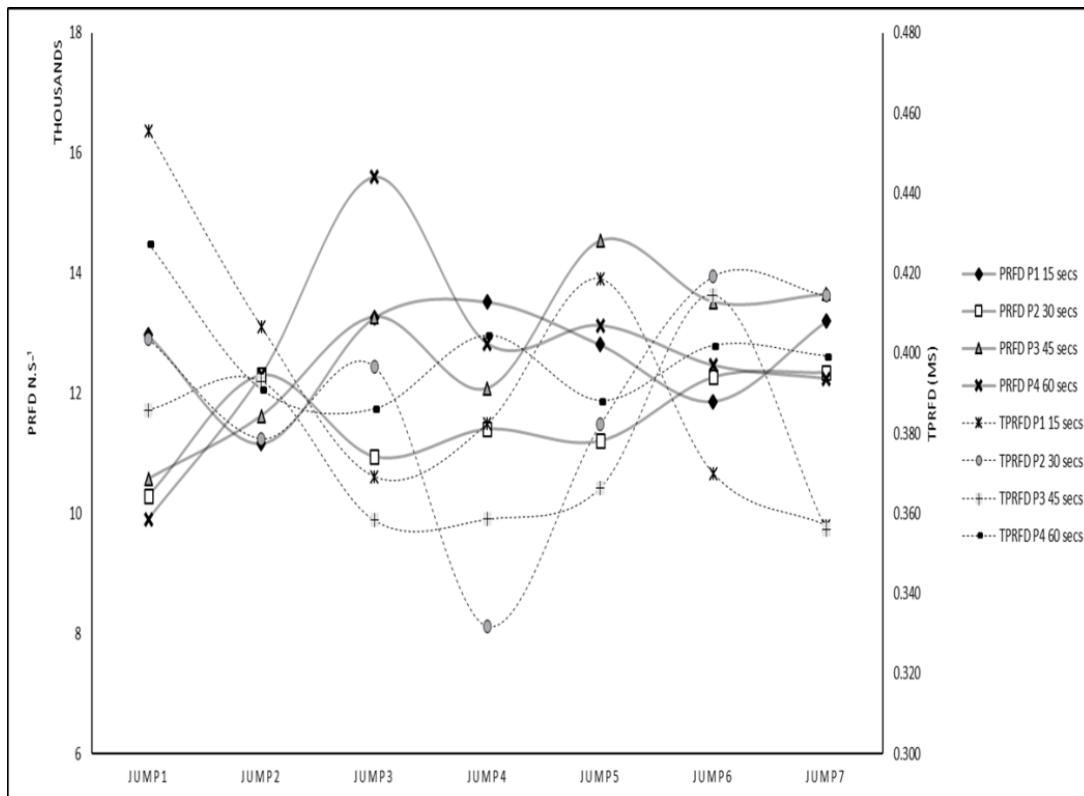
<i>RFD</i>	<i>f</i> value	Df	df error	$\alpha$	partial $\eta^2$	CL $\pm$ 90%	sphericity	
							$\chi^2(2)$	<i>p</i>
P1 15 secs	1.237	6.000	156.000	<i>p</i> = 0.290	0.045	0.045 $\pm$ 0.075	18.911	<i>p</i> = 0.007
P2 30 secs	1.442	4.026	104.668	<i>p</i> = 0.225	0.053	0.053 $\pm$ 0.079	30.116	<i>p</i> = 0.009
P3 45 secs	1.966	3.248	81.193	<i>p</i> = 0.121	0.073	0.073 $\pm$ 0.080	38.116	<i>p</i> = 0.005
P4 60 secs	0.846	2.112	48.566	<i>p</i> = 0.441	0.035	0.035 $\pm$ 0.110	59.713	<i>p</i> = 0.005
<i>TPRFD</i>	<i>f</i> value	Df	df error	$\alpha$	partial $\eta^2$	CI $\pm$ 90%	sphericity	
							$\chi^2(2)$	<i>p</i>
P1 15 secs	1.939	3.616	94.026	<i>p</i> = 0.117	0.069	0.069 $\pm$ 0.290	73.201	<i>p</i> = 0.005
P2 30 secs	2.195	4.141	107.668	<i>p</i> = 0.072	0.078	0.078 $\pm$ 0.068	36.564	<i>p</i> = 0.014
P3 45 secs	0.682	2.806	70.137	<i>p</i> = 0.556	0.027	0.027 $\pm$ 0.110	69.113	<i>p</i> = 0.005
P4 60 secs	0.610	6.000	110.982	<i>p</i> = 0.721	0.024	0.024 $\pm$ 0.021	18.912	<i>p</i> = 0.532
<i>PF</i>	<i>f</i> value	Df	df error	$\alpha$	partial $\eta^2$	CI $\pm$ 90%	sphericity	
							$\chi^2(2)$	<i>p</i>
P1 15 secs	0.550	2.881	72.023	<i>p</i> = 0.064	0.022	0.022 $\pm$ 0.017	122.010	<i>p</i> = 0.005
P2 30 secs	2.372	2.838	76.618	<i>p</i> = 0.081	0.081	0.081 $\pm$ 0.072	112.970	<i>p</i> = 0.005
P3 45 secs	0.590	2.283	52.518	<i>p</i> = 0.579	0.025	0.025 $\pm$ 0.110	100.781	<i>p</i> = 0.005
P4 60 secs	1.111	2.043	46.998	<i>p</i> = 0.339	0.046	0.046 $\pm$ 0.110	93.349	<i>p</i> = 0.005
<i>TPF</i>	<i>f</i> value	Df	df error	$\alpha$	partial $\eta^2$	CI $\pm$ 90%	sphericity	
							$\chi^2(2)$	<i>p</i>
P1 15 secs	1.934	3.972	99.308	<i>p</i> = 0.111	0.072	0.072 $\pm$ 0.076	47.959	<i>p</i> = 0.005
P2 30 secs	2.104	4.210	113.680	<i>p</i> = 0.081	0.072	0.072 $\pm$ 0.066	34.317	<i>p</i> = 0.025
P3 45 secs	0.831	3.702	88.845	<i>p</i> = 0.501	0.034	0.034 $\pm$ 0.100	43.124	<i>p</i> = 0.002
P4 60 secs	0.974	3.666	91.660	<i>p</i> = 0.421	0.038	0.038 $\pm$ 0.096	38.416	<i>p</i> = 0.008

There were no outliers in the data as assessed by inspection of boxplots, and normality was confirmed using Shapiro-Wilk's test ( $P \geq 0.05$ ). A series of within-subjects repeated measures ANOVAs were conducted on PRFD, TPRFD, PF and TPF to examine differences in means across all jump variables within each ICRI condition using SPSS statistical software package Version 24 (IBM Corporation, Armonk, NY, USA).

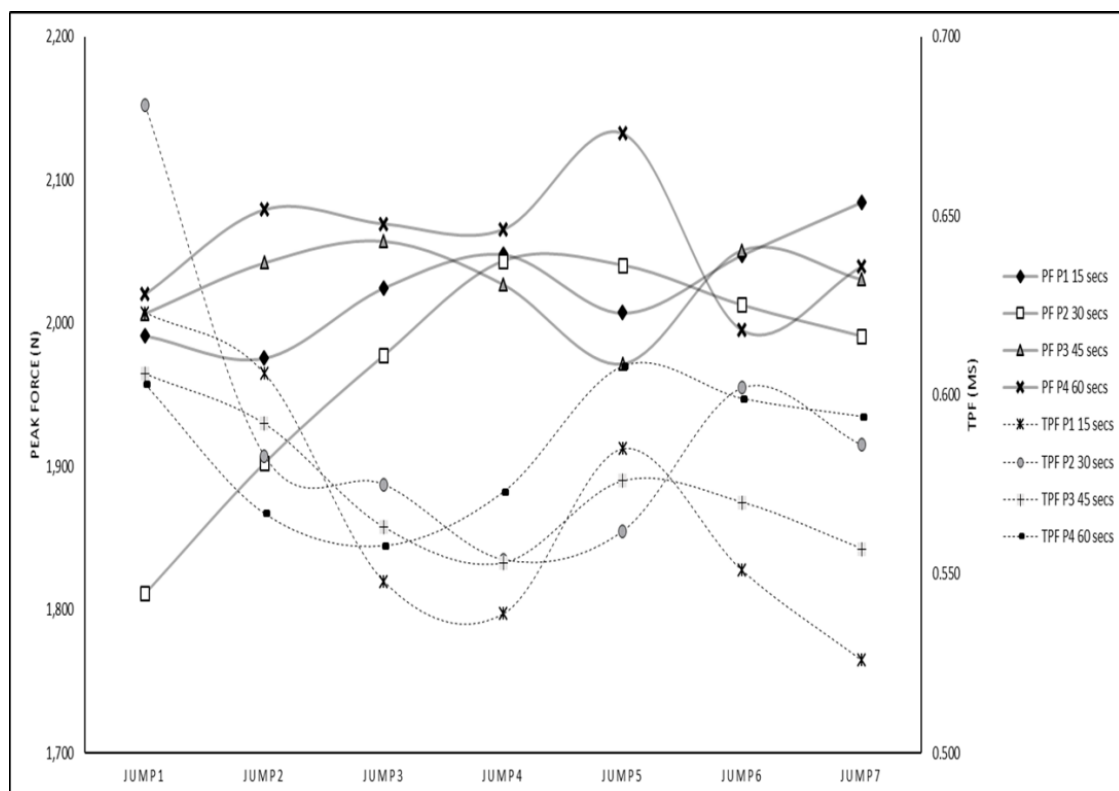
Repeated measures within-subjects' ANOVAs were conducted on PRFD, TPRFD, PF and TPF, with CMJs as the dependent variable [9] over P1-P4. Descriptive statistics were calculated for each variable across jump profiles and for each ICRI. Values are reported in Table 1.

Following Mauchly's test on each within-subjects repeated measures ANOVA, sphericity was violated on numerous instances, therefore epsilon ( $\epsilon$ ) was used to correct the ANOVAs and return valid results using the Greenhouse-Geisser adjustment. Sphericity was assumed following tests on RFD P1 ( $F(6, 156) = 1.237$ ,  $p = 0.029$ ; TPRFD P1 ( $F(3.62, 94.03) = 1.940$ ,  $p = 0.005$ ; TPRFD P4 ( $F(6, 119.82) = 0.610$ ,  $p = 0.532$  and no adjustments were required in these examples. No statistically significant differences between the means were identified across any of the seven CMJs or the four ICRI. This determined that post-hoc pairwise analyses were not required. Confidence limits were set at  $\pm 90\%$  and effect size across sample (partial  $\eta^2$ ) was calculated and is reported in Table 2 (Figure 2 & 3).





**Figure 2.** Peak rate of force development (PRFD) and Time to peak rate of force development (TPRFD) illustrated per rest intracomplex rest interval (ICRI). PRFD reported using smooth, solid line, TPRFD reported using dashed line. Note maintained responses across jump profiles.



**Figure 3** Peak force (PF) and Time to peak force (TPF) illustrated per intracomplex rest interval (ICRI)l. PF reported using smooth, solid line, TPF reported using dashed line. Note maintained responses across jump profiles

### 3. Discussion

The principle finding of the study was that there were no statistically significant positive or negative RFD and BA performance responses observed across all jump profiles (P1-P4) for PRFD, TPRFD, PF and TPF ( $p \geq 0.05$ ). Potentially trivial benefits were reported across effects for all jump profiles (P1 = 15 secs, P2 = 30 secs, P3 = 45 secs, P4 = 60 secs), with confidence limits set at  $\pm 90\%$  using probabilistic clinical inferences (see Table 2) [47, 48]. All measured RFD and BA performance responses were maintained over each ICRI jump profile of 7CMJs for PRFD, TPRFD, PF and TPF in contrast to previous research in rugby players [16-18]. These findings corroborate previously reported maintenance of explosive performance over a profile of similar dynamic BA over six squat jumps [40] where minimal amounts of intra-set rest were used. The present paper reports, in some cases peak variable responses were observed right at the very end of extended BA sets. In this case seven maximal CMJs with some performance responses in this study peaking in jumps five, six and seven (j5 = PRFD P3, TPRFD P2, PF P2, TPF P2; j6 = TPRFD P1, TPF P1; j7 = TPRFD P1, PF P1 j7), whereas Hansen and colleagues, peak RFD and BA performance responses were observed in the first repetition of each configuration of BA [38]. Although mean PF and TPF scores improved across the profile of BA, it is not adequate drawing conclusions from these variables alone, as they are less associated with a slow SSC movement like CMJ than PRFD [5-7]. To our knowledge, this is the first study to investigate performance responses associated with complex training and ICRI in talent identified adolescent rugby players therefore drawing direct comparisons is challenging. The experimental framework of the present paper was formulated to encourage practitioners to use standardised procedures and to encourage follow up research that could theoretically be integrated into the practical environment with little or no disruption to structured, periodised training at potentially any point of the season. Some of the apparently ambiguous findings in the literature relating to the effects of complex training are attributable to

inconsistencies in experimental procedures such as the number of repetitions in the PL or the way a player performs a CMJ. Previous research conducted has used 5RM rather than 3RM and BA jump profiles of between three and five jumps, with some variations in hand positioning and some using single leg CMJs [9, 16-17, 46]. The single leg CMJs were conducted on a specially constructed sled that tried to eliminate any arm swing, which made it internally valid but extremely impractical [17]. Jensen and Ebben used 10 seconds between CMJs and ICRI of 10 secs, one, two, three and four minutes. In-line with the present paper, they found no significant positive BA performance responses with a trend towards improvement over the profile of jumps and as previously noted, and statistically negative BA performance responses were observed at 10 seconds' post-complex.

In contrast to many studies, the current research found that more highly trained or stronger athletes achieved similar BA performance responses to weaker/less trained athletes [11, 12, 16]. Little is known of the effects of complex training on adolescent rugby players, it must be acknowledged the relationship between development, growth and performance may still be unstable post-maturation [4]. Some of the key complex training literature suggests proposed 'optimal' ICRI of 3-4 minutes [17] due in part to restorative processes taking 4 minutes or so to replenish PCr substrate levels in adult rugby players [45]. However, Haff and colleagues found that in some cases PCr levels recover to levels above 80% within 15 seconds of high intensity effort which can potentially allow athletes to perform many near maximal repetitions without serious deterioration [7, 35-39]. This myriad of differing individual performance responses provided in the literature confounds the use of the generic term 'optimal' when describing sometimes wholly inappropriate rest intervals. The use of shorter rest intervals or 'clusters' to maintain measures of power and velocity is widespread in the literature, and as evidenced in this study, could potentially be utilised as part of an effective strength-power complex, specifically when RFD is the principle training objective [6, 7, 29, 35-39]. It is not immediately

apparent if the maintenance in BA performance responses observed in this study is attributable to enhanced recovery processes in adolescents and children [34, 41]. Empirical evidence suggests faster restorative processes (resynthesis of energy substrates, improved neuromuscular function, faster rate of lactate clearance) in children and adolescents following high-intensity exercise in part due to lower levels of power production than adults [34, 41]. Given the absolute necessity for expression of PF and RFD in elite rugby union, it is essential that talent identified adolescent athletes begin to integrate explosive strength training in the form of plyometrics and strength-power complexes into their training [4, 29, 49]. Such physical qualities should form part of a highly-structured plan to develop and utilise the BA abilities that match the demands of the sport [2, 4, 6, 7]. The design of these complexes, in-line with those used in the current study should be practical in nature, utilising appropriate exercises and rest intervals and should be based on athlete's skills, abilities and time of season [2, 6, 7, 16, 29, 37]. As previously noted, key considerations of complex training should include the length of the ICRI, training age and history, suitable, practical PL and BA exercise selection, load, days between sessions and the individual nature of performance responses [2, 11, 12].

#### 4. Conclusion and suggestions

This paper confirms that the use of minimal ICRI (15-60 secs) form a viable means of eliciting maintained RFD and ballistic performance effects across repeated BA following PL. In challenging, time-constrained elite environments they offer coaches an efficient means of combining stimulatory activities across the force-velocity curve that not only improve kinetic and kinematic profiles but can also build capacities, and aid identification of responders to the specific strength-power complexes and ICRI's utilized. The use of the term 'optimal' when referring to either load or ICRI in the literature is both counterproductive and misleading due to the dynamic individual nature of BA responses to strength-power complexes. As the performance of sporting movements discriminates between levels, coaches must maximise the chances

of adolescent players progressing to more elite levels of competition by incorporating methods like the intended BA into training. These methods promote heightened neural excitation, motor unit synchronisation, rate coding and intermuscular coordination, which are known to enhance RFD and explosive abilities. Furthermore, coaches must become adept at manipulating both the means, load and method of PL as well as the ICRI and to monitor BA responses closely. Often there is more than one training objective, it may not always be appropriate to utilise this approach, so coaches must be aware of the implications of these and other adaptive physiological responses have on one another. Attempts to establish fatigue-potential dose-response relationships to elicit the prioritised RFD and BA performances responses may also have important implications in future research and practice as it is unclear as to the potential benefits of ICRI on other adaptive responses such as hypertrophy, endocrine etc.

The benefits of monitoring these kinds of acute (and chronic) BA performance responses in pre-pubescent children and adolescents are yet to be investigated and given their enhanced recovery processes the potential of increasing the RFD and indeed PF capabilities present interesting possibilities. Future research utilising strength-power complexes in ever younger populations might theoretically see more positive RFD and BA performances being realised due enhancement of motor unit recruitment and intermuscular coordination previously discussed. Such research is conspicuous by its absence, but given the guidelines in place for resistance training in prepubescent children and adolescents, in some instances, the use of complex training in these is highly appropriate and chronic benefits may be realised that have not been observed before due to previous investigations being conducted mainly on elite or semi-professional sportsmen. Given potentially similar performance responses to those seen in this research may be realised in other populations, further exploratory research using similar strength-power complexes and ICRI is warranted in children, adolescents and female groups with appropriate training age, status, strength and competency. If so,

there are wider implications for the use of shorter ICRI across multiple athletic populations. Further investigation needs to be conducted on the fatigue-potential relationship using the methods outlined in this paper across these populations so that coaches can establish how athletic abilities like BA can be stressed to initiate fatigue, maintained or indeed increased, depending on the desired outcome of the coaching intervention.

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