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Complex Training with Minimal Recovery Intervals and their Effect on CMJ Performance in Professional Male Rugby Union Players

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Abstract: *In modern day professional rugby union, strength and conditioning specialists have limited time to improve an athlete's physical qualities. However, Complex Training (CT) can be an efficient alternative training method. Current research suggests an intra-complex rest interval (IRI) of 4 minutes is optimal. However, in a hectic weekly training schedule, this may consume valuable preparation time. This study chose to employ shorter rest periods to determine if performance can be improved with a shorter IRI. Thirteen professional athletes from the Leicester Tigers Development Squad performed 3 repetitions of a front squat at 80% 1RM followed by 7 countermovement jumps either with a 15, 30, 45 or 60 second IRI. A repeated measures analysis of variance found that peak power output significantly improved after 60 seconds rest compared to 15 seconds. Additionally, a significant increase in peak force output was observed in the 4th, 6th and 7th jump following an IRI of 30, 45 and 60 seconds respectively. This study suggests that a 60 second IRI may prove beneficial in a time restricted environment. Furthermore, if an improvement in performance can be elicited in as little as 4 ballistic exposures, this may prove to be an effective minimal dose.*

Keywords: *complex training, power, plyometrics, intracomplex rest interval*

Abbreviations*(In order of appearance in text):* *Complex training (CT), stretch shorten cycle (SSC), Counter-movement jump (CMJ), Post activation potentiation (PAP), Intra complex rest interval (IRI), repetition maximum (RM), phosphagen creatine (PCR), drop jumps (DJ),analysis of variance (ANOVA)*

1. Introduction

Rugby union is a high intensity intermittent sport with repeated bouts of maximal efforts where impacts frequently occur above 10G and players can undergo 0.89 collisions per minute [1]. In a single match, professional rugby players can undergo 89 bouts of static exertions, as many as 59 bouts of high intensity running and be involved in up to 35 rucks [2]. Therefore, the ability to produce large muscular power outputs is considered crucial for successful performance [3]. Consequently, resistance training aimed at increasing maximum strength and improving power outputs have become an integral part of a professional player's preparation. However, due to the rigours of the modern-day training schedule, improving an athlete's strength and power capabilities during the competitive season can be difficult [4]. Consequently, time efficient methods that combine different forms of training such as Complex Training (CT) can be advantageous when programming an athlete's weekly schedule.

CT alternates a high intensity resistance exercise with a biomechanically similar ballistic exercise, set for set in one training session with the aim of improving the dynamic stimulus [5, 6]. Many definitions of CT describe the corresponding ballistic movement as a plyometric activity, however it must be highlighted that many of these movements don't involve a stretch shorten cycle (SSC), or if they do then it is commonly a counter-movement jump (CMJ) which is a slow SSC activity. It is important for the reader of any CT study to distinguish between a ballistic movement and a plyometric activity, therefore helping them to accurately interpret the results of the study.

CT is based on the premise of a physiological mechanism known as post activation potentiation (PAP) [7]. Several mechanisms have been described to explain PAP. One proposed mechanism is the phosphorylation of the myosin regulatory light chain, which results in an increased sensitivity of actin-myosin to calcium which is released from the sarcoplasmic retinaculum [8, 9]. This in turn results in a higher proportion of active-cross bridges during a muscle twitch, consequently increasing the force of each subsequent twitch contraction [10, 8]. Secondly, the improvement in the ballistic exercise may be due to an increase in neural excitability due to the initial high intensity stimulus [11]. It is also possible that a decrease in pennation angle caused by the initial stimulus may contribute to PAP [12]. However, further research is required before more definitive conclusions can be reached about the exact mechanism of PAP [8].

A critical variable that needs careful consideration in the programming of CT is the Intra-Complex Rest Interval (IRI), the time between the high intensity stimulus and the proceeding dynamic exercise. In the literature, timings have ranged from 10 seconds up to 20 minutes. Verkhoshansky and Tetyan were the first authors to explore CT [13, 5], recommending that the dynamic movement should be performed quickly after the initial stimulus, therefore taking advantage of the increased excitability of the neural system [14]. A review of CT by Ebben and Watts [5] also suggested that a very minimal IRI of 0-30 seconds should be employed, again "to take advantage of the possible heightened neural stimulation". However, some research suggests that performing ballistic movements immediately after an initial stimulus provides no benefit to the proceeding dynamic activity. Ebben and Watts [5] demonstrated that performing a ballistic movement straight after an initial stimulus had no significant effect on motor unit activity or peak forces. In fact, Jensen and Ebben [14] and Comyns et al. [15] actually reported a reduction in performance after a 10 seconds rest interval was provided. However, the reader must be cautious when interpreting these results as the differences may be due to the use of differing muscle groups in the lower limb and the upper limb.

Attitudes towards short IRI's have shifted since the initial investigations of Verkhoshansky and Tetyan [13]. More recent research suggests that a recovery time of 3-4 minutes provides the most optimal IRI. Radcliffe and Radcliffe [16] demonstrated that standing long jump performance was improved when performed 3 minutes after the initial stimulus. Similarly, further research supporting the use of a 4-minute IRI is provided by Young et al. [17]. Their research reported a 2.8% improvement in jump height following a 4-minute rest after a set of 5RM squats. Comyns et al. [15] also suggest that a rest period of 4 minutes may prove optimal to improve jump performance. They also reported that the window of improvement was different for each individual, therefore recommending that the IRI should be individually determined in order to maximise the effect from CT. When working with athletes from individual sports where time may be a little more obtainable this can be done. However, when working with a team sport with many squad members, the practicality of this is desirable, but unfortunately unrealistic.

With varied conflicting results, Jensen and Ebben [14] investigated the optimal IRI. They hypothesised that there is an optimal recovery time that allows adequate recovery time of the phosphagen creatine (PCR) system whilst still taking advantage of the heightened activation of the neural system. They reported that a gradual non-significant trend of increase in performance was observed from 10seconds up to 4 minutes following the initial stimulus, therefore suggesting that an IRI of 4 minutes may offer a small improvement in jump performance. The authors suggested that gradual improvement in performance over 10 seconds to 4 minutes could reflect the recovery of the PCR system. Previous research has demonstrated that PCR can regenerate 50% in as little as 56 seconds [18]. In an environment such as professional sport where time is limited, employing a 4-minute rest period may not be the most efficient use of time. However, shorter recovery periods (between 10 seconds and 1 minute) that potentially offer no detrimental effects to the plyometric or ballistic stimulus, could offer a more time efficient method of CT. It is intended that this study will provide an insight into CT using shorter rest periods and identify an optimal IRI, whilst contributing to the existing body of knowledge. To the authors' knowledge, very few studies have used short to intermediate (15 seconds to 1minute) rest intervals. Therefore, this study has chosen to utilise short to intermediate rest intervals as these may prove beneficial as they may achieve similar benefits as a long rest period whilst saving valuable time in the applied setting.

Additionally, this study will also explore the profile of the corresponding ballistic movements and examine the performance of the CMJ's following the initial stimulus. This information may provide a valuable insight and assist in the accurate programming of CT at various stages of the season, which in turn require different programming strategies. On occasions, fatigue will want to be induced (such as pre-season), however, during the competitive season, performance may wish to be maintained so therefore a minimum dose will be prescribed.

2. Methods

2.1. Experimental Approach to the Problem

This study involved 13 subjects performing 3 repetitions of a front squat at 80% 1RM followed by 7 CMJ's. The subjects repeated this 4 times, each with a different IRI using a randomised counter-balanced research design. Four different IRI's were used; 15, 30, 45 and 60 seconds, with 10 seconds rest given between each CMJ. The study was conducted over 2 testing sessions, with the first being a 1RM testing session, and the second for data collection. The primary aim of the study was to determine what effect the IRI had on peak force and peak power output of the corresponding CMJ's. The data collected from the 15 seconds IRI protocol acted as the control. The secondary purpose of the study was to investigate the performance of the CMJ's following different IRI's, with the first jump in each set acting as the control. A repeated measures ANOVA and a Bonferroni correction were used to determine if there was any difference in force and power outputs with different IRI's, and to assess the performance of the CMJ's following different IRI's.

2.2. Subjects

Thirteen professional healthy rugby players from the Leicester Tigers Development Squad with at least 3 years training experience volunteered to participate in the study (table 1). All players were familiar and proficient with the front squat and have been performing the exercise as part of their weekly strength and conditioning program for over a year. Players were excluded if they had a current lower limb injury. Prior to the study commencing, all participants read an information sheet detailing all information about the study and its procedures. All subjects then completed a Physical Activity Readiness Questionnaire and signed an informed consent document which was reviewed and approved by Cardiff University ethics committee.

Table1. *Physical characteristics of the subjects. Mean ±SD*

Age (years)	Stature (cm)	Mass (kg)
19.27 ± 1.47	183 ± 6.16	99.85 ± 15.82

2.3. Testing Procedure

Prior to testing commencing, all participants refrained from performing any high intensity strength training or plyometrics for 48 hours. Two testing sessions were conducted at the same time of day to control for circadian variation [19]. Testing for each participant was conducted over two sessions, with at least 48 hours separating the testing sessions. Session one begun with an athlete led warm up that consisted of 3 minutes of low-intensity jogging followed immediately by static stretching for the gluteals, quadriceps, hamstrings, adductors and the calf complex, with each stretch being held for approximately 15seconds. The participants front squat 1RM was then tested using the procedure outlined by McBride et al.[20]. The present study chose the front squat, so comparisons of plyometric performance following different lifts may be possible. Furthermore, the front squat is employed by the strength and conditioning staff at the club as it is deemed a safer lift due to less axial loading compared to the traditional back squat[21]. Additionally, it is considered an easier lift to teach developing athletes whilst still developing the quadriceps and gluteals, which are deemed important muscle groups for successful performance in rugby union.

Once a 1RM was established, each subject completed 7 familiarisation trials of the CMJ with 10 seconds rest between efforts. Participants were instructed to stand with each foot on a Pasco force plate and placed their hands on their hips for the duration of the jump to minimise upper limb contribution to the jump. The use of the upper limb provides an increase in momentum, therefore affecting jump height, and in turn the results of the study. Some researchers have utilised a sledge apparatus to standardise the jump even further [22, 15]. Although this is very advantageous for standardisation purposes, this is unrealistic in the applied setting as this piece of equipment isn't widely available. The CMJ, despite being a bilateral slow stretch shorten cycle (SSC) activity, is a safe movement which is widely used for research purposes in the applied setting, therefore, the CMJ has been employed for this study.

Session 2 then consisted of an identical warm up to session 1. In addition, a weights-specific warm up was included, with the athlete performing 8 repetitions at 50% 1RM and then 6 repetitions at 70% 1RM. Once warmed up the athlete performed 3 repetitions at 80% 1RM followed by either 15, 30, 45- or 60-seconds recovery, then immediately performing 7 double leg CMJ's with 10 seconds rest between jumps.

The rest interval between complex pairs is also important when conducting CT. Recommendations are between 2-10 mins [23], subjects had 12 minutes recovery between each complex pair and then repeated the process a further 3 times, each with a different randomly assigned IRI confirmed prior to the testing commencing.

2.4. Instrumentation

All CMJ's were performed on two Pasco force plates (35cmx35cm; model PAS 010 660), connected by a Sparklink Air cable and sampling at a frequency of 500 Hz. The data was captured using Capstone software (version 1.5.0) on a Lenovo Thinkpad X230 LAPTOP I5 2.60GHZ (Intel Core i5-3320M processor). Each subject performed their front squats in a squat rack with two spotters for safety precautions.

2.5. Statistical Analysis

Once normality had been confirmed, peak force and peak power from the 7 CMJ's from the 4 differing protocols were analysed using a repeated measures ANOVA, with the P value set at 0.05. A post hoc Bonferroni correction test was applied to determine the level of significance. The profiles of the proceeding 7 CMJ's were analysed using the same method. All statistical analysis was performed using R studio software (version R -3.4.1).

3. Results

Table 2 illustrates the difference in peak power and peak force across the CMJ's with the four different IRI's. A repeated measures ANOVA confirmed that peak power increased with 30seconds rest by 37.89W and then again with 45seconds rest by a further 12.62W compared to 15 seconds rest, but neither result proved to be statistically significant. However, peak power output significantly increased with 60seconds rest compared to having only 15seconds rest by 214.67N, a percentage increase of 4.98. The adjacent column demonstrates that peak force showed no significant results across any of the protocols. Peak force reduced marginally, however, none of these results were statistically significant.

Table2. *Peak force and peak power outputs (with 95% confidence interval) for each IRI*

Protocol	Peak power - W (±CI)	Peak force - N (±CI)
15s	4303.28 (± 179.594)	2095.70 (±101.813)
30s	37.89 (± 149.291)	-14.21 (±34.519)
45s	59.27 (±150.145)	-8.00 (±34.786)
60s	214.67 (±149.291)*	-8.39 (±34.519)

** Significant ($P < 0.05$) result compared to 15 s.*

Tables 3, 4, 5 and 6 illustrate how the peak force and peak power output changes across the profile of the proceeding CMJ's. Table 3 demonstrates that there was no significant change in peak power or force output across the 7 jumps using an IRI of 15seconds. Table 4 demonstrates that there was no significant change in peak power across the jumps, however, in comparison to jump 1, there was a significant increase in peak force output of 121.166 Newtons in jump 4.

Table 3. *Peak force and peak power output (with 95% confidence interval) for each jump following an IRI of 15 seconds*

Intercept	4164.379 (±433.822)	2037.130 (±287.620)
Jump 2	56.167 (±353.701)	22.833 (±72.011)
Jump 3	113.750 (±353.701)	46.167 (±72.011)
Jump 4	38.000 (±353.701)	69.500 (±72.011)
Jump 5	108.250 (±353.701)	26.250 (±72.011)
Jump 6	170.624 (±360.265)	6.756 (±73.847)
Jump 7	297.917 (±353.701)	53.083 (±71.811)

Table 4. *Peak force and peak power output (with 95% confidence interval) for each jump following an IRI of 30 seconds*

Jump Number	Peak power – W (±CI)	Peak force – N (±CI)
Intercept	4389.500 (±528.985)	2051.583 (±276.800)
Jump 2	-471.33 (±459.716)	46.583 (±94.732)
Jump 3	119.417 (±459.716)	40.000 (±94.733)
Jump 4	64.000 (±459.716)	121.166 (±94.732) *
Jump 5	73.167 (±459.716)	35.666 (±94.732)
Jump 6	-4.333 (±459.716)	63.166 (±94.732)
Jump 7	-2.33 (±459.716)	47.916 (±94.732)

** Significant result after a Bonferroni correction test applied, in comparison to Intercept/jump number 1*

Table 5 illustrates that following an IRI of 45seconds, compared to jump 1, there was a statistically significant increase in peak force at jump 7, but no significant change in power output across the jumps. Similarly, after a 60second rest between the initial stimulus and the 7 CMJ's, there was a significant increase in peak force after jumps 6 and 7. There was a small decrease in power output, however this wasn't shown to be significant.

Table 5. *Peak force and peak power output (with 95% confidence interval) for each jump following an IRI of 45 seconds*

Jump Number	Peak power – W (±CI)	Peak force –N (±CI)
Intercept	4385.034 (±498.312)	1991.209 (±289.103)
Jump 2	-100.167 (±381.486)	63.2500 (±79.942)
Jump 3	84.500 (±381.486)	114.583 (±79.942)
Jump 4	-127.255 (±386.643)	91.847 (±81.183)
Jump 5	-75.500 (±381.486)	21.667 (±79.941)
Jump 6	-50.833 (±381.486)	67.666 (±79.941)
Jump 7	-119.088 (±386.643)	116.097 (±81.183) *

** Significant result after a Bonferroni correction test applied, in comparison to Intercept/jump number 1.*

Table 6. *Peak force and peak power output (with 95% confidence interval) for each jump following an IRI of 60 seconds*

Jump Number	Peak power - W (±CI)	Peak force - N (±CI)
Intercept	4681.750 (±515.569)	2040.583 (±271.318)
Jump 2	-120.583 (±332.232)	68.333 (±78.402)
Jump 3	-87.250 (±332.232)	65.750 (±78.402)
Jump 4	-203.833 (±332.232)	60.083 (±78.402)
Jump 5	-200.667 (±332.232)	67.500 (±78.402)
Jump 6	-359.083 (±332.232)	117.500 (±78.402) *
Jump 7	-58.250 (±332.232)	93.083 (±78.402) *

** Significant result after a Bonferroni correction test applied, in comparison to Intercept/jump number 1.*

4. Discussion

CT can be an effective and time efficient method of training that can prove beneficial in a time restricted environment such as professional sport. However, previous research has suggested that an IRI of 4 minutes is optimal [14]. Due to the rigorous training schedule of a modern-day professional athlete, the recommended 4-minute rest period may consume valuable time from their preparation. The purpose of this study was to employ shorter rest periods and investigate their effect on peak force and peak power outputs of 7 CMJ's following an initial stimulus of a front squat performed at 80% 1RM. A secondary aim of the study was to investigate the profile of the proceeding CMJ's and determine if there was any change in performance across the 7 jumps.

This study showed a significant increase in peak power output in CMJ's that were performed 60seconds after 3 front squats at 80% 1RM compared to just 15seconds rest. Peak power output marginally increased with 30seconds and then again with 45seconds rest between the initial squat and the corresponding CMJ's, however these increases were not shown to be statistically significant. This trend of improvement in jump performance with increasing rest periods is similar to the findings of Jensen and Ebben [14]. They demonstrated a non-significant trend in improvement of jump performance from 10seconds rest up to 4minutes, with them suggesting that 4 minutes may prove the optimal time for recovery. Despite using shorter rest periods, the present study reported similar trends, except in the present study a significant increase in performance was demonstrated at 60seconds rest as opposed to the previously reported 4 minutes. If performance can be enhanced following just 60 seconds rest compared to 4 minutes, this could significantly impact on programming for CT. Having 60seconds rest as opposed to the currently recommended 4 minutes, would save valuable time in an athlete's strength and conditioning program.

Previous research has suggested that PCR can regenerate up to 50% in as little as 56 seconds [18}. This may suggest that a shorter rest period closer to 60seconds would be beneficial as it offers moderate PCR regeneration whilst taking advantage of the increased excitability of the neural system. Potentially, future research could investigate multiple timings between 1 and 2 minutes to determine more accurately if there is an optimal IRI. However, in contrast to this, the same authors [18] demonstrated a large variation in PCR resynthesis between a number of their subjects, with some subjects not having full resynthesis after 6 minutes recovery. Furthermore, previous research has demonstrated that PCR resynthesis is slower in fast twitch fibres compared to slow twitch fibres [24] perhaps owing to a poorer capillary network supplying the fast twitch fibres [25]. This highlights the variation in PCR regeneration between individuals, which is especially evident in a sport such as rugby union where athletes in different playing positions display different physical attributes. This evidence therefore supports the use of individually determined rest periods, which is the conclusion that Comyns et al.[15] presented, with recommendations that the IRI should be individually determined. This is obviously more obtainable if you are working with athletes in individual sports, however in a team environment this would be challenged by resource and time. More research is required to determine if there is an optimal IRI for different types of athletes across differing athletic populations.

Despite showing an increase in peak power with increasing rest periods (with 60seconds rest being statistically significant), the present study showed a small reduction in peak force of 14.21N when the jumps were performed shortly after the initial stimulus (30seconds). However, this was not shown to be statistically significant. Jensen and Ebben [14] similarly showed that performing a plyometric jump after a short rest (10 seconds) post initial stimulus also decreased performance. Their research is further supported by Comyns et al., [15] who demonstrated a reduction in flight time with 30seconds rest following the initial stimulus. These findings disagree with initial beliefs on having a short rest interval [23, 13]. However, the results of the present study would agree with the more contemporary research and suggest 60seconds is the minimum amount of time required to improve performance and demonstrate a statistically significant result.

The present study also investigated the profile of the 7 CMJ's and how their performance changed with varying IRI's. This study demonstrated that following a 30 second IRI, peak force output on jump 4 significantly increased in comparison to jump 1. Similarly, with an IRI of 45 seconds rest, jump 6 showed a significant increase in peak force (in comparison to jump 1), as did jumps 6 and 7 following a 60 second IRI. These results may suggest that employing as little as 4 jumps in a complex set may improve performance in the plyometric or ballistic component. This is not only valuable information from a time efficiency perspective, but beneficial when programming an athlete's weekly schedule. Previous research has suggested that between 5-15 repetitions is required for the plyometric or dynamic component [5]. Multiple sets of 15 repetitions is a high number of plyometric exposures, especially during the season where athletes' training loads can be high. Plyometrics are high demand exercises, even more so if the athlete is joint or load compromised. Having a low number of plyometric exposures in a complex set, whilst still improving performance would prove beneficial, especially to a joint compromised athlete. The athlete's physical performance is still being improved, yet exposures to high demanding forces are being reduced. Further research investigating minimal dose response in CT is required to identify a more accurate prescription. Additionally, if this could be determined in various populations.

Whilst it is important to improve performance, there are times during the season where performance will want to be maintained and fatigue will not want to be induced, for instance in the final stages of the season leading up to the play offs or a grand-final. Not only did this study demonstrate a small increase in performance at certain jumps across the IRI's, importantly it also confirmed no decrease in performance from jumps 1-7 across any of the different protocols. These results agree with previous research [23] that performing a high intensity strength training exercise before a plyometric or dynamic movement has no detrimental effect on the proceeding ballistic exercise. Despite this study showing a small decrease in peak power across the profile of the jumps (in comparison to the first jump in that set) with an IRI of 45seconds and 60seconds, this decrease was not shown to be statistically significant.

5. Practical Implications

The current study demonstrated that having 60seconds rest following 3 repetitions of front squat at 80% 1RM significantly improved peak power output compared to only having 15seconds rest. Recent research suggests that an IRI of 4 minutes is optimal, however in a time restricted environment such as professional sport, a shorter rest period may be advantageous. Furthermore, the present study observed a significant increase in peak force output on the 4^{th},6^{th} and 7^{th}jump following an IRI of 30, 45 and 60 seconds respectively. If a positive improvement in performance can be elicited in as little as 4 plyometric exposures, this could prove an effective minimal dose which may reduce the risk of injury in certain athletic populations. Further research is required to clarify this hypothesis, especially in professional rugby players. Additionally, the current study also agrees with previous research that performing a plyometric or dynamic exercise following a high intensity strength stimulus has no detrimental effects on the proceeding ballistic movement.

This study used a front squat as the initial high intensity strength stimulus. Future CT research would benefit from comparing plyometric performance following different lifts (e.g. traditional back squat vs front squat vs leg press). Similarly, researchers may also wish to investigate performance differences with differing plyometric activities. Instead of using a CMJ which is a slow SSC activity, the effect on fast SSC movements such as a DJ are required. Finally, if this could be determined in different populations, this would further enhance the accuracy of CT prescription.

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