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The Effect of Complex Training on Physical Performance in Rugby League Players

Original Investigation

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ABSTRACT

Purpose: To compare the effects of variable resistance complex training (VRCT) versus traditional complex training (TCT) on strength, power, speed and leg stiffness (K_{leg}) in rugby league players during a 6-week mesocycle.

Methods: Twenty-four rugby league players competing in the BUCS Premier North Division were randomised to VRCT (n=8), TCT (n=8) or control (n=8). Experimental groups completed a 6-week lower-body complex training intervention (2x/week) that involved alternating high-load resistance exercise with plyometric exercise within the same session. The VRCT group performed resistance exercises at 70% of 1RM + 0-23% of 1RM from band resistance with a 90 second intra-contrast rest interval (ICRI), whereas the TCT group performed resistance exercise at 93% of 1RM with a 4-minute ICRI. Back squat 1RM, countermovement jump (CMJ) peak power, reactive strength index (RSI), sprint times and K_{leg} were assessed pre- and post-training.

Results: VRCT and TCT significantly improved 1RM BS, CMJ peak power, and 5 m sprint time (all $p<0.05$) VRCT also improved K_{leg} whereas TCT improved 10 m and 20 m sprint times (all $p<0.05$). Between-groups, both VRCT and TCT improved 1RM BS compared to CON (both $p<0.001$). Additionally, VRCT improved K_{leg} compared to CON (right leg: $p=0.016$) and TCT improved 20 m sprint time compared to CON ($p=0.042$).

Conclusions: VRCT and TCT can be implemented during the competitive season to improve strength, power and 5 m sprint time. VRCT may lead to greater improvements in RSI and K_{leg} whereas, TCT may enhance 10 and 20 m sprint times.

Keywords: Variable resistance complex training, traditional complex training, force-velocity relationship, rugby league, strength and conditioning, competitive season.

INTRODUCTION

Maximum strength, power and rate of force development (RFD) are paramount for success in rugby league.[1] However, regular strength training is a challenging demand on time within a typical training week due to the multiple training modes athletes engage in, congested fixture schedules and short turn-around time between games.[2] It is therefore challenging for sports scientists and strength conditioning coaches to prescribe optimal training methods which induce adaptations required to succeed in competition, in the time available to them.[2]

The incorporation of resistance and plyometric training into an athlete's training regime is integral to the development of maximal force and power production.[3,4] However, both training methods require considerable recovery time to allow for optimal adaptation to occur. This recovery time is rarely available during the competitive season. Contrast training, a specific type of complex training, alternates high-load resistance exercise on a set for set basis with an unloaded explosive exercise.[5,6] Consequently, complex training may be an efficient training strategy since it enables two training modes (resistance training and plyometrics)to be undertaken in a single session with the aim of improving both slow and fast force expression,[3,7] which may particularly advantageous for rugby league players within the context of a busy in-season training schedule.[8]

Complex training (or more specifically, contrast training**)** is underpinned by post-activation performance enhancement (PAPE), which refers to the temporary enhancement of force and power production in skeletal muscle following a near maximal voluntary contraction.[5,9] Fatigue is simultaneously induced which inhibits the PAPE response[10] and limits the practical application of complex training since an appropriate intra-contrast rest interval (ICRI) between the heavy resistance and plyometric exercises is required to enable PAPE to predominate fatigue.[6,10] Traditionally, acute PAPE studies recommend ICRIs of 4-12 minutes when heavy load (≥ 85% of 1-repetition maximum [RM]) exercises are performed.[11,12] The use of such long ICRIs may not be practical in a real-world setting.

Furthermore, research suggests that this may not be the most appropriate loading strategy to elicit PAPE.[13]

Variable resistance training applies additional resistance, through latex bands or chains, to the barbell as it moves through the concentric phase, consequently altering the force-velocity profile of the resistance exercise and enabling increased power production.[14,15] There is evidence that PAPE may be elicited following shorter ICRIs of 90 seconds when a moderate load (60-85% of 1RM) is combined with variable resistance[14,16] which is of greater practical value in applied training settings. However, there is no empirical evidence which documents the efficacy of a complex training programme which incorporates variable resistance.

Although chronic complex training studies have reported improvements in muscular strength and power after 4-11 weeks, ICRIs of 0.5-3 minutes were prescribed which is unlikely to have been long enough for PAPE to manifest using traditional complex training methods.[3,4,17–20] In addition, no study has compared traditional complex training (TCT) to variable resistance complex training (VRCT) during a competitive season, which is arguably where complex training may have its greatest application. Therefore, the purpose of this study was to compare the effects of TCT in comparison to VRCT, when recommended ICRIs are implemented, on physical performance characteristics in rugby league players during a competitive season.

METHODS

Participants

Twenty-four male rugby league players were recruited from a University level rugby league team during the competitive season. Participant characteristics at baseline are presented in Table 1. All participants had no existing musculoskeletal injuries, were currently competing in the British University and Colleges Sport (BUCS) Premier North

Division (the highest playing standard for University-level athletes competing in the Northern Britain region), and had at least 6-months previous experience in a structured resistance training programme (at least two sessions per week). The study received full ethical approval from the Department of Sport, Health and Exercise Science Ethics Committee at the University of Hull in accordance with the Declaration of Helsinki. Each participant voluntarily gave their written informed consent to take part in the study.

Experimental Design

A between-subject, randomised design was adopted for this study. Participants were randomly assigned to either VRCT, TCT or a control (CON) group using online randomisation software. Both training groups completed 6-weeks of the corresponding training interventions which comprised of two sessions per week where the volume-load was identical between training groups. However, the prescribed ICRIs for VRCT and TCT were 90 seconds and 4-minutes, respectively, as recommended by academic literature[11,12,14,16] . Participants in the CON group did not undertake any training. Outcome measures of strength, power, reactive strength index (RSI), speed and leg stiffness (K_{leg}) were assessed at baseline (before randomisation) and post-intervention (Figure 1).

Experimental Procedures

Participants attended a familiarisation session during which, anthropometric measurements of height (The Leicester Height Measure, Seca, Birmingham, UK) and body mass (Seca 813 digital scales, Birmingham, UK) were recorded. Additionally, participants were familiarised with the standardised warm-up, experimental testing protocol, and the resistance and plyometric exercises within the training programme.

Performance testing was conducted during a single visit and consisted of a 1RM back-squat (BS), countermovement jump (CMJ), drop jump (DJ), 20-metre sprint and vertical hop test to quantify the outcome measures. The following week, participants were randomly allocated to VRCT, TCT or CON. Training load for each exercise was determined over two days separated by 48-96 hours recovery. Day 1 consisted of a 1RM hex-bar deadlift (HBD). Day 2 involved a 3RM Romanian deadlift (RDL) and Bulgarian split squat (SS_{Bulg}). We chose these resistance exercises because they are commonly prescribed within rugby league training programmes and target key lower-body movement patterns[21] that are transferrable to rugby league match-play. Participants commenced the 6-week training mesocycle the next week. Testing for the post-intervention outcome measures took place the week following the final complex training session.

Outcome Measures

This paper reports changes in strength, power, leg stifness and sprint speed. Changes in muscle architecture, including muscle thickness, pennation angle, and fascicle of the vastus lateralis and gastrocnemius medialis are reported separately.[22]

One Repetition Maximum

Lower-body muscular strength was assessed by a 1RM BS adhering to established guidelines.[23] Briefly, participants performed 1RM attempts with progressively increased loads. The attempt was only accepted if the BS was completed with correct technique and a squat-depth where the femur was parallel to the ground. Participants were allowed 2-4 minutes recovery between each attempt and were permitted a maximum of five attempts to derive 1RM. This assessment has previously demonstrated excellent reliability (intraclass correlation coefficient [ICC] = 0.99).[24]

Jump performance

CMJ and DJ performance were assessed using a strain gauge force plate (AMTI, BP600900; dimensions 900 x 600 mm, Watertown, Massachusetts, USA) where sampling frequency was set at 1000Hz. Participants performed the CMJ with their hands on their hips and descended to a self-selected depth before exploding upwards as forcefully and as quickly as possible with the aim of maximising jump height. Participants performed the DJ by stepping off a 40 cm box with their preferred leg, making a double foot contact with the force plate, and rebounding as quickly and forcefully as possible whilst minimising ground contact time and maximising jump height. Evidence suggests that a height of approximately 40 cm maximises power output in the depth jump.[25] Instruction was given to the participants to maintain their hands on their hips, keep their legs as straight as possible and maintain an upright torso throughout the jump. Three CMJs and DJs were performed with a one-minute recovery interval between each effort. Only the CMJ and DJ with the greatest power output and RSI (jump height [m] / ground contact time [s]) was used for analysis, respectively. Excellent reliability has been demonstrated in the determination of peak power (ICC = 0.96)[12] and RSI (ICC = 0.97).[26]

Sprint Performance

Participants completed one practise and two maximal 20 m sprints where time was recorded at 5, 10, 15 and 20 m intervals using wireless Brower timing gates (Brower Timing Systems, Brower Test Centre System, Draper, Utah, USA). All sprints commenced from a static start 50 cm behind the first timing gate. Five minutes recovery was allowed between each attempt. The fastest sprint was used for analysis. The 20 m sprint has previously demonstrated excellent reliability (ICC = 0.96).[27]

Leg Stiffness

A unilateral vertical hop test was administered to assess K_{leg}, which involved hopping on the force plate in time to a digital metronome set at 2.2 Hz. Participants performed the test barefoot with their hands on their hips. Once steady-state hopping was achieved, ground reaction force (GRF) data were collected for 10 s. Trials were only accepted if at least 5 of the hops were within a ±2% of the prescribed frequency. K_{leg} was expressed as the mean of five consecutive hops which was used for analysis. Participants completed one trial for each leg. The vertical hop test has demonstrated a high level of reliability for the determination of K_{leg} (TEM = 4.15%; ICC = 0.80).[28]

Determination of Individual Training Loads

Training load was determined for the resistance exercises within the training programme over two sessions which were separated by 48-96 hours. Session one consisted of a 1RM HBD and session two comprised of a 3RM RDL and SS_{Bulg}. Following the same standardised warm-up, established procedures for RM assessment were adhered to.[23] Predicted 1RM scores for RDL and SS_{Bulg} were calculated using the training load chart.[29]

For VRCT, the variable resistance from the latex bands was determined following previously established methods.[14,16] Briefly, participants stood on Seca weighing scales with the bar and mass was recorded. The bands (Pullum Sports, Leighton Buzzard, Bedfordshire) were secured to the bar and participants stood at the end range for each exercise and mass was recorded. Band tension was defined as the difference between these two measures. This process was repeated with bands of various tension until the variable resistance reached 23% 1RM at end range for each exercise.

Training Programme

Complex training sessions were completed twice per week for six weeks, with 48-96 hours recovery between sessions. Each training session commenced with a comprehensive, task-specific, and standardised warm-up (Table 2).[30] Additionally, participants were allowed two warm-up sets of each resistance exercise, which comprised of six repetitions at 50% of 1RM and four repetitions at 70% of 1RM separated by 2-3 minutes rest. Both groups performed the HBD as explosively as possible during the concentric phase. To safely minimise the amount of work during the eccentric phase, the

TCT group were instructed to drop the bar at the top of the lift whereas, the VRCT were instructed to perform the eccentric phase as quickly as possible. To replicate real-world application of complex training, multiple complex pairs (HBD + DJs, RDLs + pike jumps, SS_{Bulg} + lunge jumps) were prescribed (Table 3). Participants were encouraged to lift as explosively as possible during the concentric phase for RDL and SS_{Bulg} and complete the eccentric phase in a controlled manner. The volume-load of the prescribed exercises (defined as the product of sets x repetitions x barbell load) was consistent between training groups however, the barbell load and ICRIs varied. For TCT, resistance exercises were performed at 93% of 1RM with a four minute ICRI[11,12] whereas, resistance exercises for VRCT were performed at 70% of 1RM + 0-23% of 1RM from band resistance with a 90 second ICRI.[14–16] We chose a relative load of 93% 1RM for TCT because it aligns with previous literature[12,16] and this load is typically associated with an athlete's three repetition maximum,[31] which targets maximal strength (at least when strength is operationalised as 1RM). Participants were allowed 3-5 minutes recovery between sets. The adherence rate for the VRCT and TCT groups were 94.8% and 95.8%, respectively. Participants continued their usual in-season training routine during the study, comprising one field session (rugby league skills and conditioning) and one match per week, but did not participate in any other form of resistance training or plyometrics.

Data Analysis and Variable Extraction

All GRF data were analysed using customised coding scripts in MATLAB (MATLAB, version R2014a, MathWorks, Inc., Natick, MA). No noise was evident in the vertical GRF signal and remained unfiltered. A 5 N threshold was selected to identify the instants of take-off and landing during the jumping and hopping trials. A two second average of standing GRF data was used to calculate participants mass prior to each trial. Acceleration from the vertical GRF data during the CMJ was calculated using equation (1):

1) Acceleration [$m \cdot s^{-2}$] = (GRF [N] / mass [kg]) – g [9.81 $m \cdot s^{-2}$]

Velocity was calculated by integrating acceleration, using the Simpson's rule, where intervals were equal to the bandwidth. Integration commenced from the start of the CMJ, time point where GRF was reduced by 10% of the participant's body weight, to the point of landing. Power was calculated using equation (2):

2) Power [W] = GRF [N] x Velocity [$m \cdot s^{-1}$]

For the calculation of RSI, jump height of each DJ was determined using the flight-time method[32], equation (3):

3) Jump height [m] = (g x flight time^2 [s]) / 8

Before calculating K_{leg}, the maximum negative vertical displacement (Δz) of the participants' centre of mass during ground contact of the corresponding vertical hops was determined using equation (4)[33]:

4) $$\Delta z\,[m] = \frac{-GRF_{peak}\,[N]}{mass[kg]} \cdot \frac{\text{ground contact time}^2[s]}{\pi^2} + g \cdot \frac{\text{ground contact time}^2[s]}{8}$$

K_{leg} could then be calculated using equation (5):

5) K_{leg} [$kN \cdot m^{-1}$] = GRF_{peak} [N] / Δz [m]

Statistical Analysis

Preliminary analysis was conducted to ensure normal distribution of the data. Statistical analysis was conducted using a 3 (condition: VRCT, TCT and CON) x 2 (time: pre- and post-training) two-way ANOVA with repeated measures on time to analyse within-group changes between pre- and post-training. Between-group differences of the change score were analysed using a one-way ANOVA. If significant main effects for time were detected, pairwise comparisons were applied with Bonferroni corrections. Standardised effect size statistics (Cohen's *d*) were calculated to interpret the magnitude of within-group changes from pre-training to post-training (mean change divided by the average SD at pre- and post-training; d_{av}), and between-group differences in change scores (mean difference divided by the SD of difference; d_s).[34] Standardised effect sizes were interpreted as *trivial* (≤0.19), *small* (0.20-0.59), *moderate* (0.60-1.19), *large* (1.2-1.99), and *very large* (≥2.0).[35] Where the 95% CIs overlapped the thresholds for *small* positive and *small* negative, the effect was considered *unclear*. Statistical procedures were conducted using SPSS 26 (SPSS Inc., Chicago, IL) and standardised effect sizes were calculated using Microsoft Excel. Statistical significance was set at $p \leq 0.05$. Data are presented as mean ± SD or *d* ± 95% confidence interval (CI).

RESULTS

Descriptive statistics at baseline and follow-up, along with the within-group change scores, are presented in Table 4. Both TCT and VRCT significantly improved 1RM BS, CMJ peak power, and 5 m sprint time (all p<0.05). Additionally, significant improvements were observed for RSI (p=0.029), K_{leg} (right: p=0.013; left: p=0.003) following VRCT, whereas TCT displayed significant improvements in 10 m sprint time (p=0.029) and 20 m sprint time (p=0.006). The magnitude of within-group changes for 5 m sprint times were moderate for VRCT ($d_{av}=0.9 \pm 1.02$) and TCT ($d_{av} =0.89 \pm 1.02$); however, within-group changes for all other outcomes were classed as *unclear* because of the wide 95% CIs (see Table 4).

Between-groups, both VRCT and TCT improved 1RM BS compared to CON (both p<0.001). Additionally, in comparison to CON, the change score was significantly greater for K_{leg} (right: p=0.016) following VRCT, whereas the change score was significantly (p=0.042) greater for 20 m sprint time following TCT (Table 4). Between-group differences in change scores between TCT and VRCT were *unclear* (presented in Figure 2).

DISCUSSION

The main findings were that both complex training conditions induced similar adaptations to 1RM BS strength, peak power and 5 m sprint times. This aligns with a recent study examining the effect of 4 weeks of two different training methods (jump vs complex training), which also found that vertical jump power increased significantly in both groups.[36] However, our study provides evidence that VRCT favours improvements to RSI and K_{leg}, whereas TCT may favour 10 m, 15 m and 20 m sprint times. Therefore, both VRCT and TCT could be implemented during the competitive season depending on the objective of the training programme. The shorter ICRI associated with VRCT may further promote its value for practitioners.

The results of the present study are in agreement with previous complex training studies demonstrating increased lower-body strength[3,19], peak power[4,18,19] and reduced sprint times.[17,18] Such enhancements are largely attributed to neural and morphological adaptations.[18,19] Walker et al.[20] reported significant improvements in vertical jump performance but no significant improvement in vastus lateralis (VL) electromyography activity following an 11-week complex training intervention in recreationally resistance trained males, suggesting that adaptations were predominantly muscular. We also found changes in VL muscle thickness and fascicle length following both TCT and VRCT, which is reported separately.[22]

Previous research has demonstrated significantly greater VL muscle fibre cross-sectional area, specifically type IIa and IIx, after a six-week complex training programme in moderately trained males.[19] Additionally, a significant decrease in VL type I muscle fibre proportion was induced, suggesting transition to a greater proportion of type II muscle fibres. This is advantageous due to the greater force production, contraction velocities, power outputs and RFD associated with type II muscle fibres.[19] Although such adaptations may explain the observed improvements in physical performance, neural and morphological adaptations were not directly assessed in the present study and are, therefore, speculative. Further research is required to elucidate the neural and morphological adaptations associated with complex training. Regardless of the physiological mechanisms responsible for the observed adaptations, greater levels of strength, power and speed are integral for success within rugby league.[1]

There is evidence to suggest that favourable adaptations to RSI and K_{leg} were induced by VRCT. Increased K_{leg} enables a more efficient return of stored elastic strain energy from the stretch reflex due to reduced deformation of the muscle-tendon unit, electromechanical delay and ground contact time.[37] Interestingly, adaptations to K_{leg} are predominantly influenced by ankle stiffness and knee extensor stiffness inversely correlates with pre-stretch augmentation.[38] Further research is required to examine the effect of complex training on ankle and knee stiffness independently and their influence on stretch-shortening cycle activities. Nevertheless, K_{leg} adaptations may explain the observed improvements in RSI due to participants increased tolerance to high eccentric forces.[39]. Additionally, this improvement could be attributed to an enhanced ability to pre-tense the muscle-tendon unit prior to ground contact and the key phase of force production.[37] This is important given that the application of maximal force in minimal time characterises a large number of actions involved in rugby league match-play [1].

Similarly, there is evidence to suggest that TCT was more effective in improving 10-20 m sprint times. The different adaptations induced by VRCT and TCT could be explained by training specificity and the difference in barbell load. The 93% 1RM loads during TCT were performed at slow velocities leading to greater time under tension.[40] The production of high concentric forces over longer ground contact times is associated with the acceleration phase of sprinting.[41] This is important since rugby league match-play commonly requires players to sprint distances of 0-20 m.[1] In comparison, variable resistance is theorised to enhance utilisation of elastic energy due to an 'over-speed' eccentric phase and variation in load (73-93%) throughout the movement increasing concentric contraction velocity.[15] This may explain the adaptations to K_{leg} and RSI following VRCT. Collectively, however, these findings must be interpreted with caution since the 95% CIs for within-group changes cross the boundaries for *small* effect. Furthermore, the 95% CIs of the between-group difference scores between VRCT and TCT were wide (Figure 2), indicating a need for further research with larger samples to detect small differences between the efficacy of these two training modalities, if a difference exists.[42]

This study is not without its limitations. Although the participants were moderately trained and randomised, to avoid systemic bias, a stratification assignment may have been more effective since differences in baseline outcome measures were evident and some individuals may have had a greater reserve for adaptation.[43] The sample size was relatively small however, it is challenging to recruit participants for a training intervention study during their in-season schedule. PAPE is highly individualised[11] and the selected training variables may not have elicited the optimal response in some participants. Regular assessment of complex training variables would have enabled appropriate manipulation and progression of the training programmes because the PAPE response changes in response to training.[20] Unfortunately, time constraints meant that this was not possible within the current study. The ICRIs implemented for RDL and SS_{Bulg} were assumed to be equivalent to HBD which may not have been appropriate since the magnitude of PAPE and ICRIs have not been reported in academic literature. Although the study attempted to replicate real-world training scenarios using multiple complex pairs, the results from the study cannot be attributed to one form of training or exercise.

Finally, since this was an in-season training programme, on-field training loads could have influenced the observed adaptations.

PRACTICAL APPLICATIONS

This study suggests that VRCT and TCT are effective modalities for training both extremes of the force-velocity curve in a single session during the competitive rugby league season. Given the comparable improvements in lower body strength and 5m sprint times, VRCT is worthy of consideration when time is at a premium and both key determinants of rugby league performance can be improved in a single session. VRCT may induce favourable adaptations to RSI and K_{leg} whereas, TCT may improve 10, 15 and 20 m sprint times. Therefore, coaches should implement complex training modalities based on the objectives of the training programme. Coaching staff should make their own interpretations on the data presented in this study and implement appropriate training strategies accordingly.

CONCLUSIONS

This is the first study to demonstrate improvements in strength, power and 5 m sprint time following VRCT and TCT throughout a 6-week mesocycle within the competitive rugby league season. VRCT may lead to greater improvements in RSI and K_{leg} whereas, TCT may enhance 10, 15 and 20 m sprint times. Further research is required to confirm this and identify the underpinning physiological adaptations responsible for the observed performance enhancements.

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Table 1. Participant characteristics at baseline. Data are presented as mean ± SD.

	VRCT (n = 8)	TCT (n = 8)	CON (n = 8)
Age (years)	20.3 ± 1.0	22.8 ± 3.6	26.0 ± 4.0
Height (cm)	178 ± 8.7	185 ± 4.7	181 ± 6.9
Body mass (kg)	84.7 ± 10.6	96.2 ± 10.4	92.2 ± 10.0
Back squat 1RM (kg)	134 ± 24	119 ± 27	154 ± 36
CMJ relative peak power (W/kg)	52.4 ± 5.1	44.8 ± 6.5	52.8 ± 5.1
CMJ height (cm)	31.9 ± 5.2	25.8 ± 4.1	33.2 ± 5.8

VRCT = variable resistance complex training group; TCT = traditional complex training group; CON = control; CMJ = countermovement jump.

Table 2. Standardised warm-up for experimental protocol and training sessions.

Exercise	Sets x reps (intensity)
Cycling	1 x 3 minutes (60 W)
Body weight squats	1 x 6
Mountain climbers	1 x 6 e/s
Thoracic rotations	1 x 6 e/s
Glute bridge	1 x 6
Band pull apart	1 x 6
Submaximal CMJs	1 x 3-4
Corresponding resistance exercise	1 x 6 (50% 1RM); 1 x 4 (70% 1RM)

e/s = each side; CMJ = countermovement jump; RM = repetition maximum.
Warm-up sets of the corresponding resistance exercise were administered during the training sessions.

Table 3. Overview of the complex training programmes.

VRCT				TCT			
Complex pairs	Sets x reps	Load	ICRI	Complex pairs	Sets x reps	Load	ICRI
1a. Hex-bar deadlift	3 x 3	70 + 0-23% 1RM	90 seconds	1a. Hex-bar deadlift	3 x 3	93% 1RM	4 minutes
1b. Drop jumps (40 cm)	3 x 6	Body weight		1b. Drop jumps (40 cm)	3 x 6	Body weight	
2a. Romanian deadlift	3 x 3	70 + 0-23% 1RM	90 seconds	2a. Romanian deadlift	3 x 3	93% 1RM	4 minutes
2b. Pike jumps	3 x 6	Body weight		2b. Pike jumps	3 x 6	Body weight	
3a. Bulgarian split squat	3 x 3	70 + 0-23% 1RM	90 seconds	3a. Bulgarian split squat	3 x 3	93% 1RM	4 minutes
3b. Lunge jumps	3 x 6	Body weight		3b. Lunge jumps	3 x 6	Body weight	

Training sessions were performed twice per week. A 3-5 minute recovery interval was allowed between complex sets. A 48-96 hour recovery period was allowed between training sessions.

VRCT = variable resistance complex training; TCT = traditional complex training; ICRI = intra-contrast rest interval.

Table 4. Pre- and post-intervention scores, within-group change scores and standardised mean change. Data are presented as mean ± SD and d_{av} ± 95% CI.

		VRCT	TCT	CON
1RM Back Squat (kg)	Pre	134 ± 24.4	119 ± 27.1	154 ± 36.2
	Post	152 ± 25.4*	138 ± 25.6*	154 ± 35.1
	Change Score	17.5 ± 5.98†	19.38 ± 8.21†	0.31 ± 3.39
	Cohen's d_{av}	0.73 ± 1.01	0.77 ± 1.02	0.01 ± 0.98
CMJ Peak Power (W)	Pre	4432 ± 682	4294 ± 662	4842 ± 472
	Post	4653 ± 600*	4485 ± 722*	4818 ± 325
	Change Score	221 ± 205	192 ± 280	-23.2 ± 243
	Cohen's d_{av}	0.34 ± 0.99	0.28 ± 0.98	-0.06 ± 0.98
RSI (AU)	Pre	1.03 ± 0.26	0.82 ± 0.14	1.01 ± 0.26
	Post	1.24 ± 0.34*	0.99 ± 0.41	1.08 ± 0.29
	Change Score	0.22 ± 0.26	0.17 ± 0.34	0.07 ± 0.13
	Cohen's d_{av}	0.69 ± 1.01	0.55 ± 1.00	0.25 ± 0.98
K_{leg} Right ($kN \cdot m^{-1}$)	Pre	17.6 ± 2.9	18.4 ± 2.0	17.3 ± 3.8
	Post	18.7 ± 3.2*	19.01 ± 2.1	16.5 ± 3.3
	Change Score	1.13 ± 1.13†	0.65 ± 1.32	-0.71 ± 1.08
	Cohen's d_{av}	0.37 ± 0.99	0.32 ± 0.99	-0.20 ± 0.98
K_{leg} Left ($kN \cdot m^{-1}$)	Pre	17.5 ± 3.4	18.5 ± 1.4	17.7 ± 3.2
	Post	19.0 ± 3.6*	19.1 ± 1.3	17.8 ± 3.5
	Change Score	1.53 ± 1.94	0.60 ± 1.06	0.08 ± 0.56
	Cohen's d_{av}	0.44 ± 0.99	0.44 ± 0.99	0.02 ± 0.98
5 m sprint (s)	Pre	1.07 ± 0.08	1.11 ± 0.10	1.04 ± 0.04
	Post	1.01 ± 0.05*	1.02 ± 0.05*	1.03 ± 0.03
	Change Score	-0.06 ± 0.07	-0.07 ± 0.09	0.02± 0.04
	Cohen's d_{av}	-0.90 ± 1.02	-0.89 ± 1.02	0.57 ± 1.00
10 m sprint (s)	Pre	1.81 ± 0.09	1.92 ± 0.13	1.82 ± 0.05
	Post	1.77 ± 0.09	1.85 ± 0.10*	1.83 ± 0.04
	Change Score	-0.04 ± 0.11	-0.06 ± 0.07	0.02 ± 0.04
	Cohen's d_{av}	-0.44 ± 0.99	-0.60 ± 1.00	0.22 ± 0.98
15 m sprint (s)	Pre	2.49 ± 0.12	2.63 ± 0.15	2.51 ± 0.07
	Post	2.44 ± 0.13	2.57 ± 0.16	2.54 ± 0.04
	Change Score	-0.04 ± 0.11	-0.06 ± 0.07	0.03 ± 0.06
	Cohen's d_{av}	-0.40 ± 0.99	-0.39 ± 0.99	0.53 ± 1.00
20 m sprint (s)	Pre	3.14 ± 0.14	3.36 ± 0.21	3.18 ± 0.07
	Post	3.09 ± 0.20	3.25 ± 0.19*	3.20 ± 0.06
	Change Score	-0.05 ± 0.13	-0.11 ± 0.09†	0.03 ± 0.07
	Cohen's d_{av}	-0.29 ± 0.99	-0.55 ± 1.00	0.31 ± 0.99

* denotes a significant change from pre- to post-training (all $p<0.05$).

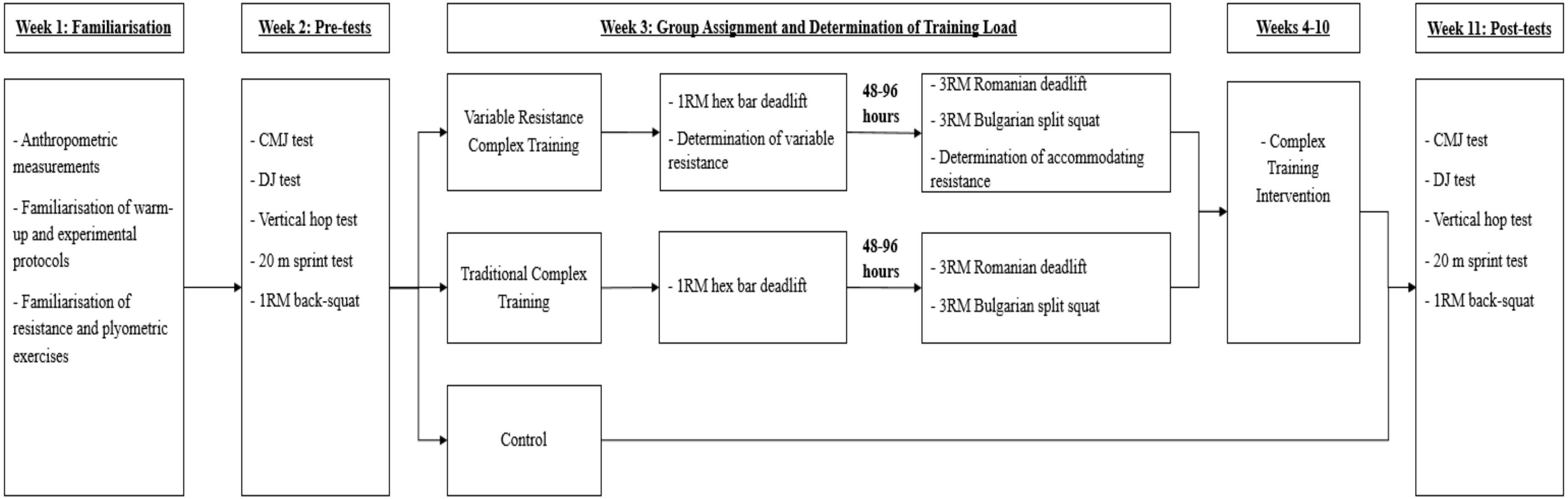
† denotes a significant difference in change scores compared to CON (all $p<0.05$).

CMJ = countermovement jump; CON = control; RM = repetition maximum; RSI = reactive strength index; AU = arbitrary units; K_{leg} = leg stiffness

Figure Captions

Figure 1. A schematic representation depicting the design and time frame of the study. CMJ = countermovement jump; DJ = drop jump; RM = repetition maximum.

Figure 2. Standardised between-group differences (d_s ± 95% CI) in change score and their corresponding 95% confidence intervals between TCT and VRCT groups. Area shaded in grey represents a trivial standardised difference (±0.20). 1RM = 1 repetition maximum; RSI = reactive strength index; K_{leg} = leg stiffness; VRCT = variable resistance complex training; TCT = traditional complex training.


Week 1: Familiarisation
Week 2: Pre-tests
Week 3: Group Assignment and Determination of Training Load
Weeks 4-10
Week 11: Post-tests
- Anthropometric measurements
- Familiarisation of warm-up and experimental protocols
- Familiarisation of resistance and plyometric exercises
- CMJ test
- DJ test
- Vertical hop test
- 20 m sprint test
- 1RM back-squat
Variable Resistance Complex Training
- 1RM hex bar deadlift
- Determination of variable resistance
48-96 hours
- 3RM Romanian deadlift
- 3RM Bulgarian split squat
- Determination of accommodating resistance
Traditional Complex Training
- 1RM hex bar deadlift
48-96 hours
- 3RM Romanian deadlift
- 3RM Bulgarian split squat
Control
- Complex Training Intervention
- CMJ test
- DJ test
- Vertical hop test
- 20 m sprint test
- 1RM back-squat

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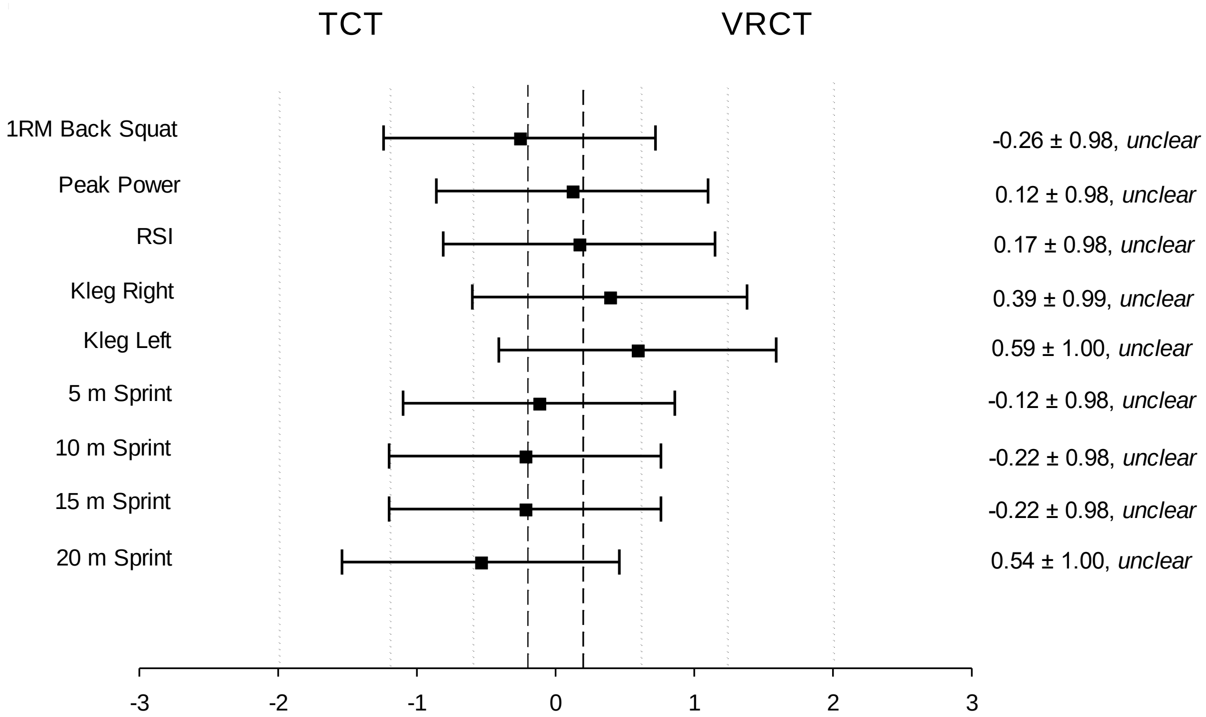
TCT
VRCT
1RM Back Squat
Peak Power
RSI
Kleg Right
Kleg Left
5 m Sprint
10 m Sprint
15 m Sprint
20 m Sprint
-0.26 ± 0.98, *unclear*
0.12 ± 0.98, *unclear*
0.17 ± 0.98, *unclear*
0.39 ± 0.99, *unclear*
0.59 ± 1.00, *unclear*
-0.12 ± 0.98, *unclear*
-0.22 ± 0.98, *unclear*
-0.22 ± 0.98, *unclear*
0.54 ± 1.00, *unclear*
-3
-2
-1
0
1
2
3