International Journal of
Sports Science
& Coaching

International Journal of Sports Science
& Coaching
2016, Vol. 11(5) 736–745

DOI: 10.1177/1747954116667112
spo.sagepub.com
SAGE

Is nine weeks of complex training effective for improving lower body strength, explosive muscle function, sprint and jumping performance?

Scott W Talpey[1,2], Warren B Young[1] and Natalie Saunders[3]

Abstract

There is currently minimal evidence from training studies that document the effectiveness of complex training to elicit gains in explosive muscle function that are greater than those obtained from a more conventional approach. Over nine weeks of training, 20 recreationally trained athletes with a minimum of one year of resistance training experience were randomly assigned to either a complex training group ($n = 9$) or a conventional training group ($n = 11$). In an attempt to capitalise on muscle's post-activation potentiation response, the complex training group performed all sets of ½ back squats prior to sets of jumps squats, while the conventional training group performed jump squats prior to sets of ½ back squats. Lower body explosive muscle function and jump performance improved significantly in both groups. The complex training group's improvement in running vertical jump performance was significantly greater than in the conventional groups. Sprint performance was not significantly improved in either training group.

Keywords

Post-activation potentiation, power, vertical jump

Introduction

Attempting to exploit muscles post-activation potentiation (PAP) response for the enhancement of explosive muscle function is an intriguing option for coaches and athletes to consider when designing resistance training programs. In 1973, Verkhoshansky and Tatyan[1] attempted to elicit adaptations in "speed-strength" performance that were greater than those obtained through conventional training by prescribing heavy resistance exercises prior to the performance of explosive movements in elite track and field athletes. Interestingly, even though PAP has received considerable interest within the scientific literature, the investigation by Verkhoshansky and Tatyan[1] remains one of the few attempts to demonstrate the long-term effectiveness of a resistance training method underpinned by PAP for creating an adaptation in explosive muscle function. Despite minimal evidence supporting chronic adaptations in explosive leg muscle function that are greater than conventional training methods, coaches promote the use of methods underpinned by PAP such as complex training for increasing power output and athletic performance. For example, May et al.[2] stated that "Complex training is a form of training that can be used throughout the year with the intent to increase power and athletic performance" (p.35).

It should be noted that there is currently a lack of consistency in the literature regarding the definition of complex training, and for the purpose of this investigation, the definitions put forth by Duthie et al.[3] will be used. Duthie described complex training as various sets of groups/complexes of exercises performed in a manner in which several sets of a heavy resistance exercise are followed by sets of a lighter resistance exercise. For example, an athlete following a complex training

Reviewers: Greg Haff (Edith Cowan University, Australia)
Harvey Newton (Newton Sports, USA)

[1]School of Health Sciences and Psychology, Federation University Australia, Ballarat, Australia
[2]Australian Collaboration for Research into Injury in Sport and its Prevention (ACRISP), Federation University Australia, Ballarat, Australia
[3]School of Exercise and Nutrition Sciences, Deakin University, Melbourne, Australia

Corresponding author:
Scott W Talpey, School of Health Sciences and Psychology, Federation University Australia, Ballarat, Australia.
Email: s.talpey@federation.edu.au

protocol would perform all of the prescribed sets of heavy back squats prior to performing their sets of jump squats. Additionally, the term contrast loading will be used to describe the approach to training where heavy and light exercises are alternated in a set-by-set fashion.

There are few training studies that have attempted to demonstrate the superiority of complex or contrast methods. Dodd and Alavar[4] used a within subjects repeated measures design to compare four weeks of contrast training, plyometric, and heavy resistance training within competitive college-aged baseball players. This study concluded that using contrast loading produced a significantly greater improvement in sprint, vertical jump and change-of-direction speed performance than the other methods. However, the short one-week period between completing one training method and starting the next may not be sufficient for adaptations to occur, making comparisons between different training approaches difficult. Mihalik et al.[5] reported that four weeks of contrast loading resulted in a significant 4.8% increase in lower body peak power (PP) output from baseline measurements. However, the improvement observed from contrast training was not greater than when strength and power exercises were performed on alternating days. Similarly, Tsimachidis et al.[6] demonstrated within a group of elite junior basketball players that contrast training twice per week over a 10-week period, resulted in significantly greater improvements in strength and sprint performance compared to basketball training only. However, there was no comparison to another resistance training approach to improve strength and sprint performance. Therefore, due to the paucity from training studies to support the use of the complex method of training, the purpose of this investigation was to assess the effectiveness of complex training where sets of squats were performed prior to sets of jumps squats against the conventional method of training where jump squats are performed prior to sets of squats. It is expected that the results of this study can be used to inform coaches who prescribe resistance training for athletic populations.

Method

Research design

A pre-post design was used to determine if nine weeks of training with complex sets were more effective at enhancing countermovement jump (CMJ) variables, sprint and jump performance than the conventional method. Figure 1 is a flow chart representing the time frame of the study. Variables associated with lower body explosive muscle function such as peak mechanical power output, jump height, peak force and peak velocity were assessed with a CMJ. Sprint performance was assessed over a 20 m distance with splits recorded at 0–10 m and 15–20 m. Vertical jumps from both a standing and running approach were used to assess jumping performance, as they have previously been shown to represent independent skills that are prevalent in sport.[7] Two training interventions, with equal volumes of work were designed, with the only difference between the groups being that the complex group executed the ½ squats prior to their jump squats and the conventional group performed their jump squats prior to the ½ squats. Informed consent was obtained from all participants prior to the start of the study, and approval was granted by the University's Human Research Ethics Committee.

Subjects

Participants were 20 injury-free recreationally trained males; participant demographic information is provided in Table 1. All participants were actively involved

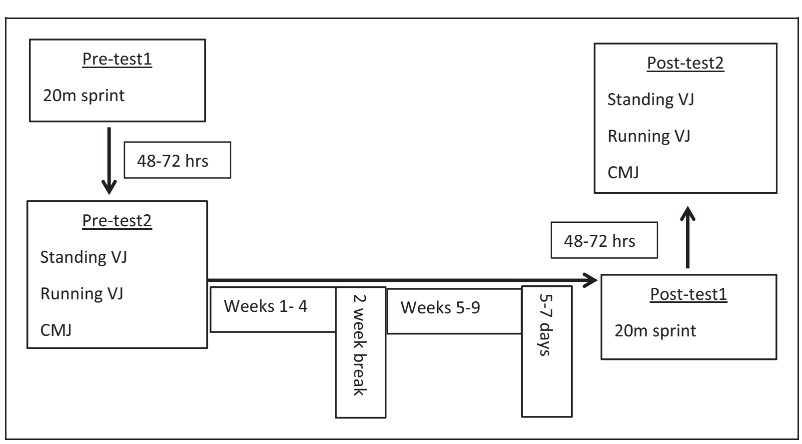

Figure 1. Flow chart depicting the time frame of the study.

Table 1. Description of subjects for each training group.

	Age (yrs)		Height (cm)		Body Mass (kg)	
	CONV	COMP	CONV	COMP	CONV	COMP
Mean	20.91	21.44	182.59	184.67	81.17	84.29
SD	3.59	3.54	8.17	4.46	13.25	14.24

CONV (n = 11) = conventional, COMP (n = 9) = complex.

in one of the following sports; Australian Rules football, rugby union, basketball and soccer and had a minimum of one year of resistance training experience. Participants were randomly assigned to either a conventional training group (n = 11) or a complex training group (n = 9).

Procedures

Both pre-and post-testing consisted of two sessions; Session 1 was to assess sprint, standing vertical jump (SVJ) performance and one repetition maximum (1RM) ½ back squat. Due to the possible potentiating influence of performing strength exercise prior to sprint and jump performance, the 1RM strength test was conducted as the final test of the session. The second testing session was to assess running vertical jump (RVJ) and lower body explosive muscle function with a CMJ using a variety of loads. Each testing session commenced with a warm-up which consisted of four minutes of moderate intensity running, followed by practice repetitions of the test which gradually increased in intensity.

CMJ assessment

A CMJ can be considered a vertical jump without the aid of an arm swing, a CMJ is typically used to assess the explosive muscle function of the leg muscles.[8] All CMJs were performed on a commercially available force plate (400 Series Force Plate-Fitness Technology, Adelaide, Australia) with a linear position transducer (LPT) (PT5A-Fitness Technology, Adelaide, Australia) tethered to the right side of an aluminium bar with a weight 0.4 kg placed across the participant's shoulders. Both force plate and LPT sampled at 500 Hz, which has been shown to be an acceptable sampling frequency.[9] Force plate and LPT were interfaced with computer software (Ballistic Measurement System, Fitness Technology, Adelaide, Australia). Data were filtered using a fourth order Butterworth method with a cut-off frequency of 9 Hz. Prior to each set of CMJs, participants were instructed to dip to a self-selected depth and "jump for maximal height". From each CMJ, PP output was calculated as the instantaneous product of the vertical ground reaction force and bar velocity. One set of four CMJs under three loading conditions, body weight (CMJBW), BW plus 10% of 1RM (CMJ10), and body weight plus 20% of 1RM (CMJ20) were used to determine the optimal loading for maximal power (Pmax). Three loading conditions were assessed because previous research has demonstrated that Pmax generally occurs with no external loading (body weight only), however some individuals may produce their Pmax against an additional external load;[10] 5 to 10 minutes of recovery occurred between sets of jumps.

CMJ variables were calculated during the concentric phase of the jump, which was determined from the lowest point on the displacement–time curve and concluded after the force reading dropped to zero. These variables demonstrated acceptable set-to-set reliability (ICC's ≥ 0.921; CV% $< 4.3\%$) which is in agreement with previously published literature.[11]

20-m sprint

The participant used a standing start with the toe of the front foot just behind the start line and was allowed to start when ready. The participant was required to commence the sprint from a stationary position so that the first forward movement would trigger the timing. Light gates (Swift Performance Equipment, Australia) were placed at the start and at 10, 15 and 20 m. The testing was conducted indoors on an all-purpose floor in a temperature-controlled building (approximately 20°C). Two 20 m sprints were performed with recoveries of 2–3 min between attempts. If the 20 m time from second trial was better than the first, a third trial was performed and times from all splits from the best trial was retained for analysis. The time to 10 m was considered as a measure of acceleration performance and the time between 15 and 20 m (flying 5 m) was considered as a measure later acceleration. The 20-m sprint was broken into these two splits because previous research by Young et al.[12] suggested that they represent independent aspects of sprint performance.

Vertical jump performance

Two separate tests of vertical jumping performance were conducted, a SVJ utilising an arm swing and a vertical jump following a run-up. For both tests, jump height was measured to the nearest cm with the Yard Stick vertical jumping device (Swift Performance Equipment, Australia). For the SVJ, participants were instructed to perform a counter movement to a self-selected depth and without pause, jump vertically. RVJs were executed off a single-leg take-off from the preferred foot following a self-selected run-up. Participants completed a minimum of three attempts for each jump; however, if performance continued to increase, additional attempts with full recovery were permitted.

1RM ½ back squat

1RM assessment occurred during the first testing session using a modified Smith machine. Participants performed a general warm-up consisting of moderate intensity running followed by three warm-up sets; 10 repetitions 50% of 1RM, 4 repetitions at 70% of 1RM and 2 repetitions at 80% 1RM. Three minutes after the final warm-up set, participants attempted their first 1RM. A 90° knee angle was measured with a goniometer, and an elastic cord was stretched between the tracking poles of the Smith machine as a reference point for the bottom position of the movement. If optimal depth was not obtained, feedback was provided to either increase or decrease the squat depth. An inability to obtain the desired squat depth on two consecutive attempts resulted in a failure. If participants were successful, the weight was increased to the nearest 2.5 kg until the participant could not lift the weight through the required range of motion. A five-minute rest was provided between each attempt, and each participant reached their 1RM within five attempts.

Training program

Participants attended two training sessions per week over a nine-week period with a two-week break between weeks four and five due to the academic calendar. The complex training group performed squats prior to jump squats, and the conventional training group executed jump squats prior to squats. Depending on the training session, three to four sets of four repetitions of jump squats with the optimal load for Pmax output development and three to six repetitions of squats were performed. Four minutes of recovery between sets of squats, and three minutes of rest between sets of jump squats were held constant throughout the study. Although, recent research has indicated that four minutes of rest between the conditioning action and the explosive movement may not be sufficient to capitalise on the PAP response.[13,14] Four minutes of rest was utilised in the current investigation because published research has indicated this to be effective in a similar athletic populations.[15] Loads ranging between three and eight-repetition maximum were prescribed for sets of back squats, as training with high-intensity loads has been recommended for the development of strength.[16] Throughout the study, all participants performed their jump squats with no external loading as body weight was the load shown to produce Pmax during the pre-testing sessions. All squats and jump squats were supervised by a member of the research team to ensure participants adhered to the prescribed training sessions. An overview of the nine-week training program is provided in Table 2.

Data analysis

Originally 24 participants commenced the study with 12 participants in each group; however, four participants were required to cease their involvement in the study for the following reasons; moved residence and was unable to complete training, anterior cruciate ligament (ACL) injury sustained during a physical education class, ankle sprain sustained during physical education, spontaneous partial lung collapse that occurred while at home. None of the injuries were related to participation in the study. All remaining participants completed a minimum of 88% of training (16 out of the 18 sessions). From the 20 participants who completed the investigation, means and standard deviations for 1RM ½ back squat, 0–20 m sprint time, 0–10 m sprint time, 15–20 m sprint time, standing VJ, running VJ and CMJ variables of JH, BV, PF and PP were collected pre- and post-training to compare group means.

Statistical analyses

Independent group t-tests were used to determine if significant differences were present between groups prior to training, and to compare per cent of training sessions completed. A 2×2 (group $\times$ test) repeated measures analysis of variance (ANOVA) was used to determine improvements within and between training groups following the training intervention. Calculations of effect sizes (ES) were performed to determine the magnitude of differences between means using a publicly available spreadsheet. Hopkins[17] descriptive terms for differences in means were used to classify ES: trivial (0.0–0.19), small (0.2–0.59), moderate (0.6–1.19), large (1.2–1.9) and very large (>2.0).

Correlations

Pre-test data were analysed using Pearson's correlations to determine relationships between CMJ variables, sprint performance, jump performance and strength. A P–value of <0.05 was considered to be statistically significant for all statistical tests. All analyses were conducted using the Statistical Package for the Social Sciences (SPSS for Windows, version 18.0; SPSS. Inc., Chicago, IL, USA).

Table 2. Overview of 9-week training program.

	Conventional (n = 11)						Complex (n = 9)					
Week #		Sets	Reps	Load (RM)	Avg. Load(kg)	Avg. Volume Load		Sets	Reps	Load (RM)	Avg. Load (kg)	Avg. Volume Load
1	Jump squats	3	4	BW			½ squats	3	6	8	100	1800
	½ squats	3	6	8	102.5	1845	jump squats	3	4	BW		
2	Jump squats	3	4	BW			½ squats	3	6	8	105	1890
	½ squats	3	6	8	105	1890	jump squats	3	4	BW		
3	Jump squats	3	4	BW			½ squats	3	5	5	122	1830
	½ squats	3	5	5	125	1875	jump squats	3	4	BW		
4	Jump squats	3	4	BW			½ squats	3	5	5	127.5	1912.5
	½ squats	3	5	5	127	1905	jump squats	3	4	BW		
5	Jump squats	3	4	BW			½ squats	3	5	5	130	1950
	½ squats	3	5	5	130	1950	jump squats	3	4	BW		
6	Jump squats	3	4	BW			½ squats	4	5	5	132.5	2650
	½ squats	4	5	5	133.5	2670	jump squats	4	4	BW		
7	Jump squats	4	4	BW			½ squats	4	5	5	132.5	2650
	½ squats	4	5	5	133.5	2670	jump squats	4	4	BW		
8	Jump squats	4	4	BW			½ squats	4	4	4	137.5	2200
	½ squats	4	4	4	136.5	2184	jump squats	4	4	BW		
9	Jump squats	4	4	BW			½ squats	4	3	3	145	1740
	½ squats	4	3	3	143	1716	jump squats	4	4	BW		

RM: repetition maximum; BW: body weight; Avg. load: mean resistance used in ½ squat exercise; Avg. volume load: sets × reps × avg.load.

Results

Independent t-tests from the pre-training data indicated that no significant differences ($P > 0.05$) between groups existed prior to training (Tables 2 and 3). No significant difference ($P = 0.783$) in adherence to training existed between the conventional training (98.4%) and the complex training (98.1%) groups. The only significant group × time interaction was observed in the running VJ, with the complex training group demonstrating significantly greater improvement than the conventional training group. Within-group results showed that the conventional training group significantly improved in 1RM strength ($P < 0.01$; ES = 1.12) and standing VJ ($P < 0.01$; ES = 0.48). Similarly, the Complex training group also displayed significant improvements in 1RM ($P < 0.01$; ES = 1.04), standing VJ ($P < 0.01$; 1.03) and running VJ ($P < 0.01$; ES = 0.41). Conventional training resulted in significant within-group improvements in all CMJ variables when there was no external load; however, JH and BV were the only variables that significantly improved within the complex training group. When CMJs were executed with an external load, the only significant within-group improvements following training were observed in the complex training group in the variables of JH, PV and PF.

Correlations

Significant correlations ($P < 0.05$) existed between CMJ variables and measures of sprint and jump performance from the post-test data (Table 4).

Discussion

Both training approaches were successful in inducing improvements in both strength and certain variables of explosive muscle function; however, the only significant group × time interaction ($P = 0.01$) was observed in the RVJ. Although not a statistically significant between-group interaction ($P = 0.08$), a significant ($P < 0.01$; ES = 0.41) within-group improvement for 10–20 m sprint time was observed in the complex training group, that was not observed in the conventional training group. The Pearson's correlations conducted from pre-testing results show that a statistically significant (r = −.617; $P = 0.004$) relationship exists between these two tests (RVJ and 15–20 m sprint time). This significant relationship indicates that successful

Table 3. Pre-Post testing mean ± SD for CMJ variables.

		Conventional (n = 11)					Complex (n = 9)				
		Pre Mean ± SD	Post Mean ± SD	P value	% Change	Effect Size	Pre Mean ± SD	Post Mean ± SD	P value	% Change	Effect size
Body weight CMJs	JH (cm)	41.9 ± 5.2	45.9 ± 4.3	< **0.01**	9.5	0.84 (M)	43.1 ± 3.9	46.6 ± 5.0	< **0.01**	8.2	0.78 (M)
	BV (m/s)	2.35 ± 0.32	2.46 ± 0.28	**0.027**	4.7	0.37 (S)	2.4 ± 0.06	2.51 ± 0 .15	**0.017**	4.6	0.96 (M)
	PF (N)	1796.63 ± 266.88	1898.11 ± 246.06	**0.032**	5.6	0.50 (S)	1951.30 ± 342.07	1996.76 ± 369.80	0.301	2.3	0.13 (T)
	PP (W)	4082.51 ± 866.00	4243.22 ± 719.22	**0.005**	3.9	0.20 (S)	4456.44 ± 908.66	4634.27 ± 1077.90	0.120	3.9	0.18 (T)
10% 1RM CMJs	JH (cm)	38.1 ± 5.4	39.0 ± 4.2	0.381	2.4	0.19 (T)	37.7 ± 4.5	41.1 ± 3.5	**0.001**	9.0	0.84 (M)
	BV (m/s)	2.15 ± 0.29	2.15 ± 0.21	0.931	0.0	0.00 (T)	2.14 ± 0.11	2.22 ± 0.13	**0.001**	3.7	0.66 (M)
	PF (N)	1940.34 ± 241.19	1991.24 ± 231.60	0.092	2.6	0.22 (S)	2087.66 ± 379.99	2101.04 ± 345.52	0.642	0.6	0.04 (T)
	PP (W)	3972.48 ± 731.41	3834.95 ± 661.88	0.265	−3.4	−0.20 (S)	4257.35 ± 1001.65	4236.12 ± 926.13	0.886	−0.5	−0.02 (T)
20% 1RM CMJs	JH (cm)	31.3 ± 4.4	32.7 ± 2.7	0.259	4.5	0.38 (S)	33.0 ± 3.9	35.0 ± 3.3	0.580	6.1	0.55 (S)
	BV (m/s)	1.84 ± 0.23	1.87 ± 0.17	0.681	1.6	0.15 (T)	1.90 ± 0.16	1.97 ± 0.10	0.147	3.7	0.52 (S)
	PF (N)	2069.55 ± 294.19	2147.07 ± 262.08	0.153	3.7	0.28 (S)	2216.31 ± 420.04	2301.70 ± 377.65	**0.042**	3.8	0.21 (S)
	PP (W)	3609.65 ± 634.50	3587.88 ± 524.51	0.823	−0.6	−0.04 (T)	3998.26 ± 879.29	4062.31 ± 786.32	0.272	1.6	0.08 (T)

P value: within-group changes; T: trivial; S: small; M: moderate; L: large. **Bold** = P < 0.05

Table 4. Pre-Post testing mean ± SD for performance measures.

		Conventional (n = 11)					Complex (n = 9)				
		Pre Mean ± SD	Post Mean ± SD	P value	% Change	Effect Size	Pre Mean ± SD	Post Mean ± SD	P Value	% Change	Effect Size
Performance Measures	0–20 m (s)	3.27 ± 0.22	3.26 ± 0.20	0.571	−0.3	−0.05 (T)	3.30 ± 0.11	3.27 ± 0.13	0.203	−0.9	−0.25 (S)
	0–10 m (s) (early acceleration)	1.96 ± 0.14	1.92 ± 0.15	0.167	−2.0	−0.28 (S)	1.97 ± 0.06	1.95 ± 0.10	0.569	1.0	−0.24 (S)
	15–20 m (s) (late acceleration)	0.64 ± 0.05	0.64 ± 0.05	0.706	0.0	0.00 (T)	0.65 ± 0.04	0.64 ± 0.03	**0.022**	−1.5	−0.28 (S)
	Standing VJ (cm)	59.5 ± 8.2	63.5 ± 8.4	< **0.01**	6.7	0.48 (S)	59.4 ± 6.4	65.1 ± 4.5	< **0.01**	9.6	1.03 (M)
	Running VJ (cm)	72.6 ± 12.0	71.8 ± 11.7	0.432	−1.1	−0.07 (T)	68.4 ± 9.0	72.2 ± 9.5*	< **0.01**	5.6	0.41 (S)
	1RM (kg)	138.6 ± 31.5	170.9 ± 26.1	< **0.01**	23.3	1.12 (M)	145.6 ± 32.6	181.1 ± 35.3	< **0.01**	24.4	1.04 (M)
	1RM/BW	1.72 ± 0.35	2.11 ± 0.34	< **0.01**	22.6	1.13 (M)	1.73 ± 0.23	2.11 ± 0.28	< **0.01**	22.6	1.13 (M)

P value: within-group change. T: trivial; S: small; M: moderate; L: large .* = significant group × test interaction P < 0.05. **Bold** = P < 0.05

Table 5. Correlations between post-test CMJ variables and measures of sprint and jump performance.

Pre-testing Correlations (n = 20)

	BW CMJ variables					10% 1RM CMJ variables					20% 1RM CMJ variables					Performance measures			
	JH	BV	PF	PP	PP/BW	JH	BV	PF	PP	PP/BW	JH	BV	PF	PP	PP/BW	Stand VJ	Run VJ	15–20 m	0–10 m
0–20 m	**−0.713**	**−0.579**	0.377	−0.002	**−0.426**	**−0.715**	**−0.710**	0.253	−0.134	**−0.524**	**−0.473**	**−0.529**	0.348	−0.031	−0.326	**−0.702**	**−0.772**	**0.836**	**0.968**
0–10 m	**−0.671**	**−0.632**	0.360	−0.033	**−0.524**	**−0.712**	**−0.776**	0.241	−0.162	**−0.611**	**−0.515**	**−0.649**	0.375	−0.077	−0.430	**−0.706**	**−0.797**	**0.693**	
15–20 m	**−0.661**	−0.370	0.261	−0.015	−0.161	**−0.531**	−0.410	0.115	−0.121	−0.266	−0.254	−0.160	0.124	−0.016	−0.088	**−0.589**	**−0.617**		
Running VJ	**0.656**	**0.575**	0.166	0.193	**0.534**	**0.636**	**0.560**	−0.012	0.305	0.314	0.311	0.400	0.167	0.167	0.314	**0.757**			
Standing VJ	**0.876**	**0.606**	−0.255	**0.494**	**0.724**	**0.842**	**0.678**	0.337	**0.594**	**0.757**	**0.625**	**0.567**	0.235	**0.545**	**0.602**				

Bold = significant correlation P < 0.05

execution of both these performance measures is underpinned by similar physical qualities. This finding highlights the possibility that complex training may possibly have elicited an adaptation in a physical quality which underlies successful performance of both 15–20 m sprint and RVJ performance. There is limited research that has utilised the RVJ as a measure of performance. However, Young et al.[8] reported that RVJ performance significantly correlated with reactive strength ($r = 0.72$; $P < 0.05$). Furthermore, investigations conducted by Comyns et al.,[18] Gullich and Schmidtbleicher,[19] and French et al.[20] have all reported that reactive strength has been acutely enhanced when preceded by three sets of a heavy resistance exercise, which is a similar to the training performed by the complex training group. The authors of these previous investigations have suggested that the heightened nervous system associated with PAP-inducing protocols may acutely enhance the function of the stretch shortening cycle (SSC) resulting in greater power output with short contact times.[18–20] Not directly assessing reactive strength is a limitation of the current investigation; however, these results may provide incentive for future research to investigate the efficacy of complex training protocols on reactive strength.

CMJ variables

Improvements in CMJ variables following nine weeks of training were evident in both training groups (Table 5); however, CMJ jump height was the variable that participants showed the greatest improvement in following training. Findings from the present investigation found that there is a non-significant correlation ($r = 0.314$; $P = 0.177$) between PF and JH in a CMJ. These results are similar to those reported by Young et al.,[8] who also reported a non-significant correlation ($r = -0.163$) between PF and JH in a CMJ test using the same procedures. Additionally, the variable of PP which is a common focus of the CMJ did not possess the highest correlation with sprint performance, highlighting that other variables obtained from the test may better relate to sprint performance. Similar to the results of the current investigation, 4.8% and 7.5% improvement in PP were reported by Mihalik et al.[5] following contrast training and compound training, respectively. Utilising similar testing protocols, however, with different training methods, Cormie et al.[21] reported larger improvements of 28% in PP, 34% in PF, 61% in PV and 50% in jump height.

Previous research has indicated that greater explosive muscle function in loaded CMJs is related to the strength capacity of the individual.[10] In the current investigation, statistically significant within-group improvements in strength were observed in both groups following the nine weeks of training. However, the improvements in strength may not have directly led to the improved ability to maintain velocity and ultimately JH with the presence of an additional external load. Surface electromyography was not utilised in this investigation, which prevents any definitive conclusion as to why, there would be a trend for the complex training group to enhance certain aspects of explosive muscle function. The inability of complex training to elicit an improvement in PP that was greater than conventional training may be related to the fatigue-potentiation relationship discussed by Sale.[22] The participants in the current study had a mean relative 1RM ½ back squat of 1.72 kg/bw, which can be considered weak when attempting capitalise on the PAP response as strength levels have been previously reported to influence the ability to exploit PAP.[14,23] Owing to the relatively low levels of strength of the participants, it is possible that the loading for the ½ squats used in this investigation may have elicited too much fatigue, or, the recovery period between sets may have been too short resulting in an inability to exploit PAP during training.

1RM ½ squat

Following nine weeks of training 1RM ½ squat improved significantly in both the conventional (23.3%) and the complex (24.4%) training groups. These improvements in strength are in line with previous results from a combined strength and power training program. For example, Hartmann et al.[24] reported a 30.4% improvement in leg strength following 10-weeks of squat training using similar training intensities and a subject cohort similar to the present investigation. Similarly, Harris et al.[25] reported an 11% improvement in parallel squat 1RM and a 37% improvement in ¼ squat 1RM following nine weeks of training designed in highly competitive American Football players.

Sprint performance

Although the 20 m sprint is a popular tool to assess sprint performance, its short distance prohibits a true assessment of maximal speed. The 20 m sprint can be classified into two distinct phases; early acceleration over the first 10 m, and late acceleration over the final 5 m. It has been shown that depending upon the phase of the sprint, different physical qualities underlie its performance.[10] From the results of the Pearson's correlations conducted from post test data (Table 4), the measures of sprint performance possessed a commonality of only 46%, highlighting that they are influenced by separate physical qualities. Following the nine-week training program, 20-m sprint time did not significantly improve in either the conventional ($P = 0.571$) or the complex ($P = 0.203$) training groups.

The conventional training group produced a 2.0% improvement in 0–10 m sprint and complex training group demonstrated a 1.0% improvement. Although there were no significant group × time interactions for any sprint qualities following training, a significant within-group improvement in 15–20 m sprint time from the complex training group was observed. The small magnitude of improvements in sprint performance was expected as all resistance training exercises were performed bilaterally in a vertical plane, where sprinting is performed unilaterally in a horizontal plane. These findings highlight the need for postural specificity between training exercises and the sport specific movement.

Vertical jump

Statistically significant improvements were observed in SVJ in both the conventional (6.7%) and complex group (9.6%). This finding is not entirely surprising, as the training undertaken by both groups consisted of exercises with substantial biomechanical and postural similarity to the performance of a SVJ. This similarity between training exercises and the measure of performance is highlighted by the significant correlation ($P < 0.01$) between CMJ height and SVJ height ($r = 0.876$). Similar improvements have been previously reported by Mihalik et al.[5] who reported a 5.6% improvement in the vertical jump height of experienced jumpers following a contrast training program consisting of two sessions of three contrasting pairs twice per week over a four-week period. Based upon the results of the current investigation, it can be concluded that when using back squats and jump squats as exercises, both training methods effectively transfer to the sport skill of a VJ with an arm swing.

A limitation of the study was that participants were involved in a range of sports with varying aerobic (soccer and Australian football) and power (rugby union and basketball) demands. Participants were not equally divided between the two groups based upon the physical demands of their sport which may have influenced their response to the training. Moreover, while all participants had previous resistance training experience, not all had previous experience specifically with complex training. Previous research[26] has indicated that athletes may be able to learn how to apply the potentiation effects of training with complexes through repeated exposure to this method of training. Additionally, participants in the current investigation did not possess high levels of strength and would likely respond favourably to any general strength/power training program, whereas stronger individuals would require a more directed power development method such as complex training.[27] Therefore, the absence of a difference in strength/power improvements between groups is not surprising.

Conclusion

Within the limitations of the study, the results of the investigation produced the following conclusions: (1) Complex training consisting of ½ back squats and body weight CMJs was as equally effective as conventional training with the same exercise, when attempting to enhance lower body explosive force production, and SVJ; (2) Complex training with ½ back squats and body weight CMJs was more effective than conventional training for the improvement of RVJ; (3) Significant improvements were observed in JH and BV in the complex training group but not the conventional training group when CMJs were executed with 10% of the participants 1RM ½ back squat.

When adhering to textbook recommendations for the design of a resistance training session, typically a coach would not prescribe strength-based exercises, such as back squats prior to power-based exercises such as a jump squats, due to the rationale that the back squats would generate fatigue that would lead to a suboptimal power training effect.[16] The results from this study indicate that if programming to enhance the strength and power qualities of the lower body for improved jump performance, then both conventional and the complex methods may potentially produce significant gains in CMJH and SVJ, when four minutes of rest are provided between sets of squats and three minutes of rest are provided between sets of jump squats. A strength and conditioning coach conducting a session with a team of athletes, with limited space or equipment could have one group of team members executing squats, while the other group performs jump squats, then following the completion of the desired number of sets the two groups could swap. This approach could lead to more time-efficient and better organised training sessions when limited space and equipment are available. However, it should be noted that these results are specific to the protocol utilised in recreationally trained athletes and the results may be different if implemented with different rest periods and with highly trained athletes.

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author(s) received no financial support for the research, authorship, and/or publication of this article.

References

1. Verkhoshansky Y and Tatyan V. Speed-strength preparation of future champions. *Soviet Sports Rev* 1973; 18: 166–170.
2. May CA, Cipriani D and Lorenz K.A. Power development through complex training for the division I collegiate athlete. *Strength Cond J* 2010; 32: 30–43.
3. Duthie GM, Young WB and Aitken DA. The acute effects of heavy loads on jump squat performance: an evaluation of the complex and contrast methods of power development. *J Strength Cond Res* 2002; 16: 530–538.
4. Dodd DJ and Alvar BA. Analysis of acute explosive training modalities to improve lower-body power in baseball players. *J Strength Cond Res* 2007; 21: 1177–1182.
5. Mihalik JP, Libby JS, Battaglini CL, et al. Comparing short term complex and compound training programs on vertical jump height and power output. *J Strength Cond Res* 2008; 22: 47–53.
6. Tsimachidis C, Patikas D, Galazoulas C, et al. The postactivation potentiation effect on sprint performance after combined resistance/sprint training in junior basketball players. *J Sport Sci* 2013; 31: 1117–1124.
7. Young W, Wilson G and Byrne C. The relationship between strength qualities and performance in standing and run-up vertical jumps. *J Sports Med Phys Fitness* 1999; 39: 285–293.
8. Young W, Cormack S and Crichton M. Which jump variables should be used to assess explosive leg muscle function? *Int J Sports Physiol Perform* 2011; 6: 51–57.
9. Hori N, Newton RU, Kawamori N, et al. Reliability of performance measurements derived from ground reaction force data during countermovement jump and the influence of sampling frequency. *J Strength Cond Res* 2009; 23: 874–882.
10. Cormie P, McCaulley GO, Triplett NT, et al. Optimal loading for maximal power output during lower-body resistance exercises. *Med Sci Sports Exerc* 2007; 39: 340–349.
11. Sheppard JM, Cormack S, Taylor KL, et al. Assessing the force-velocity characteristics of the leg extensors in well-trained athletes: the incremental load power profile. *J Strength Cond Res* 2008; 22: 1320–1326.
12. Young W, McLean B and Ardagna J. Relationship between strength qualities and sprinting performance. *J Sports Med Phys Fitness* 1995; 35: 13–19.
13. Jo E, Judelson DA, Brown LE, et al. Influence of recovery duration after a potentiating stimulus on muscular power in recreationally trained individuals. *J Strength Cond Res* 2010; 24: 343–347.
14. Setiz LB, Villarreal EJ and Haff GG. The temporal profile of postactivation potentiation is related to strength level. *J Strength Cond Res* 2014; 28: 706–715.
15. Young WB, Jenner A and Griffiths K. Acute enhancement of power performance from heavy load squats. *J Strength Cond Res* 1998; 12: 82–84.
16. Baechle TR, Earle RW and Warthen D. Resistance training. In: Baechle TR and Earle RW (eds) *Essentials of strength training and conditioning*. Champaign, IL: Human Kinetics, 2008, pp.381–412.

17. Hopkins WG. Reliability from consecutive pairs of trials (excel spreadsheet), www.sportsci.org/resource/stats/ (accessed 17 September 2014).
18. Comyns T, Harrison AJ, Hennessy L, et al. Identifying the optimal resistive load for complex training in male rugby players. *Sports Biomech* 2007; 6: 59–70.
19. Gullich A and Schmidtbleicher D. MVC-induced short-term potentiation of explosive force. *New Stud Athlet* 1996; 11: 67–81.
20. French DN, Kraemer WJ and Cooke CB. Changes in dynamic exercise performance following a sequence of preconditioning isometric muscle actions. *J Strength Cond Res* 2003; 17: 678–685.
21. Cormie P, McGuigan M and Newton R. Adaptations in athletic performance after ballistic power versus strength training. *Med Sci Sports Exerc* 2010; 42: 1582–1598.
22. Sale DG. Postactivation potentiation: role in human performance. *Exerc Sport Sci Rev* 2002; 30: 138–143.
23. Chiu LZF, Fry AC, Weiss LW, et al. Postactivation potentiation response in athletic and recreationally trained individuals. *J Strength Cond Res* 2003; 17: 671–677.
24. Hartmann H, Wirth K, Klusemann M, et al. Influence of squatting depth on jumping performance. *J Strength Cond Res* 2012; 26: 3243–3261.
25. Harris GR, Stone MH, O'Bryant HS, et al. Short-term performance effects of high power, high force, or combined weight-training methods. *J Strength Cond Res* 2000; 14: 14–20.
26. Comyns TM, Harrison AJ and Hennessy LK. The effect of squatting on sprinting performance and repeated exposure to complex training in male rugby player. *J Strength Cond Res* 2010; 24: 610–618.
27. Cormie P, McGuigan MR and Newton RU. Influence of strength on magnitude and mechanisms of adaption to power training. *Med Sci Sport Exerc* 2010; 42: 1566–1581.