Short Communication

A comparison of the effects of six weeks of traditional resistance training, plyometric training, and complex training on measures of power

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Objectives: The purpose of this work was to compare the effects of resistance, plyometric, and their combination (complex training) on countermovement vertical jumps (CMVJ) and broad jumps (BDJ).

Design: Longitudinal study design with repeated measures and group comparisons.

Methods: Thirty four recreationally trained college aged males trained using one of three methods; resistance (RT; n = 13), plyometric (PT; n = 11), or complex (CT; n = 10) training twice weekly for six weeks and were assessed pre (W1), mid (W5), and post (W9) training. Measures included: CMVJ height (cm), CMVJ peak ground reaction force (pGRF; N), peak power (Watts), peak power per kilogram (Watts/kg), peak power per kilogram of fat free mass (Watts/kg FFM), BDJ distance (cm), and BDJ peak ground reaction force (pGRF; N).

Results: Body mass significantly increased from W1 (83.85 ± 20.54 kg) – W5 (85.26 ± 20.29 kg) for RT and from W1 (81.25 ± 10.43 kg) – W9 (82.49 ± 10.19 kg) for PT. Body fat percentage significantly increased from W5 (18.0 ± 8.0 %) – W9 (20.0 ± 7.0 %) and W1 (18.0 ± 8.0 %) – W9 (20.0 ± 7.0 %) for RT and from W5 (18.0 ± 5.0 %) – W9 (22.0 ± 4.0 %) for PT. Results indicated no statistical differences between groups for any measure at any testing time point. Statistical increases in CMVJ pGRF (PT: W1 (2059.97 ± 314.83 N) – W5 (2145.02 ± 317.00 N); CT: W1 (2255.48 ± 375.79 N) – W5 (2323.19 ± 340.61 N)), CMVJ peak power/kg FFM (PT: W5 (78.32 ± 4.86 Watts/kg FFM) – W9 (82.09 ± 5.59 Watts/kg FFM)), and BDJ distance (PT: W1 (202.0 ± 27.0 cm) – W9 (214.0 ± 19.0cm)) were identified.

Conclusions: The significant increase in pGRF and peak power/kg FFM in PT and CT suggests increased force/power production in the muscle mass of their lower limbs. The significant increase in BDJ distance for the PT is likely a transfer of training effect.

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Key words: combination training ■ post activation potentiation ■ jumping ■ force production ■ strength

Introduction

Optimal training techniques designed to maximize strength/power characteristics are of considerable interest to strength and conditioning specialists, strength coaches, sport coaches, sport scientists, and researchers.[1] Athletes/clients should incorporate both resistance and plyometric training, if possible, into their training programs (during the appropriate periods of training), theoretically promoting gains in muscular strength/power.[2] Complex training is defined as alternating between traditional resistance training (heavy loads) and plyometric exercises (lighter loads) within a single session.[2,3] The plyometric exercises are performed within the same set as the traditional resistance exercises and are biomechanically similar in movement patterns and the two biomechanically similar exercises are referred to as a complex pair[2] and it may be an optimal strategy at enhancing strength\power by enhancing neuromuscular activity,[1,3,4] resulting from post activation potentiation (PAP). PAP could promote gains in strength/power by increasing: phosphorylation of myosin light chains; contractile element calcium sensitivity; motor unit synchronization; localized muscle temperature; or high threshold motor unit recruitment.[5-7]

Complex training program design literature account for exercise selection, loading, and rest within each training session.[8] Literature concerning complex training often reports enhanced measures of athletic ability when compared to other training protocols.[9,10,11] Adams et al. (1992) concluded a protocol of combined squat and plyometric training resulted in better vertical jump characteristics than a squat only protocol.[4] Duthie et al. (2002) concluded complex and contrast training improved outcome measures.[10] Mihalik et al. (2008) established short term complex and compound training both substantially improved jump heights.[12] Fatouros et al. (2000) investigated the differences between plyometric training, resistance training, and their combination, concluding the combined group jumped higher while producing greater jumping power and flight time.[11] When complex/combination research is considered, a number of studies have recommended the

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approach is best for athletes [3,12,13] (due to their trained state) and others have examined this training on specific muscle groups.[4,10,12] To date, few studies [11,14] examining the effectiveness of entire limb segment complex training on strength measures while no studies have examined changes in rest periods between complex pairs (or biomechanically similar exercises), coinciding with periodized increases in training volume during the protocols, on jumps. Therefore, the purpose of this study was to determine if complex training was more effective than resistance training or plyometric training at improving measures of lower extremity power of college aged males.

Methods

Participants

Thirty four recreationally trained college aged males trained using (a random assignment of); resistance (RT; n = 13; 180.14 ± 3.52 cm; 83.85 ± 20.54 kg; 21.3 ± 3.5 yrs), plyometric (PT; n = 11; 181.41 ± 7.97 cm; 81.25 ± 10.43 kg; 20.3 ± 3.1 yrs), or complex (CT; n = 10; 185.17 ± 5.56 cm; 87.54 ± 9.04 kg; 22.5 ± 3.2 yrs). All participants regularly performed resistance training at least six months leading up to participation.[2,3,8] and engaged in no additional lower limb resistance training for the duration of this work. Participants voluntarily signed University approved consent documents and this work was approved by the University Institutional Review Board.

Training Protocols

The following was the normalized warm up protocol (for all sessions) followed by participants: 1.) RT, PT, and CT pedaled at 50 – 60 revolutions/minute (0.5 kp) on a cycle ergometer (Monark 828 E Pendulum Ergometer; Monark Sports & Medical, Varberg, Sweden) for five minutes; 2.) RT and CT group performed 20 kg back squat for six repetitions and; 3.) RT and CT performed 50% of 1RM back squat, for 6 repetitions.

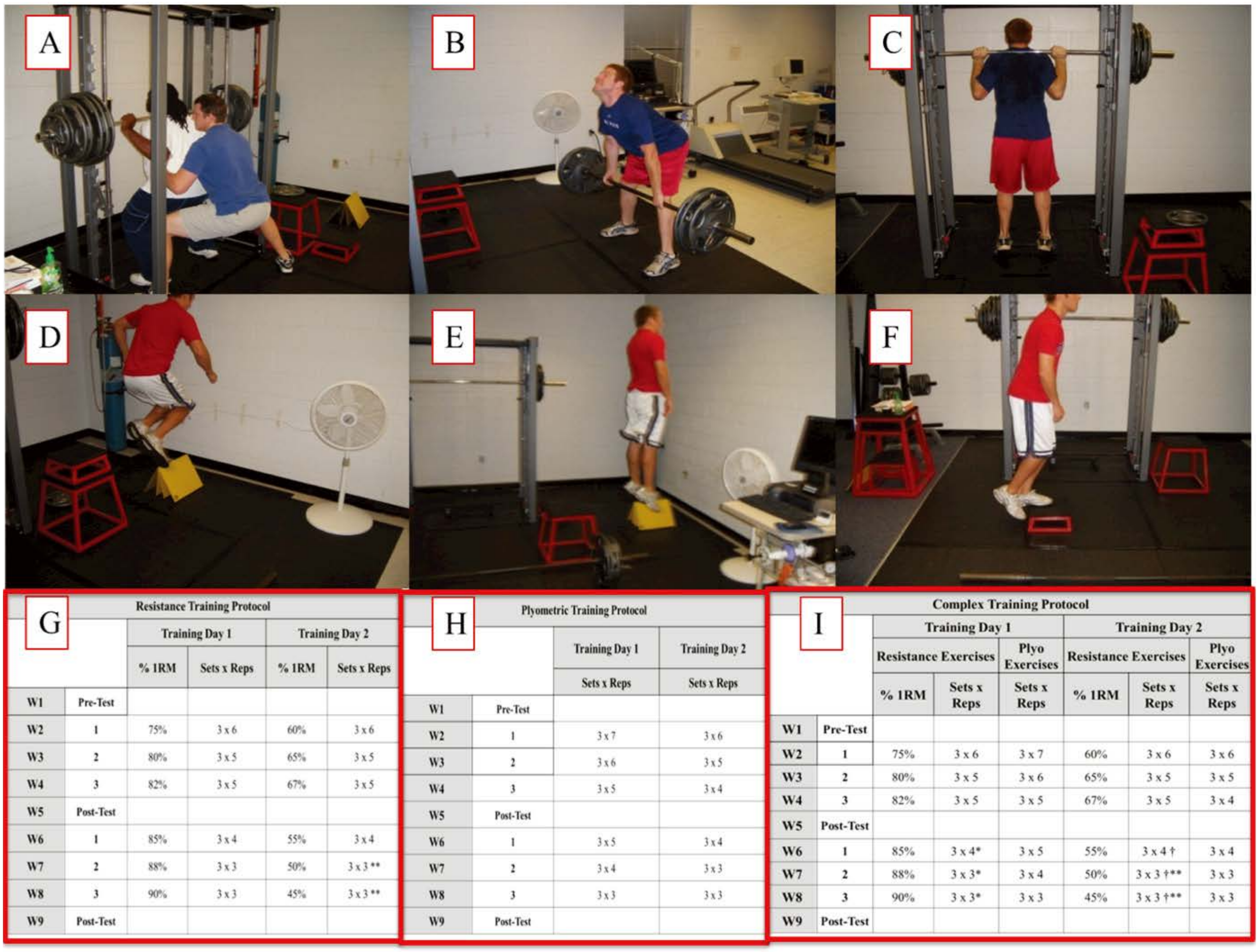
Participants trained in the lab two days a week for six total weeks with a minimum of 48 hours between sessions. Rest intervals between sets were three minutes for all groups (replenishment of anaerobic energy stores).[2] Rest between complex pairs (intra set) during the first mesocycle (W2 – W4) was at most, 30 seconds and the intra set rest during the second mesocycle (W6 – W8) was three minutes (maximize potentiation while minimizing residual fatigue).[3, 15]

The actual training protocols for the three training groups were not equal in volume and intensity, with the RT and PT protocols kept as similar as possible (with respect to volume) and the CT (combination of the RT and PT) was unavoidably greater in volume. This variation in total volume (CT > RT; CT > PT): 1.) closely mimics a practical CT protocol; 2.) the RT and PT groups can be treated as active control groups; 3.) and this increase in training volume may result in a greater increase in performance measures; and this was done in previous research.[11] The RT group performed the following exercises: high bar back squat (Figure 1A; The Jones Max Rack 3D, Body Craft; Sunbury, Ohio), stiff leg dead lift (Figure 1B; SLDL; Power Lifting Bar, Power Systems; Knoxville, Tennessee), and standing calf raise (Figure 1C; SCR; Calf Raise, Power Systems; Knoxville, Tennessee). The participants in both the RT and CT groups performed these same exercises over the two mesocycles with progressive variations in the relative intensity (% 1RM) of loads, following a periodized model.[16,17] There were also fluctuations in the loads between training days within a week and concomitant variations in repetitions performed per set within weeks, designed to allow for appropriate recovery and adaptation (Figure 1G).

The PT group performed the following exercises for their training sessions: lateral jumps (Figure 1D; LJ); depth jumps (Figure 1E; DJ); and box jumps (Figure 1F; BXJ). LJ's (designed to develop lateral movement qualities [18]) required lateral hopping across a distance of 35 cm, while minimizing ground contact time. DJ's utilized the body mass of the participant and gravity for maximal force exertion into the ground.[18] Participants began with a double leg stance from a 30.5 cm height, stepped off a box (Power Systems, Knoxville, Tennessee), with both feet contacting the ground simultaneously. The landing was an "active-reactive" movement, as the participant attempted to immediately exploded vertically from the ground as high as possible.[18] DJ repetitions were performed in five second intervals. BXJ's required a standing start position on the top of a box (30.5 cm), drop off of the back of the box, rebound as quickly as possible (minimizing ground contact time), and land on the top of the box. These exercises remained the same over the first mesocycle of training and advanced during the second mesocycle (for the PT and CT) with the intent of creating an environment more conducive to the stimulation of maximal adaptations. LJ progressed to LJ's over a 30.5 cm barrier (LJB) (Gorilla Speed Hurdles, Ann Arbor, Michigan), DJ starting height increased from 30.5 cm to 45.7 cm, and BXJ progressed from a double leg exercise on a 30.5 cm box to a single leg exercise on a 15.2 cm box (Figure 1H). The CT group performed a combination of the exercises in the RT group and the PT group in the following complex pairs and order: back squat and LJ performed in the same set; SLDL and DJ performed in the same set; and SCR and BXJ performed in the same set (Figure 1I). All participants were instructed to move with maximum movement intent during all exercises.[2]

Testing Protocol

All participants tested at W1, W5, and W9, were asked to engage in no strenuous physical activity in the 24 hours prior to testing, and were asked to consume no caffeine in the four hours prior to testing. Testing measures included are as follows (with baseline group data presented in Table 1): CMVJ height (cm); CMVJ peak ground reaction force (pGRF; N; ICCα = .972); CMVJ peak power (Watts); CMVJ peak power per kilogram (Watts/kg); CMVJ peak power per kilogram of fat free mass (Watts/kg FFM); BDJ distance (cm); and BDJ peak ground reaction force (pGRF; N; ICCα = .983). Anthropometry (all collected by the same researcher) included height (cm), body mass (kg) (SECA digital scale, Lafayette Instrument Co.; Lafayette, Indiana), and body fat percentage



Resistance Training Protocol					
		Training Day 1		Training Day 2	
		% 1RM	Sets x Reps	% 1RM	Sets x Reps
W1	Pre-Test				
W2	1	75%	3 x 6	60%	3 x 6
W3	2	80%	3 x 5	65%	3 x 5
W4	3	82%	3 x 5	67%	3 x 5
W5	Post-Test				
W6	1	85%	3 x 4	55%	3 x 4
W7	2	88%	3 x 3	50%	3 x 3 **
W8	3	90%	3 x 3	45%	3 x 3 **
W9	Post-Test				

Plyometric Training Protocol			
		Training Day 1	Training Day 2
		Sets x Reps	Sets x Reps
W1	Pre-Test		
W2	1	3 x 7	3 x 6
W3	2	3 x 6	3 x 5
W4	3	3 x 5	3 x 4
W5	Post-Test		
W6	1	3 x 5	3 x 4
W7	2	3 x 4	3 x 3
W8	3	3 x 3	3 x 3
W9	Post-Test		

Complex Training Protocol							
		Training Day 1			Training Day 2		
		Resistance Exercises		Plyo Exercises	Resistance Exercises		Plyo Exercises
		% 1RM	Sets x Reps	Sets x Reps	% 1RM	Sets x Reps	Sets x Reps
W1	Pre-Test						
W2	1	75%	3 x 6	3 x 7	60%	3 x 6	3 x 6
W3	2	80%	3 x 5	3 x 6	65%	3 x 5	3 x 5
W4	3	82%	3 x 5	3 x 5	67%	3 x 5	3 x 4
W5	Post-Test						
W6	1	85%	3 x 4*	3 x 5	55%	3 x 4 †	3 x 4
W7	2	88%	3 x 3*	3 x 4	50%	3 x 3 †**	3 x 3
W8	3	90%	3 x 3*	3 x 3	45%	3 x 3 †**	3 x 3
W9	Post-Test						

Figure 1 **Figure 1A**. back squat exercise; **Figure 1B**. SLDL exercise; **Figure 1C**. SCR exercise; **Figure 1D**. LJ exercise; **Figure 1E**. DJ exercise; **Figure 1F**. BXJ exercise; **Figure 1G**. RT protocol ** = speed squats; **Figure 1H**. PT protocol; **Figure 1I**. CT protocol, † = 3 min rest between complex pairs, ** = speed squats

Table 1 Participant baseline measures with data presented as group means ± standard deviations.

Participant Baseline Measures			
Measure	Group		
	RT	PT	CT
Standing Ht (cm)	180.14 ± 4.75	181.41 ± 7.97	185.17 ± 5.56
Body Mass (kg)	83.85 ± 20.54	81.25 ± 10.43	87.54 ± 9.04
Body Fat %	18.0 ± 8.0	19.0 ± 5.0	20.0 ± 6.0
CMVJ Ht (cm)	24.71 ± 3.07	23.08 ± 2.91	23.07 ± 3.50
CMVJ pGRF (N)	1998.55 ± 413.68	2059.97 ± 314.83	2255.48 ± 375.79
CMVJ peak power (Watts)	5552.96 ± 1196.63	5184.54 ± 660.07	5467.45 ± 615.80
CMVJ peak power (Watts/kg)	66.63 ± 5.61	64.10 ± 6.13	62.69 ± 6.61
CMVJ peak power (Watts/kg FFM)	81.75 ± 8.01	79.44 ± 4.30	78.37 ± 5.08
BDJ Distance (cm)	215.0 ± 20.0	202.0 ± 24.0	205.0 ± 27.0
BDJ pGRF (N)	1740.43 ± 470.02	1757.69 ± 327.23	1956.37 ± 460.32

(%) (Lange skinfold caliper, Beta Technology Incorporated; Cambridge, Maryland). Body fat percentage was estimated from the Jackson & Pollock three site test (ICC = .981).

All testing occurred on the same day, with anthropometrics first, CMVJ, then BDJ. Participants performed two warm up jumps (50% and 75%) before both CMVJ and the BDJ. CMVJ was performed with participants self-selecting depth of the countermovement, then attempting maximal efforts while reaching for maximum height. BDJ was also completed with participants self-selecting their countermovement depth, then maximally attempting to jump forward, maximizing their horizontal displacement. CMVJ pGRF was the measured vertical force during jumps and the BDJ pGRF was derived as the resultant force vector calculated from the horizontal and vertical force vectors measured during the jumps. All jumps were performed off of an 18.25 x 20 x 3.25 inch AMTI OR6-7 Triaxial Force Plate (Advanced Mechanical Technology, Inc.; Watertown, MA). Measures of power were derived using the Sayers Equation for peak power (incorporating CMVJ): P_{max} = ((60.7 * CMVJ peak (cm)) + (45.3 * body mass (kg)) – 2055).[19] Familiarization to all training protocols took place immediately following this testing session.

Statistical Analyses

A 3 (group) x 3 (time) repeated measures analysis of variance was used to analyze the data collected. Group x time point interactions and main effects for group and time point were assessed utilizing a Bonferroni correction for multiple comparisons. A Bonferroni post hoc test was used to highlight the nature of any within or between group differences. The a priori significance level was set at $\rho \leq 0.05$.

Results

Participant Characteristics

Results are presented as group means ± standard deviations and statistically significant results are presented with measures of statistical significance or rarity (ρ), statistical power ($1 - \beta$), and statistical effect size (partial η^2). The following anthropometric values are an evaluation of pairwise (group x time point) comparisons as the main effects/interaction effects initially flagged for statistical significance. Body mass significantly increased from W1 (83.85 ± 20.54 kg) to W5 (85.26 ± 20.29 kg) ($\rho < 0.001$; $1 - \beta = 0.974$; partial η^2 = 0.459) for RT and from W1 (81.25 ± 10.43 kg) to W9 (82.49 ± 10.19 kg) ($\rho = 0.018$; $1 - \beta = 0.641$; partial $\eta^2 = 0.283$) for PT. Body fat percentage significantly increased from W5 (18.0 ± 8.0 %) to W9 (20.0 ± 7.0 %) ($\rho = 0.018$; $1 - \beta = 0.833$; partial $\eta^2 = 0.331$) for RT and from W1 (19.0 ± 5.0 %) to W9 (22.0 ± 4.0 %) ($\rho = 0.007$; $1 - \beta = 0.999$; partial $\eta^2 = 0.639$) as well as W5 (18.0 ± 5.0 %) to W9 (22.0 ± 4.0 %) ($\rho < 0.001$; $1 - \beta$ = 0.999; partial $\eta^2 = 0.639$) for PT.

CMVJ Measures

Results indicated no statistically significant differences between groups (RT vs. PT vs. CT), for any measure at any testing time point. CMVJ height, CMVJ peak power, and CMVJ peak power/kg, for all groups, showed no statistically significant main effect for time ($\rho > 0.05$). However, the following CMVJ values are an evaluation of pairwise (group x time point) comparisons as the main effects/interaction effects initially flagged for statistical significance. There were statistically significant increases in CMVJ pGRF (Figure 2A; PT from W1 to W5: $\rho = 0.050$; $1 - \beta = 0.705$; partial η^2 = 0.312; CT from W1 to W5: $\rho = 0.035$; $1 - \beta = 0.792$; partial η^2 = 0.384) and CMVJ peak power/kg FFM (Figure 2B; PT from W5 to W9: $\rho = 0.020$; $1 - \beta = 0.816$; partial $\eta^2 = 0.369$).

BDJ Measures

For all 3 groups, BDJ pGRF showed no statistically significant main effect for time ($\rho > 0.05$). However, a pairwise (group x time point) comparison of the BDJ distance was evaluated as the main effects/interaction effects initially flagged for statistical significance and an increase in PT BDJ distance (Figure 2C; W1 to W9: $\rho = 0.022$; $1 - \beta = 0.953$; partial $\eta^2 = 0.478$) was identified.

Discussion

There were statistical variations in the body mass and body fat percentage for the RT and PT groups, however, these changes are likely due to voluntary changes in diet (which was not controlled), and not attributed to any peripheral muscular adaptation.

Statistically, no differences between groups for any measure at any testing time point, for the CMVJ were elucidated. CMVJ height, CMVJ peak power, and CMVJ peak power/kg did not change within groups. There were statistically significant increases in CMVJ pGRF from W1 to W5 for PT and CT and statistical increases in CMVJ peak power/kg FFM from W5 to W9 for PT (all with moderate to strong statistical powers and effects sizes, further strengthening the stance that the training did in fact have a consequence). The increase in pGRF (PT and CT) likely resulted from a transfer of training effect as these participants repeatedly jumped vertically during training. The statistical increase in peak power/kg FFM from W5 to W9 for PT suggests increases power production of the existing muscle mass in the lower limbs, again, a result of specificity of training as the PT only jumped during training.

There was also no statistical difference between groups for any measure at any testing time point, for the BDJ. BDJ pGRF did not statistically change within groups but a statistical increase in BDJ distance from W1 to W9 for the PT (strong statistical power and effects size), is also attributed to carryover from the PT training exercises' similarity to a BDJ. The jumping exercises (PT and CT groups) resulted in better jump measures theoretically due to the improved motor unit firing frequency and patterns of firing of the active musculature. This may have resulted in better jump characteristics from neural adaptations rather than muscle architecture changes.

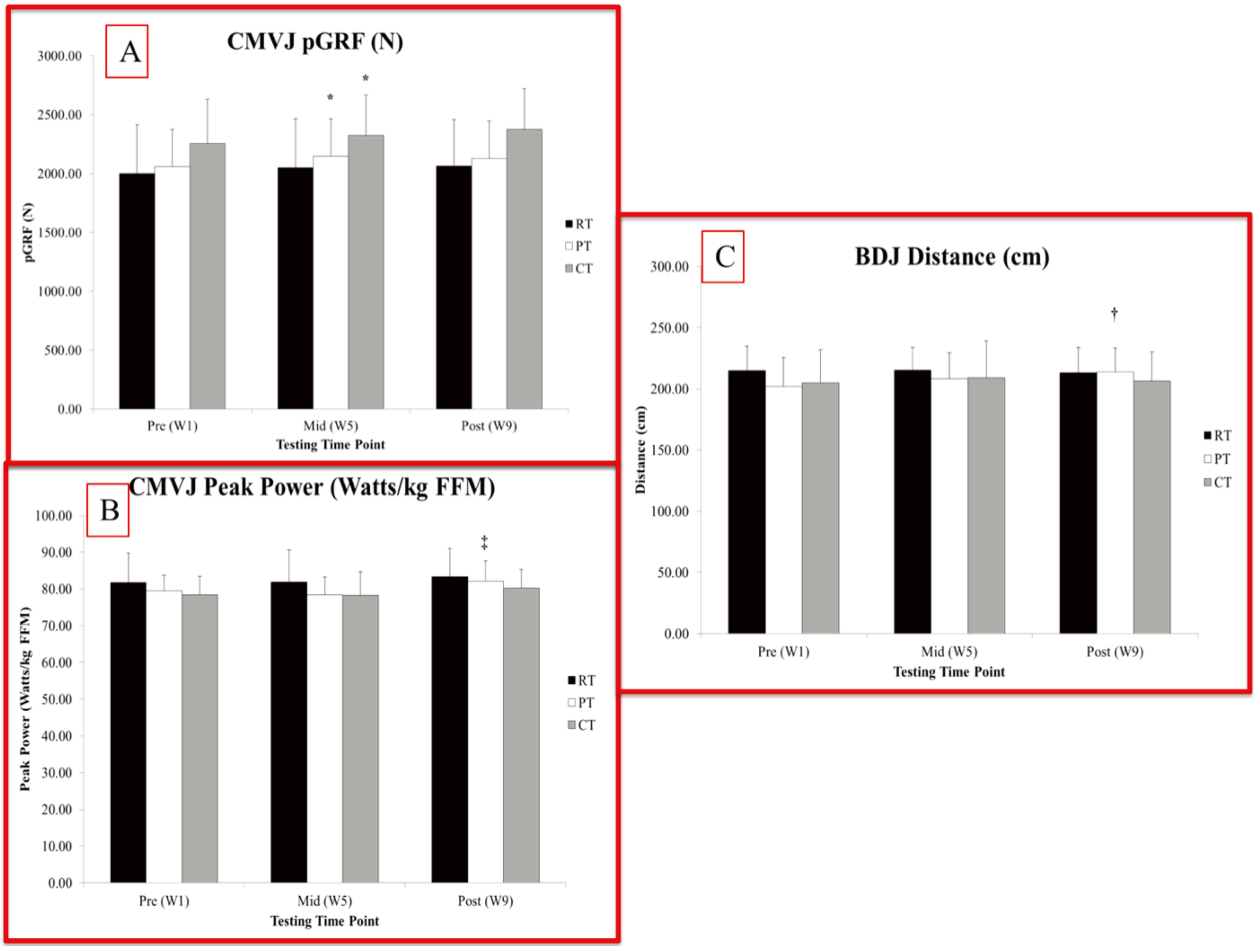


Figure 2 **Figure 2A**. Changes in CMVJ pGRF (N) for all groups; * = W5 significantly greater than W1 (PT: $\rho = 0.050$, $1 - \beta = 0.705$, partial $\eta^2 = 0.312$; CT: $\rho = 0.035$, $1 - \beta = 0.792$, partial $\eta^2 = 0.384$); **Figure 2B**. Changes in CMVJ Peak Power/kg FFM (Watts/kg FFM) for all groups; ‡ = W9 significantly greater than W5 (PT: $\rho = 0.020$, $1 - \beta = 0.816$, partial $\eta^2 = 0.369$); **Figure 2C**. Changes in BDJ Distance (cm) for all groups; † = W9 significantly greater than W1 (PT: $\rho = 0.022$, $1 - \beta = 0.953$, partial $\eta^2 = 0.478$)

Conclusion

Results from this study suggest that complex training may not be better than traditional resistance or plyometric training, at statistically improving measures of power after six weeks of training, in this population (which is limited to only males). Complex training did not, however, reveal a decrement in any jump characteristic, both over time or compared to the other training modalities. Therefore, since complex training allows for the incorporation of various modalities into a single work session, it may offer variable and time efficient training when included in certain training blocks of the periodized training program of a recreationally trained individual.

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