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The Effect of Cluster Loading on Force, Velocity, and Power During Ballistic Jump Squat Training

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Purpose: The purpose of this study was to investigate the effect of set structure, in terms of repetition work:rest ratios on force, velocity, and power during jump squat training. ***Methods:*** Twenty professional and semiprofessional rugby players performed training sessions comprising four sets of 6 repetitions of a jump squat using four different set configurations. The first involved a traditional configuration (TR) of 4 × 6 repetitions with 3 min of rest between sets, the second (C1) 4 × 6 × singles (1 repetition) with 12 s of rest between repetitions, the third (C2) 4 × 3 × doubles (2 repetitions) with 30 s of rest between pairs, and the third (C3) 4 × 2 × triples (3 repetitions) with 60 s of rest between triples. A spreadsheet for the analysis of controlled trials that calculated the *P*-value, and percent difference and Cohen's effect size from log-transformed data was used to investigate differences in repetition force, velocity, and power profiles among configurations. ***Results:*** Peak power was significantly lower ($P < .05$) for the TR condition when compared with C1 and C3 for repetition 4, and all cluster configurations for repetitions 5 and 6. Peak velocity was significantly lower ($P < .05$) for the TR condition compared with C3 at repetition 4, significantly lower compared with C2 and C3 at repetition 5, and significantly lower compared with all cluster conditions for repetition 6. ***Conclusions:*** Providing inter-repetition rest during a traditional set of six repetitions can attenuate decreases in power and velocity of movement through the set.

Keywords: strength training, sport, muscle function, physical performance, kinetics

Program variation during resistance training can be achieved by manipulating one or more of a number of acute program variables that contribute to the volume and intensity of a resistance training session and dictate acute mechanical and metabolic responses to training.[1] These variables include sets, repetitions, load, exercise selection and rest periods. One alternative training configuration to traditional resisted strength training for the practitioner is termed *cluster*, or *inter-rep*, *rest training*. This training structure involves the manipulation of work and rest periods, breaking sets into small clusters of repetitions, which may alter

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the training stimulus associated with a given resisted strength training session. It has been suggested as being a means of providing training variation, which may be well suited to the development of muscular power.[2–4]

Mechanical and metabolic stimuli both play a role in the development of strength and power. Although the importance of actual muscular fatigue and associated accumulation of metabolites in strength adaptation is unclear, [5,6] it is possible the acute buildup of metabolites during resistance training is a precursor to endocrine[7,8] and neural[8,9] responses to training. There is also evidence that mechanical stimuli such as total forces[10,11] and total mechanical work[12,13] are important in strength development. These mechanical and metabolic stimuli may also be of importance for high velocity ballistic training for developing muscular power.[14,15] However it is also possible that the velocity and power generated during ballistic power training are the more important mechanical stimuli for adaptation.[16–19] Indeed, researchers have suggested that ballistic training programs are able to achieve comparable or superior training outcomes in terms of power development in short term training periods with less total work than high load training schemes.[19,20] For example, the research of McBride and colleagues[20] showed improved power and velocity adaptation following a training program using ballistic jump squats at 30% of 1RM compared with 80% of 1RM even though the total work performed over the training period was significantly greater in the 80% load group. This research also ensured minimal fatigue during training by terminating training sets if a 15% drop in power output was observed.

In addition, there is some evidence that adaptation to ballistic performance may be principally mediated by neural mechanisms, with intramuscular[16,20] and intermuscular[10] neural adaptations contributing to performance improvements following high velocity training. It is by way of these mechanisms that cluster loading may be advantageous during training. Cluster loading configurations break sets into small "clusters" or groups of repetitions in an attempt to improve the force, velocity and power profile of the training bout. In a recent discussion of cluster training structures the authors postulated that this in turn may lead to improved training outcomes, particularly in the training of ballistic performance.[2] The short rest periods between clusters may provide enhanced metabolic recovery between sets, leading to an improved kinematic and kinetic profile in the latter repetitions of the set compared with traditional loading paradigms. If neural adaptations are important determinants of ballistic performance, it is possible that cluster loading may allow improved quality of movement during ballistic movements potentially enhancing training outcomes.

As with many resistance training configurations, however, there is limited information available regarding the kinematic and kinetic profiles of cluster training. Research has compared cluster loading patterns to traditional loading schemes during both the clean pull[21] and the bench press.[3,4,22] Haff and coworkers[21] reported that peak velocity during cluster loading (15–30 s of rest between repetitions) was significantly greater than that achieved during traditional continuous loading. This research also showed traditional and cluster loading possessed different fatigue related patterns during the sets of five repetitions, with the traditional loading technique resulting in significantly greater decreases in velocity for repetitions 3, 4, and 5. Similar findings have been reported in upper-body movements. Lawton and colleagues[4] reported significantly greater repetition power outputs during the bench press using cluster loading schemes at a 6RM load compared with a traditional continuous loading scheme. Thus it seems that there is evidence that cluster loading may affect the mechanical profile of the training set. However, at this stage the information is limited to specific movement patterns and loads.

Further investigation is required to establish the effects of cluster loading on the kinetics and kinematics of resistance training interventions for the development of explosive power. Therefore the purpose of this study was to investigate the effect of cluster loading (repetition work:rest ratios) on force, velocity and power during jump squat training. These findings should provide information regarding the acute effect of cluster loading on the kinematics and kinetics of this movement pattern, which is commonly used for the development of lower limb power in athletes.

Methods

Subjects

Twenty male professional and semiprofessional rugby union players volunteered to participate in this study. Subject age, height, and weight were 19.7 ± 1.9 y, 1.83 ± 0.1 m, and 93.9 ± 0.1 kg, respectively. All subjects were informed of the risks and benefits of participation in the research and that they could withdraw at any time, and they signed informed consent forms. All procedures were approved by Edith Cowan University's Human Research Ethics Committee.

Design

In order to investigate the effect of set structure on kinematics and kinetics, a crossover design was utilized whereby 20 subjects performed four training sessions within a 2-wk period. Each training session consisted of four sets of six repetitions of the jump squat at an absolute external load of 40 kg. Each subject performed a training session using a traditional set structure and three different cluster configurations in a randomized order. A selection of kinematic and kinetic variables was then derived from ground reaction force (GRF) data, and differences between training interventions in terms of repetition kinematics and kinetics were investigated.

Methodology

Subjects were required to report for data collection on four occasions at least 72 h apart within a 2-wk period. Before all data collection, subjects performed a standardized warm-up that included running activities with incremental increases in intensity, dynamic stretching, and submaximal jumps. Subjects then performed four sets of six jump squats using four different set configurations. Six repetitions was selected as training volume, as it has been shown that beyond six repetitions, power output in the jump squat in similar populations decreases.[23] The set configurations can be observed from Figure 1. All training sessions were equated for volume using the volume load method (sets × repetitions × load). The first involved a traditional configuration (TR) of 4 sets × 6 repetitions with 3 min of rest between sets, the second (C1) 4 sets × 6 × singles (1 repetition) with 12 s of rest between repetitions and 2 min rest between sets, the third (C2) 4 sets × 3 × doubles (2 repetitions) with

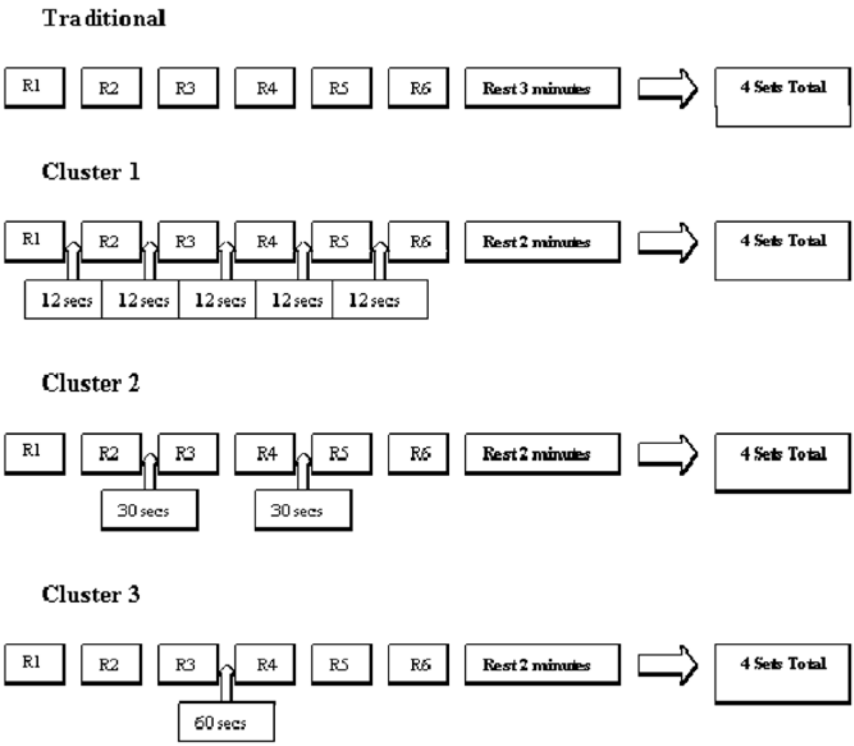

Figure 1 — Traditional and four cluster loading set structures.

30 s of rest between pairs and 2 min between sets, and the fourth (C3) 4 sets × 2 × triples (3 repetitions) with 60 s of rest between triples and 2 min between sets. Piloting showed that one set of six repetitions in the TR condition took 15 s to complete. The timings for cluster conditions were subsequently designed so that each set commenced 3 min and 15 s following the commencement of the previous set. Therefore, total work-to-rest ratios were standardized against the TR condition (15 s of work to 3 min of rest).

The exercise technique was similar to that described previously in the literature for the measurement of force and power during single rebound jump squats.[24] This involved the subjects standing at a self-selected foot width with an Olympic bar loaded with 40 kg placed on their upper trapezius immediately below C7. The subject then performed a countermovement to a self-selected depth and immediately performed a maximal jump. Subjects were instructed to attempt to keep the depth of countermovement consistent between jumps and "jump for maximum height" on each repetition. Subjects were required to reset to their original start position before all jumps. Consistency of countermovement depth was visually assessed by the researcher and where necessary feedback was provided to the subject.

As with previous research,[25] the depth of countermovement was not controlled as this technique (self-selected countermovement depth) reflects the technique most likely to be utilized in a practical situation thereby maximizing the practical application of study findings. However, to ensure findings were not affected by variation in countermovement depth between conditions, the vertical displacement of the system's center of mass during the countermovement was calculated for each repetition and averaged for each set configuration. This analysis showed no significant differences between set configurations in vertical displacement during the countermovement, which averaged 0.20 m for all four configurations. Forty kilograms represented a load that all subjects were familiarized with, as they used it both in training and testing. This external load was used by the athletes because it represented approximately 20% of the squat 1RM of the population from which the subjects were drawn. This load sits within a spectrum of loads whereby power is reported to be maximized in ballistic tasks.[26–28]

Jumps were performed on a portable force plate (Accupower, AMTI, Watertown, MA). Ground reaction force (GRF) data were sampled at 500 Hz via an analog-to-digital converter (16 bit, 250 kS/s National Instruments, Austin, TX) and collected by a laptop computer using custom-built data acquisition and analysis software (Labview 8.2, National Instruments, Austin, TX.).

Power data was calculated from GRF data using the impulse-momentum (forward dynamics) approach to calculate the system power as outlined previously in the literature.[29] As the initial velocity of the system was zero, at each time point, vertical GRF was divided by the mass of the system to calculate acceleration of the system. Acceleration due to gravity was then subtracted so that only the acceleration generated by the subject was multiplied by time data to calculate instantaneous velocity of the system's center of mass. The resultant velocity data was then multiplied by the original GRF data to calculate power. Peak force (PF) [ICC = 0.96, CV = 2.3], peak power (PP) [ICC = 0.94, CV = 4.6%], peak velocity (PV) [ICC = 0.93, CV = 3.4%] and rate of power development calculated with a 50 ms moving average (RPD) [ICC = 0.89, CV = 14.7%] were calculated from the resultant force, power, and velocity curves.

Statistical Analyses

For the purposes of statistical analysis, repetition averages were calculated for each variable for each subject. That is, the average across all four sets of each repetition (1–6) was calculated and used for analysis. Means and standard deviations were used as measures of centrality and spread of data for repetition data for each variable. A spreadsheet designed for the analysis of controlled trials[30] was utilized for further statistical analyses. The statistics derived from the spreadsheet included the P-value calculated using the unequal-variances unpaired t statistic, and percentage difference with 90% confidence limits and Cohen's effect size calculated from log-transformed data. These statistics were calculated comparing each set structure for each repetition (1–6) and comparing repetition 1 to each subsequent repetition for each set configuration. Effect sizes were described as trivial (<0.2), small (0.2–0.5), moderate (0.5–0.8), and large (> 0.8).[31,32] Alpha levels of 0.05 and 90% confidence limits are used where appropriate.

Results

Significant differences ($P < .05$) between set structures in mean repetition values were identified for PP. Peak power was significantly lower for the TR condition when compared with C1 and C3 for repetition 4, and all cluster configurations for repetitions 5 and 6. These differences can be observed from Figure 2 and a summary of percent changes with 90% confidence limits, effect sizes, and *P*-values can be observed from Table 1. Percent changes (± 90% CL) in PP from repetition 1 to subsequent repetitions for all set configurations can be observed from Figure 3. There were significant differences ($P < .05$) between repetition 1 and all subsequent repetitions for all set configurations with the exception of repetition 4 for C3 and repetition 5 for C2, which were not significantly different from repetition 1 for their respective configurations. The greatest percent changes from repetition 1 were for repetitions 3–6 in the TR condition (% change = –6.0 to –11.8). These differences can be observed from Figure 3. Effect sizes for repetitions 5 and 6 were both large (ES = –0.83 to –1.0).

Significant differences ($P < .05$) between set structures in mean repetition values were also identified for PV. Peak velocity was significantly lower for the TR condition compared with C3 at repetition 4, significantly lower compared with C2 and C3 at repetition 5, and significantly lower compared with all cluster conditions for repetition 5. These differences can be observed from Figure 4 and a summary of percent changes with 90% confidence limits, effect sizes, and *P*-values can be observed from Table 2. Percent changes (± 90% CL) in PV from repetition 1 to subsequent repetitions for all set configurations can be observed from Figure 5. For the TR condition there was a significant decrease ($P < .05$, ES = –0.24 to –0.99) in PV from repetition 1 to all subsequent repetitions. There were no significant differences for C1 between repetition 1 and any subsequent repetitions. However, there were significant differences ($P < .05$) between repetition 1 and repetitions 2, 3, and 4 for C2, and between repetition 1 and repetition 6 for C3.

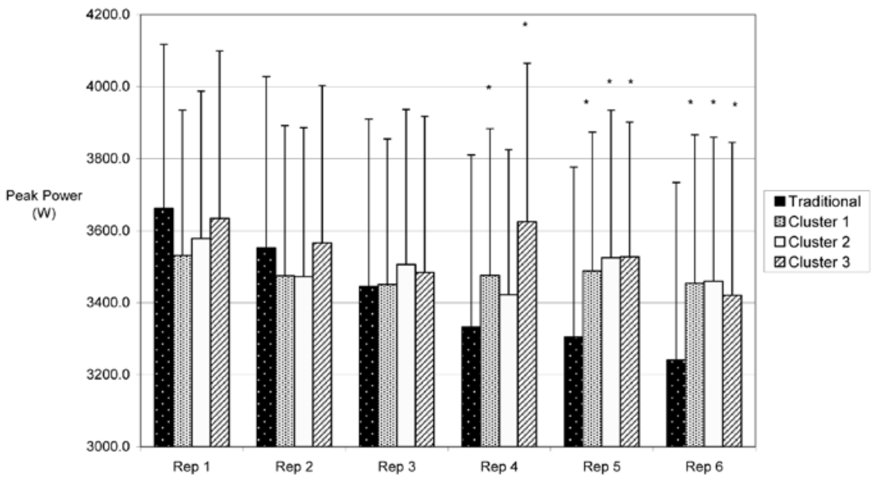

Figure 2 — Mean (± SD) repetition peak power for each set configuration. *Significantly different from control ($P < .05$).

Table 1 *P*-value, percent change (± 90% CL), and effect sizes (ES) for three cluster loading configurations when compared with the traditional configuration for repetitions 4, 5, and 6 for peak power

	Repetition 4				Repetition 5				Repetition 6			
Cluster	*P*	% Change	± 90% CL	ES	*P*	% Change	± 90% CL	ES	*P*	% Change	± 90% CL	ES
1	0.05	4.6	3.7	0.3	0.03	6.0	4.4	0.4	0.01	7.0	4.5	0.4
2	0.08	3.0	2.8	0.2	0.00	7.0	3.8	0.5	0.01	7.2	3.9	0.5
3	0.00	9.0	3.8	0.6	0.00	7.2	3.5	0.5	0.01	5.9	3.3	0.4

Table 2 *P*-value, percent change (± 90% CL), and effect sizes (ES) for three cluster loading configurations when compared with the traditional configuration for repetitions 4, 5, and 6 for peak velocity of the center of mass

	Repetition 4				Repetition 5				Repetition 6			
Cluster	*P*	% Change	± 90% CL	ES	*P*	% Change	± 90% CL	ES	*P*	% Change	± 90% CL	ES
1	0.11	2.7	2.7	0.2	0.09	3.2	3.1	0.3	0.04	4.1	3.1	0.3
2	0.12	1.9	2.1	0.2	0.02	4.2	2.8	0.4	0.01	4.9	2.8	0.4
3	0.02	3.3	2.3	0.3	0.01	5.0	2.7	0.4	0.01	4.2	2.6	0.4

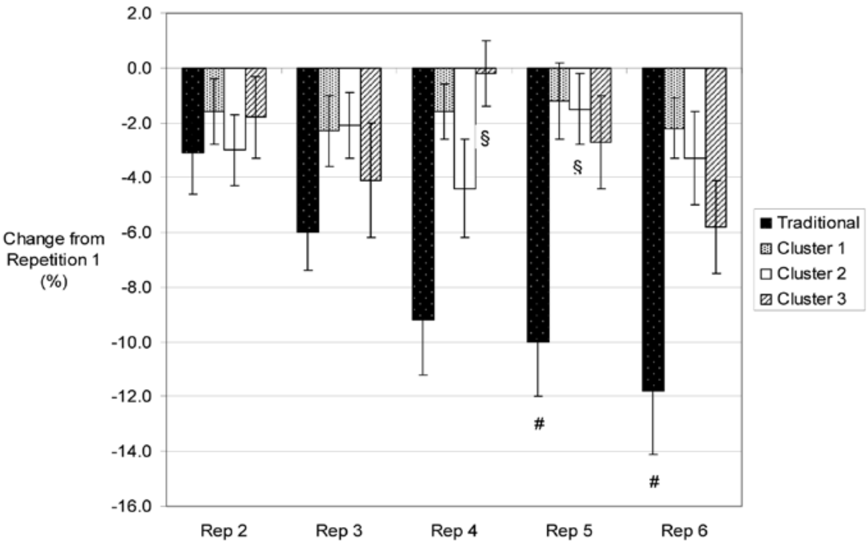

Figure 3 — Percent change (± 90% CL) from log transformed data for peak power between repetition 1 and subsequent repetitions for each set configuration. §No significant difference from repetition 1 (all other differences are significant). #Effect size for change from repetition 1 is large (> –0.8).

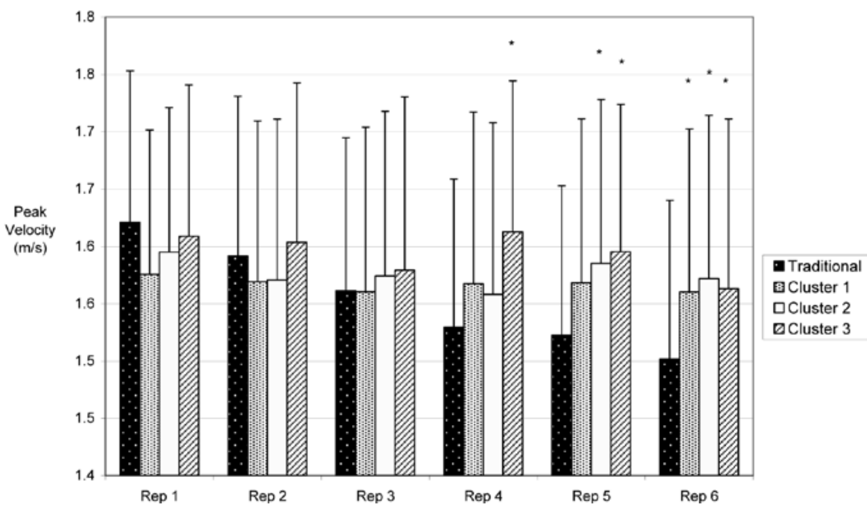

Figure 4 — Mean (± SD) repetition peak velocity of the center of mass for each set configuration. *Significantly different from control ($P < .05$).

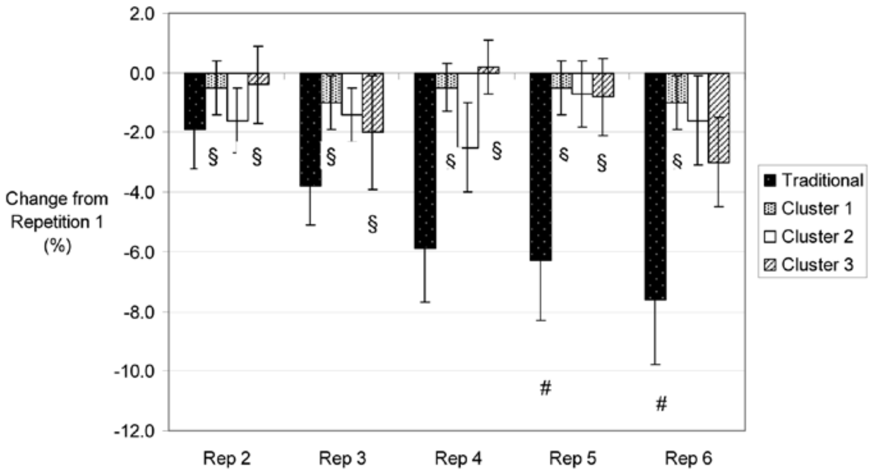

Figure 5 — Percent change (± 90% CL) from log transformed data for peak velocity between repetition 1 and subsequent repetitions for each set configuration. §No significant difference from repetition 1 (all other differences are significant, $P > .05$). #Effect size for change from repetition 1 is large (> –0.8).

There were no significant differences found in mean repetition PF (Figure 6) and RPD between set configurations. There were also no significant differences between repetition 1 and subsequent repetitions for any set configuration for RPD. However, there were significant differences between repetition 1 and selected subsequent repetitions for TR, C2, and C3 for PF. These differences can be observed from Figure 7. Peak force decreased significantly from repetition 1 to all subsequent repetitions for the TR configuration ($P < .05$, ES = –0.20 to –0.41). In addition, for C2 repetitions 2, 4 and 6, PF was significantly reduced ($P < .05$, ES = –0.19 to –0.26) from repetition 1, and for C3, repetition 6 was significantly reduced ($P < .05$, ES = –0.23) from repetition 1.

Discussion

This study aimed to establish the effects of cluster loading on force, power, and velocity profiles of a number of set configurations, specifically investigating the differences between a traditional loading paradigm and three alternative "cluster" configurations. Our results indicate that where power and velocity decrease significantly in the latter repetitions of a traditional set of six repetitions of the loaded jump squat, this decrease can be attenuated by using cluster configurations. This may have implications for the planning and prescription of training for muscular power using ballistic activities, but these implications are dependent on the key mechanical and metabolic stimuli. Should maximizing power and velocity in ballistic training be key to adaptation, cluster loading paradigms may offer a viable training option for lower-body power development.

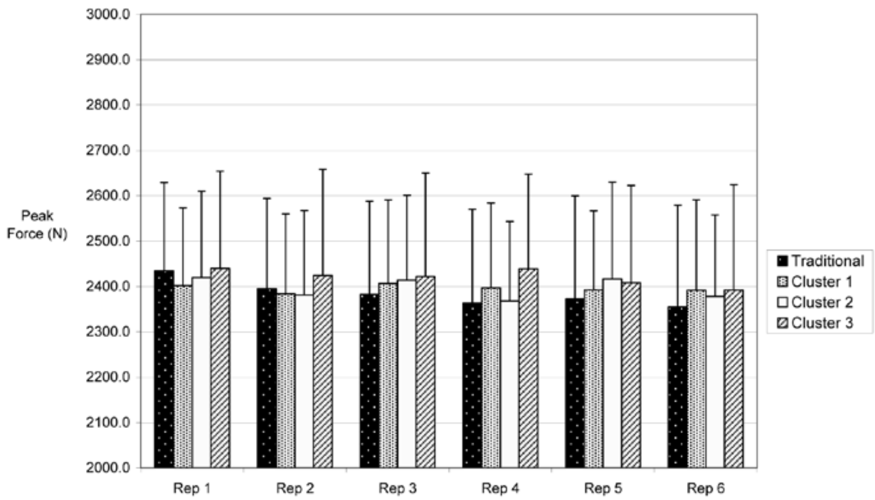

Figure 6 — Mean (± SD) repetition peak force for each set configuration.

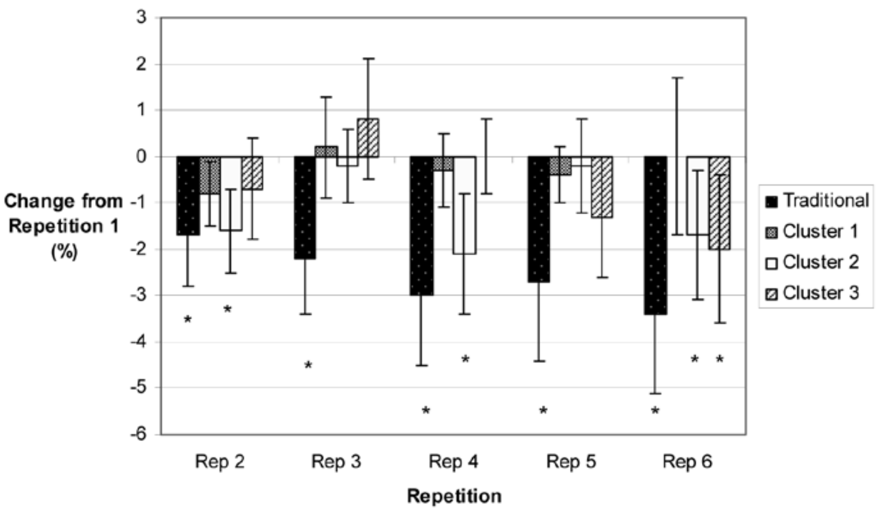

Figure 7 — Percent change (± 90% CL) from log transformed data for peak force between repetition 1 and subsequent repetitions for each set configuration. *Significant difference from repetition 1 ($P > .05$).

From the results of this study it is evident that the use of a number of cluster configurations was able to decrease the decline in peak power output during a set of six jump squats. For all set configurations, the greatest peak power occurred with the first repetition. This is in contradiction to the research of Baker and Newton,[23] which suggested that the highest power output across a set of 10 jump squats was achieved at either repetition 2 or 3 and maintained until the fifth repetition. However, it is in agreement with Haff et al,[21] who reported peak power in a set of five repetitions of the clean pull to occur in the first repetition. From the data presented it can be observed that the cluster configurations clearly attenuated the decrease of peak power through the set after repetition 1. This is evidenced by the large effect sizes for repetitions 5 and 6 for the TR condition when repetition 1 was compared with subsequent repetitions (see Figure 3). Although significant differences were evidenced when comparing repetitions with cluster configurations, none of these resulted in moderate or large effect sizes. Therefore, it seems likely that cluster configurations are superior for maintaining quality of effort (in terms of peak power) during the jump squat movement.

Decreases in peak velocity were also attenuated by the use of cluster training configurations when compared with traditional loading schemes. Similar to peak power, the only large or moderate effect sizes for differences between repetition 1 and subsequent repetitions were with repetitions 5 and 6 during the traditional set configuration (see Figure 5). Therefore, it seems that all three cluster configurations in the present study were able to improve the velocity profile of a set of six jump squats. These findings are consistent with the findings of Haff and colleagues,[21] who reported that a rest of 15–30 s between repetitions of a mid thigh pull at 90% of 1RM resulted in significantly greater peak velocity.

No significant differences between any of the set configurations at any repetition were found in force output. Therefore, in terms of peak force, each set configuration provided a similar stimulus. Results did show, however, that the force was significantly decreased from repetition 1 to all subsequent repetitions in TR and for selected repetitions for the cluster configurations. For example, the second repetition of each pair in C2 was significantly decreased compared with the first repetition of the set. Previous authors[2] have postulated that PCr can be replenished during the short rest provided during cluster loading configurations, whereas traditional configurations result in greater depletion of PCr and therefore increased use of muscle glycogen and production of lactic acid. Research has shown that the inhibition of force capabilities following as few as 5–9 maximal contractions is due to the accumulation of blood lactate.[33] The research of Salin and Ren[34] supports the contention of Haff and colleagues,[2] showing that decreases in muscular ATP and PCr concentrations were associated with increased lactate concentrations and significant decreases in force following maximal contractions. With the addition of 15–30 s rest intervals between knee extension contractions force output returned to 80–90% of initial values. These same mechanisms may explain the differences in peak power and peak velocity profiles between configurations.

Whereas it is likely that some level of metabolic fatigue is necessary for resistance training for developing muscular size (hypertrophy training) and strength,[7–9] the same may not be true of training for power. Indeed a number of researchers have suggested that the key mechanical stimuli in the development of muscular power is generating high peak velocity and power[16–19] and achieving this does not necessarily entail fatigue and associated metabolic stress. Research into traditional loading configurations using ballistic movements suggests that the lactate accumulation inhibits muscle function. Crewther and colleagues[14] investigated metabolic responses to ballistic supine squats at 45% of one repetition maximum (RM) with subjects performing sets of six repetitions with 3 min of rest between sets, similar to the traditional loading configuration in the current study. It was reported that significant increases in lactate accumulation occurred as a by-product of anaerobic glycolysis across sets of six repetitions. The reported lactate concentrations were equivalent to those generated in an equi-volume maximum strength protocol and deemed sufficient to inhibit peak power. This metabolic stress associated with a traditional ballistic training configuration, as is purported to be during maximum strength training may be a precursor to neural and endocrine adaptations for power development. In this case cluster loading may inhibit these adaptations making a traditional configuration a more appropriate prescription. However, should the peak power and peak velocity be important mechanical stimuli mediating neural responses to training cluster configurations would represent the more appropriate training prescription.

Results clearly showed that cluster configurations resulted in increased repetition peak power in the latter repetitions of the set compared with traditional loading. However, no difference in repetition peak power or peak velocity was evident between clusters (see Figures 2 and 4). This suggests that either of the cluster configurations investigated could be used to enhance peak power in ballistic tasks. These findings are consistent with previous research focusing on power output in upper-body strength movements. Lawton and colleagues[4] investigated the use of singles, doubles, and triples to improve power output in a 6RM bench press, also showing that none of the cluster configurations were obviously superior in maximizing power outputs. Likewise, in the current research peak velocity was not significantly different between the three cluster configurations. However, the cluster 1 configuration was the only configuration in which there was no significant drop off in peak velocity from repetition 1 to 6. Therefore, this may be the preferable configuration for maximizing velocity of movement. However, further research is needed to confirm this possibility.

Practical Applications

Ballistic movements are commonly utilized to develop lower-body muscular power in athletic populations. Whereas hypertrophy and strength training adaptation is dependent on mechanical stimuli such as total forces and mechanical work which are likely to induce some level of metabolic fatigue, it is possible that for the development of muscular power during ballistic training, mechanical qualities such as peak velocity and peak power are important (possibly mediating neural adaptations). Our results have shown that decreases in power and velocity of movement associated with the latter repetitions of a set of jump squats can be reduced by the use of cluster loading configurations. Dividing a traditional set of six repetitions into clusters of either one, two, or three repetitions can attenuate decreases in power and velocity of movement throughout the set. However, the practitioner needs to be aware that, should other mechanical stimuli and associated metabolic responses be important precursors to power development (or be a desired training outcome), a traditional set configuration may represent the more appropriate training prescription. In addition, this research did not directly examine metabolic, endocrine, and neural responses to training, which underpin adaptation. Future research should investigate these responses to cluster configurations together with longitudinal training adaptations to provide further information on the mechanisms that reduce neuromuscular fatigue during cluster loading and further clarify their application to training.

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