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Cluster Set Loading in The Back Squat: Kinetic and Kinematic Implications

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Cluster Set Loading in The Back Squat: Kinetic and Kinematic Implications

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A thesis

presented to

the faculty of the Department of Sport, Exercise, Recreation and Kinesiology

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In partial fulfillment

of the requirements for the degree

Master of Science in Sport Science and Coach Education

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by

Alexander B. Wetmore

August 2018

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Keywords: Training, Rest, Strength and Conditioning, Performance

ABSTRACT

Cluster Set Loading in The Back Squat: Kinetic and Kinematic Implications

by

Alexander B. Wetmore

The purpose of this study was to investigate the kinetic and kinematic implications of cluster loading as a resistance training programming tactic. Cluster loading involves introducing rest during a set which may allow athletes to train at higher absolute intensities. Eleven trained males were recruited for this study. Subjects completed two testing sessions consisting of three sets of five back squats at 80% of their one repetition maximum. Cluster loading included 30s of inter-repetition rest. All testing was done on dual-force plates with four linear position transducers. Paired sample t-tests were used to determine differences between conditions with Cohen's d effect sizes describing the magnitude of change between conditions. Both conditions had similar values for peak force and average force. Cluster loading had significantly higher power and velocity outputs, shorter times to peak power and velocity as well as greater maintenance of time to peak power. These results suggest cluster loading may be superior to traditional loading when maintaining power output and timepoint variables is the desired outcome of training.

DEDICATION

This thesis is dedicated to my family who has supported me through everything and given me the opportunity to chase my dreams. To my fiancée, Courtney, thank you for the countless times you have picked me up when I'm feeling overwhelmed. Words are inadequate to describe how much your love and support means to me. I love you.

ACKNOWLEDGMENTS

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CHAPTER 1

INTRODUCTION

Statement of the Problem

Cluster loading has been previously investigated but there is a need for a full description of the kinetic and kinematic effects of this programming tactic. The purpose of this study was to investigate the effects of cluster loading on both kinetic and kinematic outputs in order to better understand its application as a resistance training programming tactic.

Introduction

Over the past several years, new advanced training (AT) methods have been proposed. These AT include accentuated eccentric loading, contrast sets, complex sets and cluster sets. Cluster sets (CS) use short rest periods between repetitions as well as typical rest periods between sets (Haff et al., 2003; Haff et al., 2016). According to the SAID (specific adaptation to imposed demands) principle, changing variables within the application of an exercise elicits a specific response and subsequent adaptation given adequate recovery is provided (Stone et al., 2007). Thus, intra-set rest theoretically could allow CS to induce different adaptations to training by allowing for heavier loading at the same training volume (strength), potentiate explosiveness and power adaptations by maintenance of forces, rate of development (RFD), velocity, or power at a given load (Denton & Cronin, 2006; Haff et al., 2003; Hansen et al., 2011a; Hansen et al., 2011b; Hardee et al., 2012b; Iglesias-Soler et al., 2016; Joy et al., 2013; Lawton et al., 2006; Moir et al., 2013; Moreno et al., 2014; Oliver et al., 2016; Oliver et al., 2015; Tuffano et al., 2016a; Tuffano et al., 2016b). Thus, CS training could be useful for a variety of purposes such as enhancing the training effect by offering a greater stimulus or varying the stimulus to promote further adaptation. For example, training over a few years with little variation, such as can occur with

maintaining traditional protocols (TP), can limit gains and cause stagnation (Stone et al., 2007).

Introduction of CS could produce an adaptive stimulus allowing further gains in strength, RFD etc. During

peaking phases aimed at improving power, CS training could enhance P output. Thus, CS training could

be quite valuable for several aspects of the training process and possibly promote more consistent and

perhaps superior gains when used appropriately.

Traditional loading (TL) schemes are believed to enhance adaptation, at least partly through

acute fatigue. Acute fatigue could enhance motor unit recruitment (Joy et al., 2013), increase muscle

(and whole body) metabolism and metabolite production (Folland et al., 2002; Girman et al., 2014;

Gorostiaga et al., 2010a; Gorostiaga et al., 2010b; Iglesia-Soler et al., 2012; Iglesia-Soler et al., 2016;

Oliver et al., 2016; Oliver et al., 2015; Stone et al., 2007) both of which may enhance adaptation to

training. However, fatigue and increased production of metabolites as a primary stimulus for increased

strength and power have both been questioned (Drinkwater et al., 2007; Folland et al., 2002). Folland et

al. (2002) found that higher levels of training induced fatigue (4x10 to failure) did not provide additional

benefits compared to a low fatigue protocol (40x1) with 30s of inter-repetition rest designed to

minimize metabolic accumulation. Additionally, a tendency towards greater high-velocity gains in the

low fatigue protocol was noticed, suggesting that velocity and perhaps power would be higher with

greater inter-repetition rest. Indeed, further study on CS has demonstrated increased, or maintained

force, RFD, velocity and power for CS compared to TP (Denton & Cronin, 2006; Haff et al., 2003; Hansen

et al., 2011a; Hansen et al., 2011b; Hardee et al., 2012; Iglesias-Soler et al., 2012; Joy et al., 2013;

Lawton et al., 2006; Moir et al., 2013; Morales-Artacho et al., 2017; Oliver et al., 2016; Oliver et al.,

2015; Tuffano et al., 2016a; Tuffano et al., 2016b).

Although CS protocols have been previously investigated, there are few studies describing both

kinetic and kinematic characteristics and there are a number of limitations in these studies. A number of

intra-set rest periods and exercises have been used (Denton & Cronin, 2006; Drinkwater et al., 2007;

Folland et al., 2002; Girman et al., 2014; Haff et al., 2003; Haff et al., 2016; Hansen et al., 2011a; Hansen et al., 2011b; Hardee et al., 2012a; Hardee et al., 2012b; Iglesias-Soler et al., 2012; Iglesias-Soler et al., 2016; Joy et al., 2013; Lawton et al., 2006; Matuszak et al., 2003; Mayo et al., 2014; Moir et al., 2013; Morales-Artacho et al., 2017; Moreno et al., 2014; Oliver et al., 2016; Oliver et al., 2015; Tuffano et al., 2016a; Tuffano et al., 2016b). Many of the existing studies investigated CS using machines, which could alter normal technique and may not be indicative of a typical athletic setting in which CS would be logically used. Studies (Drinkwater et al., 2007; Gorostiaga et al., 2010; Gorostiaga et al., 2012; Morales-Artacho et al., 2017; Moreno et al., 2014; Oliver et al., 2015) used untrained subjects which also may limit generalizability to trained populations. Additionally, most studies used only one type of instrumentation or used solely kinetic or kinematic data to study CS which may have created errors in calculation of variables, especially power. For example, Cormie et al. (2007a) indicate that using only kinetic data (e.g. force plate) may result in underestimating power while relying solely on kinematic data (e.g. potentiometers) can result in overestimation. Combining both kinetic and kinematic data appears to be superior when investigating force and related variables such as RFD, velocity and power (Cormie et al., 2007a).

The back squat is a commonly performed exercise, particularly in athletic settings. To the authors' knowledge, only two previous studies have used a combination of kinetic and kinematic data to study the squat in previously trained subjects using CS (Tuffano et al., 2016a; Tuffano et al., 2016b). The results indicate that CS can enhance maintenance of force related variables compared to TP.

The purpose of this study was to compare CS and TP training schemes in well-trained subjects. Both kinetic and kinematic collected data will be used to investigate the effects of CS as a programming tactic.

<u>Comprehensive Review of the Literature</u>

Several key principles of resistance training include overload, specificity and variation. As athletes become highly trained, these principles often need manipulation to continue to drive adaptation (Stone et al., 2007). By utilizing more powerful stimuli, there is a larger disruption in homeostasis which requires more rest and variation to recover from training. One possible means of providing greater rest and variation in training may come in the form of cluster loading. Clusters, also known as inter-repetition rest, or rest-pause training, introduce rest during the set to minimize the effects of fatigue. It is commonly known that fatigue builds and performance decreases as a set continues into later repetitions (Gorostiaga et al., 2014). Additionally, it has been demonstrated that fatigue is not a necessary stimulus for additional gains in resistance training (Drinkwater et al., 2007; Folland et al., 2002). For example, Folland and colleagues (2002) compared a high fatigue protocol to a low fatigue protocol which aimed to minimize metabolic accumulation via inter-repetition rest. The results of this study indicate that higher training induced fatigue does not provide additional benefits when compared to the lower fatigue protocol. Additionally, there was a tendency towards greater high-velocity gains in the low fatigue protocol suggesting that power outputs may have been greater with inter-repetition rest. Drinkwater and colleagues (2007) demonstrated similar findings when investigating the effects of forced repetitions after failure on strength gains. They concluded that neither additional forced repetitions nor additional set volume improved the magnitude of strength gains once failure was reached. Therefore, fatigue may not be beneficial to training adaptations. It was also noted in a study by Sánchez and González-Badillo (2011) that velocity loss may be an objective means to quantifying neuro-muscular fatigue during resistance training. As noted earlier, power outputs had greater trends towards high-velocity gains with inter-repetition rest suggesting that cluster loading may help control fatigue during resistance training.

As stated previously, CL has been widely investigated in a number of formats. These include different set and repetition schemes, loading schemes (intensity), rest intervals between repetitions and sets, exercises used and variables analyzed. The existing literature claims many benefits of using CL including but not limited to: increased power output, greater velocity maintenance, greater total work accomplished and subsequently greater time under tension and lower ratings of perceived exertion (RPE) (Denton & Cronin, 2006; Haff et al., 2003; Hansen et al., 2011a; Hansen et al., 2011b; Hardee et al., 2012a; Hardee et al., 2012b; Iglesias-Soler et al., 2012; Joy et al., 2013; Lawton et al., 2006; Moir et al., 2013; Morales-Artacho et al., 2017; Moreno et al., 2014; Oliver et al., 2016; Oliver et al., 2015; Tuffano et al., 2016a; Tuffano et al., 2016b). There are many different studies which have shown greater power outputs and velocity while using cluster sets (Haff et al., 2003; Hansen et al., 2011a; Hansen et al., 2011b; Hardee et al., 2012a; Iglesias-Soler et al., 2012; Joy et al., 2013; Lawton et al., 2006; Mayo et al., 2014; Morales-Artacho et al., 2017; Moreno et al., 2014; Oliver et al., 2016; Oliver et al., 2015; Tuffano et al., 2016a; Tuffano et al., 2016b). One such study was done by Haff and colleagues (2003). In this study, clean pulls at 90% and 120% of 1RM were analyzed for one set of five repetitions. Their findings suggest that cluster set configurations significantly higher peak velocity (p=0.016) when compared to traditional loading. An interesting study carried out by Joy and Colleagues in 2013 demonstrated that not only did cluster sets result in greater mean power outputs (p<0.05) during the later repetitions in each set when compared to traditional loading, but traditional loading also caused greater vastus lateralis electromyography EMG values (p<0.05) during the later repetitions of a set (Joy et al., 2013). This may lend further support to the claim that cluster sets help to minimize the effects of fatigue while traditional sets may have to recruit more muscle fibers as fatigue sets in.

Several studies have attempted to investigate directly the metabolic implications of utilizing cluster loading tactics (Drinkwater et al., 2007; Escamilla et al., 2001; Hardee et al., 2012b). Iglesias-Soler et al. (2012) studied the acute effects of cluster loading on metabolic and performance measures. This

study compared the effects of three sets to failure using traditional loading to three sets not to failure using cluster loading in the smith machine squat. The findings of this study show lower post-session blood lactate values (p=0.001) in the cluster condition along with greater mean propulsive velocity (p=0.009) (Iglesias-Soler et al., 2012). In addition to this study, Girman et al (2014) compared the acute effects of cluster sets on metabolic and performance measures. Their findings further supported the findings of Iglesias et al. showing lower lactate values (p<0.05) and greater maintenance of countermovement and standing long jump performance (p<0.05). In a non-direct method of measuring the effects of cluster loading on fatigue, Hardee et al. compared the effects of clusters on ratings of perceived exertion (RPE). This protocol included three sets of six power cleans at 80% 1RM utilizing either traditional loading, clusters with 20s of inter-repetition rest or clusters with 40s of inter-repetition rest. The results showed lower levels of decline in power for the cluster conditions indicating less fatigue. The cluster condition with 40s of rest resulted in significantly lower RPE compared to the other conditions which supports the claim that CL may help minimize the effects of fatigue (Hardee et al., 2012a).

In a series of studies, Oliver and colleagues investigated the effects of cluster loading in the back squat (Oliver et al., 2016; Oliver et al., 2015). These studies found that the cluster condition was able to complete a greater volume load than the TL scheme at the same absolute load. This was due to fatigue in the TL condition causing subjects to reduce the load in the later sets while CL conditions were able to maintain their load until completion. This suggests that CL may allow athletes to complete a training session at a higher absolute load for a given volume compared to traditional loading and could have large implications for strength development.

With this background in mind as to the effects of CL, authors have turned their attention to the best means of utilizing this resistance training programming tactic. First, the intensity to be used must be considered. If the goal is to generate greater power output, a range of intensities may be considered.

It is commonly known that power is the product of force and velocity, and thus has a spectrum ranging from higher force components to higher velocity components. Cormie et al. (2007c) investigated the intensity which maximized power output in the back squat, power clean and jump squat. The results indicated that all three exercises reached their maximal power output at different intensities and it should be considered whether the sport emphasizes higher velocity or force demands when determining the intensity to be used.

There are also many different forms of set and repetition schemes that can be used with cluster loading. Cluster sets of various repetition numbers have been previously investigated. For example, Lawton et al (2006) investigated three different cluster set configurations including single repetitions (6x1) with 20s inter-repetition rest, doubles (3x2) with 50s of rest between the three sets, and triples (2x3) with 100s of rest between the two sets. All configurations trained with a 6RM load. When compared to traditional loading, all cluster conditions showed higher total power outputs with no between group differences (p=0.96) (Lawton et al., 2006). In another study, Tuffano et al. (2016a) compared traditional sets of twelve (3x12) to cluster sets of four (3x3x4) and cluster sets of two (3x6x2). The findings of this study indicate that both cluster configurations produced greater peak velocity, mean velocity, peak power and mean power when compared to traditional loading (p<0.01). Additionally, it was found that cluster sets of two produced greater results for power and velocity than cluster sets of four (p=0.02).

A multitude of exercises have been investigated utilizing CL. These exercises include: Back Squat (Girman et al., 2014; Hansen et al., 2011a; Iglesias-Soler et al., 2012; Iglesias-Soler et al., 2016; Matuszak et al., 2003; Mayo et al., 2014; Oliver et al., 2016; Oliver et al., 2015; Tuffano et al., 2016a; Tuffano et al., 2016b), Power Clean (Cormie et al., 2007a; Cormie et al., 2007b; Cormie et al., 2007c; Hansen et al., 2011b; Hardee et al., 2012a; Hardee et al., 2012b), Bench Press (Denton & Cronin, 2006; Drinkwater et al., 2007; Lawton et al., 2006; Mayo et al., 2014), Deadlift (Moir et al., 2013), Clean Pulls (Girman et al.,

2014; Haff et al., 2003), leg extension (Folland et al., 2002), Vertical Jumps (Cormie et al., 2007a; Cormie et al., 2007b; Cormie et al., 2007c; Hansen et al., 2011a; Hansen et al., 2011b; Morales-Artacho et al., 2017; Moreno et al., 2014) and Bench Throw (Drinkwater et al., 2007). It is important to consider the desired outcomes of training when determining which exercise to select for training.

Lastly, several studies have provided possible explanations for the effects of CL. As mentioned earlier, fatigue builds as a set continues and as a session continues. It has been reported that lactate values are higher for traditional loading than CL suggesting a reliance on anaerobic glycolysis for energy (Denton & Cronin, 2006; Girman et al., 2014; Oliver et al., 2015). Gorostiaga et al. (2012) has provided evidence of phosphocreatine depletion (PCr) during resistance training sets of ten. PCr depletion was found to be significantly correlated with muscle lactate ($R^2 = 0.46$) and inosine monophosphate ($R^2 = 0.44$) (Gorostiaga et al., 2012). In a separate study, Gorostiaga et al. (2010) found that power declined during a second set of an exercise which coincided with a decreased adenosine tri-phosphate (ATP) utilization from the phosphagen energy system and an increase in ATP utilization from the anaerobic glycolysis energy system. It is commonly known that the phosphagen system is the most efficient energy system for intense activities such as resistance training and that PCr acts to support this system. Any decrease in PCr or phosphagen utilization would cause a decrease in energy efficiency and possibly decreased power output.

It has been suggested that cluster sets allow partial regeneration of PCr to better maintain power output (Gorostiaga et al., 2010; Gorostiaga et al., 2012; Haff et al., 2003). This claim was supported by Matuszak et als. (2003) finding that rest intervals as short as one minute were able to replenish adequate energy stores to repeat 1RMs. This seems to suggest that very short rest intervals are able to replenish energy stores for very intense resistance training. With these findings in mind, it is possible that inter-set rest may allow partial replenishment of PCr which is a more efficient energy source and may allow for higher power outputs.

There are several gaps in the existing literature surrounding cluster sets as a programming tactic. To our knowledge, there is only one semi-long-term training study using cluster loading. This study by Morales et al (2017) was only three weeks in duration and compared the effects of cluster and traditional loading on force-velocity profiles of counter movement jumps. The results of this study found no significant differences between the two conditions (P= 0.207, ES = 0.31) but suggested that training with cluster loading is more effective at inducing velocity and power adaptations (Morales et al., 2017). Additionally, many of the studies cited in this review utilized machine-based exercises which is not indicative of typical strength and conditioning settings where cluster loading would most likely be used (Denton & Cronin, 2006; Drinkwater et al., 2007; Folland et al., 2002; Ganzález-Badillo et al., 2014; Gorostiaga et al., 2010; Gorostiaga et al., 2012; Iglesias-Soler et al., 2012; Iglesias-Soler et al., 2016; Mayo et al., 2014; Morales et al., 2017; Oliver et al., 2016; Oliver et al., 2015; Sánchez & González-Badillo, 2011). Lastly, the means of estimating power outputs must be carefully considered when interpreting the results of many existing studies. Cormie et al (2007a) assert that only utilizing kinematic data leads to over-estimation of power outputs while relying on kinetic data only may lead to under-estimation. The authors claim that both kinetic and kinematic data should be integrated to accurately estimate power. Of the included studies in this review, only eight studies integrated both kinetic and kinematic data measurement to estimate power (Gorostiaga et al., 2010; Gorostiaga et al., 2012; Hardee et al., 2012a; Hardee et al., 2012b; Moir et al., 2013; Oliver et al., 2016; Oliver et al., 2015; Tuffano et al., 2016a; Tuffano et al., 2016b).

CHAPTER 2

CLUSTER SET LOADING IN THE BACK SQUAT: KINETIC AND KINEMATIC IMPLICATIONS

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TITLE: CLUSTER SET LOADING IN THE BACK SQUAT: KINETIC AND KINEMATIC IMPLICATIONS.

<u>Abstract</u>

As athletes become well-trained, they require greater stimuli and variation to force adaptation. One means of adding additional variation is the use of cluster loading. Cluster loading involves introducing inter-repetition rest during a set which in theory may allow athletes to train at higher absolute intensities for the same volume. The purpose of this study was to investigate the kinetic and kinematic implications of cluster loading as a resistance training programming tactic compared to traditional loading. Eleven resistance trained males (age=26.75±3.98 yrs., Height=181.36±5.96 cm, Body Mass=89.83±10.66 kg, Relative Squat Strength=1.84±0.34) were recruited for this study. Each subject completed two testing sessions consisting of three sets of five back squats at 80% of their one repetition maximum with three minutes of inter-set rest. Cluster loading included 30s of inter-repetition rest with three minutes of inter-set rest. All testing was performed on dual-force plates sampling at 1000 Hz and the barbell was connected to four linear position transducers sampling at 1000 Hz. Paired Samples t-tests were used to determine differences between conditions with Cohen's d effect sizes describing the magnitudes of any differences. Both conditions had similar values for peak force, concentric and eccentric average force ($p=.25$, ES = 0.09, $p=0.25$, ES = 0.09, $p=0.60$, ES = 0.04 respectively). Cluster loading had significantly higher peak power ($p<0.001$, ES =0.77), peak and average velocities ($p<0.001$, ES=0.77, $p<0.001$, ES=0.81 respectively), shorter times to peak power and velocity (($p<0.001$, ES=-0.68, $p<0.001$, ES=-0.68 respectively) as well as greater maintenance of time to peak power ($p<0.001$, ES=1.57). These results suggest cluster loading may be superior to traditional loading when maintaining power output and timepoint variables is the desired outcome of training.

Key Words: Training, Rest, Strength and Conditioning, Performance

INTRODUCTION

Over the past several years, new advanced training (AT) methods have been proposed. These AT include accentuated eccentric loading, contrast sets, complex sets and cluster sets. Cluster sets (CS) use short rest periods between repetitions as well as typical rest periods between sets (14,15). According to the SAID (specific adaptation to imposed demands) principle, changing variables within the application of an exercise elicits a specific response and subsequent adaptation given adequate recovery is provided (36). Thus, intra-set rest theoretically could allow CS to induce different adaptations to training by allowing for heavier loading at the same training volume (strength), potentiate explosiveness and power adaptations by maintenance of forces, rate of development (RFD), velocity, or power at a given load (5,14,16,17,19,21,23,24,29,31,32,33,38,39). Thus, CS training could be useful for a variety of purposes such as enhancing the training effect by offering a greater stimulus or varying the stimulus to promote further adaptation. For example, training over a few years with little variation, such as can occur with maintaining traditional protocols (TP), can limit gains and cause stagnation (36). Introduction of CS could produce an adaptive stimulus allowing further gains in strength, RFD etc. During peaking phases aimed at improving power, CS training could enhance P output. Thus, CS training could be quite valuable for several aspects of the training process and possibly promote more consistent and perhaps superior gains when used appropriately.

Traditional loading (TL) schemes are believed to enhance adaptation, at least partly through acute fatigue. Acute fatigue could enhance motor unit recruitment (23), increase muscle (and whole body) metabolism and metabolite production (9,10,12,13,21,22,32,33,36) both of which may enhance adaptation to training (36). However, fatigue and increased production of metabolites as a primary stimulus for increased strength and power have both been questioned (7,9). Folland et al. (9) found that higher levels of training induced fatigue (4x10 to failure) did not provide additional benefits compared to a low fatigue protocol (40x1) with 30s of inter-repetition rest designed to minimize metabolic

accumulation. Additionally (Folland et al.) noted a tendency towards greater high-velocity gains in the low fatigue protocol; suggesting that velocity and perhaps power would be higher with greater inter-repetition rest. Indeed, further study on CS has demonstrated increased, or maintained force, RFD, velocity and power for CS compared to TP (5,14,16,17,19,21,23,24,29,30,32,33,38,39).

Although CS protocols have been previously investigated, there are few studies describing both kinetic and kinematic characteristics and there are a number of limitations in these studies. A number of intra-set rest periods and exercises have been used (5,7,9,10,14,15,16,17,18,19,21,22,23,24,25,26,29,30,31,32,33,38,39). Many of the existing studies investigated CS using machines, which could alter normal technique and may not be indicative of a typical athletic setting in which CS would be logically used. Studies (7,12,13,30,31,33) used untrained subjects which also may limit generalizability to trained populations. Additionally, most studies used only one type of instrumentation or used solely kinetic or kinematic data to study CS which may have created errors in calculation of variables, especially power. For example, Cormie et al. (1) indicate that using only kinetic data (e.g. force plate) may result in underestimating power while relying solely on kinematic data (e.g. potentiometers) can result in overestimation. Combining both kinetic and kinematic data appears to be superior when investigating force and related variables such as RFD, velocity and power (1).

The back squat is a commonly performed exercise, particularly in athletic settings. To the authors' knowledge, only one previous study has used a combination of kinetic and kinematic data to study the squat in previously trained subjects using CS (38,39). The results indicate that CS can enhance maintenance of force related variables compared to TP.

The purpose of this study was to compare CS and TP training schemes in well-trained subjects. Both kinetic and kinematic collected data will be used to investigate the effects of CS as a programming tactic.

METHODS

Experimental Approach to the Problem

The barbell back squat was chosen for this study because it a widely used exercise in strength and conditioning and has similar biomechanical and neuromuscular characteristics to a variety of sporting activities (6,27,36). All subjects completed one pre-testing session and two experimental testing sessions. During the pre-testing session, subjects were tested on their one-repetition maximum in the back squat to establish experimental loads. Three days separated one-repetition maximum testing and experimental conditions. The cluster and traditional loading experimental conditions were randomly assigned with seven days separating the first and second testing session. Each experimental testing session was completed at the same time of day. A within-subject design was used to test the effect of rest-distribution on kinetic and kinematic performance variables.

Subjects

Eleven male subjects (age = 26.1 ± 4.1 years, height = 183.5 ± 4.3 cm, body mass = 92.5 ± 10.5 kg, back squat to body mass ratio = 1.8 ± 0.3) were recruited for this study. All subjects were required to have at least one year of resistance training experience with the back squat, be able to squat at least 1.3x their body weight and have no major injuries within the previous three months. After explaining the risks and benefits of the study, all subjects signed informed consent documents before participation in accordance with the Institutional Review Board of the university.

Procedures

Body Composition

Body composition was estimated by a certified ISAK anthropometrist using skinfolds and Harpenden skinfold calipers (Baty International, West Sussex, United Kingdom). Skinfold sites were: subscapular, triceps, chest, midaxillary, abdomen, iliac crest, and quadricep.

Maximum Strength Testing

Prior to each maximal strength testing session, each subject completed a standardized warm-up. Subjects reported self-estimated one-repetition maximums on which warm-up repetitions were set. Warm-up repetitions began at 30% of their estimated maximum and ranged to 90% (Table 1). Subjects then performed their 1RM using a protocol modified from McBride et al. (2002) and Suchomel et al. (2015) (26,35). The first recorded trial was at 90% of their reported 1RM and jumps were made by 2.5-5% until a maximum was reached. Full depth was defined as the subjects hip crease being below the patella and was verified by multiple certified strength and conditioning specialists.

Table 2.1. Back squat warm-up	
Sets x repetitions x intensity (% 1RM)	Rest interval
1x5x30%	1 min
1x3x50%	1 min
1x2x70%	2 min
1x1x80%	3 min
1x1x90%	3 min
1RM attempts	3 min

Experimental Conditions

All subjects completed an identical standardized dynamic warm-up to the 1RM testing. Subjects were randomly assigned to either the traditional set or cluster set condition at least 2 days following the 1RM testing. The opposite testing condition was separated by one week. Subjects completed 3x5 sets at 80% of the established 1RM with three minutes rest between sets in the traditional loading (TL) condition. For the cluster condition (CL), 30s of inter-repetition rest was given with three minutes inter-set rest.

Subjects were instructed to stand up as explosively as possible from the bottom of the squat. Depth was confirmed by multiple certified strength and conditioning specialists.

Instrumentation

Data was collected using dual force plates (2 x 91 cm x 45.5 116 cm force plates, RoughDeck HP, Rice Lake, WI) sampling at 1000 Hz while connected to four linear position transducers (PT101-0100-H14-1120, Celesco Measurement Specialties, Chatsworth, CA) to collect kinematic data. All data was simultaneously integrated into LabVIEW (version 7.1, National Instruments.

Data Analysis

All data was analyzed using a custom-designed application (R Studio vers. 3.4.1.) Kinetic variables analyzed included: peak power, peak force, average power, average force, and total work. Kinematic variables included: peak velocity, average velocity, time to peak power (TTPP), and time to peak velocity (TTPV). Paired sample t-tests were used to determine effects of condition on the above listed variables. Cohen's d effect sizes were calculated for each dependent variable to determine the magnitude and meaningfulness of the differences between dependent variables across load conditions. For practical significance, effect sizes were interpreted with magnitude thresholds of 0-0.2, 0.2-0.6, 0.6-1.2, 1.2-2.0, and 2.0 and above as trivial, small, moderate, large, and very large (20). Percent changes were calculated as the change in value from repetition one to repetition five of each set and were averaged across all subjects. Statistical analysis was performed using a statistic software package (JASP vers. 0.8.2.0. Significance was defined as a p-value of $p \leq 0.05$.

RESULTS

Kinetic Variables

There were no significant differences across all sets in peak force (p=0.25, ES = 0.09) or average Force (p=0.25, ES = 0.09) between conditions. Cluster loading conditions did have statistically higher

total work across all sets than traditional loading conditions (p<0.001, ES =0.28). Additionally, Cluster

loading had a very large effect on Peak power (p<0.001, ES = 0.77). Kinetic results are shown in Table 2.

Traditional loading had statistically larger peak power losses across all sets compared to cluster loading

(p=0.005, ES=0.52) with average losses of 8.5%, 9.3% and 8.3% compared to 3.3%, +3.0% and 4.1%

across sets 1, 2, and 3, respectively. Peak Power changes across all three sets are shown seen in Figure

1.

Figure 2.1 Peak power changes across three sets
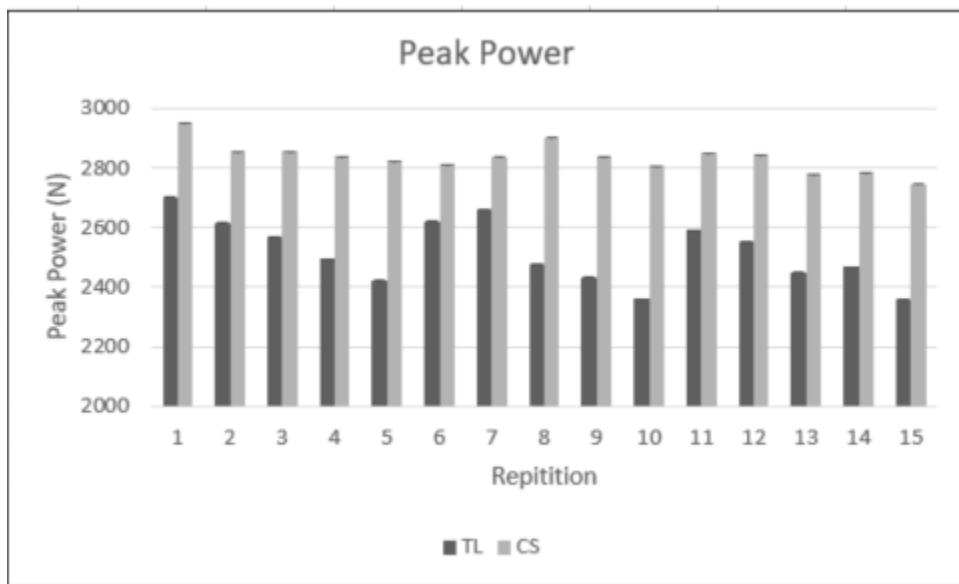
Table 2.2 Full-Rep kinetic variables

	Traditional Loading Mean	Cluster Loading Mean	P-Value	Effect Size (Cohen's d)
Peak Force (N)	3002	3012	0.249	0.091
Peak Power (W)	2518	2834	<0.001	0.770
Total Work	3035.674	3068.183	<0.001	0.279

Kinematic Variables

Clusters displayed statistically higher peak velocities (p<0.001, ES=0.77), and average velocities

(p<0.001, ES=0.81). Additionally, clusters had statistically lower times to peak power (p<0.001, ES=-0.68)

and peak velocity (p<0.001, ES=-0.68) compared to traditional loading. Complete kinematic results are listed in Table 3. Traditional loading showed statistically greater increases in time to peak power (p<0.001, ES=1.57) across all sets when compared to cluster loading with average increases of 31.6%, 37.5% and 38.4% for sets 1, 2, and 3, respectively whereas cluster loading conditions displayed only 6.5%, 9.3%, and 11.6% increases for sets 1, 2, and 3, respectively. Traditional loading conditions also demonstrated larger, although non-statistically significant, increases in time to peak velocity (p=.329, ES=0.17) with average increases of 30.3%, 35.9% and 36.5% for sets 1, 2, and 3, respectively whereas cluster loading showed only 6.2%, 9.2% and 11.4% % increases for sets 1, 2, and 3, respectively. Changes in time to peak power and velocity are shown in Figures 2 and 2 respectively.

Table 2.3 Kinematic Variables

	Traditional Loading Mean	Cluster Loading Mean	P-Value	Effect Size (Cohen's d)
Con. Peak Velocity (m/s)	1.013	1.106	<0.001	0.767
Con. Average Velocity (m/s)	0.489	0.541	<0.001	0.805
Con. Peak Acceleration (m/s^2)	4.292	4.421	0.030	0.172
Con. Average Acceleration (m/s^2)	-0.006	-0.007	0.002	0.241

| Time to Peak Power (s) | 1.267 | 1.134 | <0.001 | 0.682 |
| Time to Peak Velocity (s) | 1.311 | 1.178 | <0.001 | 0.684 |

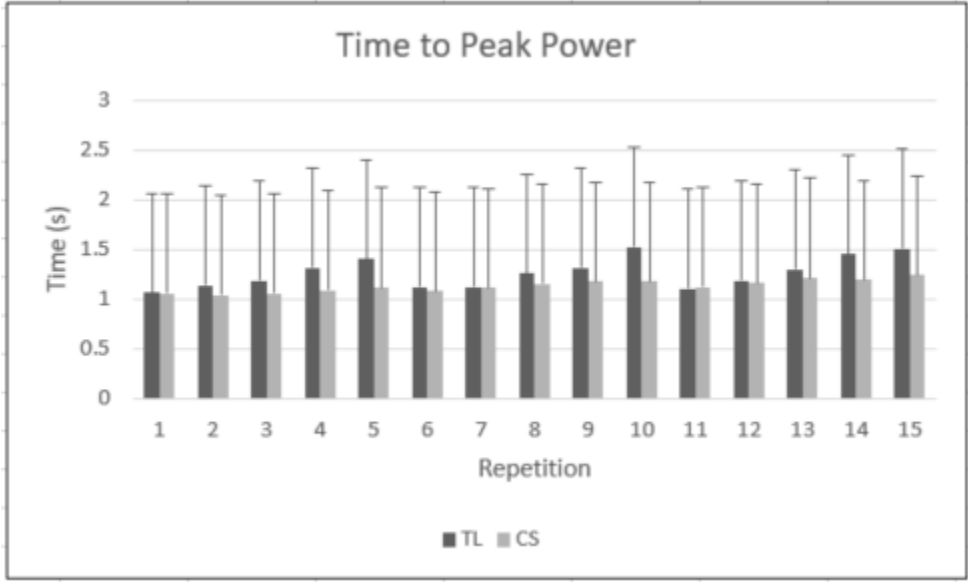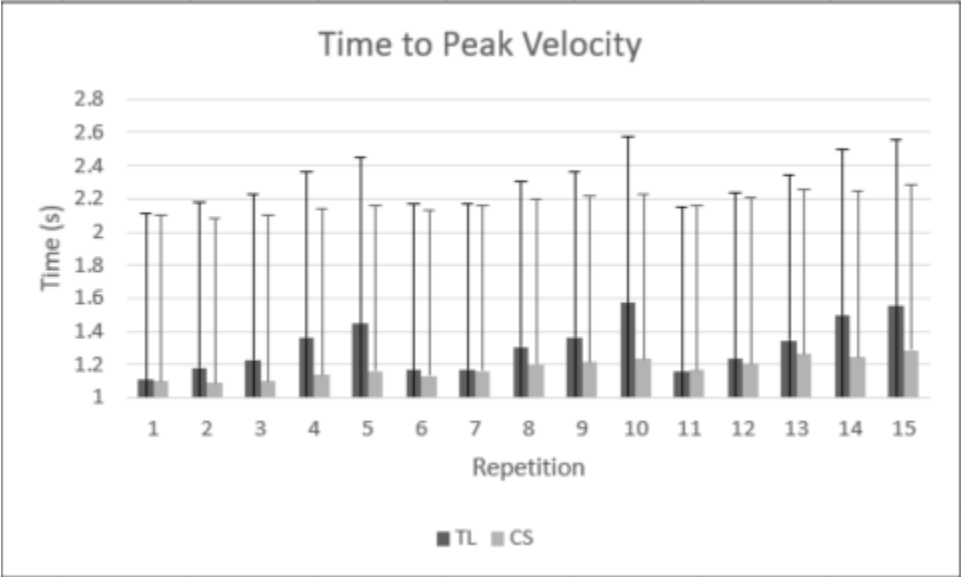Figure 2.2 Changes in time to peak power across three sets

Figure 2.3 Changes in time to peak velocity across three sets

Discussion

        This study is only the second study to the authors' knowledge that has investigated both kinetic and kinematic variables during cluster loading of the barbell back squat (36,37)**.** Cormie et al. suggest using only kinetic data may underestimate power output while relying on kinematic data may result in overestimation in the back squat, power lean and jump squat (1). Therefore, we used a combination of both kinetic and kinematic data to best estimate power outputs. Additionally, many previous studies have used machines for testing, however this may cause alterations in exercise technique and may not accurately reflect how most athletic populations train (5,21,22,26,32,33,34).

        The results of our study support the hypothesis that cluster set loading would produce higher peak and average power outputs, and velocities when compared to traditional loading**.** Tuffano et al. found similar results with cluster sets showing greater peak and mean velocity, peak and mean power with compared to traditional (38, 39)**.** Because of the effect on power, cluster sets may prove to be a valuable tool to enhance power, particularly during the later stages of a sequential training plan that emphasizes power production (6,36). Evidence has consistently shown that stronger athletes are more powerful then weaker athletes (36,37)**.** The inclusion of cluster sets once the focus of training has shifted towards power development warrants consideration.

        This leads us to consider what the mechanism is that allows regeneration of power with inter-set rest. It has been suggested that cluster sets allow partial or complete regeneration of Phosphocreatine (PCr) to better maintain power output (12,13,14). This is supported by Matuszak et als. finding that very short rest intervals as low as one minute are sufficient to repeat 1RM attempts (25). It is commonly known that high intensity exercise relies on ATP as its main energy source. However, these energy stores are limited and may be depleted during resistance training. PCr helps to sustain this energy system but is also limited and may be depleted. Therefore, it is possible that inter-set rest may allow partial replenishment of PCr which is a more efficient energy source and may allow for higher

power outputs. It has also been reported that lactate values are higher for TL than CS suggesting a reliance on anaerobic glycolysis for energy (5,10,33). Gorostiaga also reported higher reliance on lactate during the last five repetitions in a set of ten (12). These data support the claim that CS would allow less metabolic disturbance than TL.

Cluster set loading may provide beneficial training adaptations, especially for athletic populations. The results of this study and others suggest that cluster set loading consistently demonstrates greater peak and average power outputs when compared to traditional loading. Although these findings are acute, chronic adaptations to cluster loading have been previously investigated (30). Morales et al. showed three weeks of cluster training in the counter-movement jump caused greater adaptations in velocity and power (30). Additionally, athletes must be sure to maximize movement intent when trying to stimulate beneficial training adaptations (11). Percent changes are calculated as the change in a variable from the start to the end of each set. Gonzales and colleagues showed greater gains in 1RM, and average velocity in the bench press when training with maximal intent (11). In a later study, Gonzales and colleagues also showed training with maximal intent may have caused beneficial changes in myosin heavy chain isoforms, excitability, firing rate, neural drive etc., all of which support the development of power (11). Lastly, because many sports are time-limited (e.g. ground contact times in sprinting etc.), time to peak power (TTPP) and time to peak velocity (TTPV) are important to consider. Because of their greater maintenance of both TTPP and TTPV they allow athletes to train in a more explosive manner for the entirety of the set. As mentioned earlier, this may also lend support for the inclusion of traditional sets earlier in a training year and cluster sets later in a sequential phase of the training year. Traditional sets cause athletes to spend more time accelerating the bar, as seen in their longer TTPP and TTPV. This would seem to support the goals of strength endurance and general strength development. As you approach the later stages of a periodized model, shorter TTPP and TTPV are desired as the emphasis of training has shifted towards speed-strength development.

One limitation of the current study is that we investigated only one repetition scheme and one inter-repetition rest interval. Many possible configurations of cluster sets can be used. Others have previously investigated cluster sets of different configurations but utilized different rest-intervals (5,7,10,14,15,16,17,18,19,20,25,31). Future investigation should be performed to determine the optimal set and rest interval configurations to maximize training adaptations.

<u>Practical Application</u>

This study provides insight into a means of manipulating training variables to achieve the desired adaptations to training. In keeping with the principle of specificity, coaches wanting to maximize power should use programming tactics which emphasize power output. Cluster sets may provide a means of developing strength while maximizing power output by using greater absolute loads for the same volume as TL. This study demonstrates that cluster set loading maximizes power output via greater velocity both within and across sets. Therefore, cluster sets may provide a means of directing training towards greater power development. Coaches may consider utilizing cluster sets during training phases in which power is the desired training goal.

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CHAPTER 3

SUMMARY AND FUTURE DIRECTIONS

The purpose of this study was to investigate the effects of both cluster and traditional loading schemes on kinetic and kinematic outputs in the back squat. To the authors knowledge, this is only the second study that has investigated both kinetic and kinematic effects of CS in the back squat. The results of this study indicate that CS had statistically greater total work ($p<0.001$, ES=0.28), peak power ($p<1.001$, ES=0.77), peak velocity ($p<0.001$, ES=0.77), average velocity ($p<0.001$, ES=0.81). CS also had lower times to peak power ($p<0.001$, ES=0.68) and times to peak velocity ($p<0.001$, ES= 0.68). Additionally, TL had statistically greater increases in times to peak power across all sets ($p<0.001$, ES=1.57) indicating the onset of fatigue across a set. The results of this study expand upon the findings of previous studies by providing a complete description of the kinetic and kinematic effects of CS and may help the application of this programming tactic. These results suggest that CS provides a greater acute stimulus when strength and power adaptation is the desired outcome of training.

Power is widely considered the most important factor relating to sporting success (Stone et al., 2007). Because of their greater power and velocity outputs, CS may be a useful programming tactic during a training phase which is aimed at enhancing these qualities. Additionally, greater maintenance of timepoint variables in CS may further enhance the acute stimulus of resistance training.

In the current study, only one set and repetition scheme were investigated. Future studies dealing with the effects of CS should investigate other set and repetition schemes to determine the optimal configuration. Additionally, this study only investigated one rest interval. Many possible rest intervals are commonly used in strength and conditioning settings and should be further studied to determine the interval which maximizes the beneficial effects of CS. Lastly, there was no direct investigation into the mechanism behind the enhanced outputs of CS. It has previously been suggested that partial regeneration of PCr may contribute to these effects, but this claim warrants further study.

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