Archived version from NCDOCKS Institutional Repository http://libres.uncg.edu/ir/asu/

Appalachian State University
BOONE, NORTH CAROLINA

Effect of cluster set configurations on power clean technique

Authors
Justin P. Hardee, Marcus M. Lawrence, **Kevin A. Zwetsloot**, N. Travis Triplett, Alan C. Utter, & Jeffrey M. McBride

Abstract

The purpose of this investigation was to examine the effects of cluster set configurations on power clean technique. Ten male, recreational weightlifters performed three sets of six repetitions at 80% of one repetition max with 0 (P0), 20 (P20) or 40 seconds (P40) inter-repetition rest. During the first and second set of P0, the catch and first pull were in a more forward position during repetition 6 as compared to repetition 1, respectively. During the second set of P40, differences in horizontal displacement were found between repetitions 1 and 6 for the second pull and the loop. During the third set of P40, differences in horizontal displacement were found between repetitions 1 and 6 for the first pull, transition, and beginning of the second pull. No differences in horizontal displacement were found between repetitions 1 and 6 during P20. During each set of P0, vertical displacement decreased between repetitions 1 and 6 (1.02 + 0.07 m vs. 0.94 + 0.06 m; Mean + s). Cluster set configurations led to the maintenance of vertical displacement throughout all sets. The results demonstrate cluster set configurations with greater than 20 seconds inter-repetition rest maintain weightlifting technique to a greater extent than a traditional set configuration

Justin P. Hardee, Marcus M. Lawrence, **Kevin A. Zwetsloot**, N. Travis Triplett, Alan C. Utter, & Jeffrey M. McBride(2013) "Effect of cluster set configurations on power clean technique" *Journal of Sports Sciences* Vol. 31, No. 5, pg. 488–496 Version of Record Available @ (http://dx.doi.org/10.1080/02640414.2012.736633)

Effect of cluster set configurations on power clean technique

JUSTIN P. HARDEE, MARCUS M. LAWRENCE, KEVIN A. ZWETSLOOT, N. TRAVIS TRIPLETT, ALAN C. UTTER, & JEFFREY M. MCBRIDE

Neuromuscular and Biomechanics Laboratory, Department of Health, Leisure and Exercise Science, Appalachian State University, Boone, North Carolina, USA

(Accepted 1 October 2012)

Abstract

The purpose of this investigation was to examine the effects of cluster set configurations on power clean technique. Ten male, recreational weightlifters performed three sets of six repetitions at 80% of one repetition max with 0 (P0), 20 (P20) or 40 seconds (P40) inter-repetition rest. During the first and second set of P0, the catch and first pull were in a more forward position during repetition 6 as compared to repetition 1, respectively. During the second set of P40, differences in horizontal displacement were found between repetitions 1 and 6 for the second pull and the loop. During the third set of P40, differences in horizontal displacement were found between repetitions 1 and 6 for the first pull, transition, and beginning of the second pull. No differences in horizontal displacement were found between repetitions 1 and 6 during P20. During each set of P0, vertical displacement decreased between repetitions 1 and 6 (1.02 + 0.07 m vs. 0.94 + 0.06 m; Mean + *s*). Cluster set configurations led to the maintenance of vertical displacement throughout all sets. The results demonstrate cluster set configurations with greater than 20 seconds inter-repetition rest maintain weightlifting technique to a greater extent than a traditional set configuration.

Keywords: *bar path, fatigue, resistance exercise*

Introduction

Stone, O' Bryant, Pierce, Williams, and Johnson (1998) have demonstrated a relationship between barbell kinematics and successful attempts during weightlifting competition in the snatch. In addition, Winchester, Erickson, Blaak, and McBride (2005) have shown that changes in certain bar path variables in training were associated with increased power output in the power clean (Winchester et al., 2005). Therefore, it appears displacement of the barbell is of importance during weightlifting movements in terms of maximising power output, which is a common goal in the utilization of the power clean in training for improvements in power for athletic performance. It is generally accepted that fatigue induces detrimental effects on exercise performance through manipulations to motor control, and ultimately technique (Halil et al., 2009). Thus, training with multiple repetitions and sets to failure with limited rest periods may result in decreased technique proficiency during weightlifting movements and may have a negative effect on power output during each repetition. The use of a cluster set confirmation may assist in reducing fatigue and maintaining weightlifting technique and power output during training.

Numerous studies have evaluated technique in the weightlifting movements during single repetition efforts primarily in the snatch (Baumann, Gross, Quade, Galbierz, & Schwirtz, 1988; Burdett, 1982; Canavan, Garret, & Armstrong, 1996; Frolov, Lellikov, Efimov, & Vanagas, 1979; Isaka, Okada, & Funato, 1996). The most common variables that have been identified have been labelled as DxL, DxT, Dx2 and DxV (Stone et al., 1998; Winchester et al., 2005; Winchester, Porter, McBride, 2009). The first variable is the difference between the most forward position during the second pull and the catch position (DxL). The second variable is the difference between the start position and the catch position (DxT). The third variable is the difference between the start position and the beginning of the second pull (Dx2). The final variable is the difference between the beginning of the second pull and the most forward position during the second pull (DxV). A representative figure of the horizontal displacement variables has been previously published and discussed elsewhere (Stone et al., 1998; Winchester et al., 2005; Winchester et al., 2009). Stone et al. (1998) proposed in the snatch that backward movement of the barbell was typically associated with a successful attempt. This was indicated by a negative DxT value (occurring in 76% of successful attempts) and a catch position behind the starting position. Furthermore, it was reported that if forward displacement of the barbell from the start to the most forward position during the second pull (DxV) was greater than 10 cm, then the resulting catch position would be in front of the starting position and resulted in an unsuccessful attempt 64% of the time (Stone et al., 1998). In addition, excessive looping (DxL) was also associated with unsuccessful attempts as well. Thus indicating rearward motion of the barbell (Dx2 4 2 cm) during the first pull, followed by minimal looping (DxL 5 20 cm) of the barbell after the second pull as important variables for successful weightlifting attempts (Stone et al., 1998).

It should be noted, as mentioned above, that the variables previously described have been primarily analysed in relationship to the snatch and not the power clean (Stone et al., 1998). The snatch in comparison to the power clean, in general, involves larger DxT values and a lower second pull position (Häkkinen & Kauhanen, 1986; Stone et al., 1998). In addition, vertical bar displacement is much higher in the power clean in comparison to the snatch (Häkkinen & Kauhanen, 1986). In the current investigation, the variables examined were not necessarily utilized in the context of a successful or unsuccessful attempt but rather in barbell displacement variations that might occur with fatigue and thus subsequent decreases in power output. As shown previously, certain changes in weightlifting technique have been associated with increased power output in not only the snatch but in the power clean as well (Winchester et al., 2005). For example, increased power output during the power clean at 90% of one repetition max (1RM) after training (pre ¼ 3462 + 1172 W, post ¼ 3710 + 1225 W) has been associated with a significant increase in the displacement between the start and finish positions (DxT; pre ¼ 70.068 + 0.015 m, post ¼ 70.195 + 0.039 m) and the displacement between the start and second pull positions (Dx2; pre ¼ 70.063 + 0.086 m, post ¼ 70.085 + 0.024 m). In addition, a significant decrease in the displacement between the beginning and finish of the second pull was observed (DxV; pre ¼ 0.131 + 0.092 m, post ¼ 0.089 + 0.071 m). Thus, opposite changes in these variables during a power clean might represent a negative trend associated with decreased power output (Winchester et al., 2005). Therefore, the bar path outlined by Stone et al. (1998) and utilized by Winchester et al. (2005, 2009) serves as a template by which comparisons to weightlifting technique and associated changes in power output can be made. Thus, the effects of cluster set configurations on weightlifting technique can be quantified using horizontal (DxL, DxT, Dx2 and DxV) and vertical displacement values in the power clean exercise.

As mentioned previously, it is thought fatigue may affect exercise and athletic performance through changes in motor control, and ultimately technique (Halil et al., 2009). Halil et al. (2009) found postural balance to be impaired following fatiguing exercise in collegiate volleyball players. Gabbett (2008) also demonstrated reductions in tackling technique under fatigued conditions. Interestingly, individuals with the best tackling technique during non-fatigued states demonstrated the greatest decrements in technique with fatigue (Gabbet, 2008). Stone and Oliver (2009) found decreased kicking performance in fatigued soccer players. Similarly, Apriantono, Nunome, Ikegami, and Sano (2006) demonstrated reduced leg swing speed and poorer ball contact during instep kicks with fatigue in soccer players. Therefore, it was suggested reduced muscular force and ineffective inter-muscular coordination (i.e., technique) may play a role in decreased kicking performance when fatigued (Apriantono et al., 2006). Lastly, Madigan and Pidcoe (2003) demonstrated decreased vertical ground impact forces and increased maximum joint flexion during landing with fatigue. This finding may indicate fatigue induces changes to landing strategies (i.e., technique) which can lead to decreased performance. Collectively, the aforementioned studies clearly demonstrate an inverse relationship between fatigue and sports performance through alterations to technique.

It is believed fatigue may induce manipulations to lifting technique (Sakamoto & Sinclair, 2006), however few studies have examined these effects. Chen (2000) found lifting strategies to be altered following arm fatigue, which resulted in higher L5/S1 compression forces (Chen, 2000). The authors suggest altered lifting mechanics may put individuals at a greater risk for injury during fatigued conditions (Chen, 2000). With regards to resistance exercise, Duffey and Challis (2007) examined the effects of fatigue on bench press kinematics and found lifters to keep the barbell more directly over the shoulder in latter repetitions as compared to the initial repetitions. The authors also found increased measures of bar path straightness, the length of the path the bar traveled and the maximal deviation from a straight line, as the participants progressed through the set. It was suggested that if the kinematics of a lift at the end of a set are different from the desired movement pattern, it may not be beneficial to train to muscular fatigue (Duffey & Challis, 2007). Taken collectively, these studies demonstrate fatigue induced changes to lifting technique that have negative consequences on exercise performance, and could possibly increase the risk of injury.

With the understanding of the effects of fatigue on exercise technique, it is apparent why methods to minimise fatigue are of interest during exercise training. Recently, cluster set configurations have become of interest for the attenuation of fatigue and maintenance of kinetic and kinematic variables during resistance exercise. This training method employs taking brief periods of rest (15 – 45 seconds) between repetitions (Haff et al., 2003; Hardee, Lawrence et al., 2012; Hardee, Triplett, Utter, Zwetsloot, & McBride, 2012; Lawton, Cronin, & Lindsell, 2006). It has been theorized that performing repetitions in a continuous fashion without rest (traditional set configuration) will lead to decreases in kinetic and kinematic variables; whereas, a cluster set configuration (rest taken between repetitions) would lead to maintenance of these variables (Haff et al., 2003). Indeed, Haff et al. (2003) demonstrated that a cluster set produced significantly higher barbell velocities (90% and 120% of 1RM) and displacement (120% of 1RM) when compared to a traditional set configuration in the clean pull. Lawton et al. (2006) found greater mean power output across six repetitions in the bench press exercise with the use of a cluster set when compared to a traditional set configuration. Furthermore, Hardee, Triplett et al. (2012) demonstrated that cluster set configurations attenuate fatigue and allow for the maintenance of power, force, and velocity over multiple sets and repetitions in the power clean exercise. These studies demonstrate the importance of cluster set configurations for the attenuation of fatigue and maintenance of exercise performance when training for power; how- ever the aforementioned studies did not examine the effects on exercise technique. To date, the effects of a cluster set configuration on exercise technique in the weightlifting movements are unknown. Therefore, the purpose of this investigation was to examine the effects of cluster set configurations on power clean technique.

Methods

Participants

Ten male, recreational weightlifters participated in this study (age ¼ 23.6 + 1.1 years; body mass ¼ 80.3 + 2.8 kilograms; height ¼ 1.7 + 0.01 metres; power clean 1RM/body mass ¼ 1.39 + 0.03; mean + *s*). Participants had at least 4 years of weight training experience, 1 year of weightlifting experience, and were required to display proper technique of the power clean for participation in this study. Power clean technique was visually assessed without verbal cues or feedback by a certified strength and conditioning specialist prior to participation. In addition, participants were asked to refrain from strenuous activities and maintain normal dietary habits between each session. All participants read and signed a written informed consent approved by the Institutional Review Board at Appalachian State University.

Experimental design

Preliminary testing: session 1. All participants reported to the Neuromuscular & Biomechanics Laboratory at Appalachian State University for session 1 after refraining from strenuous exercise for a minimum of 72 hours. During this time participants were measured for height and weight, and a one repetition maximum (1RM) in the power clean exercise was determined. Power clean 1RM testing was performed as previously described (Hardee, Lawrence et al., 2012; Hardee, Triplett et al., 2012; Winchester et al., 2005). Briefly, participants underwent a series of warm-up sets (i.e., per cent of predetermined 1RM) and several maximal lifts until a 1RM was achieved. The predetermined 1RM was based on the participants previous strength and power training phase. It should be noted that all participants obtained a 1RM greater than their pre-determined 1RM. Proper technique of the power clean was assessed as previously described (Baumann et al., 1988; Burdett, 1982; Frolov et al., 1979; Garhammer, 1984; Isaka et al., 1996; Winchester et al., 2005).

Protocol testing: sessions 2–4. In a randomized order, each participant completed three testing sessions over a period of two weeks. During sessions 2 – 4 participants performed three sets of six repetitions at 80% of 1RM with 0 (P0), 20 (P20), or 40 (P40) seconds inter-repetition rest. Cormie, McBride, and McCaulley (2007) have shown 80% of 1RM to be the optimal load for peak and average power output in the power clean. Three minutes rest was given between sets and testing sessions were separated by a minimum of 72 hours to allow for complete recovery. Power cleans were performed with an Olympic barbell (Werksan Barbells; Moorestown, NJ) starting from the floor with each repetition. Upon completion of the catch and recovery the bar was lowered to the floor in a controlled manner and reset as quickly as possible. Inter-repetition and inter-set rest periods were started upon recovery from the catch position. Participants were verbally informed of the time remaining during each inter-repetition and inter-set rest period for each protocol. In addition, participants were encouraged to give maximal effort with each repetition; however no verbal or visual feedback was given regarding technique proficiency.

Instrumentation

Kinetic and kinematic data was collected and analysed as previously described (Cormie et al., 2007). Briefly, testing was conducted with participants standing on a lifting platform with two linear position transducers (2-LPT) (Celesco PT5A-15; Chatsworth, CA) attached to the right side of the barbell. Analogue signals from the 2-LPT were collected at 1000 Hz using a BNC-2010 interface box with an analogue-to-digital card (National Instruments PCI-6014; Austin, TX). The voltage outputs from the 2-LPT were converted to horizontal displacement (*m*). LabVIEW (National Instruments, Version 8.2) software was used to create programs used for data collection and analysis. Horizontal and vertical displacements were recorded for each repetition of each protocol. Horizontal and vertical average curves were generated for repetitions 1 and 6 within each set for each protocol and were used in analysis.

Average curves

A program created using LabVIEW allowed for the number of samples in each individuals horizontal and vertical displacement curve to be modified to equal 500 samples by changing the time delta (dt) between samples and re-sampling the signal (dt ¼ number of samples in the original signal/500). Consequentially, the frequency of the modified signals was then equivalent to a range of 293 to 502 Hz. This re-sampling allowed for the horizontal and vertical displacement curves to be expressed over equal periods of time (i.e. the 500 samples represented relative time). Each sample from the modified horizontal and vertical displacement was then averaged across all participants involved within a particular condition. This resulted in averaged curves consisting of a mean and standard deviation for each data point within the graphic representation of the barbell displacement for statistical comparison between repetitions 1 and 6 within each set of each condition (P0, P20, P40).

Statistical analysis

Due to the unique representation of the barbell displacement for each condition as an average curve, the required analysis involved a Student's *t*-test to compare each data point within the average curve for horizontal displacement between repetitions 1 and 6 of the same set of each protocol (P0, P20, P40). A Student's paired *t*-test was used to determine statistical differences between peak vertical displacement, DxL, DxT, Dx2, and DxV for repetitions 1 and 6 within each set of each protocol. Statistical analysis was performed using SPSS version 17.0 (SPSS Inc., Chicago, IL.) with significance set at *P* ::; 0.05.

Results

The effect of cluster set configurations on horizontal displacement of the barbell during multiple sets and repetitions of the power clean are presented in Figures 1 – 3. Significant differences in horizontal displacement were found between repetitions 1 and 6 for the first and second set of P0. During the first set of P0, the catch position in repetition 6 is in a more forward position as compared to repetition 1 (Figure 1A; *P* ::; 0.05). In addition, during the second set of P0 the first pull is in a more forward position during repetition 6 as compared to repetition 1 (Figure 1B; *P* ::; 0.05). No differences were found between repetitions 1 and 6 with a cluster set configuration utilising 20 seconds inter-repetition rest (P20; Figures 2A – C). During the second set of P40, differences in horizontal displacement were found between repetitions 1 and 6 (Figure 3B). The second pull and loop was in a more forward position during repetition 6 compared to repetition 1 (*P* ::; 0.05). During the third set of P40, differences in horizontal

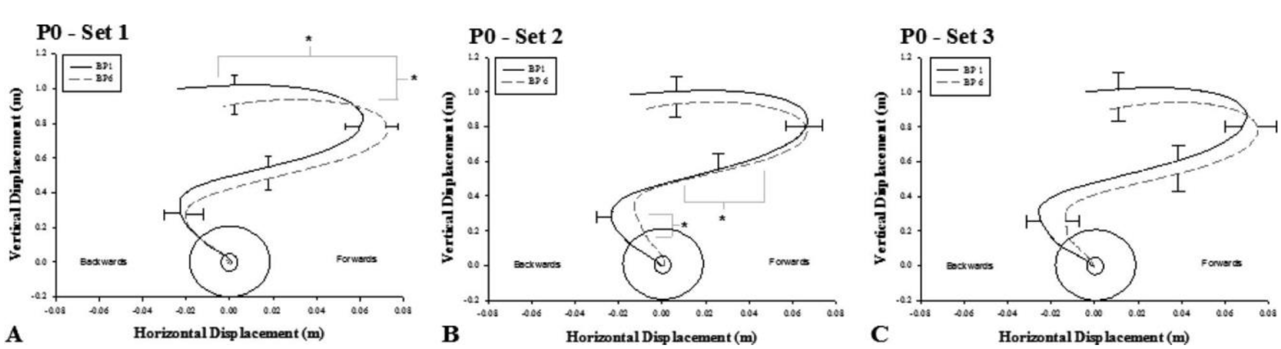

Figure 1. The effects of a traditional set configuration (P0) on barbell displacement in the power clean. * ¼ Significant differences in horizontal displacement between repetitions 1 and 6 (*P* ::; 0.05). (A – C) Average barbell displacement during repetitions 1 and 6 for sets 1, 2, and 3, respectively. m, metres

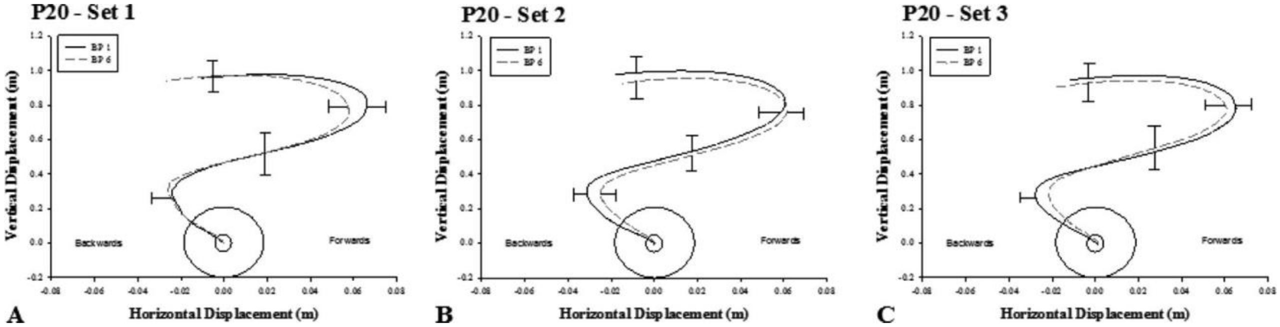

Figure 2. The effects of a cluster set configuration with 20 seconds inter-repetition rest (P20) on barbell displacement in the power clean. (A – C) Average barbell displacement during repetitions 1 and 6 for sets 1, 2, and 3, respectively. m, metres.

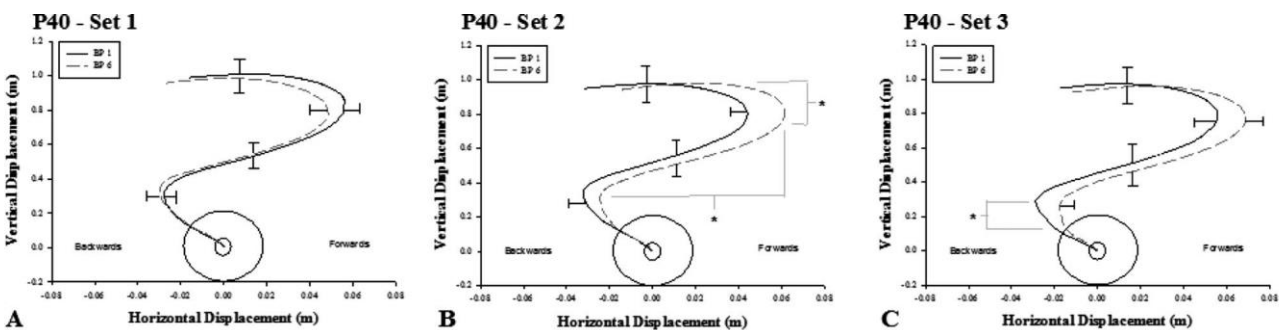

Figure 3. The effects of a cluster set configuration with 40 seconds inter-repetition rest (P40) on barbell displacement in the power clean. * ¼ Significant differences in horizontal displacement between repetitions 1 and 6 (*P* :::; 0.05). (A – C) Average barbell displacement during repetitions 1 and 6 for sets 1, 2, and 3, respectively. m, metres.

displacement were found between repetitions 1 and 6 during the first pull, transition, and beginning of the second pull (Figure 3C, *P* :::; 0.05).

The effect of cluster set configurations on peak vertical displacement of the barbell during multiple sets and repetitions of the power clean are presented in Table I. Average peak vertical displacements during repetition 1 were 1.02 + 0.07 m, 0.98 + 0.06 m, and 0.98 + 0.06 m (Mean + *s*; P0, P20, and P40, respectively). Average peak vertical displacements during repetition 6 were 0.94 + 0.06 m, 0.96 + 0.07 m, and 0.97 + 0.06 m (Mean + *s*; P0, P20, and P40, respectively). Significant decreases in peak vertical displacement were found during P0 for each set (*P* :::; 0.05). Peak vertical displacement decreased 7.3% between repetitions 1 and 6 during P0 (Table I, *P* :::; 0.05). There were no differences in peak vertical displacement between repetitions 1 and 6 within each set of P20 and P40 (Table I).

The effect of cluster set configurations on horizontal barbell variables of DxL, DxT, Dx2, and DxV during multiple sets and repetitions of the power clean are presented in Table II. No differences were found between repetitions 1 and 6 for each of the horizontal variables within each set of each protocol (Table II). The average DxL for repetitions 1 and 6 were 70.084 + 0.037 m and 70.079 + 0.034 m during P0, 70.079 + 0.032 m and 70.081 + 0.029 m during P20, and 70.075 + 0.031 m and 70.079 + 0.024 m during P40 (Mean + *s*). The average DxT for repetitions 1 and 6 were 70.015 + 0.058 m and 70.002 + 0.057 m during P0, 70.014 + 0.052 m and 70.020 + 0.040 m during P20, and 70.022 + 0.049 m and 70.018 + 0.032 m during P40 (Mean + *s*). The average Dx2 for repetitions 1 and 6 were 70.031 + 0.023 m and 70.022 + 0.028 m during P0, 70.031 + 0.019 m and 70.026 + 0.016 m during P20, and 70.033 + 0.024 m and 70.022 + 0.026 m during P40 (Mean + *s*). The average DxV for repetitions 1 and 6 were 0.10 + 0.025 m and 0.099 + 0.033 m during P0, 0.097 + 0.026 m and 0.087 + 0.022 m during P20, and 0.086 + 0.027 m and 0.084 + 0.030 m during P40 (Mean + *s*).

Discussion

The purpose of the current investigation was to examine the effects of cluster set configurations on power clean technique. The primary finding of this study was that cluster set configurations led to the maintenance of power clean technique when performing multiple repetitions. This was demonstrated by examining barbell displacement average curves and peak vertical and horizontal displacements in recreational weightlifters using traditional and cluster set configurations in the power clean exercise

Table I. The effects of cluster set configurations on peak vertical displacement.

Repetition	P0			P20			P40		
	Set 1	Set 2	Set 3	Set 1	Set 2	Set 3	Set 1	Set 2	Set 3
1	1.02+0.02	1.01 + 0.02	1.02 +0.02	0.98 + 0.02	1.00 +0.02	0.97 + 0.01	1.01 + 0.02	0.97 + 0.01	0.97 + 0.02
6	0.94 + 0.02*	0.94+ 0.02*	0.94 + 0.02*	0.98 + 0.02	0.96 + 0.02	0.95 + 0.02	0.98 + 0.02	0.98 + 0.01	0.96 + 0.02

Note: Values are mean + *s*. P0, traditional set configuration. P20, cluster set configuration with 20 seconds inter-repetition rest. P40, cluster set configuration with 40 seconds inter-repetition rest. * ¼ Significantly different from repetition 1. Values are reported in metres (m).

(Figures 1 – 3 and Tables I and II). We found greater variations in horizontal displacement and decreases in vertical displacement with a traditional set configuration when compared to cluster set configurations. The results suggest that cluster set configurations allow for the maintenance of weightlifting technique during multiple sets and repetitions of the power clean exercise. The results are supported, for example, by the fact that in P0 the displacement from the start to catch positions (DxT) was decreasing from 70.025 + 0.068 m (repetition 1) to 70.006 + 0.055 m (repetition 6) and the dis- placement from start and second pull positions (Dx2) was decreasing from 70.034 + 0.025 m (repetition 1) to 70.019 + 0.025 m (repetition 6). Winchester et al. (2005) observed an increase in the displacement from the start to catch positions (DxT; pre ¼ 70.068 + 0.015 m, post ¼ 70.195 + 0.039 m) and the displacement from start and second pull positions (Dx2; pre ¼ 70.063 + 0.086 m, post ¼ 70.085 + 0.024 m) with increasing power output in the power clean with training. Thus, with the results of P0 being the opposite, a negative effect of fatigue on power clean technique can be surmised. In comparison, displacement values of 70.011 + 0.060 m (repetition 1) and 70.019 + 0.036 m (repetition 6) were observed during P20 for the displacement between the start and catch positions (DxT). In addition, during P40 displacement values of 70.017 + 0.060 m (repeti- tion 1) and 70.012 + 0.030 m (repetition 6) were observed for the displacement between the start and catch positions (DxT). Collectively, these results indicate either an increase or attenuated decrease in displacement between the start and catch positions (DxT) may be associated with an improvement or maintenance of technique and subsequent power output with training in the power clean.

Despite the level of fatigue achieved during each protocol, participants were able to display appropriate barbell displacement patterns of towards, away, and towards the lifter in all exercise protocols (Garhammer, 1985; Stone et al., 1998; Winchester et al., 2005; Winchester et al., 2009). However, when performing a traditional set configuration in the power clean this led to greater variations in horizontal displacement of the barbell as compared to cluster set configurations. Analysis of average curves demonstrated differences in horizontal displacement be- tween repetitions 1 and 6 for the first and second set of P0. We found that during the first set of P0 the catch position in repetition 6 was in a more forward position as compared to repetition 1 (Figure 1A). Therefore, it appears as the participants became fatigued there was a more exaggerated hipping of the barbell which resulted in a more forward catch position. In addition, participants may have also

Table II. The effects of cluster set configurations on DxL, DxT, Dx2, and DxV.

Protocol	Set	Repetition	DxL	DxT	Dx2	DxV
P0	1	1	70.090+0.042	70.025+0.068	70.034+0.025	0.099+0.026
		6	70.081+0.043	70.003+0.064	70.026+0.022	0.104+0.031
	2	1	70.085+0.035	70.015+0.056	70.030+0.022	0.100+0.021
		6	70.079+0.028	70.009+0.052	70.021+0.036	0.092+0.036
	3	1	70.076+0.036	70.004+0.049	70.030+0.023	0.103+0.027
		6	70.075+0.030	70.006+0.055	70.019+0.025	0.101+0.032
P20	1	1	70.080+0.032	70.011+0.060	70.029+0.020	0.098+0.037
		6	70.085+0.029	70.027+0.042	70.027+0.017	0.085+0.019
	2	1	70.081+0.037	70.018+0.051	70.033+0.020	0.096+0.021
		6	70.077+0.028	70.015+0.042	70.027+0.018	0.089+0.019
	3	1	70.078+0.026	70.013+0.046	70.031+0.018	0.096+0.020
		6	70.081+0.030	70.019+0.036	70.024+0.014	0.086+0.027
P40	1	1	70.074+0.041	70.017+0.060	70.032+0.030	0.089+0.023
		6	70.079+0.029	70.027+0.033	70.032+0.023	0.083+0.035
	2	1	70.078+0.027	70.032+0.035	70.037+0.023	0.083+0.027
		6	70.077+0.027	70.014+0.033	70.013+0.038	0.075+0.034
	3	1	70.074+0.024	70.017+0.053	70.030+0.021	0.087+0.032
		6	70.081+0.023	70.012+0.030	70.023+0.017	0.092+0.020

Note: Values are mean + *s*. P0, traditional set configuration. P20, cluster set configuration with 20 seconds inter-repetition rest. P40, cluster set configuration with 40 seconds inte-rrepetition rest. DxL, difference between the most forward position during the second pull and the catch position. DxT, difference between the start position and the catch position. Dx2, difference between the start position and the beginning of the second pull. DxV, difference between the beginning of the second pull position and the most forward position during the second pull. Values are reported in metres (m).

started the second pull before reaching the power position in which the body would be in a more upright position to exert appropriate vertical forces. This finding would have also been indicated by decreased hip and knee angles at the time of extension (Hakkinen & Kauhanen, 1986). Although not measured in the current study, it could be speculated that hip and knee angles decreased at the time of extension as fatigue accumulated when performing continuous repetitions in the power clean. During the second set of P0 the first pull was in a more forward position during repetition 6 as compared to repetition 1 (Figure 1B). Garhammer and Taylor (1984) have discussed centre of pressure of the foot during weightlifting to be correlated with horizontal displacement patterns of the barbell. Therefore, in the current study a more forward barbell displacement, as seen during P0, may have been associated with a more forward pressure towards the balls of the feet. Lastly, our laboratory has previously shown a 7.5 and 8.6% decrease in power output during sets 1 and 2, respectively when performing a traditional set configuration in the power clean (Hardee, Lawrence et al., 2012). Taken together, it appears fatigue induced changes to exercise technique which were associated with decreases in power output when performing multiple repetitions in a continuous fashion.

It has been suggested that vertical displacement of the barbell is critical to weightlifting success (Enoka, 1979). Consequently, training methods that permit the maintenance of barbell vertical displacement may provide a superior stimulus for training-induced adaptations. Haff et al. (2003) demonstrated greater vertical displacements in the clean pull when performing a cluster set configuration as compared to a traditional set configuration (0.99 + 0.02 m vs 0.97 + 0.02 m). In the present study, peak vertical displacements were slightly lower than previously reported (Haff et al., 2003), however it has been suggested that inter-individual differences in height can account for these differences. With respect to intra-individual differences we found a 7.3% decrease in vertical displacement when repetitions were performed with a traditional set configuration. Furthermore, we extend previous literature by demonstrating cluster sets led to the maintenance of vertical displacement across multiple sets (Table I). It is generally accepted that multiple sets are superior to single set configurations for the development of muscular strength and power (Kraemer, 1997). In addition, it has been suggested that the ability to increase volume-load with cluster set configurations may lead to further neuromuscular adaptations (Haff et al., 2003). Based on the current and previous findings on vertical displacement, cluster set configurations appear to be a training method to increase total work performed over multiple sets and repetitions. Collectively, these findings may have implications on the development of muscular strength and power.

It is thought fatigue may reduce the effectiveness of power development through manipulations to resistance exercise technique (Sakamoto & Sinclair, 2006), however few studies have examined the effects of exercise technique on variables such as power, force, and velocity. Winchester et al. (2005) demonstrated that increases to peak power and peak force occurred concurrently with improvements to power clean technique. The authors found improvements to power clean technique were associated with increased rearward movement of the bar during the first pull (Dx2), decreased horizontal displacement from the second pull position to forward position (DxV), and increased barbell displacement from the start position to the catch position (DxT) (Winchester et al., 2005). Similar results have also been reported in the power snatch exercise (Winchester et al., 2009). Winchester et al. (2009) found improvements to horizontal displacement variables (DxL, DxT, Dx2, DxV) during training were associated with increases in peak power and peak force. Therefore, improvements to power and force in weightlifting assistance exercises are associated with increases in technique proficiency (Winchester et al., 2005; Winchester et al., 2009). Similar to these findings, we have previously reported that cluster set configurations maintain kinetic and kinematic variables across multiple sets and repetitions in the power clean (Hardee, Triplett et al., 2012); however, performing repetitions in a continuous fashion resulted in decreases in power, force, and velocity. Taken collectively, our current and previous data indicate cluster set configurations lead to the preservation of weightlifting technique and are associated with increased peak power across multiple repetitions in the power clean. These findings have implications for weightlifters and strength athletes concerned with maintaining proper technique and power output during a training session.

Interestingly, conflicting results were seen in average horizontal barbell displacement between the different cluster set configurations used in this study (P20 and P40). Twenty seconds inter-repetition rest resulted in maintenance of horizontal displacement of the barbell whereas 40 seconds did not. It appears that inadequate (0 seconds) or excessive (40 seconds) inter-repetition rest may lead to variations in exercise technique. It is possible that too little rest does not allow for sufficient recovery from central (i.e., neural) and/or peripheral (i.e., metabolic) fatigue. However, since 40 seconds rest would allow for the greatest recovery from central and peripheral fatigue, there may be other mechanisms (i.e., psychological) regulating weightlifting technique over multiple repetitions when cluster sets are used. It has been suggested that if the kinematics of a lift at the end of a set are different from the desired movement pattern, it may not be beneficial to train to muscular fatigue (Duffey & Challis, 2007). Results from the current investigation demonstrate a cluster set configuration utilising 20 seconds inter-repetition rest resulted in the maintenance of power clean technique, and this has been associated with the maintenance of power, force, and velocity (Hardee, Triplett et al., 2012). Therefore, cluster set configurations may be a practical method to increase the effectiveness of power training through the maintenance of exercise technique. Additional research is needed to explain the mechanisms responsible for the differences seen between the different cluster set configurations (P20 and P40). In addition, future research should examine the longitudinal effects of cluster set configurations in a periodised strength-training programme.

Conclusion

To date, numerous studies have examined appropriate technique in weightlifting movements during single repetition attempts. This is the first study to examine the effects of cluster set configurations on power clean technique during a multiple set and repetition exercise protocol. The results demonstrate variations to barbell displacement were minimized with a cluster set configuration utilizing 20 seconds inter-repetition rest. Our current and previous work suggests cluster set configurations can lead to the attenuation of fatigue, which results in the maintenance of exercise technique and power output during multiple sets and repetitions of the power clean. Therefore, cluster set configurations allow for greater work to be performed while minimizing fatigue within a training session. Cluster set configurations should be considered when designing resistance training programs for the development of muscular power and when performing exercises that require technique proficiency.

References

Apriantono, T., Nunome, H., Ikegami, Y., & Sano, S. (2006). The effect of muscle fatigue on instep kicking kinetics and kinematics in association football. *Journal of Sports Sciences*, *24*(9), 951 – 960.

Baumann, W., Gross, V., Quade, K., Galbierz, P., & Schwirtz, A. (1988). The snatch technique of world class weightlifters at the 1985 world championships. *International Journal of Sport Biomechanics*, *4*, 68 – 89.

Burdett, R.G. (1982). Biomechanics of the snatch technique of highly skilled and skilled weightlifters. *Research Quarterly for Exercise & Sport*, *53*, 193 – 197.

Canavan, P.K., Garret, G.E., & Armstrong, L.E. (1996). Kinematic and kinetic relationships between an Olympic-style lift and the vertical jump. *Journal of Strength and Conditioning Research*, *10*, 127 – 130.

Chen, Y. (2000). Changes in lifting dynamics after localized arm fatigue. *International Journal of Industrial Ergonomics*, *25*(6), 611 – 619.

Cormie, P., McBride, J.M., & McCaulley, G.O. (2007). Validation of power measurement techniques in dynamic lower body resistance exercises. *Journal of Applied Biomechanics*, *23*(2), 103 – 118.

Duffey, M.J., & Challis, J.H. (2007). Fatigue effects on bar kinematics during the bench press. *Journal of Strength and Conditioning Research*, *21*(2), 556 – 560.

Enoka, R.M. (1979). The pull in Olympic weightlifting. *Medicine & Science in Sports & Exercise*, *11*(2), 131 – 137.

Frolov, V.I., Lellikov, S.I., Efimov, N.M., & Vanagas, M.P. (1979). Snatch technique of top-class weight-lifters. *Soviet Sports Review*, *14*, 24 – 29.

Gabbett, T.J. (2008). Influence of fatigue on tackling technique in rugby league players. *Journal of Strength and Conditioning Research*, *22*(2), 625 – 632.

Garhammer, J. (1984). Power clean: Kinesiological evaluation. *National Strength and Conditioning Association Journal*, *6*(3), 61.

Garhammer, J. (1985). Biomechanical profiles of Olympic weightlifters. *International Journal of Sport Biomechanics*, *1*, 122 – 130.

Garhammer, J., & Taylor, L. (1984). Center of pressure movements during weightlifting. In *Sports Biomechanics, 2nd International Symposium on Biomechanics in Sport.* Del Mar, CA: Academic Publisher.

Haff, G.G., Whitley, A., McCoy, L.B., O' Bryant, H.S., Kilgore, J.L., Haff, E.E., . . . Stone, M.H. (2003). Effects of different set configurations on barbell velocity and displacement during a clean pull. *Journal of Strength and Conditioning Research*, *17*(1), 95 – 103.

Häkkinen, K., & Kauhanen, H. (1986). A biomechanical analysis of selected assistant exercises of weightlifting. *Journal of Human Movement Studies*, *12*, 271 – 288.

Halil, T., Nurtekin, E., Serdar, B., Turgut, K., Ahmet, S., & Dede, B. (2009). Effects of fatigue on the balance performance as measured by balance error scoring system in volleyball players. *Ovidius University Annals, Series Physical Education & Sport/ Science, Movement & Health*, *9*(2), 128 – 134.

Hardee, J.P., Lawrence, M.M., Utter, A.C., Triplett, N.T., Zwetsloot, K.A., & McBride, J.M. (2012). Effect of inter-repetition rest on ratings of perceived exertion during multiple sets of the power clean. *European Journal of Applied Physiology*, *2*(8), 3141 – 3147.

Hardee, J.P., Triplett, N.T., Utter, A.C., Zwetsloot, K.A., & McBride, J.M. (2012). Effect of inter-repetition rest on power output in the power clean. *Journal of Strength and Conditioning Research*, *26*(4), 883 – 889.

Isaka, T., Okada, J., & Funato, K. (1996). Kinematics analysis of the barbell during the snatch movement of elite Asian weightlifters. *International Journal of Sport Biomechanics*, *12*, 508 – 516.

Kraemer, W.J. (1997). A series of studies - The physiological basis for strength training in American football: Fact over philosophy. *Journal of Strength and Conditioning Research*, *11*(3), 131 – 142.

Lawton, T.W., Cronin, J.B., & Lindsell, R.P. (2006). Effect of interrepetition rest intervals on weight training repetition power output. *Journal of Strength and Conditioning Research*, *20*(1), 172 – 176.

Madigan, M.L., & Pidcoe, P.E. (2003). Changes in landing biomechanics during a fatiguing landing activity. *Journal of Electromyography and Kinesiology*, *13*, 491 – 498.

Sakamoto, A., & Sinclair, P.J. (2006). Effect of movement velocity on the relationship between training load and the number of repetitions of bench press. *Journal of Strength and Conditioning Research*, *20*(3), 523 – 527.

Stone, K.J., & Oliver, J.L. (2009). The effect of 45 minutes of soccer-specific exercise on the performance of soccer skills. *International Journal of Sports Physiology and Performance*, *4*(2), 163 – 175.

Stone, M.H., O' Bryant, H.S., Pierce, K., Williams, F.E., & Johnson, R.L. (1998). Analysis of bar paths during the snatch in elite male weightlifters. *National Strength and Conditioning Association Journal*, *20*(4), 30 – 38.

Winchester, J.B., Erickson, T.M., Blaak, J.B., & McBride, J.M. (2005). Changes in bar-path kinematics and kinetics after power-clean training. *Journal of Strength and Conditioning Research*, *19*(1), 177 – 183.

Winchester, J.B., Porter, J.M., & McBride, J.M. (2009). Changes in bar path kinematics and kinetics through the use of summary feedback in power snatch training. *Journal of Strength and Conditioning Research*, *23*(2), 444 – 454.