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Effect of 3 different set configurations on kinematic variables and internal loads during a power snatch session

Tsuyoshi Nagatani
Edith Cowan University

Kristina L. Kendall
Edith Cowan University

Stuart N. Guppy
Edith Cowan University

Wayne C. K. Poon
Edith Cowan University

G. Gregory Haff
Edith Cowan University

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Title: Effect of three different set configurations on kinematic variables and internal loads during a power snatch training session

ABSTRACT

The aim of this study was to investigate the effect of three different set configurations on kinematic variables and internal loads during multiple sets performed with the power snatch. Ten strength-power athletes with at least six months of training experience performing the power snatch participated in this study, which consisted of three experimental protocols performed in a randomized repeated measures design. The three protocols involved performing the power snatch for 3 sets of 5 repetitions at an average load of 75% 1RM with either a traditional (TRAD), cluster (CLU) or ascending cluster (A-CLU) protocol where the training load was progressively increased across the set. Kinematic variables and internal loads (heart rate, blood lactate, and rate of perceived exertion) were measured during each protocol. The athletes maintained peak velocity (PV) and peak power (PP) and exhibited lower internal loads during CLU sets when compared to TRAD sets, while they displayed significant decreases in PV during TRAD sets. However, there were no statistically significant differences in PV and PP responses between the TRAD and CLU protocol. The athletes exhibited a significant decrease in PV, whereas PP was increased across each set in the A-CLU protocol, with lower internal loads observed compared to the TRAD protocol. Overall, the training loads used in this study do not appear to maximize the benefits of using CLU set during three sets of power snatches performed for 5 repetitions. Additionally, A-CLU sets may potentially be useful as a means of maximizing the power output of the athlete.

Key Words: Cluster set, inter-repetition rest interval, velocity

INTRODUCTION

When designing a resistance training program, a training set traditionally consists of a series of repetitions that are performed in a continuous manner, with the number of repetitions manipulated depending upon individual training goals (35). It is well documented that resistance training using traditional (TRAD) sets can result in acute muscular fatigue as indicated by a reduction in movement velocity (40) and metabolic byproduct accumulation (e.g., ammonia and lactate) (12). This type of set configuration has been suggested as an primary programming strategy during a strength training session to maximize an athlete's maximal strength (1) and/or muscle hypertrophy (13). However, based upon emerging evidence, they may not be the best set configuration when technically challenging exercises, such as weightlifting movements and their derivatives, are performed. This is because acute muscular fatigue typically observed during TRAD sets tends to alter lifting technique and may potentially result in a decreased ability to complete the lift (19, 36). As such, an alternative set configuration may be considered when attempting to avoid cumulative muscular fatigue that is typically noted during TRAD sets performed with these exercises and offset fatigue-induced reductions in performance.

Modified set configurations, such as cluster (CLU) and rest redistribution sets, have been suggested as possible training variations that can be used for resistance training prescriptions (25). A CLU set is a set configuration where repetitions are performed with short rest intervals (i.e., 5-40 seconds) allotted between individual (i.e., Inter-repetition rest) or groups of repetitions (i.e., Intra-set rest) (11, 20). When compared to a TRAD set, the use of a CLU set better maintains movement velocity (40) and results in lower metabolic and perceptual stress markers (i.e., internal load) (13, 18) in response to a series of sets. To date, numerous researchers have investigated the effect of CLU sets during both upper- or lower-body multi-joint resistance exercises (25). Based upon an examination of the current body of scientific knowledge, the bench press and back squat are the most examined exercises used to investigate the implementation of CLU sets (5, 11), seemingly because of the technical simplicity of these exercises. However, this programming strategy may be better suited for more ballistic and technically challenging exercises, such as weightlifting movements and their derivatives, as the additional rest interval can offset fatigue-induced reductions in performance (38) and allow the athlete to maintain lifting technique (19). However, when looking at the effects of using CLU sets during the performance of weightlifting movements and their derivatives, there are very few studies (17, 20, 38). In addition, only one study has directly examined the difference in a perceptual response between the TRAD and CLU set during a power clean training session (18). As such, more research is warranted to develop a full understanding of the internal loads (e.g., metabolic, cardiovascular, and perceptual responses) that are associated with the TRAD and CLU set performed with weightlifting movements and their derivatives.

The power snatch is a weightlifting derivative that is commonly programmed by strength and conditioning professionals when targeting the improvement of athletic performance (42). Since the snatch and power snatch are considered technically challenging exercises (8), it may be warranted to add rest between repetitions, or clusters of repetitions, when incorporating these exercises into a resistance training program (42). To examine this practice, Tan et al. (38)

investigated the effect of CLU sets with three different inter-repetition rest intervals (i.e., 10, 30 and 50 seconds) on peak barbell velocity across a series of snatch sets performed at an intensity of 85% of 1RM. The authors suggested that a 30-second inter-repetition rest interval is the optimum inter-repetition rest duration to maintain performance when performing the snatch with CLU sets performed at this intensity. While this study provided data that partially supports the benefit of CLU sets during weightlifting movements and their derivatives, it should be interpreted with caution. Tan et al. (38) did not include a TRAD set protocol, which makes it difficult to determine if the CLU set was more effective at maintaining snatch performance. Additionally, it is unknown whether the benefits of CLU sets occur when these exercises are performed with alternative intensities.

While the modification of the inter-repetition or intra-set rest period is the main manipulation commonly used to introduce CLU sets into resistance training programs, there are different types of CLU sets that are used to alter training loads across the set (14, 16). One example of these types of CLU sets is an ascending cluster (A-CLU) set where the training load is progressively increased across the set (16). For example, when performing three repetitions with an A-CLU set where the targeted intensity is 90% of 1RM, the training load is increased with each repetition of the set, and the average intensity of the three repetitions is 90% of 1RM (e.g. rep1 = 87% of 1RM; rep2 = 90% of 1RM; rep3 = 93% of 1RM) (14, 16). The theoretical rationale for the use of this set configuration is that it may enhance muscle force production, which is termed a post-activation performance enhancement (PAPE) effect (30), during subsequent sets. For example, the first A-CLU set can act as a bout of muscular activity that may generate a PAPE effect during the beginning portion of a subsequent set(s) when multiple sets are used where this load progression is repeated. This belief is based upon the time between the last rep (i.e., heaviest rep) and the first rep (i.e., lightest rep) contained within the A-CLU set, allowing enough time for a PAPE effect to occur. In support of this contention, Stone and colleagues (37) demonstrated that performing high load sets with 2 minutes of inter-set rest intervals resulted in a PAPE effect during subsequent lower loaded sets when performing midthigh clean pulls. Since it is well documented that the PAPE effect can be maximised as early as 3 minutes after the completion of the conditioning activity (33), the A-CLU set where lower loaded repetitions are performed after a high load repetition with 3 minutes of inter-set rest intervals might induce the PAPE effect. However, to the best of the author's knowledge, the acute effect of A-CLU sets has not been directly investigated.

As such, the primary aim of this study was to investigate the effects of TRAD, CLU, and A-CLU set configurations on kinematic variables, as well as internal loads during a series of power snatch sets. We also aimed to investigate whether a PAPE effect occurs during an A-CLU set training protocol. We hypothesized that the CLU set would maintain movement velocity and power output while the TRAD set would display significant decreases in these variables. In addition, we hypothesized that there would be decreases in movement velocity and power output during the A-CLU set as a result of the progressively increased training load contained within each set. Additionally, we hypothesized that the inclusion of a 30 s inter-repetition rest interval would also result in lower internal loads during both CLU and A-CLU set protocols when compared to the TRAD set. Finally, we hypothesized that there would be a PAPE effect as a result of the A-CLU set protocol.

METHODS

Experimental Approach to the Problem

All subjects undertook a total of four sessions, which consisted of a session to test their 1RM power snatch and three experimental protocols performed in a randomized repeated measures design, which were used to test the TRAD, CLU, and A-CLU set configurations. Each session was separated by 72-96 hours and conducted at the same time of day (± 1 hour). During each power snatch repetition, displacement-time data were recorded and subsequently used to calculate barbell peak velocity (PV) and peak power (PP) data. Blood lactate, heart rate and rating of perceived exertion (RPE) were measured at several time points across the testing protocol (Figure 1). Before each session, all subjects were instructed to refrain from lower-body resistance training for at least 48 hours, to abstain from alcohol for at least 24 hours, and caffeine for at least 4 hours. Subjects were required to wear the same shoes and were allowed to use lifting belts, knee sleeves, wrist wraps and chalk in all the sessions.

(*Insert Figure 1*)

Subjects

Ten strength-power athletes (means ± SD; n = 9 males, height: 1.80 ± 0.09 m, body mass: 90.9 ± 13.4 kg, age: 28.2 ± 4.7 years; n = 1 female, height: 1.67 m, body mass: 69.4 kg, age: 34 years) with at least six months of training experience with the power snatch (1 repetition maximum (RM) of power snatch: 78.4 ± 15.6 kg, relative 1RM: 0.88 ± 0.10 $kg \cdot kg^{-1}$, power snatch experience range: 3.5 ± 0.8 years) were recruited for this study. All subjects were recruited from local strength and conditioning facilities and weightlifting clubs. Subjects had no current upper- or lower-body musculoskeletal injuries and had been injury free for at least six months prior to participation. All subjects were able to power snatch with a minimum of 0.7 x body mass. Subjects' height and body mass were measured by a calibrated electronic scale and a wall-mounted stadiometer. Based upon a priori statistical power analysis (7), 9 subjects were required to yield a statistical power of 80% (1-β = 0.8) with the alpha level set at 0.05 (Version 3.1.9.2, G*Power, Kiel, Germany) (9). All subjects read and signed informed consent forms before participation in this study in accordance with the ethical approval granted by the Edith Cowan University (ECU) Human Research Ethics Committee (Project 2020-01964).

Procedures

Session 1: One-Repetition Maximum Power Snatch Testing

All subjects performed a standardized dynamic warm-up consisting of dynamic stretches, bodyweight exercises and overhead squats with a 20 kg barbell (Armortech, Australia) for male subjects and a 15 kg barbell (Eleiko, Halmstad, Sweden) for female subjects, and completed self-selected exercises. Afterwards, the subjects performed the 1RM power snatch test based upon previously published methods (43). In brief, subjects performed five repetitions at 30%

of their estimated 1RM, followed by three repetitions at 50 and 70% of their estimated 1RM. They then performed one repetition at 90% of their estimated 1RM and moved on to 1RM attempts. The load was increased in 0.5 to 10 kg increments until subjects were unable to perform a successful repetition, with a maximum of five attempts being allowed to achieve the 1RM. An unsuccessful attempt was determined if subjects failed to fix the barbell overhead or if the upper portion of the thigh at the hip dipped below parallel (8). If a 1RM attempt was unsuccessful, subjects were allowed an additional attempt at this load. Three-minute rest periods were allotted between all warm-up and maximal attempts. During each maximal attempt, verbal encouragement, and technical feedback regarding the knee angle during the catch position of the power snatch was provided by a certified strength and conditioning specialist.

Session 2, 3, and 4: Experimental Sessions

Upon arrival in the laboratory, all subjects remained seated for 15 minutes prior to the baseline measures of blood lactate (BLaPRE1) and resting heart rate (PRE1). The baseline RPE was recorded as zero at PRE1, as the subjects completely rested during the 15 minutes. However, this baseline RPE value was not used for further analysis. After baseline data collection, subjects completed the same dynamic warm-up used in Session 1. Once the dynamic warm-up was completed, the subjects performed a specific warm-up protocol that included five repetitions of power snatches at 30% of their 1RM and three repetitions at 50% and 60% of their 1RM. Subjects had their RPE and heart rate measured 30 seconds after the last set of the specific warm-up (PRE2). They also had their blood lactate measured 3 minutes after the last set of the specific warm-up (BLaPRE2) before moving on to a TRAD, a CLU, or an A-CLU set protocol.

All working sets were completed at an average load of 75% of 1RM, as this training load has been demonstrated to be within the optimal range for PP output for weightlifting exercises (4). The TRAD set protocol involved three sets of five repetitions with the power snatch at 75% of 1RM (Figure 1). The CLU set protocol involved the performance of three sets of five repetitions performed with 30-second rest intervals placed between each repetition at 75% of 1RM (Figure 1). The A-CLU set protocol involved the performance of three sets of five repetitions with 30 second rest intervals placed between individual repetitions, with training load increments across five repetitions in the sets (rep1 = 65% 1RM; rep2 = 70% 1RM; rep3 = 75% 1RM; rep4 = 80% 1RM; rep5 = 85% 1RM) (Figure 1) (14). Inter-set rest intervals of 3 minutes were allotted between each set for all protocols. The subjects were instructed to remain standing during the 30 seconds of inter-repetition rest, whereas they were instructed to remain seated during the 3-minute inter-set rest intervals. The inter-repetition and inter-set rest intervals began when the subjects placed the barbell on the floor. In the A-CLU set protocol, the load was incremented manually by two researchers during the inter-repetition rest interval in each set. During each training set protocol, verbal encouragement, and technical feedback regarding the knee angle during the catch position of the power snatch were provided to subjects by a certified strength and conditioning specialist.

Data Acquisition and Analysis

In sessions two through four, an eight-camera 3D motion analysis system (Vicon MX; Vicon, Oxford, UK) sampling at 250 Hz was used to record the three-dimensional displacements of two 20 mm reflective markers attached to the longitudinal ends of the barbell via Vicon Nexus software (version 2.12; Vicon, Oxford, UK) (27). The vertical position of these reflective markers was extracted and processed in a custom Excel (Microsoft Corp, WA, USA) spreadsheet. Marker trajectories were filtered using a fourth-order, zero-lag Butterworth low-pass filter with a cut-off frequency of 8 Hz (45). The cut-off frequency was determined by performing a residual analysis (45). To calculate the velocity at the center of the barbell, the filtered displacements of each marker were averaged and then differentiated via the central difference method (44). The start of the trial was identified as the first frame where the vertical displacement of the barbell was >30 mm above the resting position. The end of the concentric phase was defined as the first frame where a negative velocity occurred. The barbell PV was determined as the maximum velocity value during the second pull phase of the power snatch (27). Work was calculated on a sample-by-sample basis via the work-energy theorem, with power calculated as work divided by time (10). The barbell PP was determined as the highest instantaneous power value during the second pull phase. Changes in PV and PP were determined as a percentage change from the first repetition in each set protocol (20).

Internal Loads

A disposable Unistik (Owen Mumford, Oxfordshire, United Kingdom) was used to prick subjects' earlobes to withdraw a drop of blood at the following time points: BLaPRE1, BLaPRE2, 2.5 minutes after the first (BLaSET1) and second set (BLaSET2), and 3 minutes after the third set (BLaSET3). The blood droplet was collected on a Lactate Pro 2 strip and analyzed by a Lactate Pro 2 meter (Arkray, Global business Inc, Kyoto, Japan). Gauze swabs were used to wipe away the first drop of blood, and a subsequent drop of blood was used as the blood sample. The values shown on the device were recorded for analysis. Borg Category Ratio Scale was used to quantify RPE (2). Subjects were shown the printed scale during each experimental session (29) and were instructed to report their RPE at the following time points: PRE2, 30 seconds after the first set (SET1), second set (SET2), and third set (SET3). Heart rate was monitored by Polar Heart Rate Monitor A1 (Polar Electro, Kempele, Finland). Subjects were instructed to wear a chest strap with a monitoring device attached to it during each experimental session, and their heart rates were recorded at the following time points: PRE1, PRE2, SET1, SET2 and SET3.

Statistical Analyses

The assumption of normality was checked with the Shapiro-Wilk test. 3 x 3 x 5 (protocol x set x repetition) repeated measures analysis of variances (ANOVA) were performed to determine the effect of each protocol on PV and PP across each repetition. To examine the PAPE effect on PV and PP within the A-CLU set, 3 x 5 (set x repetition) repeated measures ANOVAs were performed. 3 x 5 (protocol x time) repeated measures ANOVAs were also performed to determine the difference in heart rate values between and within each protocol. Where significant interactions were detected in each repeated measures ANOVA, paired comparisons with Holm's Sequential Bonferroni correction for type I error were performed to determine where a significant difference(s) was detected (22). Since the data for blood lactate and RPE violated the assumption of normality, an Aligned Rank Transform procedure was used to examine interactions effects in non-parametric data (46). Where significant interactions were detected, post hoc pairwise comparisons with Holm's Sequential Bonferroni correction for type I error were performed to determine where a significant difference(s) was detected. Since the Aligned Rank Transform procedure for non-parametric factorial ANOVA does not allow for the comparisons of pairwise values across factors directly, Dunn's test with Holm's Sequential Bonferroni corrections for type I error was performed to compare pairwise blood lactate and RPE values across the factors. Within-subject reliability for PV and PP was assessed using percent coefficient of variation (%CV) and intraclass correlation coefficients (ICCs) (24, 28). %CV values were interpreted as good (<5%), moderate (5-10%) and poor (>10%), whereas ICCs values were interpreted as poor (<0.5), moderate (0.5-0.75), good (0.75-0.9), and excellent (>0.9) reliability (28). For normally distributed data, Hedges *g* effect sizes (ES) with 95% confidence interval (CI) were calculated (21) and interpreted as trivial (< 0.2), small (0.2-0.59), moderate (0.6-1.19), large (1.2-1.99), and very large (>2.0) (23). For non-normally distributed data, Cliff's δ ES with 95% CI were calculated (3), with the magnitudes of the ES interpreted as negligible (< 0.147), small (0.147-0.330), medium (0.330-0.474) and large (> 0.474) (32). Repeated measures ANOVAs and post-hoc comparisons were performed using the open source jamovi software package (version 2.0; the jamovi project, NSW, Australia). The Aligned Rank Transform procedure and Dunn's test were performed in the R statistical programming language (version 4.2) using the *ARTool* package (version 0.11.1) and the *dunn.test* package (version 1.3.5), respectively (6, 26, 31).

RESULTS

Kinematic Variables

ICCs and %CV for PV were 0.88 (95% CI = 0.59-0.97) and 3.1% (95% CI = 2.1-5.7). Descriptive statistics for PV are presented in Table 1. There was a significant Protocol x Repetition interaction for PV ($p < 0.001$, $\eta^2 = 0.043$). Based upon post-hoc analyses, there was a significant difference in PV between the TRAD and A-CLU set in the first repetition. In addition, a significant difference in PV was observed between the CLU and A-CLU set in the first repetition. When looking at within-protocol differences, TRAD sets displayed significantly lower PV at the third, fourth and fifth repetition when compared to the second repetition (*g* [95% CI] = -0.21 [-0.33,-0.13], *p* = 0.011; *g* [95% CI] = -0.32 [-0.53,-0.20], *p* = 0.022; *g* [95% CI] = -0.55 [-0.88,-0.35], *p* = 0.013, respectively). In addition, A-CLU sets displayed significantly lower PV at the second, third, fourth and fifth repetition when compared to the first repetition (*g* [95% CI] = -0.33 [-0.56,-0.19], *p* = 0.037; *g* [95% CI] = -0.74 [-1.20,-0.48], *p* = 0.013; *g* [95% CI] = -1.09 [-1.66,-0.77], *p* = 0.001; *g* [95% CI] = -1.42 [-2.17,-1.02], *p* < 0.001, respectively). However, there was no significant difference in PV between the repetitions within the CLU set. The percentage change from repetition one across repetitions in PV when averaged across all 3 sets as well as the percentage change in PV when averaged across all the repetitions for each protocol are presented in Figure 2. Additionally, the percentage change in PV from repetition one across repetitions within each set for each protocol is presented in Figure 3.

(*Insert Table 1*)

(*Insert Figure 2*)

(*Insert Figure 3*)

ICCs and %CV for PP were 0.99 (95% CI = 0.97-1.00) and 3.2% (95% CI = 2.2-6.0). Descriptive statistics for PP are presented in Table 1. There was a significant Protocol x Repetition interaction for PP ($p < 0.001$, $\eta^2 = 0.011$). Based upon post-hoc analyses, there was a significant difference in PP between the TRAD and A-CLU set in the fifth repetition. When looking at within-protocol differences, A-CLU sets displayed significantly higher PP at the fourth and fifth repetition when compared to the first repetition (*g* [95% CI] = 0.27 [0.18,0.43], p = 0.021; *g* [95% CI] = 0.34 [0.23,0.54], p = 0.004). The percentage change from repetition one across repetitions in PP when averaged across all 3 sets as well as the percentage change in PP when averaged across all the repetitions for each protocol are presented in Figure 4. Additionally, the percentage change in PP from repetition one across repetitions within each set for each protocol is presented in Figure 5.

(*Insert Figure 4*)

(*Insert Figure 5*)

Post-activation Potentiation Effect

There was not a significant Set x Repetition interaction for PV within the A-CLU set protocol ($p < 0.677$, $\eta^2 = 0.002$). In addition, there was not a significant Set x Repetition interaction for PP within the A-CLU set protocol ($p < 0.536$, $\eta^2 = 0.001$). Based upon these results, the PAPE effect was not generated during the A-CLU set training protocol.

Internal Loads

Changes in internal loads (e.g., heart rate, blood lactate and RPE) are presented in Figure 6. There was a significant Protocol x Time interaction for heart rate ($p < 0.001$, $\eta^2 = 0.061$). There were significant differences in heart rate between TRAD and CLU protocols at SET1 (*g* [95% CI] = 2.15 [1.33,3.50], p = 0.009), SET2 (*g* [95% CI] = 3.57 [2.44,5.58], p < 0.001) and SET3 (*g* [95% CI] = 3.29 [2.39,4.99], p < 0.001). In addition, significant differences in heart rate were found between TRAD and A-CLU protocols at SET1 (*g* [95% CI] = 1.92 [1.13,3.20], p = 0.020) and SET3 (*g* [95% CI] = 2.24 [1.46,3.58], p = 0.003). There was no significant difference in heart rate between CLU and A-CLU protocols at any time points.

There was a significant Protocol x Time interaction for blood lactate ($p < 0.001$, $\eta_p^2 = 0.485$). Differences in blood lactate between TRAD and A-CLU protocols at BLaSET3 were significantly larger than those observed at BLaSET1 ($p = 0.022$). Similarly, differences in blood lactate between TRAD and CLU protocols at BLaSET3 were significantly larger than those observed at BLaSET1 ($p = 0.005$). Based upon results of Dunn's test, there were significant differences between TRAD and CLU protocols at BLaSET2 (δ [95% CI] = 0.92 [0.52,1.00], p = 0.003) and BLaSET3 (δ [95% CI] = 0.99 [0.88,1.00], p < 0.001). In addition, significant differences in blood lactate were found between TRAD and A-CLU protocols at BLaSET2 (δ [95% CI] = 0.96 [0.70,1.00], p < 0.001) and BLaSET3 (δ [95% CI] = 0.96 [0.70,1.00], p < 0.001). There was no significant difference in blood lactate between CLU and A-CLU protocols at any time points.

There was a significant Protocol x Time interaction for RPE (p = 0.011, η_p^2 = 0.138). Differences in RPE between TRAD and CLU protocols at SET2 (p = 0.033) and SET3 (p = 0.018) were significantly larger than those observed at PRE2. However, Dunn's test revealed no significant differences between protocols at any time points.

(*Insert Figure 6*)

DISCUSSION

The aim of this study was to explore the kinematic and internal load differences between different set configurations when performing the power snatch. Specifically, we aimed to determine a) the effect of TRAD, CLU, and A-CLU set configurations on PV and PP, as well as metabolic, cardiovascular, and perceptual responses during a series of power snatch sets and, b) whether a PAPE effect occurs during an A-CLU set training protocol. Based upon results from this study, the athletes maintained both PV and PP across each set and exhibited lower internal loads during the CLU set protocol when compared to the TRAD set protocol. Conversely, they experienced significant decreases in PV within the set and exhibited greater internal loads during the TRAD set protocol when compared to the CLU set protocol. The athletes exhibited greater decreases in PV and greater increases in PP across the sets during the A-CLU set protocol, with lower internal loads observed compared to the TRAD set protocol. Finally, a PAPE effect was not supported during the A-CLU set training protocol.

Several researchers have reported the effectiveness of CLU sets to maintain movement velocity and power output during a series of resistance training sets (5, 18, 20). Conversely, greater movement velocity and power output reductions are experienced during the TRAD set compared to the CLU set (5, 18, 20). In support of the current literature, the average percentage decline in PV across all the repetitions for the TRAD set protocol was moderately higher than the CLU set protocol (Figure 2). In addition, when looking at within-protocol differences, there were statistically significant declines in PV within the TRAD set protocol. Conversely, PV and PP were maintained during each of the CLU sets. However, there were no statistically significant differences in PV and PP responses between the TRAD and CLU set protocol. These results do not agree with the findings of previously published research looking at the use of the CLU set with weightlifting derivatives (17, 20). For example, Hardee and colleagues (20) have reported significantly greater declines in PV and PP during TRAD sets when compared to CLU sets in response to three sets of power cleans performed for 6 repetitions. One possible explanation for the disparity between our findings and those of Hardee et al. (20) may be related to the intensities used in each study. Hardee et al. (20) used a load of 80% of

1RM, which corresponds to between 95-99% of the 6RM (15), while the present study used 75% of 1RM, which corresponds to 85-89% of the 5RM (15). It is plausible that the training intensity used in the current study was not high enough to elicit enough fatigue during the TRAD set in order to result in meaningful declines in PV and PP. Since it is well documented that the CLU set allows for the use of greater training intensities, it is likely that greater training intensities are required to produce positive performance enhancements when CLU sets are implemented (39). As such, it is recommended that strength and conditioning professionals should use higher training intensities (>75% of 1RM or >90% of 5RM of power snatch) than those used in the current study when the CLU set is implemented during a series of power snatch sets performed for 5 repetitions.

To the best of the authors' knowledge, this is the first study that has examined the acute effects of A-CLU sets on kinematic variables. As expected, there were statistically significant decreases in PV within the A-CLU set protocol. These declines occurred in response to the incremental increase in training load across the five repetitions contained within each set. Additionally, there was a statistically significant difference in PP between the TRAD and A-CLU set protocol in the fifth repetition, while the athletes displayed significantly higher PP at the fourth and fifth repetition when compared to the first repetition within the A-CLU set protocol. An increased PP may be related to how PP was calculated in this study. When PP is obtained by a change in the total vertical work done during the second pull phase of the weightlifting movements, potential energy is the larger contributor to the total vertical work when compared to kinetic energy (10). Since a change in velocity is only associated with a change in kinetic energy, increased training load directly associated with potential energy and kinetic energy might offset decreased PP due to decreased kinetic energy (10). Based upon this result, the A-CLU set training protocol may be used as a means of maximizing the athlete's power output, especially during a strength-power phase of a periodized training plan in which power development is a primary focus of the resistance training program.

Another potential rationale for using the CLU set as a programming strategy is to lessen internal loads in response to a training set. Several researchers have reported that CLU sets lessen metabolic and perceptual stress markers typically seen with TRAD sets (13, 18). Similar responses were noted in the present study, where lower blood lactate was observed in response to the CLU and A-CLU set protocol when compared to the TRAD set protocol. Although adenosine triphosphate (ATP) was not measured in the current study, the inclusion of the 30 s inter-repetition rest interval within each CLU and A-CLU set with 3 min inter-set rest interval may have offset the need to maximize glycolytic contributions to ATP resynthesis as noted by the lower levels of blood lactate observed during the CLU and A-CLU sets. Additionally, in the present study, differences in blood lactate between the TRAD and CLU set as well as the TRAD and A-CLU set became larger as the acute training bout continued. Similarly, differences in RPE between the TRAD and CLU set at SET2 and SET3 were also significantly larger than those observed at PRE2. A similar trend was noted in a previous study by Wagle et al. (41) who reported that the inclusion of a 30 s inter-repetition rest period resulted in greater movement velocities being achieved at the first repetition during a series of back squat sets performed using cluster set than traditional sets, and suggested that this might be a result of less fatigue carryover from previously completed sets during cluster sets. Based upon the findings of the present and previous study, it is recommended that strength and conditioning professionals should program multiple sets when the CLU and A-CLU set are implemented within an athlete's resistance training program to maximize their benefits.

Unlike metabolic and perceptual responses, the effect of different set configurations on cardiovascular responses have not yet been extensively investigated. In the present study, elevated heart rates were observed in response to the TRAD set protocol, while lower heart rates were determined for both the CLU and A-CLU set protocol (Figure 6). The 30s inter-repetition rest interval included in the CLU and A-CLU set may have provided enough recovery time to resynthesize ATP and PCr between repetitions, which might attenuate an increase in oxygen demand during a power snatch session. Conversely, the lack of the inter-repetition rest interval within the TRAD set might have been responsible for greater cardiovascular responses as the energy supply might have shifted toward glycolysis, as noted by the higher levels of blood lactate observed for the TRAD set. However, heart rate was only recorded 30 seconds after each set for each protocol and how heart rate changed for each protocol was unknown. Therefore, future research should use a heart rate monitor that allows the researcher to monitor the heart rate throughout each training session to gain more comprehensive heart rate data.

Several review papers have presented the hypothesis that A-CLU sets may induce a PAPE effect when appropriately integrated into a resistance training program (14, 16). However, the current investigation does not support this hypothesis as there was no significant Set x Repetition interaction for PV and PP within the A-CLU set protocol. It is difficult to elucidate the reason why the PAPE effect was not observed during the A-CLU set, as numerous factors potentially influence the PAPE effect, such as the type of the conditioning activity, the degree of fatigue induced by the conditioning activity, the rest interval between the conditioning activity and the subsequent performance (34). Another possible factor that may explain the lack of the PAPE effect in the A-CLU sets may be the level of strength. Seitz, de Villarreal and Haff (33) reported that stronger individuals who were able to back squat more than 2 x body mass exhibited a PAPE effect 3 minutes after 1 set of 3 back squats at 90% of 1RM. However, weaker individuals who were able to back squat with less than 2 x body mass did not express the PAPE effect at 3 minutes after the conditioning activity but did at 6 minutes after the conditioning activity (33). Although back squat 1RM was not assessed in the current investigation, it can be speculated that the subjects' relative strength was not high enough to maximize the potential to express a PAPE effect in the A-CLU set when three-minute rest intervals are used. Future research should explore whether strength level influences the PAPE effect in the A-CLU set or if a longer duration intra-set rest (> 3 min) interval is required.

While the results of this study provides interesting insight into set manipulation that has the potential to influence the practices of strength and conditioning professionals, it is not without limitations. As previously mentioned, the use of a load that corresponded to 75% of 1RM may not have been high enough to result in meaningful differences in kinematic variables between the TRAD and CLU set protocol. As such, future researchers should replicate the current study but implement higher training intensities (> 75% of 1RM or >90% of 5RM) to investigate whether the use of the higher training intensities results in distinctive differences in kinematic variables between the TRAD and CLU set protocol. Additionally, while the A-CLU set protocol resulted in significantly higher PP at the fifth repetition when compared to the same repetition in the TRAD set protocol, it remains unknown whether this is a result of the use of the A-CLU set protocol or simply the use of higher training loads in the A-CLU set protocol when compared to those used in the TRAD set protocol. As such, to address this limitation, future researchers should implement the TRAD set protocol with the same training load that is used at the fifth repetition during the A-CLU set protocol when comparing both protocols.

PRACTICAL APPLICATIONS

Based on the results of this study, CLU sets can be used to maintain both PV and PP during a power snatch training session. However, the training intensity used in the current study (75% of 1RM, which corresponds to between 85-89% of the 5RM) was not high enough during three sets of power snatches performed for 5 repetitions to generate the decreases in PV and PP in the TRAD set. Therefore, if strength and conditioning professionals use CLU sets, they should ensure that higher training intensities are utilized (>75% of 1RM or >90% of 5RM of power snatch) to maximize benefits from the CLU set during the power snatch performed for 5 repetitions. CLU sets can also be used to modulate the internal load in response to the training session while maintaining training intensity. Since the athletes displayed significant increases in PP within the A-CLU set without eliciting high metabolic and cardiovascular responses, the A-CLU set may potentially be useful as a means of maximizing the power output of the athlete during a strength-power phase of a periodized training plan.

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Figure 1. Graphic description of the experimental design. TRAD = traditional; CLU = cluster; A-CLU = ascending cluster; RM = repetition maximum.

Figure 2. A. Percentage change from repetition one across repetitions in peak velocity when averaged across all 3 sets. A-CLU = ascending cluster; CLU = cluster; TRAD = traditional. B. Percentage change in peak velocity when averaged across all the repetitions for each protocol.

Figure 3. A-C. Percentage change from repetition one across repetitions in peak velocity within each set for each protocol. A-CLU = ascending cluster; CLU = cluster; TRAD = traditional.

Figure 4. A. Percentage change from repetition one across repetitions in peak power when averaged across all 3 sets. A-CLU = ascending cluster; CLU = cluster; TRAD = traditional. B. Percentage change in peak power when averaged across all the repetitions for each protocol.

Figure 5. A-C. Percentage change from repetition one across repetitions in peak power within each set for each protocol. A-CLU = ascending cluster; CLU = cluster; TRAD = traditional.

Figure 6. Blood lactate, rating of perceived exertion (RPE) and heart rate during each experimental session. A-CLU = ascending cluster; CLU = cluster; TRAD = traditional. * Significantly different than CLU sets at the same time point; † significantly different from A-CLU sets at the same time point ($p \leq 0.05$).

Title: Effect of three different set configurations on kinematic variables and internal loads during a power snatch session.

Authors: Tsuyoshi Nagatani, Kristina L. Kendall, Stuart N. Guppy, Wayne C. K. Poon, and G. Gregory Haff[1]

School of Medical and Health Science, Centre for Human Performance, Edith Cowan University, Western Australia

[1]Directorate of Psychology and Sport, University of Salford, Salford, United Kingdom

Corresponding author:
Tsuyoshi Nagatani, MSc
Edith Cowan University
School of Medical and Health Science
Postal Address: 270 Joondalup Drive, Joondalup, Western Australia 6027, Australia
[redacted]

Tsuyoshi Nagatani
School of Medical and Health Sciences
Edith Cowan University
270 Joondalup Drive, Joondalup WA, 6027

8th December 2022

Dear Journal Strength & Conditioning Research Editorial Team

We wish to re-submit the manuscript entitled "*Effect of three different set configurations on kinematic variables and internal loads during a power snatch session*" for consideration by *Journal Strength & Conditioning Research* for publication after addressing the revisions requested by the reviewers.

We again confirm that this work is original, has not been published elsewhere, nor is it currently under consideration for publication elsewhere. We also have no potential conflicts of interest to disclose.

Based on the feedback received form the reviewers on the 17th of November in 2022, we have made revisions and believe that the revised manuscript satisfies the standards for publication. Where we have not made any amendments to the manuscript, we have outlined the rationale for doing so. We would like to thank the reviewers for thoroughly reviewing the previous version of the manuscript as we believe that their suggested edits have made our manuscript better.

If there are any questions or issues relating to our review article or its submission, please contact me at: [redacted]

Thank you for your consideration of this manuscript.

Kind Regards

Tsuyoshi Nagatani

Figure 1

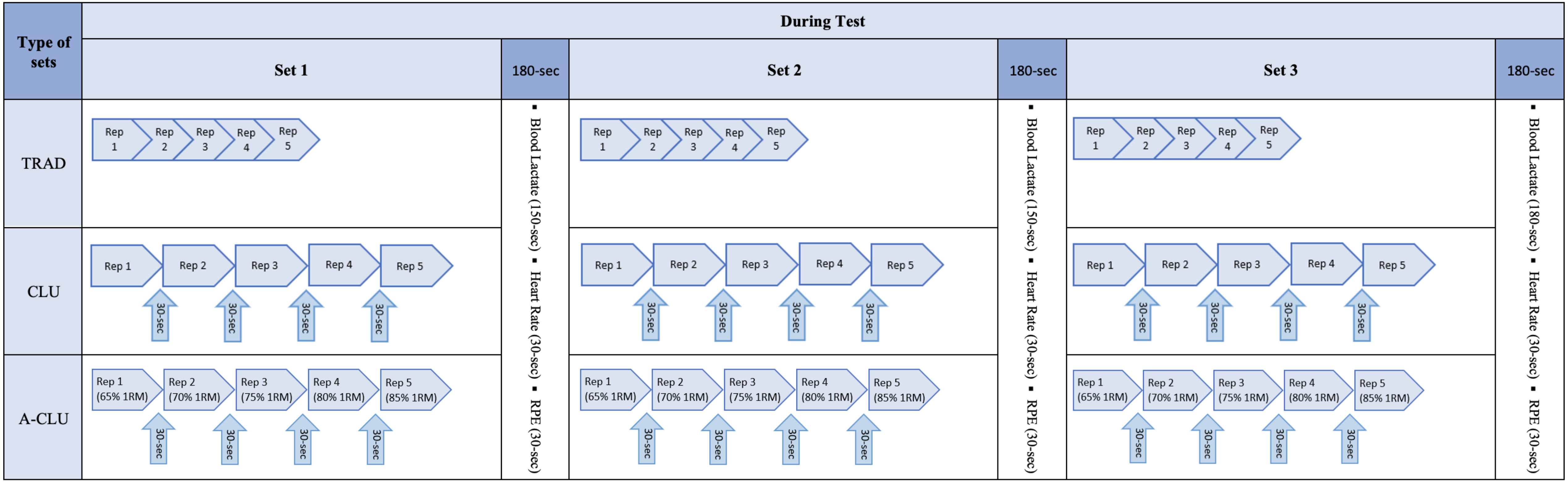
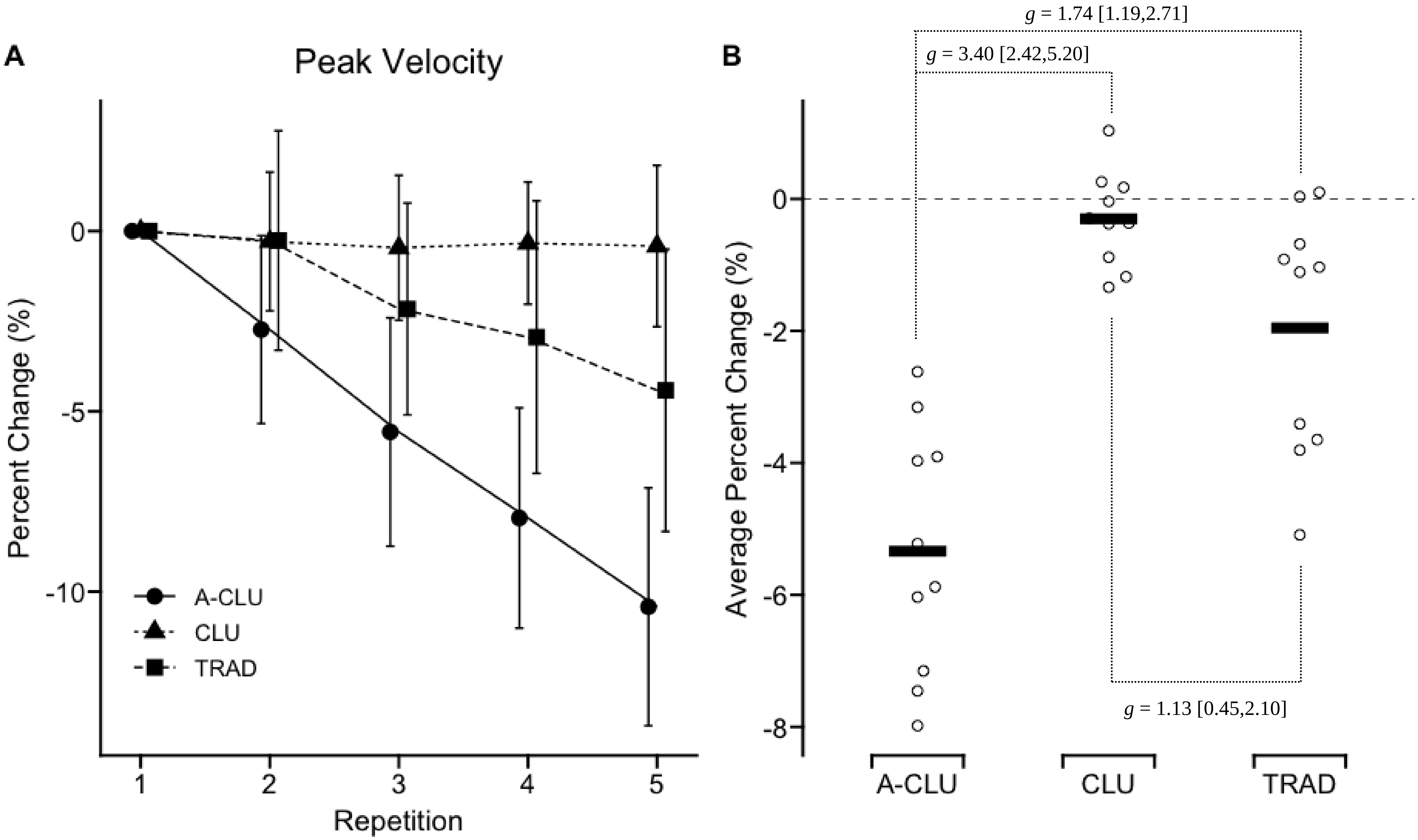
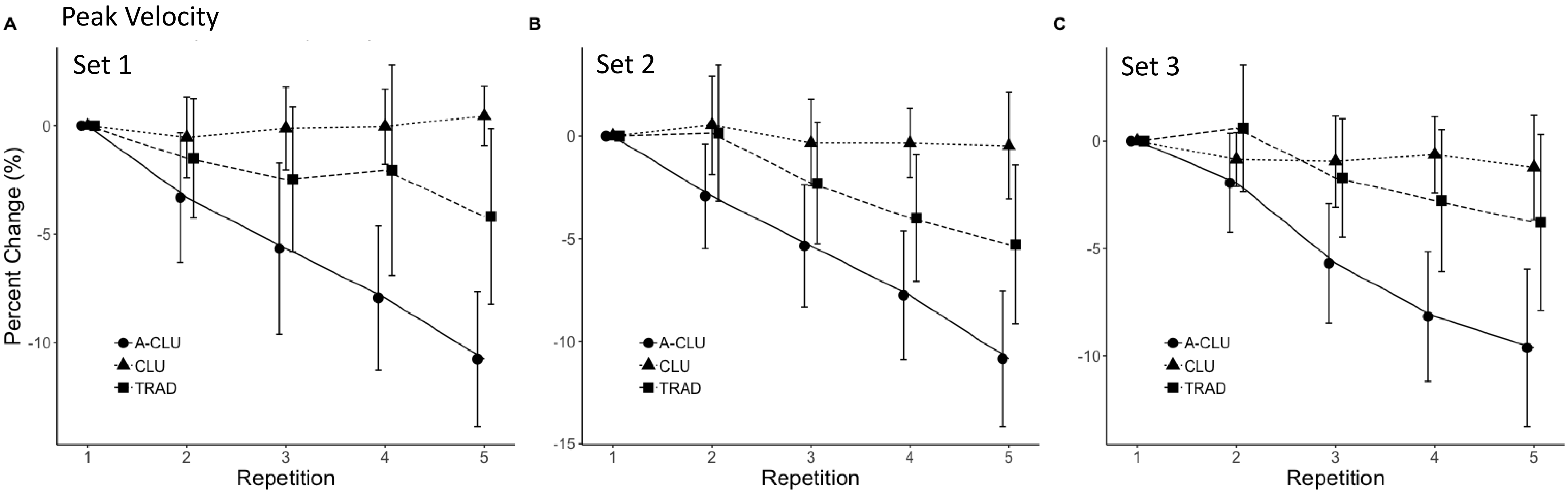

Type of sets
During Test
Set 1
180-sec
Set 2
180-sec
Set 3
180-sec
TRAD
CLU
A-CLU
Rep 1
Rep 2
Rep 3
Rep 4
Rep 5
Rep 1 (65% 1RM)
Rep 2 (70% 1RM)
Rep 3 (75% 1RM)
Rep 4 (80% 1RM)
Rep 5 (85% 1RM)
30-sec
▪ Blood Lactate (150-sec) ▪ Heart Rate (30-sec) ▪ RPE (30-sec)
▪ Blood Lactate (150-sec) ▪ Heart Rate (30-sec) ▪ RPE (30-sec)
▪ Blood Lactate (180-sec) ▪ Heart Rate (30-sec) ▪ RPE (30-sec)

Figure 2



A
Peak Velocity
Percent Change (%)
0
-5
-10
1
2
3
4
5
Repetition
A-CLU
CLU
TRAD
B
Average Percent Change (%)
0
-2
-4
-6
-8
A-CLU
CLU
TRAD
g = 1.74 [1.19,2.71]
g = 3.40 [2.42,5.20]
g = 1.13 [0.45,2.10]

Figure 3



Peak Velocity
A
Set 1
B
Set 2
C
Set 3
Percent Change (%)
Repetition
A-CLU
CLU
TRAD
0
-5
-10
-15
1
2
3
4
5

Figure 4

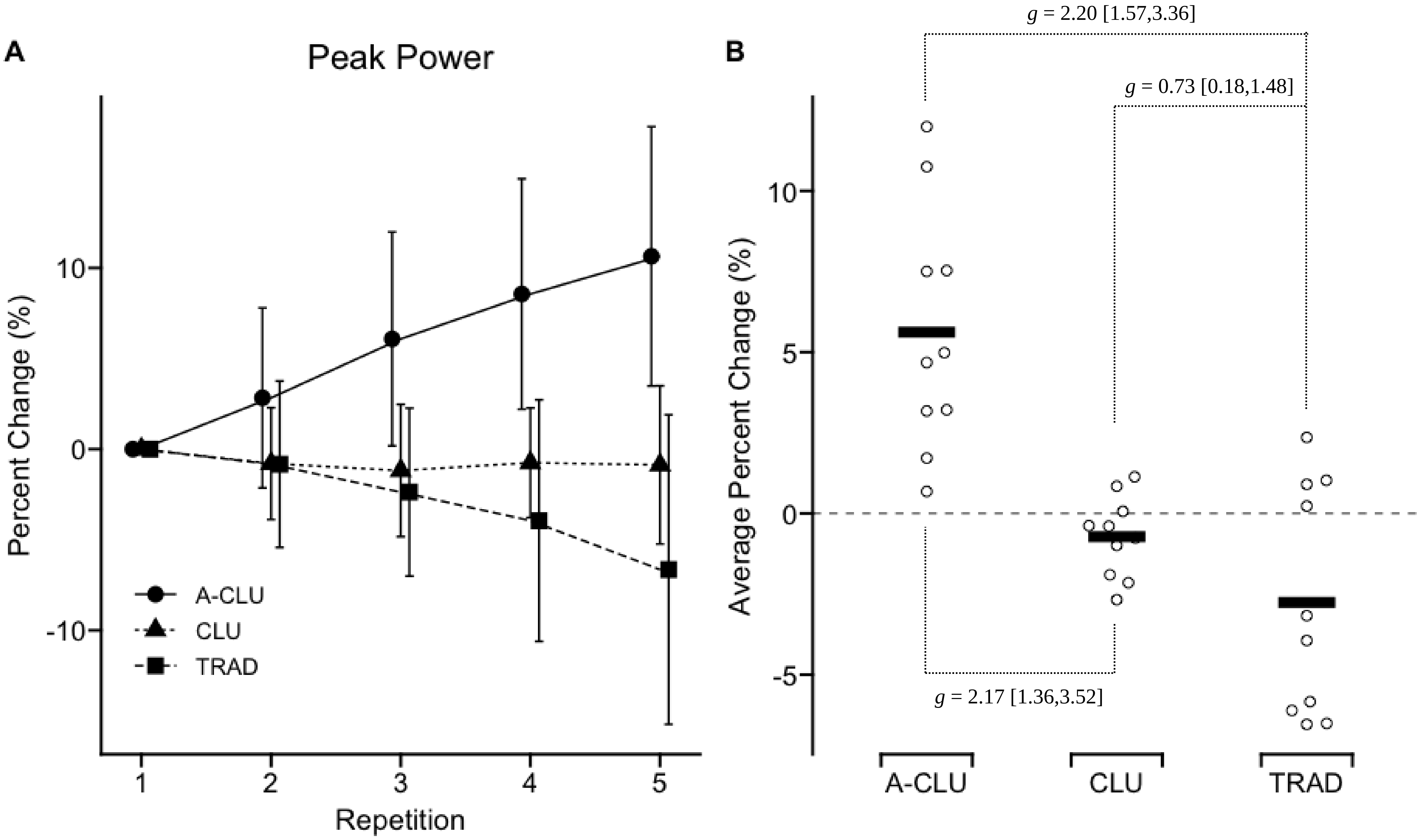

A
Peak Power
Percent Change (%)
10
0
-10
1
2
3
4
5
Repetition
A-CLU
CLU
TRAD
B
g = 2.20 [1.57,3.36]
g = 0.73 [0.18,1.48]
g = 2.17 [1.36,3.52]
Average Percent Change (%)
10
5
0
-5
A-CLU
CLU
TRAD

Figure 5

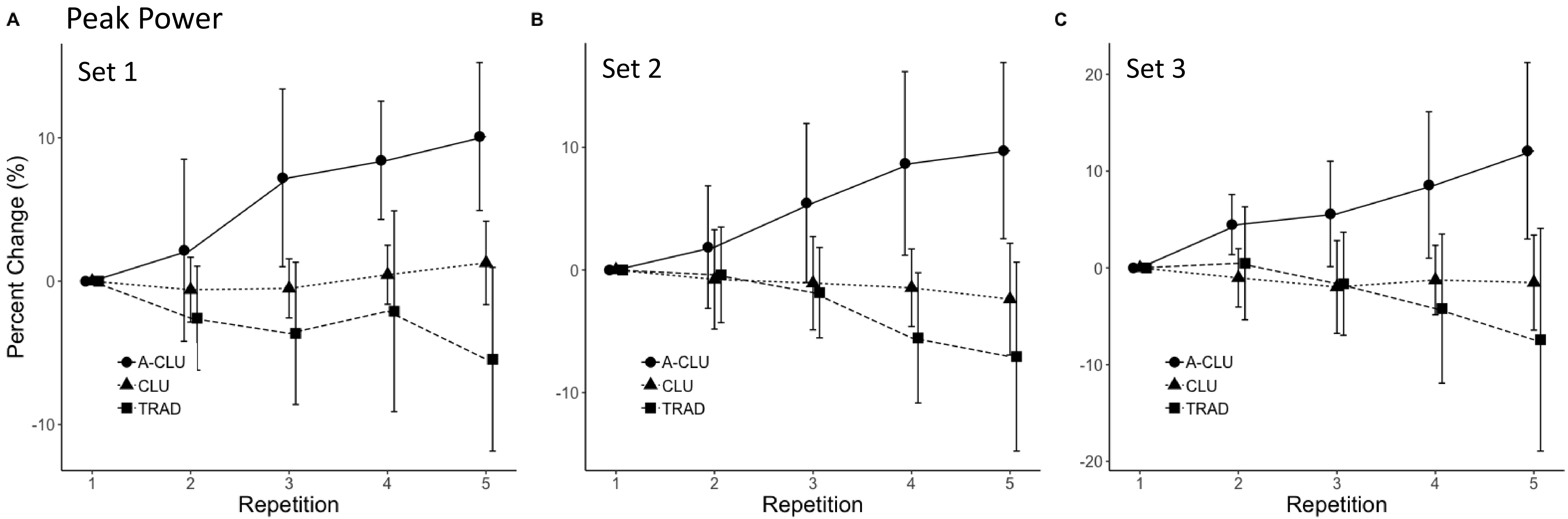
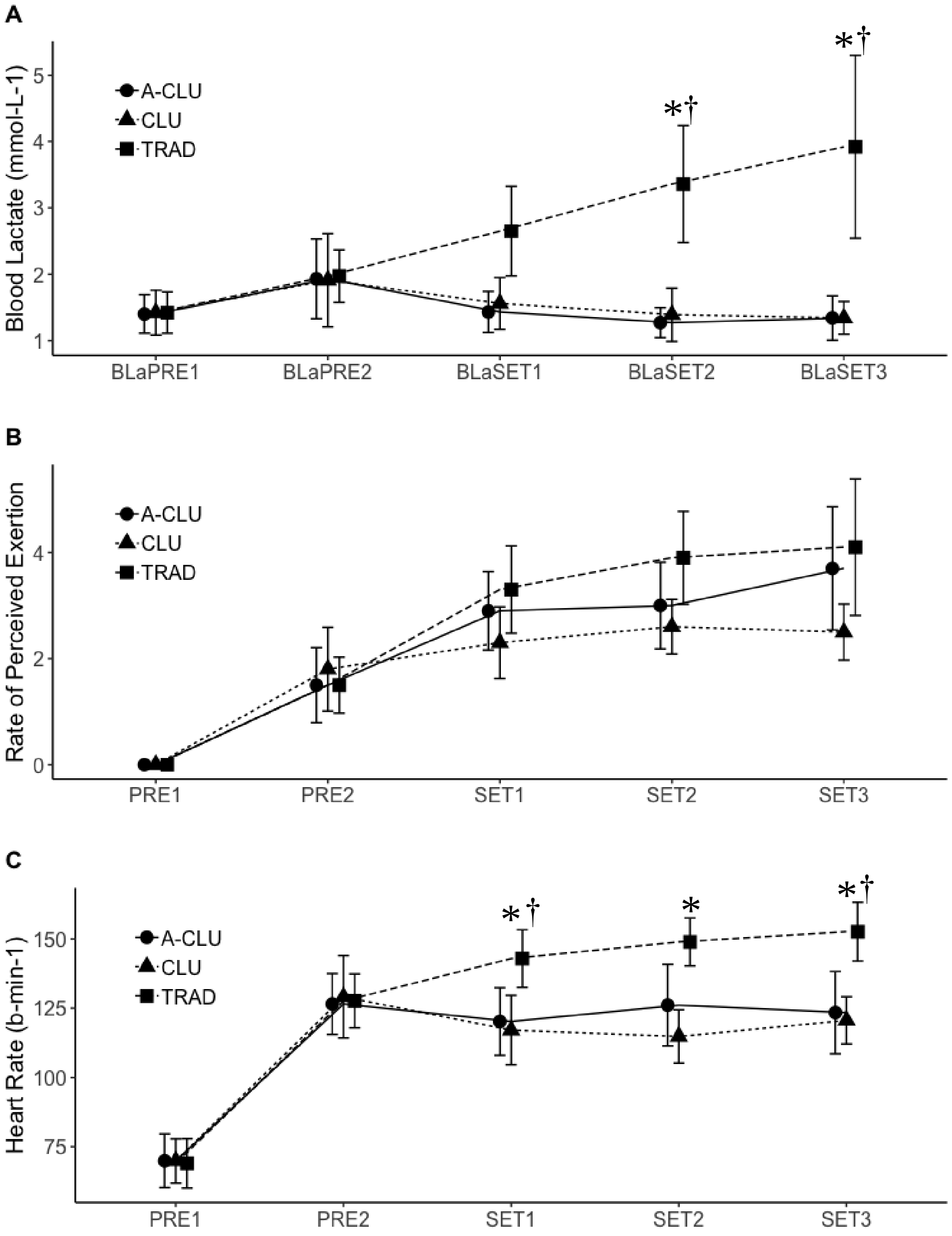

A
Peak Power
Set 1
B
Set 2
C
Set 3
Percent Change (%)
Repetition
A-CLU
CLU
TRAD
10
0
-10
20
-20
1
2
3
4
5

Figure 6



A
Blood Lactate (mmol-L-1)
A-CLU
CLU
TRAD
*†
*†
BLaPRE1
BLaPRE2
BLaSET1
BLaSET2
BLaSET3
B
Rate of Perceived Exertion
A-CLU
CLU
TRAD
PRE1
PRE2
SET1
SET2
SET3
C
Heart Rate (b-min-1)
A-CLU
CLU
TRAD
*†
*
*†
PRE1
PRE2
SET1
SET2
SET3

Table

Table 1. Descriptive statistics for peak velocity and peak power.

	Rep	TRAD (Mean ± SD)	CLU (Mean ± SD)	A-CLU (Mean ± SD)	Set Comparison		ES (95% CI)		*p*
Peak Velocity ($m·s^{-1}$)	R1	2.31 ± 0.19	2.31 ± 0.15	2.46 ± 0.20	TRAD	CLU	-0.01 (-0.23 to 0.20)	Trivial	1.000
						A-CLU	0.72 (0.49 to 1.13)	Moderate	0.001
					CLU	A-CLU	0.80 (0.50 to 1.31)	Moderate	0.038
	R2	2.30 ± 0.18	2.30 ± 0.16	2.39 ± 0.19	TRAD	CLU	-0.01 (-0.18 to 0.16)	Trivial	1.000
						A-CLU	0.43 (0.23 to 0.74)	Small	0.077
					CLU	A-CLU	0.47 (0.26 to 0.79)	Small	0.115
	R3	2.26 ± 0.18	2.30 ± 0.16	2.31 ± 0.16	TRAD	CLU	0.22 (0.03 to 0.46)	Small	1.000
						A-CLU	0.32 (0.14 to 0.58)	Small	0.411
					CLU	A-CLU	0.10 -0.04 to 0.28)	Trivial	1.000
	R4	2.24 ± 0.18	2.30 ± 0.15	2.26 ± 0.15	TRAD	CLU	0.34 (0.16 to 0.61)	Small	0.345
						A-CLU	0.09 (-0.19 to 0.41)	Trivial	1.000
					CLU	A-CLU	-0.27 (-0.60 to -0.02)	Small	1.000
	R5	2.20 ± 0.16	2.30 ± 0.16	2.19 ± 0.15	TRAD	CLU	0.53 (0.29 to 0.92)	Small	0.077
						A-CLU	-0.05 (-0.30 to 0.18)	Trivial	1.000
					CLU	A-CLU	-0.63 (-1.08 to -0.35)	Moderate	0.063
Peak Power (W)	R1	1826.79 ± 486.05	1840.37 ± 450.02	1737.96 ± 455.74	TRAD	CLU	0.03 (-0.06 to 0.13)	Trivial	1.000
						A-CLU	-0.18 (-0.29 to -0.10)	Trivial	0.136
					CLU	A-CLU	-0.21 (-0.36 to -0.12)	Small	0.075
	R2	1808.24 ± 460.25	1826.53 ± 458.90	1780.77 ± 450.46	TRAD	CLU	0.04 (-0.01 to 0.10)	Trivial	1.000
						A-CLU	-0.06 (-0.15 to 0.02)	Trivial	1.000
					CLU	A-CLU	-0.09 (-0.20 to -0.01)	Trivial	1.000
	R3	1773.30 ± 451.49	1817.15 ± 452.03	1825.16 ± 420.20	TRAD	CLU	0.09 (0.02 to 0.18)	Trivial	1.000
						A-CLU	0.11 (0.03 to 0.21)	Trivial	1.000
					CLU	A-CLU	0.02 (-0.06 to 0.10)	Trivial	1.000
	R4	1739.62 ± 411.32	1825.95 ± 450.79	1864.26 ± 411.63	TRAD	CLU	0.20 (0.12 to 0.32)	Small	0.144
						A-CLU	0.29 (0.17 to 0.50)	Small	0.059
					CLU	A-CLU	0.08 (-0.02 to 0.21)	Trivial	1.000
	R5	1693.32 ± 391.72	1818.21 ± 450.79	1899.56 ± 423.27	TRAD	CLU	0.31 (0.17 to 0.54)	Small	0.243
						A-CLU	0.51 (0.34 to 0.79)	Small	0.004
					CLU	A-CLU	0.18 (0.07 to 0.33)	Trivial	0.535

Note: R1 = first repetition; R2 = second repetition; R3 = third repetition; R4 = fourth repetition; R5 = fifth repetition; TRAD = traditional; CLU = cluster; A-CLU = ascending cluster; SD = standard deviation; Cl = confidence interval; ES = Hedges *g* effect size (trivial: < 0.2, small: 0.20-059., moderate: 0.60-1.19, large: 1.20-1.99, and very large: > 2.0).