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ARTICLE

The effects of muscle action, repetition duration, and loading strategies of a whole-body, progressive resistance training programme on muscular performance and body composition in trained males and females

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Abstract: Research has produced equivocal results with regard to eccentric (ECC) only compared with traditional concentric/eccentric resistance training (RT). When considered in relation to load- and repetition duration-accentuated (ECC) training as well as the use of isokinetic and isoinertial training methods, there is a relative dearth of literature considering multi-joint, multi-exercise RT interventions. The present study considered 59 male and female participants randomly divided in to 3 sex counterbalanced groups; ECC only (ECC, $n = 20$), repetition duration-accentuated ECC (ECC-A, $n = 20$), and traditional (CON, $n = 19$) performing full-body, effort matched RT programmes for 2 days·week^{-1} for 10 weeks. Outcomes were muscular performance, including absolute muscular endurance and predicted 1-repetition maximum, in addition to body composition. No significant between-groups differences were identified for change in muscular performance measures for leg press or chest press exercises, or for body composition changes. Analyses revealed a significantly greater improvement for CON compared with ECC groups ($p < 0.05$) for change in absolute muscular endurance for the pull-down exercise. Effect sizes for muscular performance changes were moderate to large for all groups and exercises (0.75–2.00). The present study supports previous research that ECC-only training produces similar improvements in muscular performance to traditional training where intensity of effort is controlled. Data herein further supports the use of uncomplicated, low-volume RT to momentary failure as an efficacious method of improving muscular performance in trained persons.

Key words: advanced techniques, muscle, lean mass, body fat, negative.

Résumé : La recherche a produit des résultats divergents à propos de l'entraînement contre résistance (« RT ») au moyen de contractions pliométriques (« ECC ») seulement en comparaison à l'entraînement classique contre résistance au moyen de contractions miométriques/pliométriques. Que ce soit au sujet de l'accentuation de la charge ou de la durée de l'action pliométrique (ECC) ou même au sujet des méthodes d'entraînement isokinétique et iso-inertiel, il y a peu d'études en RT sur les interventions incorporant des exercices multiples et polyarticulaires. La présente étude comprend 59 femmes et hommes répartis aléatoirement en 3 groupes équilibrés selon le sexe : ECC seul (ECC, $n = 20$), accentuation de la durée de l'action pliométrique lors de la répétition (« ECC-A », $n = 20$) et classique (« CON », $n = 19$); tous les groupes se soumettent à un RT mobilisant tout l'organisme, apparié selon l'effort, durant 10 semaines à raison de 2 d·sem^{-1}. Les résultats présentent la performance musculaire incluant l'endurance musculaire absolue et le maximum de la charge levée prédite (« 1RM ») et la composition corporelle. On n'observe pas de différences significatives entre les groupes en ce qui concerne la performance musculaire au développé des membres inférieurs, des pectoraux et la modification de la composition corporelle. L'analyse révèle une plus grande amélioration significative de l'endurance musculaire absolue à l'extension des bras vers le bas dans le groupe CON versus le groupe ECC ($p < 0,05$). Les modifications de la performance musculaire présentent une ampleur de l'effet variant de modérée à importante dans tous les groupes et pour tous les exercices (0,75–2,00). La présente étude appuie les recherches antérieures rapportant que l'entraînement en mode ECC seulement suscite des améliorations de la performance musculaire similaires à l'entraînement classique quand on contrôle l'intensité de l'effort. Les présentes données appuient la thèse de l'utilisation de RT simple et de faible volume jusqu'à l'échec momentané du mouvement en tant que méthode efficace pour l'amélioration de la performance musculaire chez des personnes entraînées. [Traduit par la Rédaction]

Mots-clés : techniques avancées, muscle, masse maigre, gras corporel, négatif.

Introduction

Traditional resistance training (RT) includes active shortening (concentric; CONC) and lengthening (eccentric; ECC) of muscle fibres under tension. Evidence suggests that for most people muscular force production is 20%–60% higher in ECC compared with CONC muscle actions (Dudley et al. 1991; Hollander et al. 2007; Jones and Rutherford 1987). However, research has shown higher surface electromyography amplitude and motor unit activation (measured by intramuscular spike–amplitude–frequency histograms) for CONC muscle actions where loading strategies are equated (Moritani et al. 1987). Furthermore, hormonal responses in growth hormone and blood lactate are higher for CONC compared with

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load-accentuated ECC (+35%) muscle actions (Durand et al. 2003). With this in mind, ECC training has been of interest as a result of the capacity to use increased loading strategies (Hollander et al. 2007) or reduce metabolic cost (Vogt and Hoppeler 2014). Furthermore, research has considered the application of both load-accentuated ECC RT (additional load through the ECC muscle action whilst maintaining a comparable load through the CONC phase; Brandenburg and Docherty 2002; Hortobágyi et al. 2001), and repetition duration–accentuated ECC RT (using the same load for each muscle action but extending the time duration for the ECC phase of the repetition; Dias et al. 2015).

To date the literature suggests equivocal results for load-accentuated ECC RT. Nichols et al. (1995) reported greater gains in strength when training with an accentuated ECC load compared with traditional RT in older adults. Conversely, other research has found no such differences, reporting similar increases in strength between load-accentuated ECC training and traditional RT (Godard et al. 1998). However, further research has reported no differences for strength increase but reported significant differences for peak power increases (measured as single leg vertical jump) in favour of load-accentuated ECC training (Friedmann-Bette et al. 2010), as well as more favourable results for ECC-only training at faster velocities (180°s^{-1}) compared with slower velocities (30°s^{-1}) as well as CONC training at both faster and slower velocities (Farthing and Chilibeck 2003).

However, many of the studies comparing CONC and ECC training utilised isokinetic exercise (Blazevich et al. 2007; Higbie et al. 1996; Farthing and Chilibeck 2003; Moore et al. 2012). Authors have stated that ECC isokinetic movements involve performing maximal CONC contractions to resist a forceful ECC action (Blazevich et al. 2007; Moore et al. 2012). Furthermore, research has shown that isokinetic muscle actions produce higher peak EMG values for ECC compared with CONC actions (Bishop et al. 2000), contrasting with the aforementioned load matched isoinertial methods (Moritani et al. 1987). As such, we argue that ECC isokinetic resistance exercise is not representative of traditional training methods.

Other research considering load-accentuated ECC overload strategies using isoinertial resistance (e.g., Hortobágyi et al. 2001; Jones and Rutherford 1987; Pavone and Moffat 1985) have also reported equivocal results. Hortobágyi, et al. (2001) compared a group performing traditional CONC/ECC muscle actions at ~60% 1-repetition maximum (RM) to a group using an ECC overload of +40%–50% 1RM. To create parity in total training load between groups the volume (number of repetitions) was manipulated.[1] The authors reported significantly greater strength gains for ECC 3RM and ECC and isometric (ISO) force measured by isokinetic dynamometry for ECC overload compared with the traditional training groups. However, maximal ECC training is often characterized by considerable structural damage and reduced muscle function (Baroni et al. 2015). Hortobágyi et al. (2001) included "normally sedentary women" training for 7 consecutive days and reported "neither the young nor the older subjects reported muscle soreness associated with the training"; as such, it appears that the authors likely neither considered nor equated intensity of effort in either group, and that a higher intensity of effort for both groups might have attained a more meaningful and equated training response. In contrast, other research has reported no significant differences for ISO strength increases for load-accentuated ECC compared with traditional or CONC training (Jones and Rutherford 1987; Pavone and Moffat 1985), or greater adaptations for CONC training despite a 35% load-accentuated ECC muscle action (Smith and Rutherford 1995). However, once again these studies failed to control intensity of effort between training groups.

More recent studies have controlled intensity of effort between groups by having all participants train to momentary failure (MF) or perform maximal contractions, reporting no significant differences between CONC and ECC training groups (Fisher and Langford 2014; Moore et al. 2012). However, the present body of research dominantly considers single joint (SJ) movements (e.g., knee extension (Baroni et al. 2015) or elbow flexion (Brandenburg and Docherty 2002; Farthing and Chilibeck 2003; Moore et al. 2012)). Since research has suggested that the addition of SJ exercises to multi-joint (MJ) protocols might be unnecessary (de França et al. 2015; Gentil et al. 2013), it is important for research to compare CONC and ECC resistance training using MJ exercises. Literature searches revealed only 3 research articles utilising MJ and multi-exercise protocols; the first having included community-dwelling older adults (Nichols et al. 1995), and the second being an acute study of cytokine responses (Bazgir et al. 2015). The final study considered untrained young women performing ECC-only training at heavy (125% CONC 1RM) and light (75% CONC 1RM) loads (Schroeder et al. 2004). The results revealed similar between-groups improvements in strength, with the exception of chest press. The authors reported favourable adaptations to the heavy-load group; however, the data presented within Table 3, page 230, of the article suggest a favourable adaptation to the light-load group. Whilst this study utilised a 16-week multi-exercise approach, the training groups were equated for training volume (load × sets × repetitions) rather than intensity of effort which might have affected the results.

To date there appear to have been no large-scale studies utilising a whole-body RT protocol comparing practical approaches to RT by manipulating and controlling muscle action, repetition duration, and loading strategies in trained participants whilst controlling for intensity of effort. With the above in mind, the aim of the present research piece is to consider the effects of repetition duration-accentuated ECC-only training, the addition of an ECC-only training, and traditional RT upon muscular performance and body composition in previously trained males and females.

Materials and methods

Study design

A randomised, controlled trial design was adopted, with 3 experimental groups included. The effects of 3 RT interventions were examined in trained participants upon muscular performance and body composition. The study design was approved by the relevant ethics committee at the first author's institution.

Participants

Sixty participants (males = 30, females = 30) were recruited from the present membership pool in a United States strength training facility (Discover Strength, Plymouth, Minn., USA). All participants were required to have had >6 months RT experience at the present facility, incorporating low-volume (single set) RT to MF for most major muscle groups for ~2 days·week^{-1}. All participants were currently physically active (e.g., walking, jogging, cycling, swimming, or yoga) outside of participation in RT and were instructed to not change their physical activity habits or to begin any other structured exercise programs (with the exception of the RT interventions examined in the present study). Participants were also free from any medical condition for which RT is contraindicated. Written informed consent was obtained from all participants prior to any testing and group allocation was performed by computer randomisation to 1 of 3 groups; additional ECC-only

[1]The example provided by the authors is 5 sets of 12 repetitions with 23 kg for CONC and ECC (traditional training) = 2760 kg, compared with 5 sets of 10 repetitions with 23 kg for CONC and 32 kg for ECC (ECC overload) = 2750 kg (Hortobágyi et al. 2001).

(n = 20 (males = 10, females = 10)), repetition duration-accentuated eccentric (ECC-A; n = 20 (males = 10, females = 10)), and a control group (CON; n = 20 (males = 10, females = 10)). Participants were asked regularly about external exercise habits, which resulted in 1 female participant being removed from the study (CON group) at week 9 when she expressed that she had begun attending another structured exercise program. All remaining participants completed all required exercise sessions (e.g., 2 days·week^{-1} for 10 weeks).

Procedures

Testing

Pre- and post-intervention muscular performance testing was performed in the following order with 120 s rest between exercises using chest press (CP), leg-press (LP; both MedX, Ocala, Fla., USA), and pull-down (PD; wide pull-down, Hammer Strength, Rosemonth, Ill., USA) resistance machines. Since all participants were existing members of the facility where testing and training took place, all participants used their pre-existing training load for testing. It was estimated that this load would evoke MF in 8–12 repetitions at the 2-s CONC, 4-s ECC (2:4) repetition duration used for testing and training in the CON group. Mean repetitions at baseline confirmed this with 9.8, 9.1, and 8.6 repetitions for CP, LP, and PD, respectively. Pre- and post-testing used the same absolute load allowing total volume load (e.g., load × repetitions) to be calculated as has been completed in previous research (e.g., de Souza et al. 2010; Fisher et al. 2014, 2015). This method allows comparison of absolute muscular endurance and, since previous research using a large sample size (n = 171) has reported no change in number of repetitions performed at the same relative load (% 1RM) despite increases in maximal strength (Mayhew et al. 1992), an increased number of repetitions at an absolute load represents adaptations in muscular performance. Further, predicted 1RM was also calculated using the Brzycki (1993) equation (predicted 1RM = load lifted/(1.0278 – (0.0278 × number of repetitions)), which has been shown to have a very high correlation to actual 1RM (r = 0.99; Nascimento et al. 2007). In addition, this method provides strong ecological validity to realistic training conditions as most people infrequently test or use their maximal strength. The test was ceased when the participant failed during the CONC phase of a repetition or could not maintain the required repetition duration. Post-testing was performed at least 48 h following the final training session as per previous research (Fisher et al. 2014, 2015). The instructor performing the pre- and post-testing was blinded to group assignment.

Body composition was estimated using air displacement plethysmography (Bod Pod GS; Cosmed, Chicago, Ill., USA). Details of the test procedures for estimation of body composition have been previously described in detail elsewhere (Dempster and Aitkens 1995). Briefly, whilst wearing minimal clothing (swimsuit or tight fitting underwear) and a swim cap, participants were weighed using a calibrated digital scale. The participant was then seated in the Bod Pod for body volume measurement. From the body mass and body volume measurements and predicted thoracic lung volumes, body density was estimated by the Bod Pod software and lean and fat mass estimations calculated using the Siri equation.

Training intervention (ECC, ECC-A, CON)

Training was performed 2 days·week^{-1} (with at least 48 h between sessions) for 10 weeks. RT exercises included leg extension, leg curl, leg press, (MedX) overhead press (Nautilus 2ST; Nautilus, Vancouver, Wash., USA), chest press (MedX), pec-fly (Nautilus Nitro Plus; Nautilus), pull-over (Nautilus 2ST) and pull-down (wide pull-down, Hammer Strength) performed for a single set per session to MF.

The ECC group performed 1 × traditional and 1 × ECC-only workout each week. For the traditional workout, each of the exercises were performed using a 2-s CONC, 4-s ECC (2:4) repetition duration reaching CONC MF in 8–12 repetitions. All participants in the study had previously been performing RT using this repetition duration for the majority of their training. For the ECC-only workout, participants performed only ECC muscle actions (the load was lifted by trainers) with a load ~30% greater than their traditional workout load whilst repetition duration was controlled at 10 s. Loads were increased when participants could perform ≥8 repetitions. Participants performed repetitions to ECC MF, which was defined as occurring when the participant could no longer control the load for the required duration (i.e., where despite attempting to maintain the prescribed repetition duration the participant could not prevent the ECC contraction from occurring at a shorter repetition duration than prescribed). To manage the risk of overtraining suggested by excessive training to MF (Willardson 2007), it was felt that training 1 × traditional (e.g., CONC MF) and 1 × ECC-only (e.g., ECC MF) was a realistic approach to testing ECC-only training. In addition, since ECC-only training requires the assistance of either a trainer or training partner, we suggest it is not performed in high frequency. This research design served to reach MF for CONC training but also utilise the hypothesised greater motor unit fatigue and potential greater adaptations by training to ECC MF (Schoenfeld 2011). Further, as ECC-only training is predominantly used as an adjunct to traditional CON training by trained persons, it was felt that this represented a more ecologically valid examination of its application. All training sessions were performed at a 1:1 (trainer/trainee) supervision ratio. Where necessary to help perform the lifting of the weight for the ECC-only sessions, a second trainer assisted but did not provide coaching/instruction.

The ECC-A group performed 2× eccentric-accentuated workouts per week using the above exercises. Repetition duration was controlled at 2-s CONC, 10-s ECC (2:10), reaching CONC MF in ~6 repetitions.

The CON group performed each of the above exercises using the traditional protocol highlighted above; 2:4 repetition duration to CONC MF in 8–12 repetitions. In addition, for all of the groups, at the end of each workout lumbar extension (MedX Core Lumbar Strength, MedX) and abdominal flexion (MedX Core Ab Isolator, MedX) exercises were performed using the traditional, aforementioned 2:4 repetition duration reaching CONC MF in 8–12 repetitions. Based on the aforementioned calculation (Brzycki 1993), the training load equated to ~75% 1RM for the tested exercises (CP, LP, and PD) for the traditional and ECC-A workouts, and was ~30% greater for the ECC-only workouts. Once participants could perform more than the desired repetitions (e.g., ≥12 repetitions for traditional training protocol, ≥8 repetitions for ECC-only protocol, and >6 for ECC-A protocol), load was increased by ~5% as per previous recommendations and research (Fisher et al. 2014, 2015). Parity was maintained between groups by all participants in all groups training to MF for a similar maximal total (CONC + ECC) time under load (traditional workouts, ~72 s; ECC-only, ~80 s; ECC-A, ~72 s).

Statistical analyses

Power analysis of research using low-volume RT in trained participants (Fisher et al. 2014) was conducted to determine participant numbers (n) using an effect size (ES), calculated using Cohen's d (Cohen 1992) of 1.25 for improvements in strength. Participant numbers were calculated using equations from Whitley and Ball (2002), revealing that each group required 9 participants to meet required β power of 0.8 at an α value of $p \le 0.05$.

After dropouts (n = 1), data were available from 59 participants (ECC, n = 20; ECC-A, n = 20; CON, n = 19). Data met assumptions of normality of distribution when examined using a Kolomogorov–Smirnov test. Baseline data were compared between groups using a 1-way analysis of variance (ANOVA) to determine whether randomisation had succeeded. Between-groups comparisons for absolute changes in muscular performance and body composition outcomes were performed using 1-way ANOVA. Where assump-

Table 1. Participant baseline characteristics.

	ECC	ECC-A	CON	*p*
Age (y)	39±12	40±11	39±14	0.734
Stature (cm)	172.68±7.79	169.81±10.84	170.19±10.15	0.674
Body mass (kg)	77.98±14.15	72.88±14.99	73.28±14.26	0.519
BMI	26.08±4.13	25.04±3.00	25.12±2.95	0.577

Note: Results are means ± SD; *p* values for between group effects using ANOVA. BMI, body mass index; CON, control; ECC, eccentric; ECC-A, eccentric accentuated.

tions of homogeneity of variance were violated, the Welch's *F* test statistic was used. Any significant between-group effects were examined further with post hoc Tukey, or Games–Howell where assumptions of homogeneity of variance were violated, testing to determine the location of significant differences. Statistical analyses were performed using IBM SPSS Statistics for Windows (version 20; IBM Corp., Portsmouth, Hampshire, UK) and $p \leq 0.05$ set as the limit for statistical significance. Further, 95% confidence intervals (CI) were calculated in addition to ES using Cohen's *d* (Cohen 1992) for each within-participant changes in each outcome to compare the magnitude of effects between groups where an ES of 0.20–0.49 was considered to be small, 0.50–0.79 moderate, and ≥0.80 large. The researcher who performed the data analyses was blinded to group assignment.

Results

Participants

Participant baseline demographics are shown in Table 1. Demographic variables did not differ between groups at baseline.

Absolute muscular endurance

ANOVA did not reveal any significant between-group effects for baseline absolute muscular endurance data for any exercise. Figure 1 shows the individual responses and mean changes in absolute muscular endurance with 95%CIs for each group and exercise with 95%CIs indicating that significant changes in muscular performance within each group occurred for every exercise. ANOVA did not reveal any significant between-group effects for change in absolute muscular endurance for chest press (mean ± SD for volume-load change: ECC = 165.9 ± 212.8, ECC-A = 252.8 ± 152.3, CON = 258.7 ± 133.1; $F_{[2,35.962]} = 1.350$, $p = 0.272$) or leg press, (mean ± SD for volume-load change: ECC = 456.7 ± 379.5, ECC-A = 525.9 ± 319.2, CON = 461.8 ± 328.0; $F_{[2,55]} = 0.211$, $p = 0.810$), but did for pull-down (mean ± SD for volume-load change: ECC = 66.4 ± 44.8, ECC-A = 126.9 ± 107.7, CON = 116.2 ± 58.0; $F_{[2,55]} = 4.000$, $p = 0.024$). Post hoc Tukey testing revealed a significant difference between ECC and CON ($p = 0.035$) and nonsignificant differences between ECC-A and CON ($p = 0.963$) and between ECC and ECC-A ($p = 0.065$). ESs for absolute muscular endurance changes were all considered to be moderate to large for ECC, and large for ECC-A and CON groups and were 0.78, 1.65, and 1.94, respectively, for chest press; 1.20, 1.68, and 1.41, respectively, for leg press; and 1.48, 1.46, and 2.00, respectively, for pull-down.

Predicted 1RM

ANOVA did not reveal any significant between-group effects for baseline predicted 1RM data for any exercise. Figure 2 shows the individual responses and mean changes in predicted 1RM with 95%CIs for each group and exercise with 95%CIs indicating that significant changes in muscular performance within each group occurred for every exercise. ANOVA did not reveal any significant between-group effects for change in predicted 1RM for chest press ($F_{[2,55]} = 0.442$, $p = 0.645$), leg press, ($F_{[2,55]} = 0.918$, $p = 0.405$), or pull-down ($F_{[2,55]} = 3.108$, $p = 0.053$). ESs for predicted 1RM changes were all considered to be moderate to large for ECC, and large for both ECC-A and CON groups, and were 0.75, 1.09, and 1.87, respec-

Fig. 1. Individual and mean absolute muscular endurance changes with 95% confidence intervals for each group and exercise. CON, control; ECC, eccentric; ECC-A, eccentric accentuated. *, Significant difference between ECC and CON with post hoc Games–Howell testing.

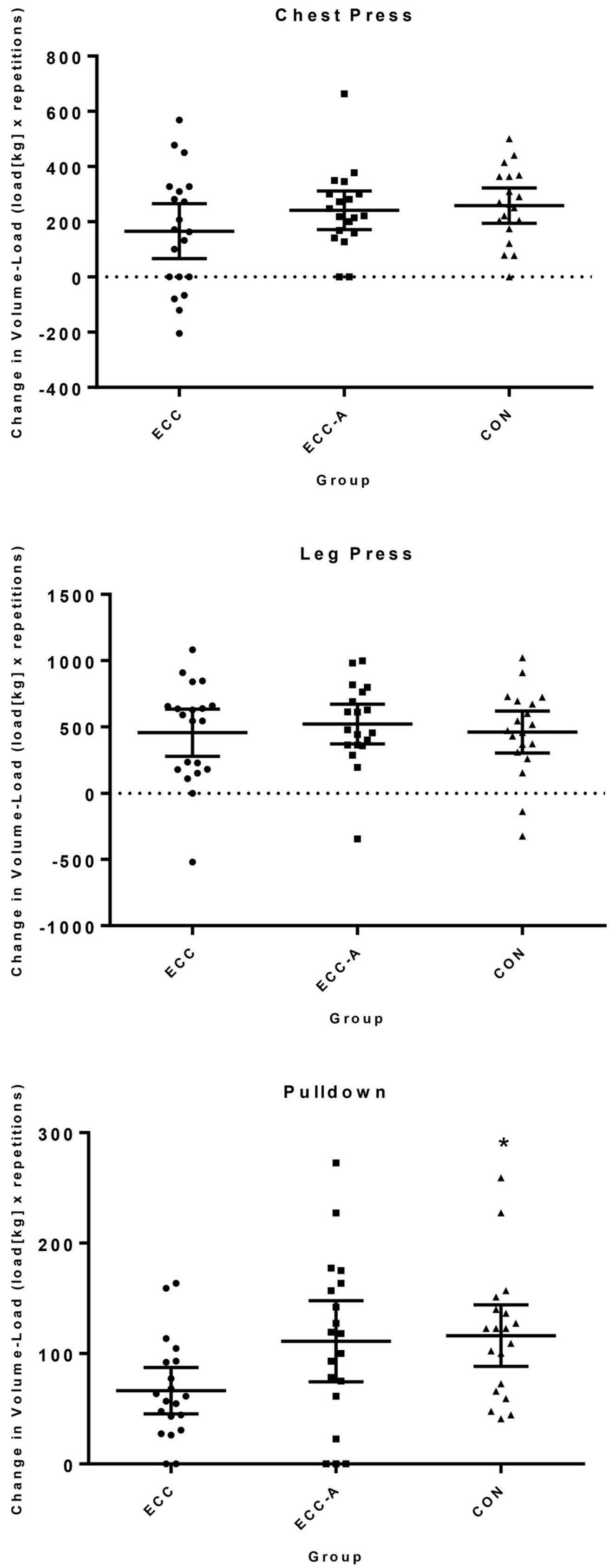
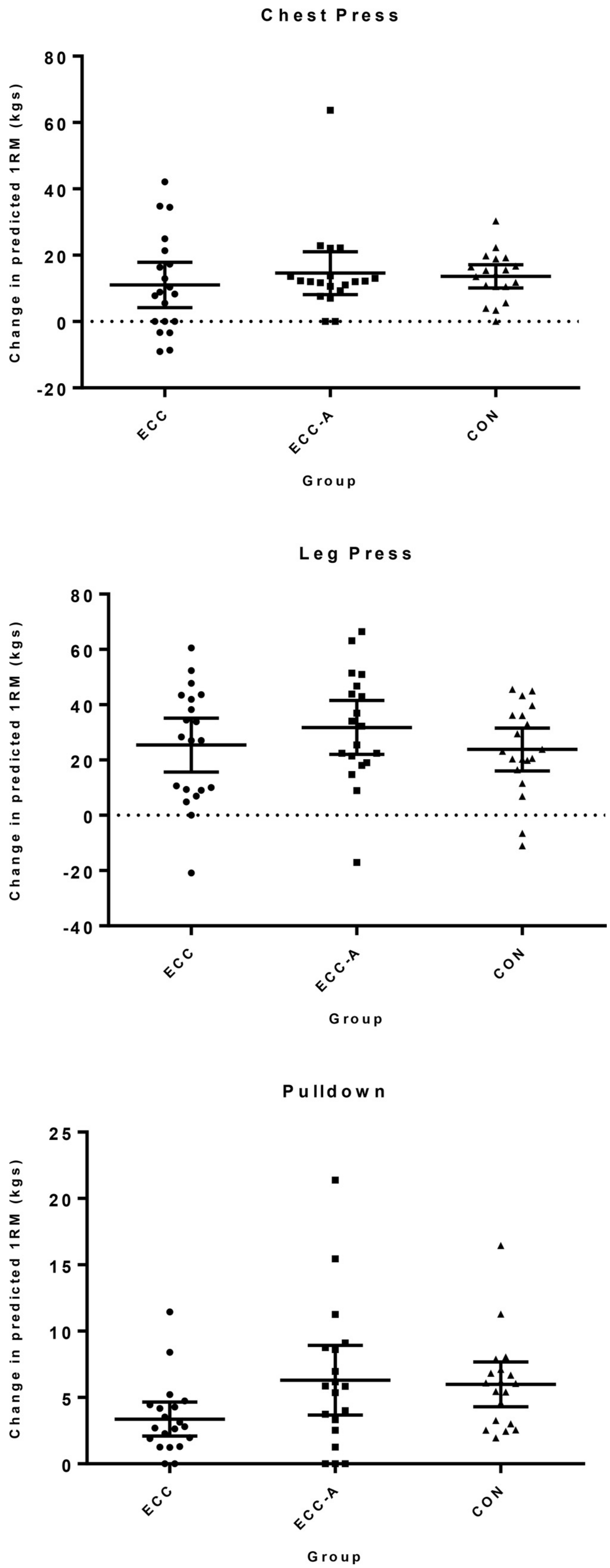


Fig. 2. Individual and mean predicted 1-repetition maximum (1RM) changes with 95% confidence intervals for each group and exercise. CON, control; ECC, eccentric; ECC-A, eccentric accentuated. *, Significant difference between ECC and CON with post hoc Games–Howell testing.



tively, for chest press; 1.22, 1.58, and 1.48, respectively, for leg press; and 1.24, 1.15, and 1.72, respectively, for pull-down.

Body composition

ANOVA did not reveal any significant between-group effects for baseline body composition data. Table 2 shows mean changes, 95%CIs, and ESs for body composition changes. ANOVA did not reveal any significant between-group effects for change in either body mass ($F_{[2,55]}$ = 1.652, p = 0.201), body fat percentage ($F_{[2,54]}$ = 0.607, p = 0.549), or lean mass ($F_{[2,55]}$ = 1.253, p = 0.294).

Discussion

The present study examined the effects of the addition of ECC only and repetition duration-accentuated ECC-only RT protocols compared with a control group training to MF in trained males and females. Results suggested that all groups made significant improvements in muscular performance in the form of absolute muscular endurance and predicted 1RM. The only between-groups statistically significant difference occurred in favour of greater gains for the CON group compared with the ECC-only group for pull-down exercise; however, ESs were qualitatively large for all groups. To date this appears to be the first empirical research trial that has applied a practical approach of ECC only, and repetition duration-accentuated ECC exercise in a whole-body RT intervention. The data presented suggest that performing additional heavy ECC only or repetition duration-accentuated ECC-only RT produces no greater gains in muscular performance improvement beyond that of performing more simple RT protocols of 8–12 repetitions to MF. ESs for all groups for all exercises were considered to be moderate to large, suggesting meaningful change supporting a significant magnitude in improvement.

Previous publications have reported equivocal results following ECC only, and both load-accentuated and repetition duration-accentuated ECC training compared with CONC-only and traditional (CONC/ECC) RT interventions. However, much of this research has been limited by use of isokinetic muscle actions (Farthing and Chilibeck 2003), volume rather than intensity of effort control between groups (Hortobágyi et al. 2001), or use of SJ movements (e.g., knee extension (Baroni et al. 2015; Fisher and Langford 2014), elbow flexion (Brandenburg and Docherty 2002; Farthing and Chilibeck 2003;Moore et al. 2012)). Therefore, this study adds an ecologically valid training approach to the body of literature.

Hypotheses have been proposed that since muscles can produce a greater force during ECC contractions, true MF does not occur during the CONC phase of an exercise (Willardson 2007). As such authors have suggested that training to ECC MF or using greater loads for ECC muscle actions could promote greater motor unit fatigue and thus elicit greater muscular adaptations (Schoenfeld 2011). Whilst this hypothesis seems logical (and might have application with regards to muscle hypertrophy), previous studies, which have been controlled for intensity of effort, have reported similar strength adaptations for groups performing ECC only (Fisher and Langford 2014; Moore et al. 2012), load-accentuated ECC (Godard et al. 1998), and repetition duration-accentuated ECC (Dias et al. 2015) approaches compared with traditional RT. The present study supports this and other previous research that have suggested that training to MF appears sufficient stimulus to catalyse similar muscular performance adaptations independently of load (Schoenfeld et al. 2016), repetition duration (Schoenfeld et al. 2015), and without the need for advanced or complicated training methods (Fisher et al. 2014, 2011, 2013).

However, analyses did reveal a statistically significant difference between CON and ECC-only groups for PD exercise in favour of greater muscular performance adaptation for the CON group in absolute muscular endurance (p = 0.035; ESs were 1.48 and 2.00 for ECC and CON, respectively). Qualitatively ESs were both large but were more favourable for the CON group. Previous research has reported that strength adaptations are more specific to training

Table 2. Mean changes and effect sizes for body composition outcomes.

	ECC			ECC-A			CON			
Outcome	Change	95% CI	ES	Change	95% CI	ES	Change	95% CI	ES	*p*
Body mass (kg)	−0.17±1.77	−1.00 to 0.65	−0.10	−3.67±13.17	−10.01 to 2.68	−0.28	0.55±1.57	−0.21 to 1.30	0.35	0.210
Body fat (%)	0.05±1.62	−0.81 to 0.71	0.03	−0.44±1.95	−1.41 to 0.53	−0.23	0.25±2.14	−0.78 to 1.28	0.12	0.519
Lean mass (kg)	−0.03±1.26	−0.62 to 0.56	−0.02	−2.19±9.06	−6.56 to 2.17	−0.24	−0.30±1.22	−0.29 to 0.88	−0.25	0.311

Note: Results are means ± SD; *p* values for between group effects using ANOVA. BMI, body mass index; CON, control; ECC, eccentric; ECC-A, eccentric accentuated.

type, e.g., that CONC training improves CONC strength to a greater degree than ECC training, and ECC training improves ECC strength to a greater degree than CONC training (Higbie et al. 1996). This significant difference within the present study might be explained by the ECC-only group having performed a reduced frequency of CONC muscle actions for the PD exercise (1 days·week^{-1}) compared with the other training groups (2 days·week^{-1}), impairing CONC strength adaptations. However, this was not true for CP and LP exercises. As such this could be interpreted to suggest that there is a larger heterogeneity of adaptations to PD strength than for other exercises. Alternatively this may simply be considered a type I error as the authors are not aware of any other plausible explanation for this difference in the PD exercise only.

Body composition changes within the present study were minimal in all participants across all training groups, and were likely within the margin of error, as has been reported previously (Fisher et al. 2014, 2015), for the method of measurement used (Collins et al. 2004; Dempster and Aitkins 1995). However, earlier research has reported large increases in cross-sectional area (CSA) of the quadriceps in young and older females (ESs = 1.08 and 2.23, respectively) without significant change in body mass, body composition, and fat free mass (Ivey et al. 2000). In addition, large increases in quadriceps CSA, following 9 weeks of lower body RT in young and older males (ESs = 1.61 and 4.64, respectively) were apparent with only small increases in body mass with no change to body composition. Furthermore evidence suggests morphological adaptations, such as greater increases in muscle fascicle length and reduced pennation angle without change to muscle thickness, following ECC compared with CONC training (Timmins et al. 2015), or with similar changes to muscle volume for CONC and ECC training groups (Franchi et al. 2014). There is also evidence of increase in muscle fascicle length without change in pennation angle (Potier et al. 2009), which suggests morphological adaptations without change to physiological cross-sectional area (PCSA) are possible following ECC training. With this in mind, morphological adaptations might have occurred within the present study but simply were unidentifiable by our anthropometric measurements. We should also acknowledge that no effort was made to control or monitor dietary intake, which, whilst a potential limitation of the present study, adds ecological validity of real people doing real workouts and is thus representative of the population group considered.

The present study has considered trained participants and as such adds to the limited research considering this population group. In addition this represents the first ECC study to consider chronic adaptations of a MJ, multi-exercise protocol appropriately controlled for intensity of effort. However, we should consider the respective limitations of the present study. First, our strength data presented are based on a predictive equation and so do not have the same validity as maximal testing performed using isometric or isokinetic dynamometry. Second, whilst presenting an ecologically valid approach, our intervention only considered resistance training for 2 days·week^{-1} and ECC-only training in 1 of 2 weekly workouts to attempt to avoid overtraining. In addition, whilst using a greater load than the other groups, the ECC only group did not use a supramaximal (e.g., >1RM) training load. Further research should consider higher training loads and frequencies and perhaps apply periodization based on personal fatigue, rather than attempting to preempt overtraining. Another direction might investigate the perceived effort and muscular discomfort associated with ECC-only and repetition duration-accentuated ECC training, along with potential psychological effects such as motivation, enjoyment, etc.

Practical applications

Results from the present study suggest that considerable increases in muscular performance can be attained by the use of brief, infrequent, and uncomplicated RT, specifically in persons with previous RT experience. Furthermore, this study adds to the relative dearth of empirical research that advanced training techniques appear to produce no greater gains in muscular performance than traditional sets of RT performed to MF. From a practical perspective, whilst the addition of ECC training represents an alternative to traditional RT, it appears to hold no greater gains in improving muscular performance. However, it might retain application in use as therapeutic treatment for musculoskeletal injuries because of the lower suggested muscle activation and thus relative effort than CONC training at the same absolute load. For strength coaches and athletes with limited time resources and engaging in sport-specific skill training, the present study supports that a time-efficient manner of uncomplicated training appears an efficacious approach to improving muscular performance.

Conflicts of interest statement

The authors declare that there are no conflicts of interest.

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