12-2021

Transfer Effects of a Multiple-Joint Isokinetic Eccentric Training Intervention to Nontraining-Specific Traditional Muscle Function Measures

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TRANSFER EFFECTS OF A MULTIPLE-JOINT ISOKINETIC ECCENTRIC TRAINING INTERVENTION TO NONTRAINING-SPECIFIC TRADITIONAL MUSCLE FUNCTION MEASURES

by

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A plan B research project submitted in partial fulfillment
of the requirements for the degree

of

Master's of Science

in

Kinesiology

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Logan, Utah

2021

Abstract

The transfer effects of isokinetic, eccentric-only resistance training programs on non-specific measures of muscle function such as isometric peak force, isokinetic concentric peak force and dynamic constant external resistance 1-repetition maximal strength (DCER 1RM) have been researched extensively in a single joint context, yielding mixed results. However, investigations involving multiple-joint isokinetic eccentric-only training models have been sparse. The purpose of this study was to investigate the transfer effects of a short-term multiple-joint isokinetic eccentric leg press (Eccentron) training program on several measures of lower-body strength and performance. Fifteen participants performed Eccentron training three times/week for four weeks and were evaluated for the training specific Eccentron peak force (EccPF), DCER 1RM on a leg press (LP 1RM), vertical jump height (VJ), as well as single-joint isokinetic eccentric (Ecc30), isokinetic concentric (Con150) and isometric peak torque (IsomPT) of the knee extensors before and after the training period. The training elicited a large improvement in EccPF (37.9%; Cohen's *d* effect size (ES) = 0.86). A moderate effect was observed on LP 1RM (19.0%; ES = 0.48), the magnitude of the strength improvement being about one-half that of EccPF. There was a small effect on VJ, IsomPT and Ecc30 (ES = 0.30, 0.29 and 0.20 respectively), however, pre-post changes were not significant for IsomPT and Ecc30 ($p = 0.16$ and 0.33 respectively). Con150 testing showed no effect (ES = 0.04). These results suggest this type of training program elicits large strength improvement in the training specific measures, with a moderate transfer effect on concentric DCER strength of a similar movement (DCER LP), small effect on functional measures (VJ), and relatively poor transfer to single-joint measures. These results may be relevant to practitioners and clinicians to consider depending on the desired measurement outcomes of prospective training programs when using multiple-joint eccentric training modalities.

Introduction

The specific adaptations that occur in response to the type of training performed, as well as the transfer of these adaptations, to performance testing is termed specificity (Sheppard & Triplett, 2016). The specificity of training adaptations to training stimuli is a key consideration for developing resistance training programs. The existence of specificity in resistance training models has been well documented such that training adaptations to resistance training display specificity across movement patterns (Wirth et al., 2016), range of motion (Graves et al., 1989), joint angles (Kitai & Sale, 1989; Thepaut-Mathieu et al., 1988), velocities (Aagaard et al., 1996; Behm & Sale, 1993; Coyle et al., 1981), force levels (Aagaard et al., 1996; Moss et al., 1997; Poprawski, 1987) and skeletal muscle action types (Reeves et al., 2009; Seger et al., 1998), as well as external loading types such as with isometric, isokinetic, and isotonic conditions (Lee et al., 2018; Vidmar et al., 2020). The ability to transfer gains (and observe this transfer) from training to testing or functional outcomes is an important overall consideration because understanding the particular performance enhancements achieved from a given training method is instrumental in identifying how well a program is working and informing what and when adjustments need to be made in order to continue progress.

Eccentric-based resistance training has received considerable attention by researchers and practitioners in recent years. Accumulating empirical observations reveal eccentric exercise may yield superior results on muscle mass and strength (English et al., 2014; Farthing & Chilibeck, 2003; Paddon-Jones et al., 2001) with a lower rating of perceived exertion (Penailillo et al., 2013) and metabolic demand (Meyer et al., 2003) compared to concentric-only or traditional isotonic resistance training. These factors may make eccentric overload training an attractive training model for both athletic and clinical populations because it may provide the opportunity for substantial gains to be achieved in a more tolerable and time-efficient manner, and it may be especially well-suited for those who may have a limited capacity to perform traditional forms of resistance training. As it is a common goal of strength training to increase functional capacity, it is important to measure how well eccentric-based strength improvements are able to transfer to other measures of muscular strength and performance that are characteristically different than that conducted during training. At present this is especially true of eccentric training transferability characteristics since it has been an area less investigated in the context of specificity than more traditional forms of resistance training.

The effect of a single-joint, isokinetic, eccentric-only (SJIE) training paradigm and its specificity to other measures of strength has been studied with conflicting results. Duncan et al. (1989) observed that 6 weeks of isokinetic (120 $^{\circ}sec^{-1}$) eccentric-only training of the knee extensors yielded significant improvements in eccentric peak torque (PT) at 90, 120, and 180 $^{\circ}sec^{-1}$ velocities (corresponding to 27.5%, 34.1%, and 25.1% improvements, respectively). Conversely, concentric PT at the same angular velocities did not reach significance, with only 5.1%, 4.3, and 1.2% increases, respectively, indicating that a high degree of specificity was present for the muscle action type factor (Duncan et al., 1989). Moreover, other studies have similarly observed no significant increases in concentric or isometric torque after similar (i.e., SJIE) training programs despite large improvements in eccentric PT (Higbie et al., 1996; Reeves et al., 2009).

Furthermore, several studies have observed significant increases in eccentric and isometric, but not concentric torque production following SJIE (dos Santos Rocha et al., 2011; Hortobágyi et al., 1996; Hortobagyi et al., 1996). After 12 weeks of isokinetic SJIE training of the knee flexors at 60$^{\circ}sec^{-1}$, dos Santos Rocha et al. (2011) observed significant velocity-specific increases in eccentric torque at 60$^{\circ}sec^{-1}$ and 120$^{\circ}sec^{-1}$ (an increase of 58.89% and 29.24%, respectively), as well as in isometric torque (23.51% increase). However, concentric torque at all velocities increased only by a negligible amount. These observations are in agreement with results from other studies (Hortobágyi et al., 1996; Hortobagyi et al., 1996) that suggest SJIE training has a significant training effect on eccentric and isometric, but not concentric strength.

Contrasting these observations within an SJIE context, Farthing and Chilibeck (2003) observed that eccentric-only isokinetic training of the elbow flexors elicited significant gains in both eccentric and concentric PTs when comparing concentric-only and eccentric-only isokinetic training at two different velocities (30°sec^{-1} and 180°sec^{-1}). Interestingly, fast eccentric training showed the greatest improvement in PT, yielding the greatest improvement in eccentric PT at both 30°sec^{-1} and 180°sec^{-1}, as well as 180°sec^{-1} concentric PT (Farthing & Chilibeck, 2003). Additionally, Farthing and Chilibeck (2003) observed fast eccentric training elicited significantly greater PT gains in 30°sec^{-1} concentric measures than either concentric-only training group. Other studies have also observed increases in SJIE, concentric, and isometric strength measures after SJIE strength training of the knee extensors (Baroni et al., 2013; Coratella et al., 2015). Furthermore, following similar training methods (i.e., SJIE), other studies which did not measure isometric strength observed significant increases in eccentric and concentric strength in the knee (Blazevich et al., 2007) and elbow flexors (Vikne et al., 2006). Collectively, these observations seem to suggest that SJIE training can induce a rather strong strength transfer effect to concentric or isometric muscle actions.

Quantifying the effects of eccentric isokinetic training on more traditional strength assessment outcomes, such as with isotonic one repetition maximum (1RM) strength, would be important in order to determine the transferability between the dissimilar training and testing modalities. Given that 1RM strength is primarily dependent on concentric strength, the types of eccentric interventions that more successfully transfer to concentric measures would likely have a greater effect on 1RM strength and potentially beyond 1RM outcomes to more functional strength-based performances (i.e., vertical jump etc.). Previously mentioned studies may suggest contraction velocity of the eccentric training plays a role in the overall transferability of gains across isokinetic contraction modality, such that higher velocity training may potentially lead to a greater transfer effect from eccentric- to concentric-based isokinetic contractions as well as to isotonic 1RM, perhaps due to increased protein synthesis achieved during fast velocity eccentric training programs resulting from increased muscle damage (Farthing & Chilibeck, 2003; Shepstone et al., 2005).

However, few studies have directly examined the effects of eccentric isokinetic training on isotonic 1RM. Coratella et al. (2015) observed that SJIE resistance training of the knee extensors increased isotonic 1RM performed on a dynamic constant external resistance (DCER) leg extension machine by an average of 4.4 kg (effect size = 0.60). The results of this study suggest that isokinetic eccentric exercise may have a moderate effect on isotonic 1RM performance, with the limitation that the results only examined this transfer in a single-joint context. Further research is needed to determine if this strength gain transfer from isokinetic eccentric-only training to isotonic/DCER testing occurs in a multi-joint context.

Investigations examining an eccentric training modality from a multiple-joint perspective have increased in recent years (Crane et al., 2020; Gordon et al., 2019; Johnson, 2018; Kay et al., 2020; Lim & Lee, 2018) due to the time efficiency, and assumed functional advantages of multiple-joint training. Unfortunately, research on eccentric-only multiple-joint training in the context of specificity, is relatively sparse. Papadopoulos et al. (2014) observed that eight weeks of twice-weekly isokinetic eccentric leg press training with high loads (70-90% max eccentric strength) and a fast repetition speed (~700ms eccentric contraction phase) induced large improvements in maximal force during isokinetic eccentric (64.9%) and isokinetic concentric (32.2%) leg press at the same contraction length, suggesting a moderate transfer effect to the concentric muscle action. The authors additionally observed significant improvements in drop jump measures, reporting that drop jump rebound height increased by 13.6%, ground contact time decreased by 17.6%, maximal power increased by 25.8%. During the eccentric phase (between ground contact and zero velocity) of a drop jump , the joint angle excursion of the hip, knee, and ankle joints decreased by 18-22°, or by 33.9, 31.1, and 32.4%, respectively after the eccentric training program (Papadopoulos et al., 2014). These observations may indicate increased that the eccentric training resulted in greater eccentric loading capacity through stiffness of the musculotendinous units. Partially contrasting these observations, research from our laboratory has demonstrated mixed results on the transfer of increases in eccentric strength following training performed on an isokinetic, eccentric-only leg press machine (Eccentron, BTE Technologies) to improvements in functional performance tasks such as the vertical jump or sprint speed, which are stretch-shortening cycle (SSC) tasks (Crane et al., 2020; Gordon et al., 2019). For example, our recent study (Gordon et al., 2019) reported a 19% (Cohen's *d* = 1.06) increase in eccentric strength from twice-weekly, eccentric-only multiple-joint overload training; however, this improvement in eccentric strength did not transfer to improvement in 40m sprint or vertical jump performance. In partial contrast to the previous observations, Crane et al. (2020) observed that four weeks of Eccentron training induced a large gain in eccentric strength (36.8%, effect size = 0.78) but there was only a moderate positive effect on vertical jump performance (6.4%, effect size = 0.26) and 40m sprint was not measured. Thus, the literature contains mixed results regarding transferability of multiple-joint eccentric strength gains to measures of functional strength and performance requiring SSC skeletal muscle actions.

One major limitation of the previously mentioned studies using multiple-joint eccentric training models is that the eccentric training groups were not evaluated on their isotonic strength (1RM) that is similar in form (other than contraction type) to the multiple-joint eccentric leg press (Gordon et al., 2019; Papadopoulos et al., 2014). Given a multiple-joint model has more specificity to measures of function, such as walking, running, jumping, etc., it would be valuable to further investigate regarding its ability to transfer to a multitude of different strength and functional measures. Further investigation of this area would elucidate the ways in which eccentric gains may be best utilized for developing an individual's specific areas of weakness, and may be useful as a monitoring tool for providing insight on how a given magnitude of eccentric strength gains may relate to a given magnitude of gains across a number of other types of strength and performance outcomes. Therefore, the purpose of this study was to determine the extent to which multiple-joint eccentric isokinetic leg press training-induced strength gains influence isotonic leg press 1RM, single-joint isometric and isokinetic PT of the knee extensors, and vertical jump performance. We hypothesize that there will be significant transfer of muscular strength and functional performance from the eccentric training mode to the DCER leg press movement, moderate transfer to the vertical jump, and poor transfer to single-joint isokinetic and isometric movements.

Materials and Methods

Participants

Fifteen college-aged men and women volunteered to participate in the study and completed all trainings and testing satisfactorily. The demographics of the study sample are as follows: n = 6 females, 9 males; mean ± SD: age = 22.6 ± 2.0 years, height = 176.03 ± 7.65 cm, mass = 73.28 ± 18.20 kg. Eligibility criteria to participate in the study required the participants to be between the ages of 18-30 years. Participants were required to be informally classified as recreationally active, such that they were allowed to be involved in sports and moderate dose physical activity but were not allowed to be regularly engaging in resistance training (< three times in the previous month) or a dose of aerobic exercise (jogging, aerobics) of more than 30 minutes per day, five days per week. Participants must not have had any lower limb injuries or had surgery on the lower limbs within one year prior to the beginning of the study. Participants were required not to consume nutritional supplements for muscle growth (i.e., Creatine) during the study or three months prior and were additionally not allowed to consume nonsteroidal anti-inflammatory drugs (NSAIDs) during the study period. Participants were encouraged to keep their dietary intake as consistent as possible during the study.

The study was be approved by Utah State University's Institutional Review Board and all participants read and signed an informed consent document prior to study participation.

Experimental Procedures

This study utilized a repeated measures (pretest/posttest) group design to test the hypotheses following a four-week training intervention. The present study uses a subset of data from a larger investigation (Crane et al., 2020). Specifically, the training protocol was used, and the Eccentron maximal strength and vertical jump data was reported in the previous study, but these were not used in the context of the specificity question per the current study. These particular variables are reported again in the present study, but are being used to compare with new (not published before) strength measures (e.g., leg press 1RM and all Biodex data) for the benefit of assessing and comparing a broad range of muscle function specificity measures. Upon enrollment, participants completed one practice session to become familiarized with all performance testing procedures prior to the formal pretest in an attempt to minimize the influence of learning on testing outcomes. All testing was performed at the same time of day (± 2 hours), and always occurred in the order as presented below. Post testing occurred 4 – 6 days following the last training session to allow for full recovery. All exercise training and testing was closely supervised by experienced research investigators.

Outcome Measures

Countermovement Jump

Participants performed a brief warm-up beginning with five minutes of cycling on a cycle ergometer at 50 watts. Following this, participants performed a dynamic stretching routine consisting of five repetitions each of glute pulls, quad pulls, inside pull, outward pull, and toe touches (Crane et al., 2020). Following the warmup, participants performed three maximal counter movement vertical jumps on a jump mat (Just Jump Technologies, Huntsville, AL), a device that measures jump height based on flight time (Crane et al., 2020; Gordon et al., 2019). Participants were instructed to stand on the mat with their feet shoulder width apart and with their hands on their hips. Participants were instructed to quickly lower themselves to a self-selected, comfortable depth then immediately jump as high as possible while landing with their legs relatively straight. A successful countermovement jump attempt was counted if the participant landed on the mat with both feet and did not take a step before jumping (Palmer et al., 2014). A one-minute rest period was provided between each jump attempt. Countermovement jump data has been reported previously by Crane et al. (2020), however it was included in this analysis for comparative purposes.

Biodex

Participants were tested for single-joint isokinetic and isometric strength capacities of the knee extensor muscle group on an isokinetic dynamometer (Biodex System 3, Biodex Medical Systems, Shirley, N.Y., USA) and followed the procedures previously reported by Gordon et al. (2019).

The participant was seated on the Biodex and the restraining straps were placed over the waist, chest, and thigh. The seat was adjusted such that the rotational axis of the knee joint was aligned with the rotational axis of the dynamometer. This seat position was recorded and used for the posttest for each individual. The arm of the Biodex was secured to the lower leg approximately five cm above the malleolus. Participants performed a brief warm-up of ten isokinetic knee extension and flexion repetitions at $120°sec^{-1}$ with 75% of maximal effort.

Participants then performed two maximal voluntary isometric contractions (MVICs) of the knee extensors set at a joint angle of 60° below the horizontal plane (Conchola et al., 2013), with a one-minute rest between MVICs. This was followed by the isokinetic testing that was based on a previously established testing protocol (Cramer et al., 2007; Gordon et al., 2019). For this, participants performed three maximal isokinetic concentric knee extensor actions at $150°sec^{-1}$. These were followed by two maximal isokinetic eccentric knee extensor actions at $30°sec^{-1}$ with a two-minute rest between each attempt.

The Biodex dynamometer was configured with a Biopac data acquisition system (MP150, Biopac Systems Inc., Santa Barbara, Calif., USA) which sampled the torque signal at 2000 Hz. Custom written software (LabVIEW 2016, National Instruments, Austin, Tex., USA) was used to process the data following the methods of Gordon et al. (2019). Briefly, the voltage signals were converted and scaled to torque units (Nm), and filtered using a zero phase shift, fourth-order Butterworth filter with a 50-Hz low-pass cut-off frequency.

The isometric signal was gravity-corrected by subtracting the baseline value of the participant's limb weight from the entire torque signal. Isometric PT (IsomPT) was quantified as the highest 500-ms epoch during the plateau phase of the MVIC. The isokinetic torque signal was also gravity-corrected for limb weight in accordance with the procedures of Aagaard et al. (1995). The isokinetic concentric PT (Con150) and eccentric PT (Ecc30) were calculated as the mean value of the highest 25-ms epoch of the torque-time signal and the highest contraction was used for data analysis.

Eccentron Strength Test

Participants were tested for their maximal eccentric strength (peak force, N) on a multiple-joint, isokinetic eccentric dynamometer (Eccentron, BTE Technologies Inc., Hanover, MD). These testing procedures have been reported in our previous study (Crane et al., 2020). Briefly, participants were seated on the machine with the seat adjusted per the manufacturer guidelines so that the knee joint was set to an angle of 30° when fully extended. During the testing, the pedals moved toward the participant in an alternating motion, so that each leg worked isolaterally in a repetitive manner. The speed of this motion was set at 23 cycles per minute (a medium velocity for this movement). The testing consisted of a total of 12 maximal effort repetitions, six for each leg. Participants were instructed to maximally resist the motion of the pedal as it moved towards them, then relax that leg as it moved away, at which point they pushed maximally with the other leg. Participants were given a brief familiarization of the testing protocol ~72 hours prior to the testing session. During the testing period, participants received verbal encouragement to reinforce maximal effort.

Leg Press Strength Test

Participants were assessed for lower-body dynamic strength utilizing a traditional leg press machine set at a 45° angle, and followed the NCSA guidelines for 1RM testing. Briefly, the participant was instructed to warm-up with a light resistance that easily allowed the completion of 5-10 repetitions, after which they rested for one-minute. For the following set, 10-20% of the initial warm-up weight was added to create a weight that could be lifted 3-5 times, followed by a two-minute rest period. The next set added an additional 10-20%, to produce a weight that could be lifted 2-3 times followed by a 2-4 minute rest period. The 1RM attempts followed, with the default condition of adding 10-20% additional weight with each successful attempt, or based off of participant preference. Each 1RM test was followed by a 2- 4-minute rest period (Sheppard & Triplett, 2016).

Eccentric Training Program

The eccentric training has been described previously (Crane et al., 2020). Briefly, the motor-driven eccentric isokinetic dynamometer (Eccentron, BTE Technologies) was used as the multiple-joint training modality. Prior to all training sessions, a brief warm-up was performed consisting of cycling on an ergometer at 50 watts for two minutes, followed by a brief dynamic stretching routine which was described in the previously published report (Crane et al., 2020). For the Eccentron training, the manufacturer-designed protocol consists of a one-minute warmup at half of the workout target force, followed by the workout period, then a one-minute cool down period also at half of the workout target force. The participants completed a two-minute workout phase (excluding the one-minute warm up and cool down phases) three times per week on non-consecutive training days. The training velocity was set at 23 cycles per minute for all training, and this may be considered as a moderate velocity for this dynamometer.

During the first week of the study, two relatively light sessions were performed with a target force of 45 and 50% maximum effort for sessions 1 and 2 respectively, to allow for familiarization to the movement and to mitigate extreme soreness levels.

The training load progression has been reported for the study (Crane et al., 2020) and was increased incrementally throughout the duration of the training program. Briefly, the intensity progression was based on the percentage of baseline maximum eccentric strength and was as follows: week 1 = 50, 52.5, and 55%; week 2 = 60, 62.5, and 65%; week 3 = 70, 72.5, and 75%; week 4 = 75% for all three sessions.

Statistical Analyses

A repeated-measures group design was utilized to test the hypotheses of this study. Dependent *t*-tests were used to evaluate the effects of the training program (pretest vs. posttest) on all dependent variables. The Cohen's *d* effect size (ES) statistic was calculated to evaluate the meaningfulness of the training effects, with values of 0.2, 0.5, and 0.8 being considered as small, medium, and large effect sizes, respectively (Cohen, 1969). Pretest to posttest relative change (%) scores were calculated for each participant using the means for each dependent variable, and assessed for normal distribution using the Kolmogorov-Smirnov test of normality. Pearson correlation coefficients (*r*) were used to assess the relationship between the change scores of the dependent variables unless Kolmogorov-Smirnov results indicated that normality was violated, in which case relationships between the change scores were assessed using Spearman's rho correlation coefficient. SPSS software (version 25; IBM SPSS, Inc., Chicago, IL) was used for all statistical analyses. An alpha level of $p \leq 0.05$ was used to determine statistical significance.

Results

All subjects completed all training and testing sessions during the 4-week intervention. However, two subjects' posttest eccentric strength exceeded 3,338 N, which is the upper limit capability of the Eccentron, thus, the final sample size was n = 13 for the testing data after removing these two subjects from the analyses.

Means and standard deviations, relative change scores, and ES values for all variables are presented in Table 1. For the Eccentron peak force, there was a training effect showing a significant increase ($p < .001$) and the Cohen's *d* ES was large (0.86). The leg press measure also presented a significant increase ($p < 0.001$) and the ES was moderate (0.48). The vertical jump measure also increased ($p < 0.01$) but the ES was small (0.30). All single-joint variables including IsomPT, Ecc30 and Con150 did not show significant improvements (p = 0.16 – 0.81), but the ES values for IsomPT and EccPT30 suggest a small training effect (ES = 0.29 and 0.20, respectively) was present. Con150 was the only variable to show no training effect based on the Cohen's *d* ES (0.04). Figure 1 shows the mean relative change scores across all muscle function variables for each participant as well as the overall mean.

Correlations between all muscle function measures for the pretest to posttest relative change scores are presented in Table 2. The change score distribution for the Ecc30 variable was observed to be the only variable to violate normality (Kolmogorov-Smirnov $p < 0.001$), therefore correlations for this variable are reported as Spearman's rho. All other variables are reported as Pearson's *r.* Analyses revealed the correlations between the Eccentron peak force change scores and the other muscle function measures were significant for IsomPT ($p = 0.04$, approached significance for leg press 1RM ($p = 0.055$) and Con150 ($p = 0.057$) and was not significant for vertical jump ($p = 0.28$) and Ecc30 ($p = 0.16$).

Table 1. Mean (SD), change scores, p-values, and Cohen's *d* effect size values for muscle function variables before (Pre) and after (Post) the training period

Action	Variable	Pre	Post	Change score (%)	p-value	Cohen's *d*
Eccentron	Peak Force (N)	1364.58 (599.23)	1882.28 (600.58)	37.94	$p < 0.001$	0.86
Leg Press	1 RM (N)	1909.31 (730.12)	2272.01 (793.18)	19.00	$p < 0.001$	0.48
Vertical Jump	Height (cm)	43.12 (10.31)	46.38 (11.35)	7.57	$p < 0.01$	0.30
Knee Extensors (Biodex)	IsomPT (Nm)	171.19 (42.30)	182.16 (33.65)	6.41	$p = 0.16$	0.29
	Ecc30 (Nm)	216.65 (59.89)	227.14 (44.29)	4.85	$p = 0.33$	0.20
	Con150 (Nm)	128.47 (40.73)	130.08 (37.66)	1.25	$p = 0.81$	0.04

Note: Cohen's *d* values compare within-group pretest and posttest differences and are identified as being small, moderate, and large on the basis of values of 0.2, 0.5, or 0.8 respectively. Ecc30 = Biodex knee extensor eccentric muscle action at $30^{\circ}sec^{-1}$; Eccentron = maximal multiple-joint eccentric force on the Eccentron device; IsomPT = isometric PT of the knee extensors on the Biodex; Con150, Biodex knee extensor concentric muscle action at $150^{\circ}sec^{-1}$.

Figure 1. Pretest to posttest individual relative change scores (main plot) for all muscle function variables. Mean relative change scores (inset).

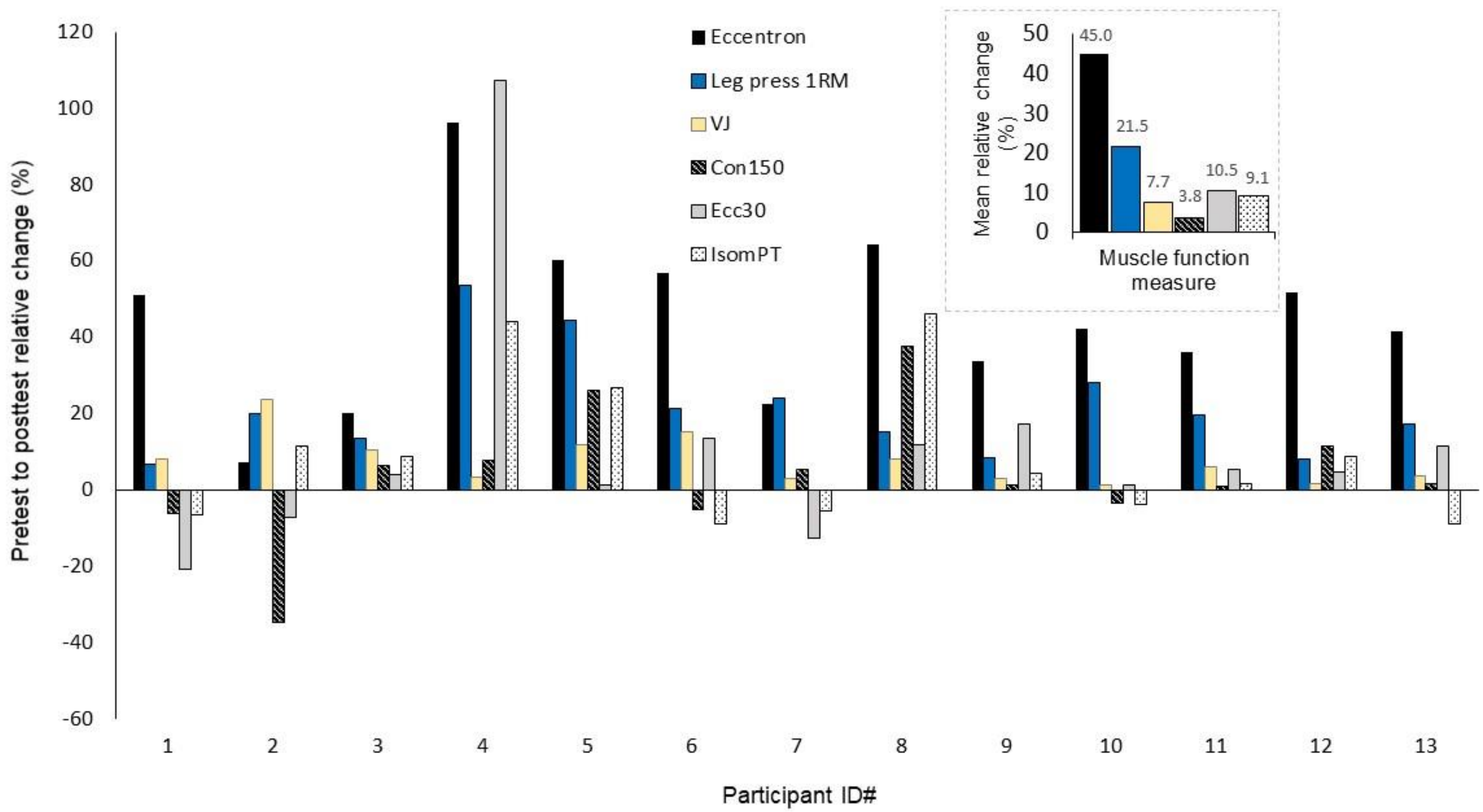

Table 2. Correlation matrix for the pretest to posttest relative change scores for all the muscle function testing variables. Correlations are reported as Pearson's r with the exception of the Ecc30 variable, which are reported as Spearman's rho.

Variable	EccPF	LP 1RM	VJ	IsomPT	Ecc30	Con150
EccPF		0.54[a]	-0.324	0.57*	0.41	0.54[b]
LP 1RM			0.01	0.05	0.07	0.18
VJ				0.06	-0.11	-0.44
IsomPT					0.17	0.56*
Ecc30						0.18
Con150						

All correlations are reported as Pearson's r with the exception of the Ecc30 variable, which are reported as Spearman's rho see text). EccPF = eccentron peak force; LP 1RM = leg press one-repetition maximum; VJ = vertical jump; IsomPT = isometric peak torque (Biodex); Ecc30 = eccentric peak torque at 30°sec^{-1} (Biodex); Con150 = concentric peak torque at 150°sec^{-1} (Biodex). * $p < .05$, [a] $p = 0.055$, [b] $p = 0.057$.

Discussion

The primary observations of the study were that the four-week multiple-joint eccentric isokinetic leg press training resulted in, 1) increased strength gains for the training specific variable (Eccentron peak force) as well as for the non-training specific strength measures of leg press 1RM and vertical jump (see Table 1), 2) marked differences in the magnitude of transfer of training-specific gains to the various non-specific outcome measures, and 3) a correlation between the training-specific (Eccentron peak force) pretest to posttest change scores and the leg press 1RM, IsomPT, and Con150 variables.

An important finding of the present study was the significant increase observed in the DCER leg press 1RM measure, which showed a mean improvement of 19.0%. Comparatively, the mean improvement in DCER leg press 1RM was about half that of that observed in peak force on the Eccentron (19.0% and 37.9%, respectively). This finding seems to support previous observations from Papadopoulos et al. (2014), who observed an improvement of 64.9% in isokinetic eccentric leg press strength and a 32.2% improvement in isokinetic concentric leg press strength following 8 weeks of isokinetic eccentric leg press training. These observations suggest that multiple-joint isokinetic eccentric-only exercise has a moderate effect on strength gains of a similar movement pattern that is concentric-based such that the magnitude of concentric DCER gains can be expected to be approximately half of what the training-specific gains are for this type of training routine.

The single-joint testing of the knee extensors produced overall low transferability across the three variables. There were no significant pre-post changes observed in IsomPT, Ecc30 or Con150 (p = 0.16, 0.33 and 0.81 respectively). However, ES values suggest that there was a small training effect for IsomPT (ES = 0.29) and Ecc30 (ES = 0.20), but no effect for Con150 (ES = 0.04). These results suggest that the training effect from the Eccentron to single-joint measures is quite negligible. The lack of specificity in terms of both the joints recruited and movement pattern differences between the multiple-joint leg press movement and the single-joint knee extension movement likely explained this poor transfer outcome. During the Eccentron workouts, participants anecdotally reported feeling the resistance mostly in the hip extensors, specifically the glutes, as well as reporting the greatest amount of soreness in the same muscle group. The movement pattern is also vastly different between these movements such that the leg press incorporates a closed kinetic chain pressing movement, whereas the isokinetic knee extension incorporates an open kinetic chain widely angular pattern. Based on our observations, it seems that single-joint measurements of the knee extensors are a poor measurement of muscle function changes when this training modality (multiple-joint, eccentric) is utilized in an active young adult population.

However, contrasting the observations of the current investigation, Kim et al. (2019) observed substantially improved performance in single-joint isometric knee extension (ES = 3.43), isokinetic knee extension at 60°sec^{-1} (ES = 1.71), and a ten-second test of power in the knee extensors and flexors (ES = 0.72) following an eight week Eccentron training routine with older adults. These results showed the Eccentron training induced a large improvement in these measures despite the lack of training specificity including the joint and movement pattern discrepancies as noted above. The diverging results may stem in part from the differences between the methods and training procedures. The testing and training parameters performed in the Kim et al. (2019) study differed from those of the current study in that Eccentron strength was not reported for either pre or post testing (it was measured only during pretesting for the purpose of resistance dosing for the training) and so the changes in the training-specific multiple-joint eccentric strength are not available for comparison with the non-training specific variables. Also, for the training, Eccentron loading was set at 50% of pretest strength for the duration of the training period versus beginning at 50% for the first week and progressing to 75% in the present study, and the training sessions were performed twice a week compared to three times a week in this study. Also, and perhaps most importantly, their training sessions were overall much longer in that they were 20 minutes each session for week one (at 18 reps/min) and increased to 30 minutes each session during weeks 2-8 (at 23 reps/min) with two 2-minute rest periods and their program duration was eight weeks compared to four weeks in this study. Overall the training program implemented by Kim et al. (2019) had a much higher training dose compared to the present study, given that the sessions were at least three to five times longer and their training duration was twice as long. These differences in training period length and volume would likely have contributed to the larger non-training specific strength testing gains observed in the Kim et al. (2019) study. Unfortunately, their study did not report on the Eccentron strength variable, and so it is not possible to make direct comparisons between the training specific eccentric strength gains and the non-training specific gains among the variables assessed in their study with the present study's specificity values. Finally, it is likely the case that the older adults in the Kim et al. (2019) study were relatively weaker than the active young adults in the current study, and therefore had greater potential for overall strength gains, which were able to be more easily and effectively transferred and displayed in the non-specific strength testing measures. Some support for the effect of their study population's propensity for gains may be seen in their data, as the large effect sizes observed in the Kim et al. (2019) study were partially the result of small standard deviations in the outcome measures which reflects the low variability or high consistency in the gains among the study subjects.

A mean improvement of 7.57% was observed on vertical jump which yielded a small effect size (0.30). This improvement in this lower body "functional measure" is relatively small compared to the Eccentron's large gains in peak force, which represent the training-specific response. Several features of the specific training modality (Eccentron) may have contributed to the relatively small transfer effect from the Eccentron training to this measure, and the details of this specific outcome have been discussed in our prior paper (Crane et al., 2020). Briefly, as the Eccentron is an eccentric-only training device, there is no utilization (training) of the SSC which is an important component of the vertical jump movement. Additionally, training on the Eccentron is performed seated, and with high loads, thereby training the lower limbs in a different range of motion and a different portion of the power spectrum (i.e., high load power for the Eccentron versus high velocity power application for the vertical jump) than is used for optimal performance of the vertical jump.

As noted above, the vertical jump variable had been reported in our prior paper along with Eccentron peak force, but it was included in this study as a functional task to directly compare with the magnitude of specificity of the several novel variables examined in this study (leg press 1RM and Biodex variables). In this context, the eccentric training-induced improvement in the vertical jump was considerably less than the leg press 1RM, was similar to the IsomPT variable, and was greater than the Ecc30 and Con150 variables. The smaller improvement in vertical jump compared with leg press 1RM is likely explained by the lack of training of the SSC component (which is considerably more important for vertical jump than leg press 1RM), as well as differences in the force-velocity specificity between the vertical jump and leg press movements such that the vertical jump is a lower force and higher velocity movement in comparison. The vertical jump had about the same magnitude of improvement as the IsomPT variable (albeit with more consistency as shown by the statistically significant p value in the vertical jump vs. the non-significance observed for IsomPT), but neither showed particularly good training to testing specificity. Also, the reasons for the modest performance transfer to each of these are likely different. The transfer to the vertical jump is likely due to the more specific movement pattern respective to the joints and muscles recruited for the movement (involving the hip, knee, and ankle as did the training), whereas the transfer to the IsomPT was probably due more to the straightforward similarity to the strength-specific (high load) component, particularly for the strength adaptation of the leg extensors muscle group from the Eccentron training. To enhance training specificity to vertical jump, mixed training methods involving a high force loading (e.g., eccentric-based) coupled with high velocity/SSC (plyometrics) exercises may be more effective than either component alone. However, more research is needed that compares mixed training models using multiple-joint movements and their effects on the adaptations that lead to a transfer to both strength-based and functional performances.

Analysis of the correlation between change scores of the dependent variables revealed a significant correlation between the training specific Eccentron peak force and non-training specific IsomPT ($p = 0.04$; $r = 0.57$), as well as correlations with leg press 1RM ($p = 0.055$; $r = 0.54$) and Con150 ($p = 0.057$; $r = 0.54$) that approached significance. The change scores of Eccentron peak force were not significantly correlated with those of VJ ($p = 0.28$; $r = -0.32$) or Ecc30 ($p = 0.41$; $r = 0.41$).

The relationships in the change scores between the training specific variable (Eccentron peak force) and non-specific variables of leg press 1RM, IsomPT, and Con150 yielded a remarkably similar level of correlation ($r^2 = 29.2 – 32.3$), indicating approximately a third of the variance in Eccentron peak force changes explained the changes in these non-training specific variables. This is an interesting finding given the magnitude of change among these three non-specific measures were considerably different, and since testing on the Con150 variable did not indicate any improvement occurred. In light of these observations, it is worth noting that correlations do not assess differences among variables, only how one variable moves (i.e. increases or decreases) in comparison to another variables movement for each participant. A close examination of the data, as shown in Figure 1 seems to support this finding. For example, the participants that showed large gains on the Eccentron peak force variable (see participants 4, 5, and 8) also tended to show relatively large gains on the leg press 1RM, IsomPT, and Con150 variables, even though the magnitude of these gains was lower, to varying degrees, than the Eccentron variable. For participants who showed the lowest gains in Eccentron peak force, the changes in these same variables is, in general, relatively small (see participants 3 and 7). As a result, gains in Eccentron peak force were related to relative gains in some of the non-specific variables, even though the magnitude of these gains differed dramatically. On a per subject basis, change scores for IsomPT and

Con150 tended to move similarly to Eccentron peak force change scores, but the magnitude of the change was drastically lower across the study sample.

There were some notable limitations of this study. As this analysis was done on a subset of a larger study there was a relatively small sample size for this study. Of this sample, two participant's results had to be omitted from the statistical analysis, as their eccentric strength during post testing exceeded 3338 N, the maximal force the Eccentron machine is capable of measuring. Additionally, the proprietary Eccentron strength testing protocol does not record the maximal force produced by the participant on the 12 repetitions of the testing, but instead eliminates the repetition with the highest force value for each leg and then takes the next highest value (so usually the third or fourth highest repetition is what is reported). Although, this way of determining maximal eccentric strength is likely appropriate for tracking changes in maximal eccentric force production capability over time, it does not report the actual highest eccentric value out of the multitude of maximal repetitions performed, which was the way the other variables were assessed (i.e., as the highest measure of several attempts). However, the difference between the highest and third or fourth highest repetition in a 12 maximal repetition test is quite miniscule.

A 4-week multiple-joint eccentric only training program elicited significant increases in performance on the training-specific outcome measure (Eccentron peak force), as well as on DCER 1RM strength measured on a biomechanically similar movement (leg press) and the vertical jump. It was observed that the strength gain in the leg press 1RM was about half that of the Eccentron strength gain, suggesting a moderate transfer effect from an eccentric-only training protocol to a DCER concentric-based 1RM movement that reflects a similar movement pattern that mostly only differs in type of contraction (eccentric- vs. concentric-based). Improvements in vertical jump performance were statistically significant but were relatively small in comparison to those of the Eccentron suggesting that eccentric-only multiple-joint training (i.e. one that does not contain an SSC component) is a relatively poor method of improving performance on SSC tasks, at least in the first four weeks of a training program. Further research is needed to determine if power and/or plyometric training programs may compliment similar eccentric training methods when performed during the same training period as a means to potentially yield a greater transfer of eccentric strength improvements to SSC performance outcomes of interest (e.g. sprint speed, vertical jump). There was generally a poor transfer of Eccentron performance improvements to isolated (single joint) strength measurements of the knee extensors on the Biodex, suggesting that these types of measurements are a poor indicator of muscle performance improvements from a multiple-joint isokinetic eccentric training routine. The present observations may be of particular interest to professionals who work in clinical, rehabilitation or performance settings, where the potential for large strength improvements from short duration training sessions make eccentric exercise a particularly useful exercise modality for training specific strength improvements. However, the transfer of these improvements to assessments of various non-training specific strength and functional tasks is, to varying degrees, limited. Practitioners may consider the present observations to inform testing protocols for research designs that implement multiple-joint lower body eccentric training with the intent to most effectively capture the training gains in their designated outcome measures. In particular, when using the vertical jump and single-joint isokinetic (Biodex) assessments, these observations show it takes very large improvements in eccentric-based strength to produce minimal changes in these parameters, which is most likely due to a lack of training to testing specificity.

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