8-2018

Effects of Isokinetic Eccentric versus Traditional Lower Body Multiple-Joint Resistance Training on Muscle Function in Recreationally Trained College-Aged Adults

Joshua P. Gordon
Utah State University

EFFECTS OF ISOKINETIC ECCENTRIC VERSUS TRADITIONAL LOWER BODY MULTIPLE-JOINT RESISTANCE TRAINING ON MUSCLE FUNCTION IN RECREATIONALLY TRAINED COLLEGE-AGED ADULTS.

by

Joshua P. Gordon

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

of

Master's of Science

in

Health and Human Movement

Approved:

Brennan Thompson, Ph.D. Major Professor	Dale Wagner, Ph.D. Committee Member

Eadric Bressel, Ph.D.
Committee Member

UTAH STATE UNIVERSITY

Logan, Utah

2018

ABSTRACT

Purpose: Early adaptations of eccentric training show several advantages over concentric training. The purpose of this study was to quantify the effects of 4 weeks of multi-joint eccentric training versus traditional leg press training on muscle strength, rate of torque development (RTD; rapid strength) and jump and sprint performance adaptations.

Methods: Twenty-six resistance trained college-aged men and women performed either an eccentric or a traditional (control) resistance training program twice per week for 4 weeks. Single-joint isometric maximum and rapid strength (Biodex dynamometer; peak torque and RTD, respectively) and isokinetic strength of the knee extensors and flexors, maximum multi-joint eccentric strength (Eccentron dynamometer), leg press strength (1-RM), and vertical jump, long jump, and 40 m sprint were measured before (Pre), at the midpoint (Mid; week 2; for strength tests only), and after (Post) a 4 week training period.

Results: Four weeks of isokinetic multi-joint eccentric training elicited greater test-specific (Eccentron) strength gains (effect size; ES = 1.06 for Pre-vs. Post) compared to traditional leg press training (ES = 0.11). The eccentric group (ES = 0.51 and 0.54 for flexors and extensors) also yielded moderate improvements in the early-middle phase RTD (RTD100-200]) whereas the control group showed small-moderate improvements (ES = 0.37). The majority of the single-joint (Biodex) strength variables showed no to small improvements. Neither of these training programs provided short-term (4 week) meaningful improvements in jump or sprint performance.

Conclusion: Eccentric multi-joint training displayed test specific improvements for lower body strength in a relatively short amount of time for a trained population. These accelerated adaptations and also the lowered energy requirements of eccentric exercise may be particularly

useful for allied health professionals or other practitioners in need of appropriate training programs for those who are injured, sedentary, or less abled (elderly), for time efficient muscle function improvements.

INTRODUCTION

Resistance training is widely regarded as the most effective method to develop muscular strength and power, as well as facilitating a myriad of other health and performance benefits such as improved metabolism, cognitive abilities, management of type 2 diabetes, cardiovascular health, bone development, and functional independence (Westcott, 2012; Paschalis et al., 2011). Although traditional resistance exercise programs typically include dynamic movements involving both concentric and eccentric muscle actions, recent research has shown beneficial effects specifically for the eccentric phase of the resisted movement. An eccentric muscle action is characterized as an active muscle lengthening action in which the load torque exceeds the active muscle torque production (Orer, Guzel, & Arslan, 2016). Thus, eccentric actions are typically the lowering phase of a lift and usually function to decelerate a dynamic constant external resistance (DCER; Bridgeman, McGuigan, & Gill, 2015 b).

Eccentric muscle actions feature some unique characteristics, among the most notable being the capability of producing greater force than either isometric or concentric actions (Bridgeman, McGuigan, & Gill, 2015 a). Previous research has demonstrated that eccentric overload training can lead to greater improvements in muscle hypertrophy (Farthing and Chilibeck, 2003; Norrbrand et al., 2008), power (Bridgeman, McGuigan, & Gill, 2015 b), plyometric and change of direction drills (de Hoyo et al., 2016), and strength (Farthing and Chilibeck, 2003; Sorichter et al., 1997) compared to concentric training. One potentially useful attribute of eccentric exercise is that the energy requirements are lower when compared with concentric exercise. This attribute could be beneficial for populations who have lowered fitness capabilities, which may limit their ability to produce higher intensity muscular contractions, such as those who may be injured, sedentary, or the elderly who find higher intensity resistance exercise to be too difficult. Tendinopathy can also be improved from eccentric training, potentially through increased collagen synthesis and increased tensile strength (Bridgeman, McGuigan, & Gill, 2015 b). Thus, eccentric resistance training appears to have several advantages over concentric training alone, and moreover, these metabolic and neuromuscular improvements can often be observed relatively early in the time course of training (Orer, Guzel, & Arslan, 2016; Sorichter et al., 1997).

Previous studies have revealed distinct adaptations for eccentric overload training. English et al. (2014) showed that 8 weeks of eccentric training using a leg press exercise performed at an intensity of 138% of the concentric one-repetition maximum (1-RM) load elicited a 20.1% increase in muscle strength (1-RM), and a 2.4% increase in leg lean mass, both of which were significantly higher than the concentric only group. Oliveira and colleagues (2016) revealed that in addition to a 28% increase in maximal strength, there was a more pronounced increase of 48% in the peak rate of force development (RFD) resulting from 8 weeks of eccentric training of the knee extensors training on a Biodex dynamometer. However, in their study, there was no change in the later RFD time phases (beyond 150 ms from contraction onset), indicating that this form of training may induce gains in strength- or explosive strength-based parameters somewhat selectively in regards to the time phases of muscular contraction.

Notably, the majority of the previous research has investigated the effects of eccentric training using a single joint model (Ando et al., 2016; Guex et al., 2016; Sharifnezhad, Marzilger, & Arampatzis 2014). However, research examining the effects of eccentric training using a multiple joint exercise mode is limited. English et al. (2014) tested the response of five different eccentric loading conditions (0, 33, 66, 100, or 138% of concentric 1-RM) performed on the leg press and calf press for 3 days per week for 8 weeks on thigh muscle mass, bone mineral density, and 1-RM strength gains. The greatest increases in strength and thigh muscle mass were shown for the 138% condition, suggesting that relatively higher intensity eccentric loads may be the most effective loading stimulus for inducing neuromuscular gains. More research is warranted using a multiple joint eccentric training mode in order to investigate the potential benefits that may be provided by the functional features of this type of training. For instance, multiple joint training may induce a greater transfer of strength gains to performance-based activities such as jumping or sprinting because of the greater muscular recruitment and inter-muscular coordination characteristics of this type of training. A particularly appealing feature of using a closed kinetic chain leg press-like exercise is the simultaneous training of not only the knee joint but also the recruitment of the lesser investigated hip musculature, which is a primary muscle group contributing to locomotor-based performances. It is noteworthy that a previous limitation of examining multiple joint eccentric training was the lack of control necessitated by using a DCER system (i.e., a standard leg press machine) which does not allow the ability to control for the velocity of movement. Fortunately, recent technology has developed eccentric dynamometers for multiple joint actions, offering the capability to control the velocity of movement. This would help standardize this particular training model and allow better control of the important confounding factors (e.g., force-velocity relationship, relative intensity etc.) for determining the influence of specific exercise programming elements on key outcome measure responses.

Although many studies across the decades have investigated the effects of myriad resistance training programs on strength, power, and hypertrophy variables using medium and long term training interventions (e.g., 8 weeks – 2 years), relatively few studies have focused on the early phase adaptations that may be achieved in the first few weeks. Short-term training programs may be valuable for allied health professionals (i.e., physical therapists, athletic trainers) who often depend on rapid improvements in strength or muscle morphology to benefit their patients or athletes. Other advantages for various populations may include increased compliance to training programs, reduced risk of early re-injury, and possibly may help prevent more expensive and invasive medical procedures (Costa et al., 2016; Cramer et al., 2007). Enhanced understanding of the short-term training adaptations characterized by different training protocols may also provide important information regarding the time course capabilities of the neuromuscular systems that may realistically be achieved with optimal training, and may serve as an early indicator of how effective the training program is likely to be, which could inform programming decisions when making comparisons among various types of training programs. Eccentric training in particular (for the aforementioned reasons) may be well suited for such early adaptations. Therefore, the purpose of the present study was to investigate the effects of 4 weeks of multiple joint isokinetic eccentric training versus traditional leg press training on muscle strength, rate of torque development (rapid strength) and jump and sprint performance adaptations in recreationally resistance trained college-aged men and women.

METHODS

Participants

Twenty-six resistance trained college-aged men and women volunteered to participate, and satisfactorily completed the study (twenty-eight volunteered, but did not complete all training or testing), and were randomly assigned to either an eccentric (n = 13, 4 females; mean ± SD: age = 22.1 ± 2.9 years, height = 173.3 ± 10.6 cm, mass = 71.6 ± 12.5 kg) or traditional leg press (n = 13, 5 females; age = 23.0 ± 2.3 years, height = 175.2 ± 10.0 cm, mass = 70.4 ± 13.1 kg) training condition. Eligibility criteria required participants to be between the ages of 18 and 30 years, currently engaged in lower body resistance training (at least 1 time per week for at least 6 months) and willing to forego their current training program for the duration of the study (no outside resistance training for the study duration). In addition, they were not allowed to have performed more than 3 hours per week of aerobic-based exercise in the previous 6 months. For the course of the study, participants were instructed to maintain their current physical activity patterns and to refrain from muscle building nutritional supplements during the study (e.g., Creatine). All participants were free of lower limb injuries and had not had surgery of the lower limbs within 1-year of the study. The study was approved by the university's Institutional Review Board, and all participants read and signed an informed consent document prior to study participation.

Experimental Procedures

The experiment used a between-within (mixed) groups design to examine the effects of a 4-week eccentric versus traditional resistance training program on changes to neuromuscular performance. Testing was performed before (Pre), at the midpoint (Mid; week 2), and after (Post) a 4-week training period. Participants reported to the laboratory for a familiarization session which occurred 3-7 days prior to the baseline test and was administered 3-7 days before the first training session. Strength tests included isometric and isokinetic strength measurements of the knee extensors and flexors and performance tests included vertical jump, long jump and 40 m sprint. All tests occurred a minimum of 3-days following the final training session in order to allow for muscle recovery and prevent the influence of residual muscle damage on the outcome measures.

Strength Testing and Signal Processing

Following a standardized general warm-up (~5 min) on a cycle ergometer at an intensity of 50% of maximum perceived exertion, participants were seated on an isokinetic dynamometer (Biodex System 3, Biodex Medical Systems, Shirley, NY) with restraining straps placed over the chest, waist, and thigh in accordance to the manufacturer's instructions. The knee joint was aligned with the input axis of the dynamometer and the lower limb secured to a padded lever arm at ~5 cm above the malleolus. Individualized seat positioning was recorded, and the same settings were used for all testing occasions. Participants performed a localized warm-up of the lower limb consisting of 10 isokinetic muscle actions at $120°\cdot s^{-1}$ at an effort corresponding to approximately 75% of the person's perceived maximum. Isometric testing using the Biodex was performed for the knee extensors and flexors at knee angles of 60° and 30° (0° = horizontal), respectively, which were set using a manual goniometer (Conchola, Thompson, & Smith, 2013). Two maximum voluntary contractions (MVCs) were performed for each muscle group. An additional MVC was performed if either of the two trials was unsatisfactory for the isometric testing. Following the isometric testing, participants performed isokinetic testing at the velocity of $150°\cdot s^{-1}$. Three concentric knee extension/flexion repetitions were performed. The isokinetic testing was based upon a similar isokinetic testing program used by Cramer et al. (2007). This was followed by two eccentric isokinetic repetitions of the knee flexors performed at $60°\cdot s^{-1}$. An additional MVC was also performed if one of the two trials was unsatisfactory for the eccentric testing. A 2-min rest period was provided between all isometric MVCs and tests. Following a 5-min rest, participants performed MVCs on the multiple joint eccentric device (Eccentron, BTE Technologies Inc., Hanover, MD). Briefly, participants were seated on the Eccentron at a position which placed the knee joint at 30° while at the most extended position per the manufacturer's recommendation. Participants performed six eccentric MVCs for each leg, alternating legs every other repetition in a consecutive manner. The traditional group performed 1RM testing of the leg press before, in the middle, and after training. For the leg press 1RM testing, participants performed a localized warm-up of 5 leg press repetitions at 50% of their estimated maximum or with no weight added onto the 22.7 kg leg press apparatus. This was followed by up to 5 sets of a single repetition, each increasing the load until maximum effort was required to complete the final repetition. Mid and Post testing used the previous maximum score to more precisely progress the sets. Strong verbal encouragement was given throughout all strength testing MVCs/1RMs.

The torque signal was sampled at 2000 Hz from the Biodex dynamometer with a Biopac data acquisition system (MP150, Biopac Systems Inc., Santa Barbara, CA) and processed offline using custom written software (LabVIEW 2016, National Instruments, Austin, TX). The signals were scaled to appropriate units (Nm) and filtered using a zero phase shift, 4^{th}-order Butterworth filter with a 50 Hz low-pass cutoff frequency. For the isometric signal, the torque signal was gravity corrected by subtracting the participant's limb weight's baseline value from the entire torque signal. Isometric peak torque (PT) was quantified as the highest 500 ms epoch during the plateau phase of the MVC. The rate of torque development (RTD) was calculated from the linear slope ($Nm \cdot s^{-1}$) of the ascending portion of the torque-time curve at time intervals of 0-200RTD200) and 100-200 (RTD100-200) ms from the onset. These RTD time phases represent traditional/global (RTD20050) and late (RTD100-200) rapid strength characteristics, respectively, due to the possibly distinct physiological attributes they may represent (Gerstner et al., 2017; Thompson et al., 2014; Thompson et al., 2015). Onset was determined manually by visually inspecting the signal and selecting the point at which the torque signal visually deflects from baseline, similar to the procedures of Gerstner et al. (2017). The isokinetic torque signal was corrected for the effect of gravity in accordance to the procedures of Aagaard et al. (1995). The isokinetic PT (PT150) was calculated as the highest 25 ms epoch of the torque signal.

Performance Testing

Vertical and Long Jump

Following a standardized dynamic warm-up of five lower body dynamic stretches for five repetitions, participants performed three maximal countermovement vertical jump attempts on a jump mat (Just Jump Technologies, Huntsville, AL), a device that measures jump height based on flight time. For the countermovement jumps, participants stood on the mat with their feet shoulder width apart and their hands positioned on their hips. A successful jump attempt required no stepping prior to the jump and the hands remaining on the hips throughout the jump (Palmer et al., 2014).

For the standing long jumps, participants stood on the edge of a long jump pit with their feet slightly apart. A bilateral take-off and landing technique was used to determine a successful jump attempt. The participants were instructed to perform a countermovement forward jump incorporating an arm swing in order to maximize propulsive forward drive (Runner et al., 2016). The participants were instructed to jump as far as possible and to land on both feet without falling forward. A tape measure was used to measure the distance, and the measurement was taken from the takeoff line to the rear-most heal on landing (Runner et al. 2016).

40 m Sprint

Participants performed three maximal effort 40 m sprints on a hard indoor track surface. Timing gates (Dashr Motion Performance Systems, Dashr LLC, Lincoln, NE) were used to measure sprint time and the two gates were set at 40 m apart. The participants started in a 3-point stance with their feet staggered and one hand on the ground (Rimmer & Sleivert, 2000). The front of either the left or right foot (based on lead foot preference) was positioned on a line 30 cm behind the starting line and the athlete touched the line with the opposite hand as the lead foot (Rimmer & Sleivert, 2000). Appropriate running shoes were required, and participants wore the same shoes for each testing session. The sprint start was initiated on a verbal command and the participants were instructed to sprint to a point that was 10 m past the final timing gate to ensure maximal speed was maintained through the finish line.

Resistance Training Procedures

Participants were randomly allocated into two training groups (traditional or eccentric training). The traditional group performed traditional resistance training on a leg press machine and the eccentric group trained using a motor driven eccentric training machine. Both groups trained twice per week for 4 total weeks. To allow the participants to optimize their training technique and reduce the effects of training-induced soreness, a 1-week (2 sessions) familiarization period was performed (using their assigned training mode) prior to the 4-week training program at an intensity of 45-50% of their predetermined maximum concentric (traditional group) or eccentric load. For the traditional group, the participants performed all training using a supine leg press machine. Training sessions lasted approximately 20 minutes, and included a one set warm up of five repetitions at 50% of their 1-RM. The traditional leg press program was based upon similar leg press training program variables used by previous investigations (Boone et al., 2015; Rossi et al., 2018) and included 6 sets of 8-12 repetitions at a progression of the participant's baseline 1-RM with 90-120 seconds allotted between sets and performed at a cadence of approximately 1-second for the concentric and 2-sec for the eccentric phases.

The training program for both groups followed a progression that was developed based on pilot work. Specifically, intensity was the only variable involved in the progression and represented a percentage of the pretest 1RM. The progression was as follows: week 1 – 50 and 55% for sessions 1 and 2, respectively; week 2 – 60 and 65%; week 3 – 70 and 75%; and week 4 – 75-80%. Intensity at week 4 either remained at 75% or increased to 80% based off of the RPE (if $\geq$ 8 on a scale of 10 it remained at 75%). For the leg press training, when necessary, loads were adjusted for subsequent sets and workouts in order to keep the sets in the 8-12 repetition target range. Verbal questioning of soreness and fatigue were assessed before each session using a scale of 1-10, and if 8 or above, then no adjustments were made in training load (e.g., used the previous training intensity instead of progressing forward).

The eccentric group performed all training on a motor-driven eccentric machine (Eccentron). Participants were seated on the device with their feet placed on separate pedals with their knee joint angle set at 30° in the most extended position. The training protocol involved an on screen visual of a target force zone which participants were required to reach by pressing their foot against the pedal as it moves toward them one pedal at a time in an alternating fashion. Training sessions lasted a total of 5 minutes, which included a 1-minute warm-up and 1-minute cool-down each at 50% of the training load, with a 3-minute training period. Training sessions were performed twice per week for 4 weeks. The eccentric training program followed the same progression as the leg press group that was developed based off of pilot work, except during the last week of training, a 30 second break was administered during the training session's if the participants could not finish the 3 minute training period continuously due to fatigue. During the course of the training sessions, strong verbal encouragement was provided to an equivalent degree for both groups. A make-up session was allotted each week on a non-consecutive day to allow for missed sessions to be made-up.

Statistical Analyses

A mixed analysis of variance (ANOVA) (trial [Pre vs. Mid vs. Post; or Pre vs. Post for variables without Mid] × group [traditional vs. eccentric]) was used to compare differences for each of the dependent variables. When appropriate, significant interactions and main effects were further decomposed with repeated measures ANOVAs (interactions) and Bonferroni-corrected pairwise comparisons. Additionally, Cohen's *d* effect size statistics were used to evaluate the meaningfulness of the changes, with values of 0.2, 0.5, and 0.8 corresponding to small, medium, and large effect sizes, respectively. Statistical analyses were performed using SPSS software (version 25, IBM SPSS Inc., Chicago, IL) and an alpha level of $P < 0.05$ was used to determine statistical significance.

RESULTS

All participants completed all the training sessions during the 4 week intervention. However, one subject was removed from the study due to illness for the posttest trial and also for not meeting the minimum days off from training required prior to the posttest (yielding a final n of 13 per group). Also, two participants (traditional group) exceeded the load limit of 3,338 N for the maximum testing on the Eccentron machine, so for this variable only, sample size is 11 rather than 13, however, they did complete all the training and were able to successfully complete all other tests.

The means and SDs for all variables are presented in Table 1. There was a significant interaction ($P < 0.01$) for the Eccentron strength variable. Post hoc analyses revealed a significant effect ($P < 0.01$) for trial for the eccentric group, whereas the traditional group approached significance ($P = 0.054$). For the eccentric group, strength improvements were shown between the Pre and Mid ($P < 0.01$), Pre and Post ($P < 0.01$), and Mid and Post ($P = 0.04$) test trials. For the traditional group, the only improvement was shown between the Mid and Post ($P = 0.05$) trials. Figure 1 shows a scatterplot of the absolute changes scores from Pre to Post for each training group for the Eccentron maximum strength test. For the leg press 1RM, only the traditional group performed this test, and showed a significant effect for trial ($P < 0.01$), with improvements for Pre (233.2 ± 54.4 kg) versus Mid (249.0 ± 57.1 kg), Pre versus Post (264.0 ± 60.4 kg), and Mid versus Post ($P < 0.01$ for all comparisons).

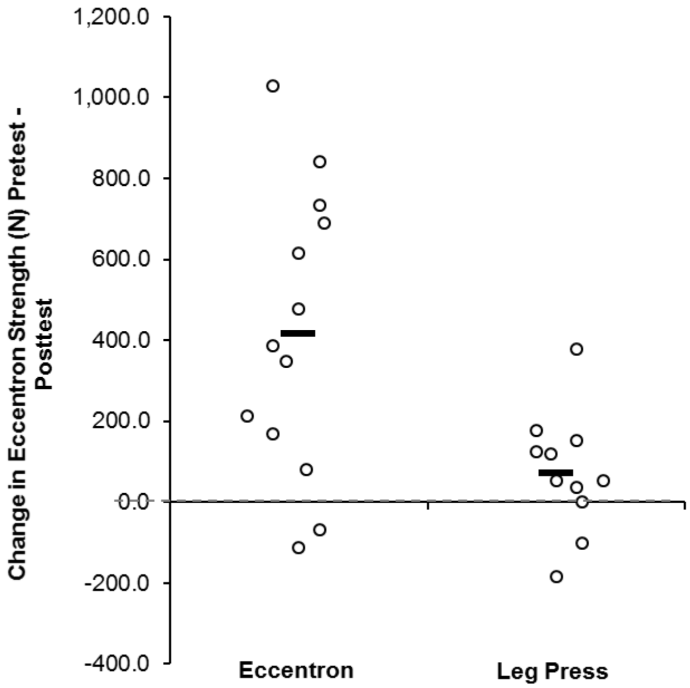

Figure 1. Scatterplot showing each participants' absolute changes scores (N) from pretest to posttest for the Eccentron and leg press groups. Horizontal bars represent the mean change score for each group.

For the isokinetic PT150 variable, there were no interactions for the knee extensors or flexors ($P = 0.46$ and 0.45, respectively), but both muscle groups showed a significant main effect for test trial ($P \leq 0.01$). Pairwise comparisons (collapsed across groups) for the knee extensors revealed that the Mid and Post trials were greater than the Pre ($P < 0.01$ for both comparisons), however, there was no difference between the Mid and Post trials ($P = 1.0$). Pairwise comparisons (collapsed across groups) for the knee flexors revealed that Mid was greater than the Pre ($P = 0.03$) but the Post versus Pre only approached statistical significance ($P = 0.07$). There was no interaction ($P = 0.11$) or main effect for trial ($P = 0.43$) for the eccentric knee flexors PT variable (Biodex).

For the isometric PT variable, there were no interactions for the knee extensors or flexors ($P = 0.55$ and 0.24), nor main effect for trial for the knee extensors muscle ($P = 0.43$). However, there was a main effect for trial (collapsed across groups) for the knee flexors ($P = < 0.01$), such that the Mid ($P = 0.02$) and Post tests ($P < 0.01$) were greater compared to Pre.

For the isometric RTD200 variable, there were no interactions ($P = 0.18$ and 0.87), or main effects for trial ($P = 0.85$ and 0.45) for the knee extensors and flexors muscle groups. However, for the RTD100-200 variable, there were no interactions for the knee extensors or flexors ($P = 0.25$ and 0.29) or main effect for the knee extensors ($P = 0.30$), but there was a main effect for trial for the knee flexors ($P < 0.01$) muscle group. Pairwise comparisons (collapsed across groups) revealed that Post was greater than Pre ($P < 0.01$), whereas Mid only showed a trend for being greater than Pre ($P = 0.07$) and no differences were shown between Mid and Post ($P = 1.0$) (Figure 2).

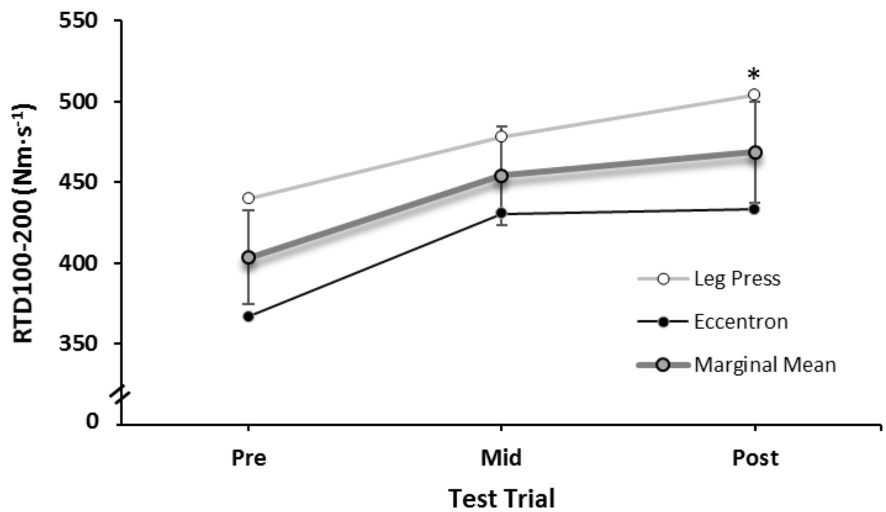

Figure 2. Changes in the rate of torque development at 100-200 ms of the isometric torque-time curve for the knee flexors muscle group at 2 weeks (Mid) and 4 weeks (Post) of training for the leg press and eccentron training groups. Center grey line is marginal means (collapsed across groups). * denotes significantly different versus Pre for marginal mean ($P < 0.05$). Values are means ± standard error

For the vertical jump, there was no interaction (P = 0.72), but there was a main effect for trial (collapsed across groups; P = 0.02). However, when analyzing the Post hoc pairwise comparisons there were no significant differences between Pre versus Mid (P = 0.09), Pre versus Post (P = 0.07) or Mid versus Post (P = 1.0). For the long jump, there was no interaction (P = 0.52), nor main effect for trial (P = 0.88). The 40 m sprint showed no interaction (P = 0.36), nor main effect for trial (P = 0.53), however, pairwise comparisons showed a trend for improvement in the control group (P = 0.06; ES = 0.57).

Table 1. Mean (SD) and Cohen's *d* effect size values for the muscle function variables for the eccentric and traditional (leg press) groups at pretest (Pre), midtest (Mid), and posttest (Post).

		Eccentric				Leg Press			
Action	Variable	Pre	Mid	Post	Cohen's *d*	Pre	Mid	Post	Cohen's *d*
Eccentron ¥	Peak Force (N)	2170.4 (512.4)	2467.4 (497.4)*	2585.7 (540.5)*†	1.06	2403.8 (495.1)	2343.1 (436.1)	2477.3 (461.0)†	0.11
Vertical Jump	Height (cm)	50.8 (8.1)	51.8 (8.4)	51.8 (7.7)	0.14	52.6 (10.3)	53.9 (10.0)	54.5 (10.2)	0.19
Long Jump	Distance (cm)	225.2 (31.5)	-	226.6 (27.8)	0.05	228.6 (35.6)	-	226.6 (28.0)	-0.07
Sprint (40 m)	Time (s)	6.07 (0.47)	-	6.08 (0.40)	-0.02	5.97 (0.45)	-	5.91 (0.42)	0.57
Knee Extensors (Nm or Nm·s^{-1})	PT150	131.9 (36.5)	144.6 (44.6)	140.3 (41.6)	0.21	148.3 (42.8)	156.3 (42.6)	159.4 (42.9)	0.26
	PT	207.7 (52.3)	218.1 (57.7)	207.7 (57.7)	0.0	216.4 (57.2)	216.8 (63.9)	215.3 (46.90)	-0.02
	RTD200	623.9 (221.4)	653.4 (279.6)	678.8 (251.1)	0.23	823.4 (247.2)	823.9 (245.6)	770.7 (230.6)	0.22
	RTD100-200	511.2 (126.1)	555.9 (165.1)	587.5 (155.4)	0.54	494.6 (215.2)	543.1 (296.4)	484.3 (160.9)	-0.05
Knee Flexors (Nm or Nm·s^{-1})	PT150	87.8 (31.9)	94.3 (35.4)	91.6 (33.4)	0.12	94.6 (26.1)	100.2 (29.2)	102.7 (32.6)	0.28
	ECC60	137.2 (36.3)	135.7 (39.4)	132.3 (33.6)	-0.14	140.6 (42.4)	150.7 (42.1)	148.8 (43.4)	0.19
	PT	116.3 (31.5)	125.4 (35.7)	121.1 (34.8)	0.14	121.4 (34.8)	127.9 (36.9)	132.5 (37.1)*	0.31
	RTD200	413.3 (161.6)	426.7 (150.02)	422.2 (160.3)	0.06	472.5 (222.5)	498.3 (189.9)	498.9 (218.9)	0.12
	RTD100-200	366.9 (114.9)	430.5 (142.4)	433.1 (146.6)*	0.51	440.1 (174.8)	477.8 (168.5)	503.8 (172.3)	0.37

Eccentron = maximal eccentric multi-joint strength on the Eccentron device; PT150 = isokinetic peak torque at 150°·s^{-1}; PT = isometric peak torque; RTD = rate of torque development. ECC60 = Biodex eccentric action at 60°·s^{-1}. Cohen's *d* values are comparing within group pretest and posttest differences and are identified as being small, moderate and large, based on values of 0.2, 0.5, and 0.8, respectively. ¥ denotes group by trial interaction; * denotes different vs. pretest. † denotes different vs. midtest. $P \leq 0.05$

DISCUSSION

The primary findings of the present investigation were: 1) 4 weeks of isokinetic multi-joint eccentric training elicited significantly greater test-specific strength gains compared to traditional leg press training, 2) both training protocols induced improvements in middle time phase RTD (100-200 ms), 3) both training protocols elicited small but statistically significant improvements in isokinetic PT, but there was generally no effects for the single-joint PT, traditional RTD (0-200 ms) and eccentric strength variables, and 4) small but statistically significant increases in vertical jump performance were found for both groups (when examining marginal means/main effects).

The isokinetic eccentric training elicited substantially greater improvements (ES = 1.06 for Pre vs. Post) compared to the leg press training (ES = .11) on the multi-joint eccentric strength test, and these gains also occurred early in the training program (showing significant improvement at week 2 as well as week 4). Specifically, the eccentric training group demonstrated a 13.7 and 19.2% increase in strength at weeks 2 and 4 of the program, respectively, compared with a gain of only 3% for the leg press training after 4 weeks. These findings agree with the previous work of English et al. (2014) regarding high eccentric loads leading to greater adaptations for strength. In their study, they reported that 8 weeks of DCER eccentric training on a leg press exercise performed at an intensity of 138% of the concentric one-repetition maximum (1-RM) load elicited a 20.1% increase in muscle strength (1-RM) compared to the concentric-only training group. Given the significant strength gains following only 2 weeks of training, our study uniquely showed that these gains may occur early during a training program when using an isokinetic eccentric protocol (showing similar 20% gains after only 4 weeks, versus the 20% gains after 8 weeks in the English et al. study). However, much of the observed adaptations were likely caused by the specificity of the training program to the test. Because the eccentric group trained on the same machine using the same movement as the maximal eccentric strength test, the adaptations were more specific compared to the leg press training protocol. Fochi et al. (2016) showed similar findings regarding exercise-induced muscle damage for larger versus small eccentric ranges of motion. They found that the larger range of motion caused a greater magnitude for muscle damage compared to a smaller range of motion control group (120° vs 60°). Nevertheless, these findings demonstrate that isokinetic multi-joint eccentric training is capable of inducing large improvements in eccentric strength and to a higher magnitude and earlier on in the training program compared to traditional DCER multi-joint training. Moreover, a direct comparison between test and training specific gains between groups reveals that, although the leg press group significantly improved 1RM strength during the 4 weeks, their gains were lower (13%) and the ES was notably smaller compared to the eccentric group (ES = .55 for leg press vs. 1.06 for eccentric). Thus, superior gains in the eccentric group from short-term strength training are not solely explained by training-testing specificity responses. Regarding the test-specific responses for each training condition, it is worth noting that the leg press condition exhibited a 6.7% (ES = .28) increase in test-specific strength (leg press 1RM) compared to the greater 14% improvement of the eccentric training group for the midtest (2 weeks of training), further showing that greater improvements were also achieved by the eccentric training group after only 2 weeks of training.

The eccentric training induced strength gains may have occurred due to the novelty of the training stimulus, as well as the loading nature imposed by the eccentric contractions. For example, there are practically no available machines for persons to train on using an isokinetic eccentric-only multi-joint mode, and thus the stimulus was almost completely novel for all participants. Perhaps the more likely explanation for the strength gains is the high loads imposed on the muscle by the eccentric overload, as well as the neural adaptations that may be specific to eccentric muscle actions. Greater force production has been proposed to be an important precursor for muscle adaptations (Farthing and Chilibeck, 2003), and the eccentric group would have been exposed to greater muscle forces during their training due to the high load demands of the eccentric training. Also, neural mechanisms are likely responsible for the observed adaptations, especially given the short term duration of the study. Hortobagyi et al. (1996) showed that eccentric training increased EMG activity seven times more than concentric training, and provided support that eccentric actions preferentially recruit type II motor units. Type II motor units tend to be larger, more forceful motor units which may respond with greater muscle size and strength versus type I units. Therefore, recruiting proportionally more type II units/fibers during training may help selectively train the larger units yielding more potential for strength-based adaptations, as well as improve the capability to recruit these units following training (i.e., learned recruitment of type II motor units). The large and early gains in strength from eccentric overload training have practical application as a means to more rapidly improve strength, which may be desirable by clinicians and practitioners who often operate under time constraints for improving or restoring function/performance in their patients or athletes (e.g., physical therapists, athletic trainers).

Another key finding from the present study was that neither training program elicited improvements in traditional RTD measured from onset to 200 ms (RTD200), but that the eccentric group yielded moderate improvements in the early-middle phase RTD (RTD100-200) variable for both muscles (ES = .51 and .54 for flexors and extensors), and the leg press group for the knee flexors muscle group (ES = .37). The finding that global RTD (RTD200) did not improve may be due to the lack of early explosive force during either training program, which were heavily based on maximum rather than early rapid strength production characteristics. It is also possible that more substantial RTD adaptations require longer training periods than the duration of the present 4-week training program provided, but as there are no other eccentric training studies which have examined short-term (< 4 weeks) training adaptations specifically on RTD variables, no direct comparisons are able to be made with other findings for this variable. Another explanation may be a loss of transfer of RTD adaptations from training to testing as a result of specificity issues, such that the RTD test was performed in an isometric condition as well as in a single-joint action, compared to the dynamic and multi-joint (including a different movement type altogether) training mode performed by both training groups.

However, an interesting finding was that the early-middle phase RTD variable showed moderate improvement, being more pronounced in the eccentric group (both muscle groups), and the knee flexors muscles. The RTD100-200 variable represents the rate of torque increase between the 100 and 200 ms time interval from onset of the torque-time curve. Because this variable omits the first 100 ms of the torque curve (starting at 100 ms after torque onset), it provides a measure of the physiological capacity of the muscle-tendon unit to rapidly increase force at this distinct time phase of the muscle contraction. Specifically, it represents a phase which is largely, but not primarily, predominated by neural factors, such as motor unit recruitment and motor unit discharge rate (Maffiuletti et al., 2016). For instance, the early phase (<75 ms) is suggested to be influenced primarily by neural factors, whereas the late phase (200 ms) is more strongly influenced by muscle morphological factors (size and architecture). Because the 100-200 interval occurs after the first 100 ms, but before 200 ms, it is likely still predominantly influenced by improvements in neural recruitment factors. The premise that early adaptations in strength are mostly neurological based, and that morphological adaptations do not appreciably occur until after several weeks of training would also provide support for the rationale that the observed RTD responses were primarily of neurological origin. However, as the present study lacked neuromuscular measures (EMG, H-reflex recordings), we can only speculate as to the neural mechanisms involved in the RTD responses. An additional explanation for the finding of improved RTD100-200, is that it may correspond to a muscle contraction time point that is similar to the pattern of contraction incurred by the muscle loading pattern during the training program. It is possible that very early rapid contractions were not initiated by the participants due to the lack of necessity for early explosive force development during training, but that shortly after force initiation (e.g., 100 ms), higher amounts of force were required to overcome inertia (leg press) or resist the motor-driven movement of the machine (Eccentron). Interestingly at first glance, these findings would appear to conflict with those of Oliveira, et al. (2016), who showed that it was the early (< 100 ms), but not the later RTD phases that responded from isolated eccentric training of the knee extensors. However, upon closer inspection, the present findings may align with theirs, because the torque onset method in their study was automated and initiated at a relatively robust threshold of 8 Nm, whereas the present methods used a manual onset detection method. The manual method onset used here yields a much earlier onset, and thus includes an earlier phase of the muscle contraction (perhaps as much as 100 ms earlier). Therefore, it is possible that the 100-200 ms phase in this study, aligns more closely to the early (0-100 ms) RTD phases in their study. Also, we note that this study was only half the training duration, and longer training periods may be required to realize more significant gains in certain RTD parameters. As very few studies have investigated eccentric-specific training models on RTD variables, more research is warranted in this area to elucidate the patterns and torque-time periods that are responsive to this form of training, the mechanisms that contribute to eccentrically induced RTD adaptations, and the degree to which these effects would transfer to more functional movement tasks.

Although PT150 reached statistical significance (when collapsed across groups) the effect sizes were small (.12-.28) and the remainder of the isolated (Biodex) strength (PT) variables showed virtually no effects. The lack of strength gains on the knee extensors and flexors for the isolated testing likely reflects a testing specificity effect. This effect may be deduced because of the substantially larger strength gains seen by both the training groups for their respective test-specific assessment mode. It is likely that both the mode (single-joint) as well as the specificity of muscles involved in this test did not capture the true training-induced gains. In particular, the muscles tested on the isolated knee joint tasks may not have represented, in the correct proportion, the muscles and recruitment patterns which were heavily utilized when performing the multi-joint training. Indeed, a limitation of using the isolated testing paradigm to assess gains induced by the multi-joint training program is that it did not incorporate the hip muscles, which were an important muscle group for the multi-joint training.

It was initially assumed that the hip and knee joints would bear a similar amount of the training load due to both the hip and knee loading requirements of the leg press movements; however, it is possible that the hip joint was responsible for a proportionally higher amount of the gains than the knee joint, and that this was neglected to be observed in the isolated testing due to its exclusive measurement of the knee joint performance. Based on these findings, we therefore conclude that isolated knee joint assessments may not be good indicators of global lower body strength gains from training programs utilizing leg press type movements (either DCER or eccentric-only) as they reveal a lack of transfer effect for these particular variables.

Although it’s possible that the short-term duration of the study may have prevented larger isolated strength testing gains to manifest in the isolated testing mode, these findings highlight the premise that early gains from multi-joint lower body training do not transfer well to isolated testing models for PT variables, particularly for using the knee flexor or extensor muscle groups to represent the more global lower body muscle responses from training with leg press-based movement and loading patterns.

For the vertical jump test, there was a statistically significant effect on jump height (when collapsed across groups), but a closer inspection of this data suggests a small effect (ES = .14 - .19). Thus, we do not conclude that either of these training programs, in this short term (4 week) training duration, provided meaningful improvements in jump performance. It will likely take a longer training period to yield changes in performance measures, possibly due to a loss of transfer of gains between the training and functional performance. It is also possible that the small effect of the training on the vertical jump may be due to the lack of a stretch shortening cycle characterized by these types of training (e.g., eccentric-only training utilizes practically no stretch shortening cycle component during the movement, and the controlled leg press training herein only a small recruitment of the stretch shortening cycle component). More research is needed that investigates longer duration training programs to determine the effects that this type of eccentric training model may have on functional performance adaptations (e.g., vertical jump, sprint speed etc.), as well as the incorporation of ballistic type exercises in conjunction with eccentric training (such as including plyometrics into a mixed training paradigm).

It was observed that the eccentric overload training program caused temporary knee problems for two participants (one at the end of the study, whose data was discarded; and another in the third week of the training program, who was asked to discontinue the study). Thus, the Eccentron training intensity progression used in this study, which was developed to induce a large overload for trained individuals, may have been somewhat excessive toward the latter half of the study (especially the last two training sessions). This finds support from the informal soreness/fatigue assessments used in this study, for which it was noted that toward the end of the program, the eccentric training generally produced a noticeable amount of delayed onset muscle soreness (DOMS) and subjective fatigue. Specifically, subjective verbal questioning of fatigue and soreness were evaluated before each session using a scale of 1-10, and all but one participant reported a score of 8 or higher during the last week of training. Therefore, future work is warranted which investigates the effects of a lowered intensity progression on muscle function adaptations using this type of eccentric training model.

A limitation of this study was that hip joint strength was not assessed for the single-joint testing assessments (partially because it was initially assumed that the knee extensors and flexors would effectively capture the overall lower body strength gains, but this may not have been so). It is possible that the hip muscle group may have shown more lower body single-joint strength gains for both the training groups compared to the knee extensors of flexors. Another restriction was that the eccentric group was not tested for the leg press 1RM variable. We chose not to have them perform this test because of time limitations and limited leg press equipment resources, and we also wanted to avoid placing an excessive muscular overload on them prior to the eccentric specific training (e.g., they were already performing several maximum strength tests between the Biodex and Eccentron assessments and we desired to avoid inducing undue pretest overloading). However, this does not diminish the present findings of quantifiable strength gains in 2 and 4 weeks, but only precludes the evaluation of across test specificity, which was not the primary aim of this study. Future investigations are needed which specifically examine the transferability of gains induced by this type of isokinetic multi-joint eccentric overload training to traditional DCER strength improvements using a similar movement type (e.g., leg press).

In summary, 4 weeks of isokinetic multi-joint eccentric training elicited significantly greater test-specific strength gains compared to traditional leg press training. The eccentric group also yielded moderate improvements in the early-middle phase RTD (RTD100-200) over the control group. Also, the effects of both eccentric and traditional short term (4 weeks) training only elicited a small improvement in vertical jump. An eccentric multi-joint training using a novel motor driven device yielded substantial improvements in strength in a short amount of time for a recreationally trained population. These accelerated adaptations and also the lowered energy requirements of eccentric exercise may be particularly useful for allied health professionals or practitioners looking for appropriate training programs for those who are injured, sedentary, or less physically abled (older adults). The use of eccentric multi-joint training may enhance progress in short-term strength-related adaptations in a time efficient manner. In particular, the eccentric training sessions in the present study were only 5 minutes in length, such that considerable gains were achieved with a minimum time commitment.

REFERENCES

Aagaard, P., Simonsen, E. B., Trolle, M., Bangsbo, J., & Klausen, K. (1995). Isokinetic hamstring/quadriceps strength ratio: influence from joint angular velocity, gravity correction and contraction mode. *Acta Physiologica Scandinavica, 154*(4), 421-427.

Ando, R., Nosaka, K., Tomita, A., Watanabe, K., Blazevich, A. J., & Akima, H. (2016). Vastus intermedius and vastus lateralis fascicle length changes during maximal eccentric knee extensor contractions: 692 Board #8 June 1, 3: 30 PM - 5: 00 PM. *Medicine and science in sports and exercise, 5 Suppl 1,* 184.

Boone, C. H., Stout, J. R., Beyer, K. S., Fukuda, D. H., & Hoffman, J. R. (2015). Muscle strength and hypertrophy occur independently of protein supplementation during short-term resistance training in untrained men. *Applied Physiology, Nutrition, and Metabolism, 40*(8), 797-802.

Bridgeman, L. A., McGuigan, M. R., & Gill, N. D. (2015 a). Eccentric exercise, exercise induced muscle damage and the repeated bout effect: a brief review. *Journal of Australian Strength & Conditioning*, *23*(3), 74-84.

Bridgeman, L. A., McGuigan, M. R., & Gill, N. D. (2015 b). Eccentric exercise as a training modality: a brief review. *Journal of Australian Strength & Conditioning*, *23*(5), 52-64.

Conchola, E. C., Thompson, B. J., & Smith, D. B. (2013). Effects of neuromuscular fatigue on the electromechanical delay of the leg extensors and flexors in young and old men. *European Journal of Applied Physiology, 113*(9), 2391-2399.

Costa, P.B., Herda, T.J., Herda, A.A., and Cramer, J.T. (2016). Effects of short-term dynamic constant external resistance training and subsequent detraining on strength of the trained and untrained limbs: A randomized trial. *Sports*, 4(7), 1-10.

Cramer, J.T., Stout, J.R., Culbertson, J.Y., and Egan, A.D. (2007). Effects of creatine supplementation and three days of resistance training on muscle strength, power output, and neuromuscular function. *Journal of Strength and Conditioning Research*, 21(3), 668-677.

de Hoyo, M., Sañudo, B., Carrasco, L., Mateo-Cortes, J., Domínguez-Cobo, S.,Fernandes, O., & ... Gonzalo-Skok, O. (2016). Effects of 10-week eccentric overload training on kinetic arameters during change of direction in football players. *Journal of Sports Sciences*, *34*(14), 1380-1387.

Eccentron. (n.d.). Retrieved December 1, 2016, from http://www.btetech.com/product/eccentron/

English, K., Loehr, J., Lee, S., & Smith, S. (2014). Early-phase musculoskeletal adaptations to different levels of eccentric resistance after 8 weeks of lower body raining. *European Journal of Applied Physiology*, *114*(11), 2263-2280.

Farthing & Chilibeck. (2003). The effects of eccentric and concentric training at different velocities on muscle hypertrophy. *European Journal of Applied Physiology, 89, 578-86.*

Fochi, A. G., Damas, F., Berton, R., Alvarez, I., Miquelini, M., Salvini, T. F., & Libardi, C. A. (2016). Greater eccentric exercise-induced muscle damage by large versus small range of motion with the same end-point. *Biology of Sport*, *33*(3), 285-289.

Gerstner, G. R., Thompson, B. J., Rosenberg, J. G., Sobolewski, E. J., Scharville, M. J., & Ryan, E. D. (2017). Neural and muscular contributions to the age-related reductions in rapid strength. *Medicine & Science in Sports & Exercise*, 49(7), 1331-1339.

Guex, K., Degache, F., Morisod, C., Sailly, M., & Millet, G. P. (2016). Hamstring architectural and functional adaptations following long vs. short muscle length eccentric training. *Frontiers in Physiology*, *7*, 340.

Hortobagyi, T., Hill, J., Houmard, J., Fraser, D., Lambert, N., & Israel, R. (1996). Adaptive responses to muscle lengthening and shortening in humans. *Journal of Applied Physiology*, 80(3), 765-772.

Maffiuletti, N., Aagaard, P., Blazevich, A., Folland, J., Tillin, N., Duchateau, J., & ... Blazevich, A. J. (2016). Rate of force development: physiological and methodological considerations. *European Journal of Applied Physiology*, 116(6), 1091-1116.

Norrbrand, L., Fluckey, J. D., Pozzo, M., & Tesch, P. A. (2008). Resistance training using eccentric overload induces early adaptations in skeletal muscle size. *European Journal of Applied Physiology*, *102*(3), 271-281.

Oliveira, A. S., Corvino, R. B., Caputo, F., Aagaard, P., & Denadai, B. S. (2016). Effects of fast-velocity eccentric resistance training on early and late rate of force development. *European Journal of Sport Science*, *16*(2), 199-205.

Orer, G. E., Guzel, N. A., & Arslan, E. (2016). Recovery levels after eccentric and concentric loading in maximal force. *Journal of Physical Therapy Science*, *28*(6), 1743-1747.

Palmer, T. B., Thompson, B. J., Hawkey, M. J., Conchola, E. C., Adams, B. M., Akehi, K., . . . Smith, D. B. (2014). The influence of athletic status on the passive properties of the muscle-tendon unit and traditional performance measures in division I female soccer players and nonathlete controls. *Journal of Strength and Conditioning Research*, *28*(7), 2026-2034.

Paschalis, V., Nikolaidis, M. G., Theodorou, A. A., Panayiotou, G., Fatouros, I. G., Koutedakis, Y., & Jamurtas, A. Z. (2011). A weekly bout of eccentric exercise is sufficient to induce health-promoting effects. *Medicine & Science in Sports & Exercise, 43*(1), 64-73.

Rossi, F., Schoenfeld, B., Ocetnik, S., Young, J., Vigotsky, A., Contreras, B., et al. (2018). Strength, body composition, and functional outcomes in the squat versus leg press exercises. *The Journal of Sports Medicine and Physical Fitness*, *58*, *263-70*.

Rimmer, E., & Sleivert, G. (2000). Effects of a plyometrics intervention program on sprint performance. *Journal of Strength and Conditioning Research, 14*(3), 295.

Runner, A. R., Lehnhard, R. A., Butterfield, S. A., Tu, S., & O'neill, T. (2016). Predictors of Speed Using Off-Ice Measures of College Hockey Players. *Journal of Strength and Conditioning Research, 30*(6), 1626-1632.

Sharifnezhad, A., Marzilger, R., & Arampatzis, A. (2014). Effects of load magnitude, muscle length and velocity during eccentric chronic loading on the longitudinal growth of the vastus lateralis muscle. *The Journal of Experimental Biology, Pt 15*, 2726–2733.

Sorichter, S., Mair, J., Koller, A., Secnik, P., Parrak, V., Haid, C., & … Puschendorf, B. (1997). Muscular adaptation and strength during the early phase of eccentric training: influence of the training frequency. / Adaptation musculaire et force pendant le commencement de la phase de l ' entrainement excentrique: influence de la frequence de l ' entrainement. *Medicine & Science in Sports & Exercise*, *29*(12), 1646-1652.

Thompson, B. J., Ryan, E. D., Herda, T. J., Costa, P. B., Herda, A. A., & Cramer, J. T. (2014).

Age-related changes in the rate of muscle activation and rapid force characteristics. *Age, 36(2), 839-849.*

Thompson, B. J., Stock, M. S., Shields, J. E., Luera, M. J., Munayer, I. K., Mota, J. A., . . . Olinghouse, K. D. (2015). Barbell deadlift training increases the rate of torque development and vertical jump performance in novices. *Journal of Strength and Conditioning Research*, *29*(1), 1-10.

Westcott, W. L. (2012). Resistance training is medicine. *Current Sports Medicine Reports*, *11*(4), 209-216.