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Effects of Resistance Training Frequency on Muscle Function Adaptations Using a Multiple-Joint Eccentric Training Model

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EFFECTS OF RESISTANCE TRAINING FREQUENCY ON MUSCLE FUNCTION

ADAPTATIONS USING A MULTIPLE-JOINT ECCENTRIC TRAINING MODEL

by

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ABSTRACT

Eccentric resistance training has been shown to be beneficial for improving multiple performance and health metrics. However, recommendations on eccentric training frequency have not been established. PURPOSE: To investigate the effects of volume-matched resistance training frequency comparing one versus three training days per week of isokinetic multiple-joint eccentric training on strength and lower body function adaptations during a 4-week training period. METHODS: Thirty recreationally-trained men and women were randomly assigned to either a high frequency (HF), three times per week, or low frequency (LF), once per week, training group for four weeks. A motor-driven isokinetic eccentric dynamometer was used for the training and testing. Eccentric strength and vertical jump (VJ) measures were taken at Pre, Mid (two weeks), and Post (four weeks) intervention. Soreness and ratings of perceived exertion (RPE) were taken throughout the training period. RESULTS: There was no significant group × trial interaction for eccentric strength or VJ. For eccentric strength, all trials were significantly different from each other. For VJ, there was a main effect for trial such that VJ increased from Pre to Post and Mid to Post but was not different between Pre and Mid. The HF reported significantly lower RPE and soreness compared to the LF condition. CONCLUSIONS: Both HF and LF protocols elicited large and rapid neuromuscular strength adaptations. Eccentric-based workload may be dispersed across the week to allow for reduced soreness and exertion levels without compromising neuromuscular adaptations. Some transfer to functional (VJ) task may also be observed, independent of training frequency.

INTRODUCTION

Resistance training is one of the most effective means to improve a multitude of health and physical performance parameters (Winett & Carpinelli, 2001; Westcott, 2012). The American College of Sports Medicine's most recent exercise guidelines recommend that adults perform resistance exercise 2-3 days per week using two to four sets per exercise across a variety of exercises (Garber et al., 2011). These and other similar guidelines have been put forth as a result of well-documented scientific evidence demonstrating the benefits of resistance training for health and function. For example, resistance training has been shown to improve a variety of health-centered conditions that include overall functional capacity and performance, cardiovascular health and disease prevention, insulin sensitivity, sarcopenia, frailty syndrome and chronic pain (Evans, 1999; Garber et al., 2011; Kraemer, Ratamess, & French, 2002; Paschalis et al., 2010; Westcott, 2012). However, these recommendations and associated benefits are largely based on the traditional model of resistance training, which predominantly involves the use of dynamic constant external resistance (DCER) exercises typically performed in a concentric and eccentric reciprocating pattern.

The prevailing consensus from the literature is that resistance training provides beneficial effects in a dose-response manner with increasing levels of exercise frequency depending on the experience of the subjects (Braith et al., 1989; McLester, Bishop, & Guilliams, 2000; Rhea, Alvar, Burkett, & Ball, 2003; Schoefeld, Ratamess, Peterson, Contreras, & Tiryaki-Sonmez, 2015). McLester et al. (2000) compared traditional DCER training of one versus three days per week on recreationally trained individuals, while controlling for the weekly training volume. The one day per week training group experienced ~62% of the total body strength gains that the three day per week group received. However, two movements of the posterior chain (namely the leg press and curl) showed a relatively lower response (48 and 53% of the three day per week gains for the leg press and curl, respectively) with the lower frequency training, suggesting that some lower body movements may be more sensitive to adaptations as a result of training frequency than the upper body. Moreover, the findings of Braith et al. (1989) compared variable resistance training on a knee extensor machine at either two or three days per week and found that the lower frequency training (two days per week) was able to elicit 80% of the isometric strength gains that the three days per week group received. In contrast, Candow & Burke (2007) found no significant difference in the strength gains of the squat and bench press between DCER training frequencies of two versus three days per week following the 6-week training period. Thomas and Burns (2016) conducted a similar 8-week whole body DCER training study and reported no difference in lean tissue and strength gains between the high (three days per week) and the low frequency (one day per week) groups. The conflict in the DCER training literature may be due to differences in how strength was assessed. McLester et al. (2000) measured the one repetition maximum (1RM) of upper and lower body exercises (nine exercises in total), whereas Candow & Burke (2007) and Thomas & Burns (2016) measured only the 1RM of the bench press and squat, and chest press and hack squat exercises, respectively. McLester et al. (2000) did not include the squat exercise in their DCER training program and neither did Braith et al. (1989) who assessed isometric torque of the knee extensors after a variable resistance training program, making comparisons between previous studies difficult and interpretations ambiguous. Also, training duration varied from 6-8 weeks (Candow & Burke, 2007; Thomas & Burns, 2016) to 10-18 weeks (Braith et al., 1989; McLester et al, 2000) with the longer studies reporting the more positive frequency effects on strength outcomes.

As reported in the studies above, previous work investigating the effects of varying resistance training frequency on muscle strength and morphological adaptations has almost exclusively used DCER or variable resistance training models. However, eccentric-only training has grown in popularity and exhibits some unique training and adaptation characteristics versus concentric or combined concentric-eccentric training paradigms. For example, eccentric overload training studies have reported larger and more rapid strength gains versus traditional resistance training (Gordon et al., 2018; Hilliard-Robertson & Schneider, 2003) and concentric-only training (Farthing & Chilibeck, 2003; Roig et al., 2008; Seger, Arvidsson, & Thorstensson, 1998) and have also shown a trend toward greater hypertrophy (Farthing & Chilibeck, 2003; Roig et al. 2008; Seger, Arvidsson, & Thorstensson, 1998). Farthing and Chilibeck (2003) trained the elbow flexors of relatively untrained healthy adults at different isokinetic velocities using either an eccentric or concentric training condition. Following the 8-week training period, they found a substantial 13% increase in muscle thickness for the isokinetic eccentric training group compared to a 5.3% increase for the isokinetic concentric group, as well as significantly higher strength gains for the fast eccentric (~16% and ~22.5% increase in eccentric and concentric strength respectively) compared to the slow concentric training group (~6% for both eccentric and concentric strength increases).

To the best of our knowledge, only Sorichter et al. (1997) have compared different training frequencies using an eccentric-only resistance training model. Participants in their study trained the knee extensors (leg extension at 150% of isometric MVC) using eccentric DCER resistance training for five weeks in either a low frequency (one day per week) or high frequency condition (two days per week for two weeks then three days per week for three weeks). They found the high frequency group responded with greater isometric strength gains (4.4% compared to 2.2% for low frequency group). However, their results may have limited implications for elucidating eccentric resistance training frequency-response effects as they varied the frequency in their high frequency group mid-study, did not control for volume, and assessed isometric rather than eccentric strength. Furthermore, this study investigated an isolated (single-joint) resistance training exercise; however, in practice, muscle groups operate under complex multiple-joint synergistic conditions, and training models using a multiple-joint movement for both the training and testing may more accurately capture the applicable gains in lower body strength.

From a physiological perspective, multiple-joint isokinetic eccentric-only resistance training may also be more effective for inducing relatively short-term adaptations than traditional resistance training models because of the higher muscular forces that are characteristic of eccentric muscle actions. In addition, combining the higher forces and adaptive responses of eccentric training with a multiple muscle group model (e.g., complex exercise) may result in more superior and comprehensive muscle function gains in a relatively short amount of time (Gordon et al, 2018). Given the uniquely high force and muscle damage responses experienced with eccentric training, it is possible that the ideal training frequency model for this type of training may be different than that of more traditional training. For instance, because of the greater force demands and muscle damage elicited by eccentric training, it is possible that greater between session rest periods, that occur from a lower training frequency, may be more beneficial for eliciting greater muscular adaptation responses than higher frequencies with lower between session rest time. Thus eccentric-only training in a multiple-joint exercise model may require a different training frequency approach than has been described by the previous literature on traditional and/or concentric-only resistance training, but more research is necessary to help inform the best frequency for this relatively novel type of resistance training. Therefore, the purpose of this study was to quantify the effects of volume-matched resistance training frequency comparing one versus three days per week of isokinetic multiple-joint eccentric training on strength and lower body function adaptations in recreationally trained men and women during a short-term (four week) training period. A secondary aim was to assess the rating of perceived exertion and soreness levels between the low (LF) and high (HF) frequency training conditions to assess potential advantages of exercise tolerance that may be useful for more clinical and/or sedentary populations.

METHODS

Participants

Thirty college-aged men and women volunteered to participate in the study. Upon study enrollment, participants were randomly assigned to either the HF (mean ± SD: age = 22.6 ± 2.0 years, mass = 73.3 ± 18.2 kg, height = 176.0 ± 7.7 cm) or LF (age = 22.9 ± 1.5 years, mass = 71.0 ± 14.5 kg, height = 172.6 ± 11.3 cm) training groups. Eligibility criteria to participate in the study required the participants to be between the ages of 18-30 years who regularly engaged in lower body resistance exercise (perform the squat, leg extension, leg press, etc. at least three times per month, but no more than two times per week) for at least three months within the past year. Participants were required to not consume (within the past three months and during study) nutritional supplements specifically for muscle growth (e.g., creatine). In addition, participants were required to be free of lower limb injuries and could not have had surgery of the lower limbs within one 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 one versus three weekly resistance training sessions on the selected outcome measures described below. The experimental training program was four weeks in duration. Lower body eccentric strength and functional performance (countermovement vertical jump) were measured at baseline, during (after two weeks, mid) and following the training period. Participants reported to the laboratory for a familiarization session, which occurred three to seven days prior to the baseline test and three to seven days before the first training session and included all training and testing measures as described below. Tests included maximum isokinetic eccentric multiple-joint strength and vertical jump (VJ) height. All muscle function testing occurred three to four days following the last training session for midtests and four to six days following the last training session for posttests in order to allow for adequate recovery. Prior to all testing and training, participants followed a standardized warm-up consisting of two parts: 1) 5-minutes on a cycle ergometer at ~50 rpm at a fixed torque of 10 Nm, and 2) five lower body dynamic stretches for five repetitions each.

Functional Performance Testing

Participants performed three maximal countermovement VJ 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 were allowed to keep their shoes on and stood on the mat with their feet shoulder width apart and their hands positioned on their hips. Participants were instructed to bend to a comfortable depth and jump as high as possible while landing with legs relatively straight. A successful jump attempt required no stepping prior to the jump and a landing with both feet on the mat (Palmer et al., 2014). A 1-minute rest period was provided between each jump attempt.

Strength Testing

Participants were seated on an isokinetic dynamometer (Eccentron, BTE Technologies Inc., Hanover, MD) and adjusted to a position that placed the knee joint at 30° in the most extended position per the manufacturer's recommendation (Gordon et al., 2018). Participants performed six eccentric maximum voluntary contractions (MVCs) for each leg, alternating legs every other repetition in a consecutive manner. The pedal movement was set at 23 rpm (dynamometer range = 12 – 48 rpm) and may best be classified as a medium pedal velocity. Strong verbal encouragement was given throughout all strength testing MVCs.

Training Protocol

All training was performed on the same motor-driven isokinetic eccentric machine (Eccentron) as the testing. A relatively light 1-week training familiarization period was performed (two total sessions for all participants) prior to the 4-week experimental training program to allow the participants to become acquainted and proficient with the training technique and procedures and to help standardize the effects of training-induced soreness for both groups. These sessions were conducted at an intensity of 45 and 50% (for session one and two, respectively) of their predetermined maximum eccentric force based on pilot work.

For the training, 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 line, which participants were required to reach by pressing their foot against the pedal as it moved toward them one pedal at a time in an alternating fashion (Gordon et al., 2018). This study was designed to equate the training volume between the LF and HF conditions. Thus, both groups performed a total training time of 6-minutes per week; however, the training time for each session was different depending on the frequency condition. In order to match the training volume, the per session training length was 6-minutes (separated into 2 sets of 3 minutes with a 2-minute break) for the LF and 2-minutes for the HF training conditions. Thus, because the isokinetic velocity was held constant, and the training intensity (% of maximum eccentric strength) followed the same progression scheme for both conditions, the total training volume was assumed to be equal between conditions given the matched weekly and total training length. Each of the two training sets per session of the LF group consisted of a 1-minute warm-up and 1-minute cool-down (a feature designated by the devices proprietary software program), performed at 50% of the training load for a total of 4-minutes across the week. To keep the total volume matched, the HF group performed a 1-minute warm up and 1-minute cool down on the first session of each week and a 1-minute warm-up with no cool down for the remaining two sessions of the week also performed at 50% of the training load for a total of 4-minutes across the week.

The training program followed an intensity progression that has been previously used for Eccentron dynamometer training (Gordon et al, 2018) and was initially developed from pilot work. Specifically, intensity was the only variable involved in the progression and represents the percentage of the baseline maximum eccentric strength. The training load progression was as follows: HF: week 1 – 50, 52.5, and 55%; week 2 – 60, 62.5, and 65%; week 3 – 70, 72.5, and 75%; week 4 – 75%, and LF: week 1 – 50 and 55%; week 2 – 60 and 65%; week 3 – 70 and 75%; and week 4 – 75%. For the LF training, the progression was conducted intrasession such that the weekly progression occurred in the single weekly session with the lower and higher weekly progression loads being performed in the first and second 3-minute bouts, respectively.

In addition, soreness was assessed using a visual analog scale (VAS), which was administered for five consecutive days following the first training session of the first experimental week and then three nonconsecutive, non-training days per week for the remaining three weeks (Krentz, Chilibeck & Farthing, 2017). Participants were instructed to perform three air-squats to parallel, at the same time of day, and record their perceived soreness of the posterior hip and anterior thigh on a 100 mm line with the left and right ends of the line corresponding to "no soreness" and "most soreness ever experienced," respectively. Furthermore, immediately upon completion of each training session, ratings of perceived exertion (RPE) were taken on a scale of 0-10, which included a written description of the intensity level of the training session next to the numbers (Foster et al., 2001). Strong verbal encouragement was provided for all participants and a make-up training session was allotted each week on a non-consecutive training day to allow for missed sessions to be made-up.

Statistical Analyses

Independent t-tests were used to compare group baseline demographics and strength and VJ height data. Mixed analyses of variance (ANOVA) (trial [pretest vs. midtest vs. posttest] × group [LF vs. HF]) were used to examine differences for strength and VJ variables. When appropriate, significant interactions were further decomposed with repeated-measures ANOVAs and/or t-tests. Independent t-tests were used to compare LF and HF groups for weekly RPE scores (four time trial comparisons) and VAS soreness scores (pooled across all assessment points weeks 1 – 4). Additionally, Cohen's effect size (*d*) statistic was used to evaluate the meaningfulness of the changes across the testing trials 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

The LF and HF groups were not significantly different at baseline for age ($P = 0.61$) and body mass ($P = 0.70$) but the HF group was significantly taller at baseline ($P = 0.04$). The groups were similar at baseline for eccentric strength ($P = 0.83$) and VJ height ($P = 0.42$) and the proportion of women was similar per group (6/15 for the HF and 7/15 for the LF). All participants completed all training and testing sessions during the 4-week intervention. However, two participants in each group failed to complete all soreness assessments and so the sample size is n =13 per group for the VAS data.

The means and SDs are presented for the strength and VJ data in Table 1. For the eccentric strength variable, there was no significant group × trial interaction ($P = 0.06$), however, a significant main effect was observed for trial ($P < 0.001$). Follow-up analyses showed that all trials were significantly different ($P < 0.001$) from each other when collapsed across groups (marginal means: 1544.0 ± 466.9, 1851.2 ± 498.9, 2038.7 ± 524.8 N for the pretest, midtest, and posttest, respectively). For the VJ variable, there was no significant group × trial interaction ($P = 0.87$), however, a significant main effect was observed for trial ($P < 0.001$). Follow-up analyses showed that that the posttest was greater than the pretest ($P < 0.001$) and the midtest ($P < 0.01$), but no difference was found between the pretest and midtest ($P = 0.13$) when collapsed across groups (marginal means: 41.8 ± 7.7, 43.3 ± 7.7, 44.8 ± 8.5 cm).

The LF group reported higher ($P < 0.01$) RPE scores across all four weeks compared to the HF group (8.0 ± 0.3 and 5.3 ± 0.3, respectively; Figure 2). Average VAS scores (across 14 assessment points) were significantly higher (P = 0.04) for the LF (31.2 ± 10.8 mm) compared to the HF (20.2 ± 7.9 mm) group (Figure 3).

Discussion

The primary findings of the current investigation were as follows: (*i*) isokinetic multiple-joint eccentric training elicited significant strength gains regardless of frequency protocol; (*ii*) both protocols elicited significant VJ improvements; and (*iii*) RPE and VAS scores were significantly lower for the HF protocol in comparison to LF.

The isokinetic multiple-joint eccentric training protocol induced significant eccentric muscular strength adaptations at both the 2- and 4-week benchmarks. Although there was no significant interaction between groups (P = 0.06), a close inspection of the data reveals that there was a trend for the HF group to have higher strength gains earlier than the LF condition such that at two weeks the HF strength gains were 26.2% compared to 13.8% for the LF (ES were .54 and .35 for the pretest – midtest comparison for the HF and LF groups, respectively). However, the groups tended to have somewhat closer strength improvements at four weeks (36.8% and 27.4%, for the HF and LF, respectively), although the HF condition appeared to still have a modest advantage (also reflected in the larger ES of the HF condition of .78 vs. .63 for the LF). Moreover, the individual change scores in Figure 1 shows that the HF condition showed a modest, but very consistent improvement over the LF condition such that all 15 participants of the HF had higher gains compared to each corresponding participant in the LF group. This could be explained in part by the total weekly intensity of the HF being spread across three sessions which induced lower RPE (average of all regular training was 5.3 versus 8.0 for HF and LF, respectively) and soreness scores, and may have allowed for slightly faster neuromuscular adaptation. It is possible that greater soreness in the LF condition in the first two weeks (Figure

3) was indicative of higher muscle damage and lower recovery. If that is the case, the lower level of muscle recovery from elevated muscle damage induced from the LF protocol may be delaying the gains in strength until recovery is able to be achieved at a later time.

Our findings contradict that of Sorichter et al. (1997) who found a strength difference between their high and low frequency protocols. It is important to note, however, that several differences between these studies (i.e., training period, type of strength assessed, volume used, and joints trained) restrict any kind of direct comparison on the effects of eccentric-only training frequency. A previous study in our lab (Gordon et al., 2018) followed a similar eccentric training protocol, however, participants in that study trained on the Eccentron at a medium training frequency (MF) of two times per week with one day of rest in between sessions. The training volume for the earlier study's MF protocol and the present study's protocols was matched, however, the relative eccentric strength gains being somewhat lower for the previous MF (19.1% pretest to posttest gains) protocol compared to the present LF (27.4%) and HF (36.8%) protocols. The smaller gains in the previous MF study protocol could be due to the study population being slightly more athletic such that their baseline eccentric strength was 2171.3 N versus an average of 1544 N for the present study population. Additionally, the baseline VJ height values for the previous MF group were ~ 20% greater compared to values in the current study. The greater baseline muscle function in that sample may have caused a diminishing return in both strength gains and VJ. However, the previous MF and the current LF groups exhibited nearly identical two-week eccentric strength increases of 14%. The present study's HF protocol showed a moderately higher improvement especially for the earlier (two week) period than either of the lower frequency protocols (LF and MF). This may be explained by the single session volume-load being higher for the lower frequency protocol as a result of performing the matched training volume all in one weekly session. The greater per session volume-load is an inherent feature of lower frequency training and may have caused enhanced muscle damage and an interruption in neuromuscular recovery and delayed adaptation at the earlier phase in the training time course. Taken together, the present findings suggest that multiple-joint eccentric training can induce substantial and rapid improvements in eccentric strength in a short time period with various training frequency protocols and that a HF training protocol may elicit a slight advantage for eccentric strength gains following both two and four weeks of training, with a more robust advantage in the early (2-week) training period. However, further research is needed to, 1) establish the mechanisms that may contribute to any differential training adaptations invoked by varying training frequency, and 2) determine the longer term effects in the framework of eccentric, multiple-joint training programs in order to determine and compare the longstanding influences and/or advantages of higher versus lower training frequencies using this rather novel eccentric training model.

Training-induced improvements in the VJ variable were modest but statistically significant at both the 2- and 4-week time points for both training conditions (3.4% and 6.7%, respectively for combined groups). Training of the stretch shortening cycle through traditional concentric work and plyometric training has been shown to be effective at increasing VJ (Baker, 1996; Fatouros et al, 2000; Gehri, Ricard, Kleiner, & Kirkendall, 1998). However, due to the lengthening nature of eccentric work, and the relaxation of the leg during the concentric phase of the present training program, there was no stretch shorting cycle implemented which may partially explain the lower improvement in the VJ compared to the strength gains. However, since strength is an important contributor for the application of force to the ground to accelerate body mass, it does appear that improved lower body strength resulting from multiple-joint eccentric overload training may transfer, at least partially, to the VJ movement. This is supported by the findings of Clark et al. (2005) who showed a 6.3% improvement in VJ from eccentric-only nordic hamstring training over the course of four weeks. Thus, although eccentric-only training may lead to improvements in VJ, it is likely that training programs may need to incorporate other, more explosive-based forms of concentric stretch-shortening training for more substantial improvements. For example, lower body plyometrics could be included along with eccentric-only training in order to develop both strength and explosive stretch shortening capacities simultaneously as a means to yield superior results, but studies are still needed to confirm this hypothesis. It is interesting to note that only the current study's HF and LF protocols induced VJ improvements, whereas the earlier MF protocol (Gordon et al., 2018) failed to improve VJ in a 4-week training period. One explanation for this may be the present HF and LF sample having a lower baseline VJ than the earlier MF sample (41.8 and 50.8 cm respectively) suggesting this sample may have had more potential for short-term training-induced improvement. Furthermore, the somewhat larger training-induced increases in strength for the current LF and HF groups versus the MF group may have provided the ability for a greater lower body performance transfer to the VJ. In contrast, the stronger MF group may have already had sufficient baseline strength and so additional increases in VJ may have required more explosive training (such as plyometric exercises) to further improve VJ rather than solely eccentric resistance training. Although soreness measures were not collected for the earlier MF protocol, it is possible that heightened soreness (i.e., muscle damage and delayed short-term recovery) from the twice per week eccentric overload training schedule could have been a factor in interfering with muscular power adaptations.

Perceived exertion and soreness were significantly lower ($P < 0.01$ and $P = 0.04$ respectively) for those participating in the HF versus LF protocols in the current study. RPE has been shown to be effective in monitoring steady state and interval training (Foster et al., 2001) as well as resistance training sessions (Day, McGuigan, Brice, & Foster, 2004; Sweet, Foster, McGuigan, & Brice, 2004). The reason for the difference between frequency protocols is likely due to the dispersion of weekly workload across three sessions (HF) versus all in a single session (LF). The lower workload spread across three sessions resulted in a lower RPE for each session, as well as apparently lower muscle damage as assessed through muscle soreness (see Figures 3 and 4). In practice, the HF feature of spreading a given workload more frequently across a given time period may carry large implications for clinical populations. For example, Williams et al. (2007) suggested that resistance training can be beneficial for those with cardiovascular disease so long as the exertion does not require utilizing the Valsalva maneuver. In addition, Paschalis et al. (2011) compared maximal eccentric or concentric-only training of the knee extensors with untrained females once per week over an 8-week period. Their findings showed that eccentric-only training may be more beneficial than concentric-only training for a number of health-related metrics including: resting energy expenditure (REE), carbohydrate and fat oxidation, blood lipid profiles, and blood insulin resistance indices. Several of these parameters (REE, substrate oxidation, and blood lipid panels) were significantly improved for the eccentric group after only 48 hours. Therefore, in light of these combined findings, those populations seeking earlier adaptations at a lower workload may be benefitted by higher frequency training protocols because they may lead to less soreness and lower perceived exertion without compromising (and possibly even enhancing) strength gains. This may prove useful in programming resistance training for clinical, diseased, and sedentary populations that need to recover or build strength and improve overall health in a short amount of time while also keeping intensity and soreness at a manageable level. The main disadvantage posed for following the HF training schedule is the time and effort commitment to multiple sessions a week. Perceived lack of time has been suggested to be a barrier to exercise adherence (Grubbs & Carter, 2002; Reichert, Barros, Domingues, & Hallal, 2007; Silliman, Rodas-Fortier, & Neyman, 2004) and although the training sessions as conducted in this study were fairly time-efficient (10-min total including warmup), the preparation time (e.g., travel) needed for the multiple weekly sessions may be an exercise compliance barrier. However, the lower soreness and easier exertion levels may counteract the possible disadvantage of increased weekly sessions in regards to exercise compliance. In contrast, the LF protocol also provided substantial gains in a short time period, suggesting this type of protocol may be well suited to benefit individuals that are able to withstand (e.g., healthy, athletic) greater soreness and exertion levels but prefer to do all their training in a single, weekly session as a means to be more time efficient. The LF regimen may allow for greater flexibility within a training program to adapt to the need of the population so long as they are willing and healthy enough to engage in a higher single session workload. These findings may help extend training programming options for practitioners, coaches, and individuals as a way to provide training options at the most appropriate frequency and workload while also eliciting significant strength increases and removing common barriers to exercise compliance.

A limitation to the current investigation was the mode of obtaining soreness measures. Participants were taught how to assess and record soreness and then carried out the recording at home. It was assumed that each participant correctly performed air-squats to the appropriate depth at the same time each morning the measures were to be taken. Participants received verbal follow up and confirmation that they were correctly recording their soreness every time they reported to the lab. However, it is possible that some of the measures on the soreness scales had been produced errantly. Another restriction was the lack of a true control group, limiting our comparisons to the training conditions without an examination of nontraining condition. Future studies are needed to assess the extent to which different mechanisms contribute to soreness caused by this novel type of eccentric training (i.e., inflammation and structural damage).

In summary, multiple-joint eccentric-only training significantly increased eccentric strength at both two and four weeks and VJ at four weeks, and this was independent of whether the workload was conducted in a high or low frequency training model. However, the HF training protocol revealed a slight advantage for higher strength gains especially in the early (2-week) period of training. Perceived exertion and soreness differed between groups such that the HF protocol experienced lower scores compared to the LF protocol. These findings should be considered alongside time, exercise tolerance, and performance ability constraints while developing optimal resistance training programming for different populations. Multiple-joint eccentric overload training may be an effective resistance training model to be used by practitioners, trainers, and coaches alike for eliciting rapid and large strength gains with minimal time investment. Further research is needed to identify the mechanisms underlying any performance, soreness, and adaptation responses evoked by varying the frequency of training for a matched workload, as well as to establish the long-term effects of multiple-joint eccentric-only training.

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Table 1. Means (SD) and Cohen's *d* effect sizes for the Eccentron strength and vertical jump variables for the low and high frequency training conditions at the pretest (Pre), midtest (Mid), and posttest (Post).

		Low Frequency				High Frequency			
Action	Variable	Pre	Mid	Post	Cohen's *d*	Pre	Mid	Post	Cohen's *d*
Eccentron	Strength † (N)	1570.3 (633.4)	1786.8 (614.5)	2000.4 (729.2)	.63	1517.7 (687.1)	1915.6 (787.1)	2076.9 (755.9)	.78
Vertical Jump	Height (cm)	40.2 (12.1)	41.8** (12.3)	43.4* (13.1)	.26	43.5 (10.1)	44.8 (9.8)	46.3* (10.9)	.26

Cohen's *d* values compare only the pretest and posttest differences in this table.

† All trials are different from the other two for both groups

* Different compared to pretest

** Different compared to posttest

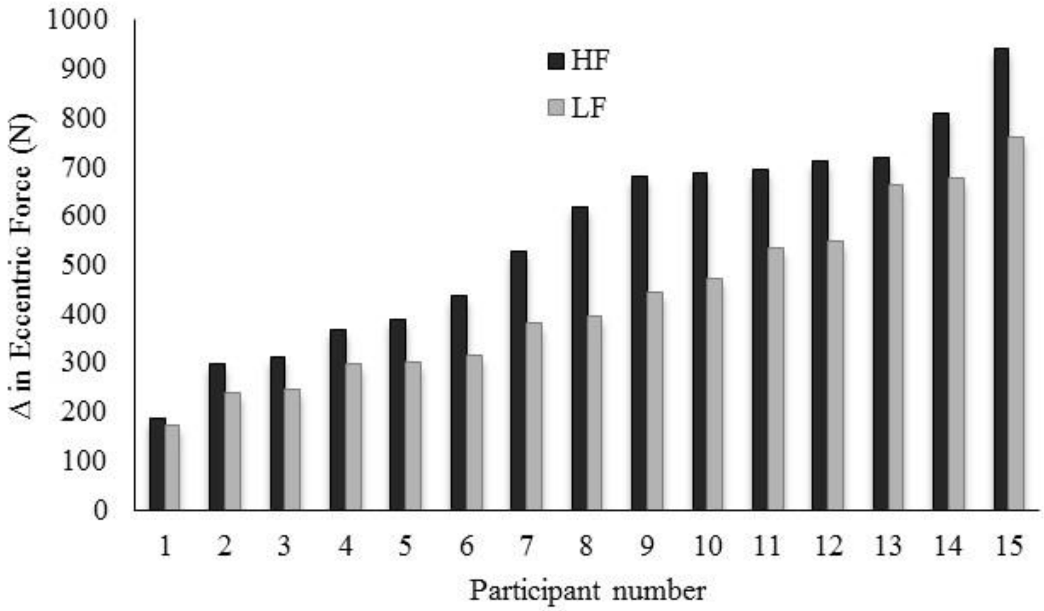
Figure Legends

Figure 1. Individual participant absolute change scores (N) in maximum eccentric strength from pretest to posttest for the low frequency (LF; gray) and high frequency (HF; black) training groups.

Figure 2. Ratings of perceived exertion (RPE) scores for the low frequency (LF; solid line) and high frequency (HF; dashed line) groups across the 4-week training period. Note: RPE data for the three weekly sessions were averaged for the HF group data to provide one RPE value per week. Values are mean ± SE. * indicates significantly different for all weeks ($P < 0.01$).

Figure 3. Visual analog scale (VAS) soreness scores for the low frequency (LF; solid line) and high frequency (HF; dashed line) groups. Soreness assessments were taken each day for the first five days of the first week and then on three nonconsecutive, non-training days each week for the following three weeks of the study. Values are means (error bars omitted for clarity). The mean soreness ratings across the 14 assessments was used for statistical comparison between groups (mean ± SE: LF = 31.2 ± 3.0; HF = 20.2 ± 2.2; $P = 0.04$).

Figure 1.



1000
900
800
700
600
500
400
300
200
100
0
Δ in Eccentric Force (N)
HF
LF
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Participant number

Figure 2.

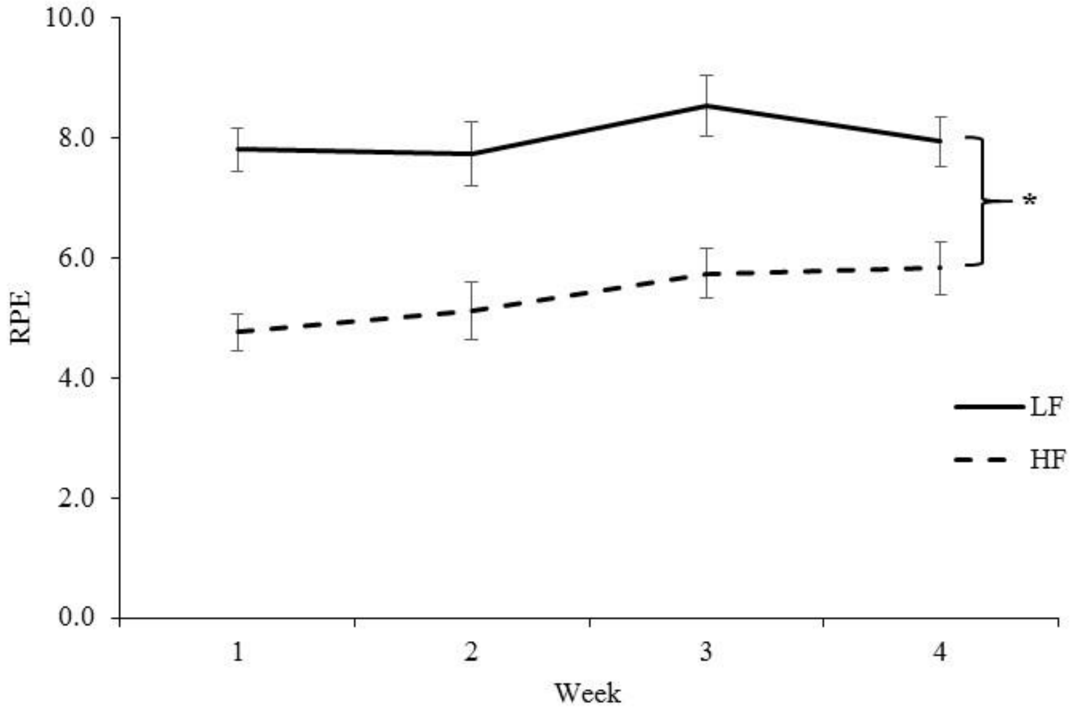
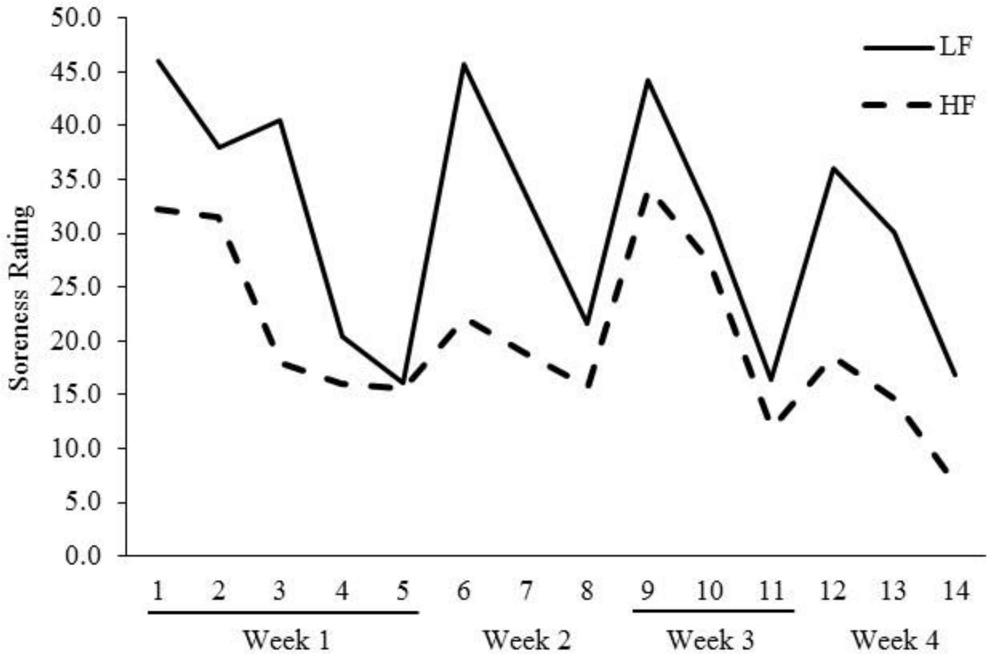


Figure 3.



50.0
45.0
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
Soreness Rating
LF
HF
1 2 3 4 5 6 7 8 9 10 11 12 13 14
Week 1
Week 2
Week 3
Week 4