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Eccentric Resistance Training in Adults with and without Spinal Cord Injuries

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ABSTRACT

International Journal of Exercise Science 10(1): 154-165, 2017 The purpose of this study was to examine the effects of active lower body eccentric resistance training (ERT) in individuals with incomplete spinal cord injury (iSCI) and controls (CON). Specifically, the study was designed to determine if those with iSCI adapt similarly to ERT as CON participants as well as the overall safety and efficacy of ERT in this population. This pilot investigation involved the recruitment of persons with iSCI (n = 3) and age- and sex-matched able-bodied CON (n = 3). The 8-week intervention focused on building lower extremity eccentric strength by progressively increasing the duration and intensity of training sessions. Control participants completed the same training intervention. Main outcome measures were eccentric strength (eccentric ergometer), isometric strength (hand held dynamometer), and leg muscle mass (DEXA). All participants completed the ERT. At posttest, eccentric strength improved from pretest (p = .044, η_p^2 = .68) with similar changes between groups (p > .05). The percent improvement in isometric strength for those with iSCI (41.5%) was different than CON (-2.8%) after training (p = .044). Neither group demonstrated muscle mass gains at posttest (p > .05). Active lower body ERT is well tolerated and effective at increasing lower extremity strength in those with iSCI. These adaptations are likely attributable to neuromuscular development rather than a hypertrophic response.

KEY WORDS: Active lower body, strength-training, voluntary, paraplegia

INTRODUCTION

The human spinal cord transmits neural impulses between the brain and the peripheral nervous system. When damaged, these transmissions are interrupted, resulting in neuromuscular dysfunction. The attenuated motor control leads to smaller muscle fibers (4-6, 12-13) and diminished peak contractile force (21, 23), resulting in a potential loss of functional independence.

A promising exercise modality to target the specific deficits in physical capacity in people with incomplete spinal cord injury (iSCI) is eccentric resistance training (ERT). While the effects of eccentric training have not been established specifically in persons with iSCI, it has been shown to increase muscle size in those following anterior cruciate ligament repair, younger, and older adults (10, 17, 25), strength in younger and older adults with and without heart disease (9, 17, 20, 22, 25), and aerobic capacity in young and older adults with heart disease (11, 18). Further, the lower metabolic cost of ERT may allow individuals with iSCI to perform more work during an exercise session compared to concentrically-based programs (18).

Eccentric resistance training can be completed on a recumbent isokinetic stair stepper by resisting the upward movement of the pedals, rather than pushing down on the pedals. In those with iSCI, eccentric loading of the legs may allow intact neurons, below the injury level, or compensatory alternative neural pathways, to respond reflexively to the pushing stimulus (3). Against this backdrop, this study was designed to investigate if ERT could be utilized to safely overload the musculoskeletal system in individuals with iSCI. In conjunction, age- and sex-matched, able-bodied controls (CON) also completed the 8-week training protocol and changes were compared between groups.

METHODS

Participants

Participants with iSCI (n = 3) and CON participants (n = 3) completed the training protocol. There were two females and one male in each group. Descriptive characteristics of the full samples are presented in Table 1. Additional data, regarding descriptive characteristics for participants with iSCI, appear in Table 2. Height, body mass, and age were similar between the groups. Participants with iSCI were required to be at least 1-year post injury and be capable of eccentrically producing force on the training ergometer. Control participants were age-matched within 5 years of the participant with iSCI and the same sex. Participants were excluded if an acute lower extremity injury existed or if eccentric resistance training was not a novel exercise modality. Prior to training, participants signed an informed consent approved by the University's Institutional Review Board in accordance to the standards provided by the Helsinki Declaration.

Table 1. Descriptive statistics for participants (N = 6).

	Age	Height	Mass
Control (n = 3)	42±11	165.5±3.2	76.7±24.0
P1	43	162.0	50.6
P2	30	168.3	81.7
P3	53	166.4	97.8
iSCI (n = 3)	46±12	166.0±17.9	99.9±46.8
P4	46	156.2	80.5
P5	34	187.7	153.4
P6	58	156.2	66.0

Note: Age = years. Height = centimeters. Mass = body mass in kilograms. Data are presented as means ± standard deviations.

Table 2. Descriptive characteristics of participants with iSCI.

	Level of Lesion	Years Post-Injury	Assistive Device*
1	T9	18.5	None
2	T9	9.0	Rolling Walker
3	C5	8.5	Rolling Walker

Note: * = device used during ambulation. Participants were predominately non-wheelchair users. T = thoracic. C = cervical.

Protocol

Prior to collecting outcome variables, investigators gathered preliminary measures on participants' height (Seca model 222, Seca, UK) and body mass (Healthy O Meter model 753KL, IL, USA). Height was measured in centimeters to the nearest tenth with shoes removed and the participant facing away from the stadiometer with his or her nose parallel to the floor. Participants remained unshod for the mass measurement, which was recorded in kilograms to the nearest tenth. Perception of muscle soreness was assessed using a 10 cm VAS where 0 = no soreness and 10 = worst possible soreness (9). On day one, participants were asked to mark their perception of leg muscular soreness on the VAS. A VAS score was also collected prior to each training session to evaluate any change in discomfort when compared to baseline soreness. In the instance that the variance between baseline VAS and session VAS exceeded 3 cm, any scheduled increase in training load was not imposed and instead, implemented at the next training session.

A full body DEXA scan (Hologic, Bedford, MA, USA) was run on each participant. Scans were conducted according to manufacturer guidelines following multi-density calibration before each assessment and all scans were performed by the same certified technicians to maintain reliability. On the resulting image, the lower extremity was divided into segments so that the technician could analyze lean mass (g/cm^3) of the left and right legs from the most superior portion of the iliac crest to the toes, with the two legs divided by a vertical line bisecting the pelvis. Bone mineral content was subtracted from lean body mass to obtain muscle mass in g/cm^3.

A hand-held, digital dynamometer (JTech Commander PowerTrack II, Midvale, UT, USA) was used to quantify peak isometric force of the knee extensors and knee flexors of each leg. This dynamometer has been deemed reliable (r = 0.81 to 0.93) and valid (R^2 = 0.66 to 0.76) (24). The isometric station was created to aid in the positioning of the limb and to assist the investigator in collecting data by providing an immovable resistance. For the knee extensor assessment, the dynamometer was placed between the participant's ankle and a rigid strap affixed to the testing station (see Figure 1). For two of the participants with iSCI, the procedure had to be modified and the investigator held the dynamometer in place, without use of the strap, because they could not exert forces necessary to keep the strap from slipping off the monitor, resulting in no reading by the dynamometer. The knee of the leg being tested during the extension assessment was placed at a 45-degree angle, the angle used during training, while the inactive leg rested on the testing station. When instructed, the participant extended the knee against the dynamometer as hard as possible for three seconds. The participant continued this procedure with 60-second rest intervals between trials until he or she stopped improving. For knee flexor testing, the same procedures were followed except the dynamometer was placed on the posterior aspect of the ankle and the strap was affixed to the front portion of the testing station (see Figure 1). Procedures were conducted in a random order for each participant and then repeated in the same order during the post-testing session.

Figure 1. Device used to assess isometric strength.

Training was completed on a motor-driven, eccentric ergometer (BTETech, Hanover, MD, USA). Participants sat in a recumbent position and resisted the force produced by the pedals of the ergometer as the pedals moved towards them. The seat was adjusted so that knee angle was no less than 45° and no more than 55° when participant's legs were fully extended on the pedals. Prior to testing and training on the ergometer, participants were familiarized with the machine and given time to practice. To evaluate maximal eccentric strength, participants completed the manufacturer designed dosing protocol. Following a warm up consisting of six contractions per leg at approximately 50% effort, peak forces were collected during two trials, each consisting of six maximal efforts (6-RM) per leg. The trial with the second highest peak force from the weaker leg was used for exercise prescription. This dosing procedure was repeated at the beginning of weeks five and seven to modify the exercise prescription and at the end of the study to assess changes in eccentric leg strength.

On visit one, participants completed the informed consent form and pre-testing assessments. Data were collected for height, body mass, baseline VAS score, lower body muscle mass, isometric strength, and 6-RM eccentric strength. The ERT protocol was eight weeks long. The training protocol provided in Table 3 was designed from a successful ERT prescription in older adults (16), but was modified after the re-dose at week five to emphasize muscular strength and hypertrophy instead of muscular endurance. The first two weeks included two training sessions per week so that individuals could become accustomed to the training regimen. The following six weeks included three days of training per week. All ERT sessions were separated by two to four days to allow for recovery. During the muscular endurance component of the training protocol (weeks 1-4), there were no structured rest intervals during the work bout. During the strengthening/ hypertrophy component (weeks 5-8), participants completed one to two minutes of work with one to three minutes rest until the total duration of the session was completed.

Table 3. Eccentric training protocol.

	Week	Duration	Intensity (%)
Endurance	1	5	50
	2	10	50
	3	15	50
	4	20	50
Strength/ Hypertrophy	5	10-15	45-55 †
	6	8-12	50-60
	7	10-15	50-60 †
	8	8-12	60-70

Note: Duration = in minutes. Intensity calculated as a percentage of the second highest peak force exerted by the weaker leg during the 6-RM test. † = 6-RM test repeated.

Per manufacturer recommendations, the initial training intensity for the ERT protocol was set as 50% of the second highest peak force exerted by the weaker leg during the 6-RM pre-test assessment. The training intensity was modified at week 5 and week 7, when the 6-RM test was repeated (see Table 3). The repetitions per minute (rpm) ranged from 23-30 and were set according to participant preference and remained the same for each participant across all training sessions. Prior to the start of each training session, participants completed the VAS to assure that any level of muscular soreness did not preclude a scheduled increase in intensity. Following 8 weeks of training, lower body muscle mass, isometric strength, and 6-RM eccentric strength were re-assessed.

Statistical Analysis

Data were analyzed using IBM SPSS Statistics for Windows, Version 23.0 (Armonk, NY: IBM Corp). Descriptive statistics were calculated for all study variables. A two-way repeated measures analysis of variance (ANOVA) was used to assess group interactions (Groups x Time). The effect of the ERT within groups was determined using the main effect outcomes. Further, Welch one-way ANOVAs were used to evaluate differences in percent change in muscle mass, isometric strength, and eccentric strength between groups. The magnitude of effect between groups and pre- and post-intervention were estimated by calculating effect sizes. Statistical significance was set at $p < 0.05$.

RESULTS

Following training, all participants showed significant improvement in eccentric strength (78.8%). See Figure 2. There were no significant differences across time in muscle mass (0.4%); or isometric strength (19.3%). Likewise, there were no significant differences between groups for muscle mass, eccentric strength, or isometric strength. See Table 4 for statistical values and Figure 4 for graphical depictions.

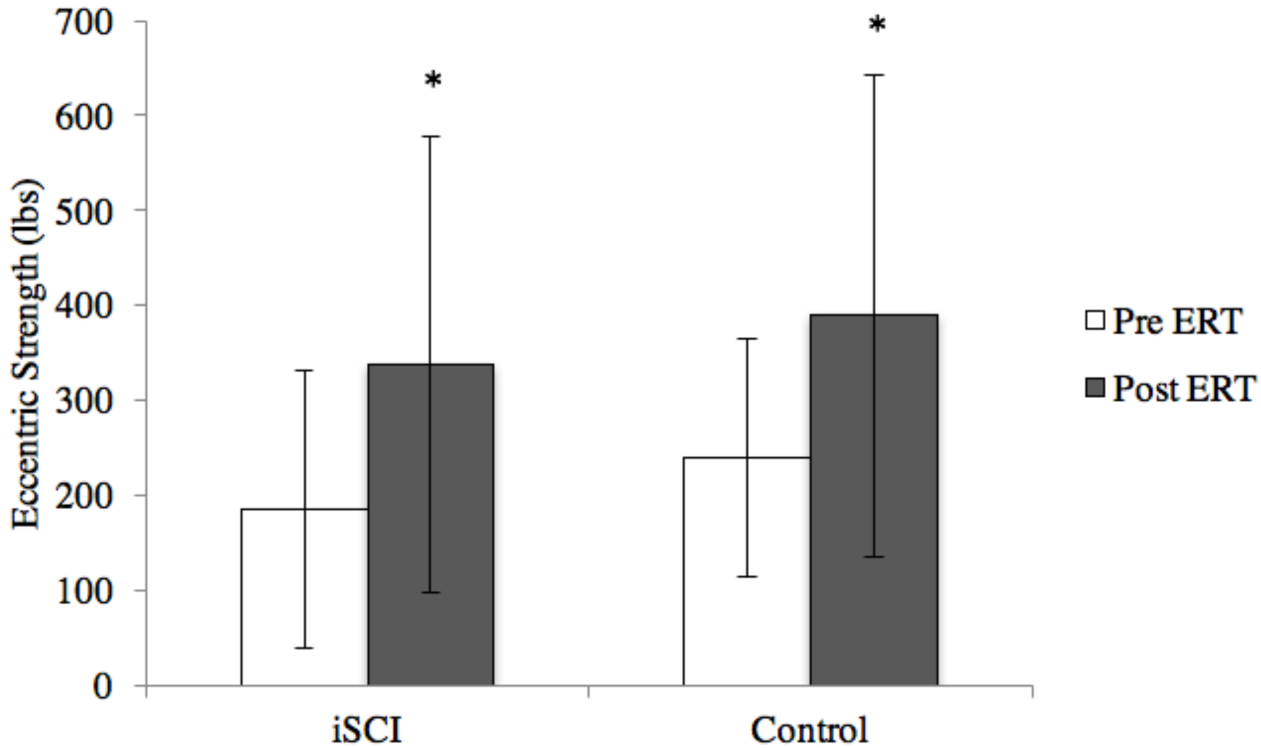


Figure 2. A comparison of the summed absolute eccentric peak strength for both legs between groups pre ERT and post ERT. Data are presented as means and standard deviations. * = Post ERT eccentric strength was significantly higher than pre ERT eccentric strength for the full sample ($p < 0.05$).

Table 4. Results from statistical analyses.

Statistical Test	Variables	Statistical Value	Significance	Effect Size
2wRM-ANOVA	Eccentric x Time	$F(1, 4) = 8.38$	.04*	.68
	Muscle mass x Time	$F(1, 4) = 0.40$	.56	.09
	Isometric x Time	$F(1, 4) = 2.35$	.20	.37
	Eccentric x Interaction	$F(1, 4) = 0.00$	.98	.00
	Muscle mass x Interaction	$F(1, 4) = 0.55$	.50	.12
	Isometric x Interaction	$F(1, 4) = 2.45$	.19	.38
Welch 1wANOVAs	%Δ Eccentric x Group	$F(1, 2.2) = 0.38$	.60	.09
	%Δ Muscle mass x Group	$F(1, 3.8) = 0.67$	.46	.14
	%Δ Isometric x Group	$F(1, 3.3) = 9.92$	.04*	.71

Note: Statistical test = Two way repeated measures ANOVA and Welch one-way ANOVA. F values for 2wRM-ANOVA were based on Wilks' tests and effect sizes represent □$_p^2$ values. %Δ = the percent change between pre and post ERT assessments. * represents statistical significance.

There were no statistically significant differences in the percent change between iSCI (99.1%) and CON (58.4%) for eccentric strength or muscle mass (CON=1.5% and iSCI=0.08%). However, there was a significant difference in the percent change in isometric strength between groups, where those with iSCI improved to a greater extent (41.5%) when compared to the CON (-2.8) [calculated as SS Between/SS Total]. See Figure 3.

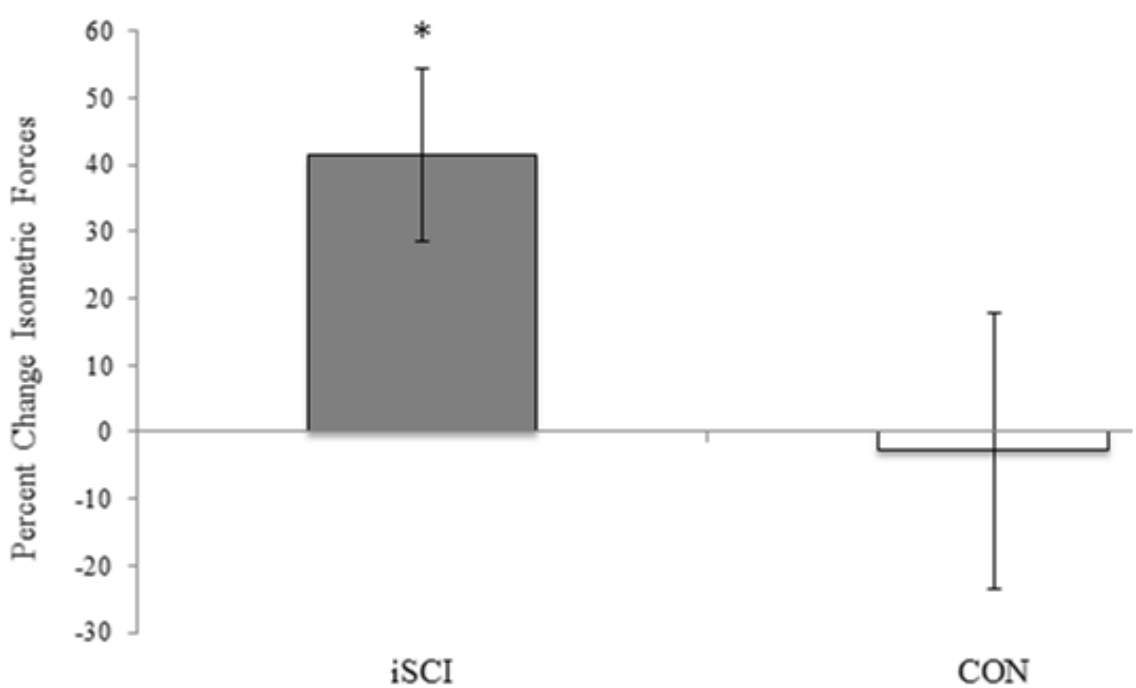
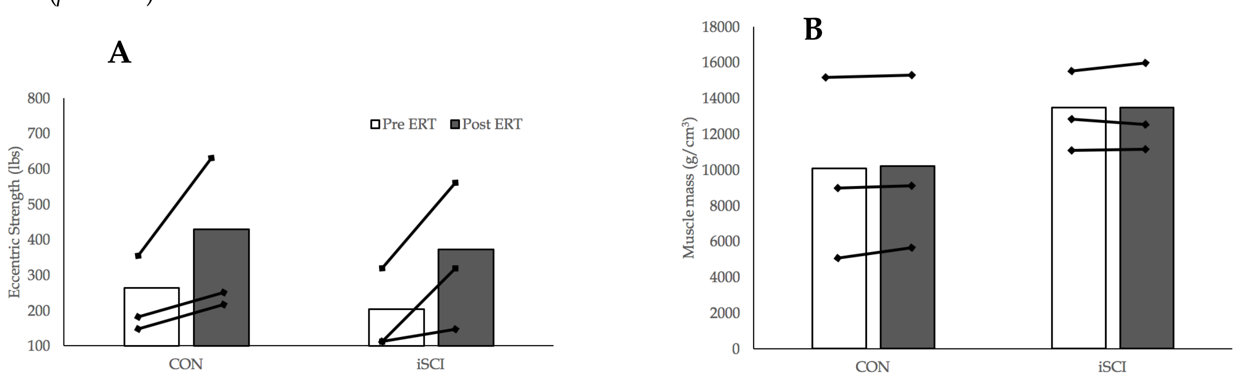


Figure 3. Data are presented as percent change and standard deviations. Sum of isometric forces exerted during flexion and extension of both legs. * = Percent change in isometric strength was significantly higher in those with iSCI ($p < 0.05$).



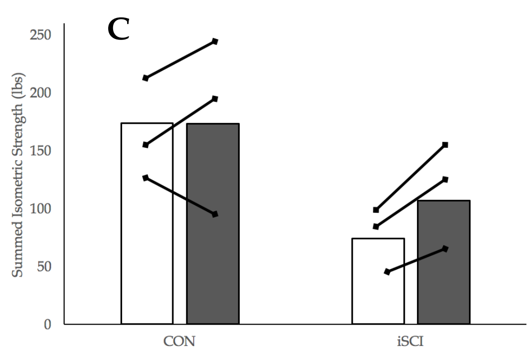


Figure 4. Effects of ERT on strength and muscle mass between groups (columns) across time with pre-post changes for individual participants noted with lines. (A) eccentric strength, (B) muscle mass, (C) summed isometric strength for flexion and extension.

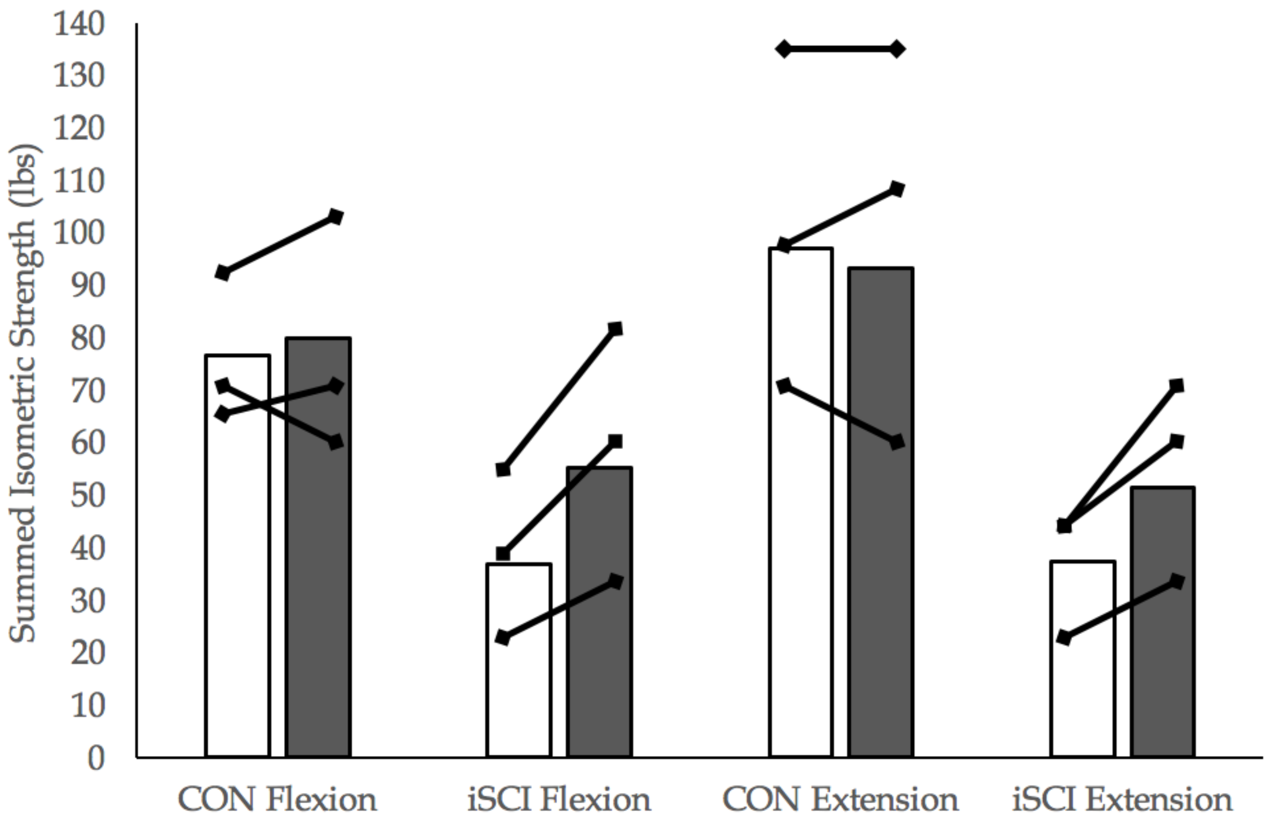


Figure 5. Summed isometric forces for the right and left legs before and after ERT, separated into muscle actions of flexion and extension. Individual participant data are provided by lines and group means by columns.

DISCUSSION

Eccentric exercise increases strength with minimal oxygen requirement (17, 18), making this mode of exercise optimal for individuals with iSCI. The ERT protocol utilized in this study safely and effectively increased eccentric leg strength in all participants and isometric leg strength in those with iSCI. The ERT did not affect leg muscle mass in either group. We believe this is the first study to document the efficacy and safety of active lower-body ERT in those with iSCI.

No participants reported undue muscle soreness or dropped out of the study before completion. Participants completed on average 93.5% of ERT sessions. There were no instances where training intensity was delayed due to participant request or muscle soreness, based on the predetermined VAS criterion. However, one of three CON participants complained of knee pain towards the end of the training. This participant completed the ERT, but continuing the structured intensity progression would have been difficult with continued training. Overall, the ERT was safe and effective for individuals with and without iSCI.

All individuals who participated in the ERT exhibited significant improvements in eccentric strength, with CON averaging 58% improvement and iSCI averaging 99% improvement after 8 weeks of training. The nearly doubled eccentric strength in those with iSCI following ERT is twice the improvement, noted as torque improvement, by Jayaraman et al. (2013) following a four-week maximal isokinetic training program in men with chronic iSCI. The improvement described in the current study may be due to a greater volume of work per session and training duration when compared to a resistance style isokinetic training program (14). In the current study, the progressive increases in intensity and/or duration of ERT resulted in mode specific strength gains and also translated into isometric strength in those with iSCI. While a direct comparison of eccentric strength gains between our participants with iSCI and other samples is not possible due to variability in study designs, it does appear that an appropriate dose of ERT will allow those with iSCI to improve in eccentric strength similarly to populations who have other neurological disorders and able-bodied young adults (8, 18).

Participants with iSCI improved in isometric strength similarly to participants who completed a 12-week ERT protocol with Parkinson's disease (8). However, the participants with iSCI in the current sample demonstrated a greater ability to apply strength from ERT to isometric actions than older adults in a prior investigation, improving 41.5% post ERT versus 7.5%, respectively (22). Participants in the CON group improved isometric strength more similarly to the older adults with gains of 8.5-9.5%, when excluding the participant with osteoarthritis (22). Inconsistency in isometric force improvement between individuals in the CON and iSCI groups may be attributed to a greater capacity for neural improvement because of the lower baseline neural capabilities for those with iSCI. Because neural drive is negatively affected by injury, those with iSCI may stand to experience greater benefits to strength training by improving motor control and activation via increased V-wave and H-reflex responses, succinct neural recruitment, synaptogenesis, and decreased presynaptic excitability threshold (1, 2, 26).

Studies evaluating the effects of ERT on strength often show improvements in isometric force in young adults (15, 18). Although the insignificant change in isometric strength for CON contradicts previous literature, evaluating the current participants individually may explain where this disparity originates. Two of the three CON participants improved isometric strength by approximately 9% whereas one individual lost almost 27% strength from pre to post ERT. This individual was not statistically an outlier, but over the course of the training developed significant knee pain from pre-existing osteoarthritis. The two individuals without knee pain adapted similarly to previous literature that reported an 11% improvement in isometric strength in healthy adults (15). Aggregated, these data lead to three conclusions: [1] the ERT allowed CON to improve similarly to other eccentric training protocols; [2] those with iSCI can adapt to ERT similarly to CON and have the potential to translate improvements to non-mode specific strength; [3] the current ERT program may be too aggressive and inappropriate for individuals with osteoarthritis.

There appeared to be no change in muscle mass from the prescribed ERT. Similar to previous literature, continued eccentric strength gains across a training program might be attributed to neural adaptations rather than a hypertrophic response (7, 19). Being that those with iSCI progressed similarly in eccentric strength to the able-bodied controls, the improvement may be credited to either intact neural communication from higher brain centers, reflexive responses at the spinal cord level initiated from the stepping motion, or a combination of both (3). Further investigation is needed to determine if one method of neural response dominates the drive for this adaptation. However, it is reasonable to conclude that those with incomplete iSCI can safely participate in ERT and reap musculoskeletal benefits.

Despite the improvements seen in all participants after the 8-week ERT, limitations exist in this pilot study. Future investigations into the use of ERT will benefit from a larger sample size. A longer training duration may highlight changes in muscle size, in addition to muscle strength. Because the development of knee pain in one of the control participants may have influenced group mean differences, developing more stringent guidelines for matching controls in future studies is recommended. Forthcoming investigations may also consider evaluating a group of individuals with homogenous iSCIs and ambulatory ability. Additionally, an evaluation of electromyography and walking measures following ERT may allow for the quantification of functional changes after training.

Participants with iSCI significantly improved eccentric and isometric strength as a result of the 8-week ERT. The magnitude of improvement in eccentric strength did not differ between individuals with iSCI and CON participants, but those with iSCI saw greater benefits in isometric strength than CON. No changes in leg muscle mass were observed in either group. Active lower body ERT was safe and effective at improving strength in those with iSCI. Future investigation is needed to ascertain the effect ERT on functional activities of daily living and quantifying the degree of neuromuscular improvement.

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