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Comparative Effects of Eccentric Overload Training On Muscle Function Measures When Combined With Aquatic Plyometric Training

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COMPARATIVE EFFECTS OF ECCENTRIC OVERLOAD TRAINING ON MUSCLE FUNCTION MEASURES WHEN COMBINED WITH AQUATIC PLYOMETRIC TRAINING

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Abstract

Although there is a growing body of knowledge on eccentric resistance training and aquatic plyometric training on muscle function measures alone, no research to date has investigated the effects of a mixed training model. Aquatic plyometrics and overload eccentric training are two different training models which could work synergistically because the shortcomings of one model are the virtues of the other (i.e., plyometrics are not as effective at producing large muscle size and strength gains and eccentric-only training largely lacks the functional SSC component). The purpose of this study was to examine and compare the effects of a combined eccentric overload and aquatic-based plyometric training program on muscle function, sport-specific performance measures, and soreness versus an eccentric-only training protocol. Twenty-five participants were randomized into either an eccentric-only training group (ECC) or a combined eccentric and aquatic plyometric group (AQP) and participated in a 6-week training intervention. The ECC group performed eccentric training on a motor-driven isokinetic dynamometer (Eccentron) once a week for 3 minutes while the AQP group performed the same eccentric training once a week with an additional aquatic plyometric training session. Isokinetic eccentric strength, isometric strength, depth jump height, countermovement jump height, and sprint time were taken pre and post training. Muscle soreness was taken weekly throughout the training. There was no significant group × trial interactions for any of the variables indicating that combined eccentric and aquatic plyometric training did not increase muscle function measures more than eccentric training alone. The training elicited a significantly large improvement in isokinetic eccentric strength in both ECC (27%; ES = 1.33) and AQP (17%; ES = .86) groups. Isometric strength improved moderately for ECC and AQP groups (17.2%, ES = .53; 9%, ES = .45). A moderate effect was observed for depth jump height improvement for both

ECC and AQP groups (13.1%, ES = .48; 8.8%, ES = .36). No significant changes were observed for countermovement jump or sprint time. However a moderate, though not significant, effect was found for 5-m sprint time in the ECC group (ES = .52). Muscle soreness did not significantly differ between groups but was considerably less than previous studies (8-10 mm vs. 20-30 mm). In conclusion, minimal dose multi-joint eccentric overload training significantly improved maximal eccentric strength, isometric peak force, and depth jump height after 6 weeks regardless of the training condition (ECC vs. AQP).

Introduction

Eccentric-based resistance training has gained popularity in recent years for various populations including athletic and recreational populations as well as those participating in physical rehabilitation. Eccentric-based resistance training emphasizes the force generated during the muscle lengthening phase. Accumulating scientific data has shown eccentric exercise to elicit superior muscle strength and mass gains (English et al., 2014; Farthing & Chilibeck, 2003) with lower rates of perceived exertion and less metabolic demand (Harper & Thompson, 2021; Peñailillo et al., 2013) than traditional resistance training. These characteristics make eccentric exercise suitable for a range of settings from athletic to clinical populations because of the substantial gains that can be made in a relatively time and energy-efficient manner. For example, clinicians may find eccentric exercise especially desirable for clinical populations that may not tolerate traditional resistance exercise due to the elevated perceived exertion and metabolic demands.

Some evidence suggests that eccentric exercise is highly correlated to improvements in countermovement jump and vertical jump height indicating the possible ability of eccentric strength to transfer to explosive power movements (Bridgeman et al., 2018). Bridgeman et al. (2018) found that eccentric force and power correlated with countermovement jump peak power and jump height, whereas, for the concentric measures, only absolute concentric force was correlated with any of the jump measures. Another study done by Papadopoulos et al. (2014), found eccentric training performed on a custom-made isokinetic leg press led to significant increases in depth jump height (14%) and peak power (26%). These results suggest the eccentric phase of the stretch shortening cycle (SSC) and eccentric strength may be important for SSC-based performance (Bridgeman et al., 2018; Papadopoulos et al., 2014).

However, the aforementioned results appear to partially conflict with recent research from our lab. In one study, a 19% increase in eccentric strength was observed following twice-weekly training using a multi-joint closed chain isokinetic Eccentron machine (Eccentron, BTE Technologies Inc., Hanover, MD) for 4 weeks but no improvements were shown for 40-m sprint or vertical jump height (Gordon et al., 2019). Crane et al. (2020) found that 4 weeks of eccentric-based lower limb resistance training on a multi-joint isokinetic eccentric machine (Eccentron, BTE Technologies Inc., Hanover, MD) significantly increased eccentric muscle strength by 32%. Interestingly, vertical jump did show a statistical improvement in this study, but the gains were much smaller at only 7%, compared to the large eccentric gains. These findings suggest that the transfer of large eccentric training gains are modest at best for vertical jump performance and not present for sprint speed, possibly indicating a limited use for this modality in training the SSC.

A plausible reason for this discrepancy in the literature may be due to the training models used. For instance, the Eccentron only involves muscle recruitment during the eccentric phase and thus lacks a concentric component (Crane et al., 2020; Gordon et al., 2019) despite the high overload imposed during this phase. Both the training interventions used by Bridgeman et al. (2018) and Papadopoulos et al. (2014) utilized concentric muscle action alongside the eccentric training. This differs from the Eccentron which lacks concentric muscle action and therefore is not training the entire SSC. According to Nicol et al. (2006), a true SSC involves a pre-activation of the extensor muscles before ground contact to prepare to resist impact followed by braking (eccentric action) and muscle shortening (concentric action). The SSC component of training is a critical contributor to functional and sport performance measures (Lockie et al., 2016; Ramirez-Campillo et al., 2020; Van Roie et al., 2020). In a longitudinal study, Cormie et al. (2010) found improvements in peak and average eccentric force and power as well as peak eccentric velocity following a ballistic training program that involved training SSC. Thus, high eccentric load training that is combined with the use of the SSC may be necessary to induce more pronounced performance-based/functional task improvements.

It is well established in the literature that plyometric training is exceptionally effective for training the SSC (Flanagan & Comyns, 2008; Turner & Jeffreys, 2010) as it involves high velocity, explosive movements which utilize both eccentric and concentric actions that are specific to a particular sport or function. Plyometric training combined with resistance training may produce greater improvements in functional tasks than either training protocol alone indicating that plyometrics may be more effective when paired with some form of resistance training (Fatouros et al., 2000). In a study by Lambert et al. (2015), aquatic treadmill running and land treadmill running were both combined with traditional resistance training to determine if underwater running interfered with skeletal muscle hypertrophy and strength gains. The researchers found a 12-week concurrent training intervention of aquatic treadmill running and traditional resistance training elicited greater increases in total lean mass and total strength than land treadmill running plus resistance training or traditional resistance training alone (Lambert et al., 2015). It is reasonable to believe plyometrics could complement eccentric training which, as previously shown, elicits large muscle increases in strength and mass. High velocity plyometrics and overload eccentric training are two different training models which could work synergistically because the shortcomings of one model are the virtues of the other (i.e., plyometrics are not as effective at producing large muscle size and strength gains and eccentric-only training largely lacks the functional SSC component). More research is needed to examine a mixed training model of plyometrics and eccentric overload training to determine if greater improvements in functional performance tasks could occur.

It is plausible that an interference effect may exist if eccentric overload training and land-based plyometric training are performed parallel to each other due to the high force typical of eccentric training and the high velocity typical of land plyometric training. There is potential for high soreness levels from the large ground reaction forces typical of land-based plyometric training and the overload of eccentric training. High soreness levels could make performing high intensity plyometrics uncomfortable, difficult, and/or less effective, but if done in an aquatic environment levels of soreness could be decreased while maintaining or even increasing movement velocity. Robinson et al. (2004) compared land-based and aquatic-based plyometrics in college-aged volleyball players and found both groups had significant improvements in vertical jump, peak torque, and velocity but the land-based group reported significantly greater perception of pain with muscle soreness than the aquatic-based group. The presence of buoyancy in aquatic environments allows for decreased landing forces (Miller et al., 2002) as well as diminished levels of pain and soreness (Robinson et al., 2004) and warm water temperatures (>88°F) and hydrostatic pressure are other factors which may be beneficial in decreasing soreness acutely or chronically (Miller et al., 2002).

The unloading effects from buoyancy would also provide more rapid velocity concentric movements of the plyometric exercises possibly leading to an increase in power output because with deeper immersion comes greater buoyant effects and greater resistance against upward motion (Louder et al., 2016). Studies have found increases in vertical jump, torque, and sprinting speed following aquatic-based plyometric programs (Arazi & Asadi, 2011; Martel et al., 2005; Rimmer & Sleivert, 2000). Based on these findings, aquatic-based plyometrics could be an effective method for explosive power training utilizing the SSC in conjunction with an eccentric-based resistance training program. Given the high loading and potentially damaging nature of eccentric overload training, performing the plyometric training in an aquatic environment may be favorable for managing the risk of muscle soreness while allowing for uncompromised muscle strength gains and perhaps even enhanced functional performance gains.

A feature of our prior work is the use of a minimal dose training model. Notable results have been achieved with only 6 minutes of eccentric exercise training per week (Crane et al., 2020; Gordon et al., 2019). This approach is useful as a means to help achieve a more tolerable exercise program that would likely not be prohibitive to many populations, thus potentially increasing exercise adherence across many populations (Harper & Thompson, 2021). In line with this concept, a minimal dose plyometric training program would be useful to best compliment such an eccentric routine in order to maintain the minimal dose feature of the program.

To our knowledge there is no research to date that investigates the effects of combining aquatic-based plyometric training with minimal dose multi-joint eccentric overload training on muscle strength, power and functional tasks, as well as soreness measures. The purpose of this study was to compare the effects of a combined eccentric overload and aquatic-based plyometric training program on muscle function, sport-specific performance measures, and soreness versus an eccentric-only training protocol. Our hypothesis is aquatic-based plyometric training combined with minimal dose multi-joint eccentric overload training will increase the functional performance beyond eccentric-only training gains without compromising muscle strength gains. Additionally, we hypothesize that performing plyometric training in an aquatic environment will lead to reduced levels of soreness compared to the eccentric-only group.

Methods

Participants

Thirty-three college-aged men and women volunteered to participate in this study. Inclusion criteria included being between the ages of 18 and 35 years old and informally classified as recreationally active which was defined as participating in recreational activities or moderate dose physical activity. Exclusion criteria included not regularly engaging in resistance training (< 3 times in the previous month) or aerobic exercise more than 30 minutes per day, five days a week, having any lower limb injuries or surgeries within a year before the study or any musculoskeletal/neurological disorders that may affect the lower limbs, or having an eccentric isokinetic baseline strength level of < 3225 N (more on this below). Participants were required to complete at least 80% of the training sessions and if unable to they were withdrawn from the study. The study was approved by the university's Institutional Review Board and all participants read and signed an informed consent before participating.

Experimental Procedures

This study utilized a randomized, parallel-group design with repeated measures to test hypotheses following a 6-week training intervention. Upon enrollment, participants were randomly assigned to one of two groups: 1) eccentric-only exercise (ECC) (n = 12; mean ± SD: age = 21.0 ± 3.0 years, mass = 76.2 ± 13.3 kg, height = 173.9 ± 8.1 cm), or 2) eccentric and aquatic plyometric exercises (AQP) (n = 13, age = 22.8 ± 2.6 years, mass = 74.1 ± 8.7 kg, height = 173.9 ± 8.7 cm). The design aimed, at minimum, to match groups for sex and baseline eccentric strength. Prior to pretesting all participants participated in a separate familiarization session to minimize a possible learning curve which occurred between 3-4 days before the pretest. All testing occurred at the same time of day (± 2 hours) and occurred in the following order: depth jump, countermovement jump, dominant leg isometric maximal strength, Eccentron maximal eccentric strength, and 15-m sprint. Posttesting occurred 4-6 days following the last training session to allow for full recovery as per previous procedures (Crane et al., 2020). All training was closely supervised by experienced research investigators.

Training Interventions

Eccentric Training

All eccentric training was completed using the Eccentron once per week for both groups for 6 weeks (Crane et al., 2020). A brief warm-up was performed prior to each training session and involved cycling at 50 watts for 2 minutes on a cycle ergometer followed by two sets of 10 bodyweight squats separated by a 1-minute rest period. The Eccentron's protocol consisted of both a 1-minute warm-up and 1-minute cool down performed at half the day's target workload. The training consisted of a 3-minute workout period at the specified workload so that the total workout lasted 5 minutes including warm-up and cool down. The velocity was set at 23 rpm (a medium speed) which matched the velocity used in our previous studies that elicited large gains in strength (Crane et al., 2020; Gordon et al., 2019). The training progression was based on previous studies completed in our lab (Crane et al., 2020; Gordon et al., 2019) as well as additional pilot work. Progression was derived from a percentage of the baseline maximal eccentric strength recorded during pretesting. The progression was as follows: week 1- 50%, week 2- 55%, week 3- 60%, week 4- 60%. After week 4 the intensity was individually adjusted based on the participant's ability to meet the target force. If they were able to meet the target force with 85% or more accuracy the force was increased by 5% in the next session. If less than

85% accuracy was achieved the target force remained the same in the next session until 85% accuracy was achieved.

Aquatic Plyometric Training

The combined eccentric and aquatic plyometric group completed one additional training session a week consisting of plyometrics performed on an aquatic treadmill (Hydroworx 2000; Middletown, PA, USA) at 32°C. The training program was based on recommendations by Miller et al. (2001) on how to implement aquatic plyometric programs as well as additional pilot work. The aquatic session occurred 96 hours after the Eccentron training to promote recovery. The aquatic training program warm-up consisted of a 3 minute, 5 mph aquatic treadmill jog at 20% jet resistance at a depth consistent with the participant's anterior superior iliac spine. A 2 minute rest then occurred between the warm-up and the plyometric program. The aquatic plyometric exercises and progressions are found in Table 1 and were all performed at a depth consistent with the participant’s xiphoid process to allow for greater resistance to upward motion and therefore greater power development (Louder et al., 2016). Each session concluded with three, 15 second sprints at a depth consistent with the participant's anterior superior iliac spine. All sprints were performed at 100% jet resistance and separated by a 1 minute rest period. For the first two weeks, the sprints were set at 6 mph and at week three, the sprints were set at 7 mph. Following week three, the sprints would move up by 0.5 mph if the participant ran above the halfway mark of the pool and would go down 0.5 mph if they finished below the halfway mark whereas it would stay the same if they maintained the halfway mark. The last 15 second set was used to determine the speed change. This program consisted of about 80-100 touches per session as recommended by NSCA guidelines for beginner plyometric volume and increased to 100-120 touches per session indicated as intermediate (Potach & Chu, 2008). Strong verbal encouragement was provided through the training sessions to encourage maximal effort. Participants were also frequently reminded to maintain an intensity of around 90% of their maximum effort.

Outcome Measures

Depth Jump

Participants performed three maximal effort depth jumps from a height of 0.3 meters onto a force plate (AMTI Model OR6-WP; Columbus, OH, USA). The participants were instructed to place their hands on their hips, to step straight off the box without lowering themselves, then land and quickly jump as high as they could with minimal ground contact time. A successful jump attempt required landing on the force plate with both feet after the drop and the rebound jump. The participants were also instructed to stand static at the end of the rebound jump for the remaining data acquisition time. A 1 minute rest period was provided between each jump attempt.

Countermovement Jump

Participants performed three maximal countermovement vertical jumps on a force platform (AMTI Model OR6-WP; Columbus, OH, USA). The participants were instructed to stand on the platform with their feet shoulder-width apart and their hands on their hips. They were instructed to quickly lower themselves to a comfortable depth then immediately jump as high as possible while landing with their legs relatively straight (Crane et al., 2020). A successful countermovement jump was counted if the participant landed on the platform with both feet and did not take a step before jumping. A 1 minute rest was provided between each jump attempt.

Maximal Isometric Contraction

Participants performed three isometric maximal voluntary contractions (MVCs) with their dominant leg using the Eccentron. They were instructed to place both feet on the pedals with their heel positioned at the bottom of the pedal. The seat position was adjusted such that their knee angle was set at 45°. A block was placed under the appropriate pedal to prevent the pedal from moving and the participants were instructed to push into their dominant foot pedal as fast and as hard as they could and to hold that for approximately 3 seconds until the researcher told them to let off. A 1 minute rest was provided between each MVC. Participants were given verbal encouragement to enforce maximal effort.

Eccentron Strength Test

Participants were tested for maximal isokinetic eccentric strength on the Eccentron. The testing procedures were in accordance with our previous studies (Crane et al., 2020; Gordon et al., 2019). Participants were instructed to sit in the seat and place their feet in the middle of the pedals with their heel positioned at the bottom. The seat position was adjusted such that the knee joint angle was set to 30° at the most extended position, per the manufacturer's recommendation. The pedals moved towards the participant in an alternating motion so that each leg worked isolaterally in a repetitive manner. A total of 12 maximal efforts, six per leg were performed. Testing speed was set at 23 rpm, which is defined as moderate speed (Gordon et al., 2019). Participants were instructed to maximally resist the motion of the pedal as it moves towards them and relax as it moves away. During testing the participants were given verbal encouragement to reinforce maximal effort.

15-m Sprint

Lastly, participants performed three maximal effort 15-m sprints. Sprint time (s) was measured using timing gates (Dashr Motion Performance Systems, Dashr LLC, Lincoln, NE, USA) positioned at the start, 5-m mark, and endpoint of the distance. All sprints were performed in a lab on wood floors. Participants were instructed to start in a 3-point stance with their feet staggered and one hand on the ground. They were also instructed to place the front of their lead foot on a line 30 cm behind the start line and to place the opposite hand on the starting line (Rimmer et al., 2000). The sprint started with the covering of the laser on the timing gate and the sound that followed. Participants were instructed to run through the last timing gate to ensure full effort throughout the entire distance. A rest period of 2 minutes was given between each trial. The participants were instructed to wear shoes appropriate for sprinting and to wear the same shoes for both the pre- and posttest. Both 5-m and 15-m sprint time data was analyzed.

Muscle Soreness

During the training period, soreness levels were assessed using a visual analog scale (VAS) per our previous procedures (Crane et al., 2020). For both groups, the VAS was administered at baseline a few minutes before the pretest, for five consecutive days following the pretest, and then three consecutive days per week following the eccentric training session for the remaining six weeks (Crane et al., 2020). To assess their soreness, the subjects were instructed to perform three air squats to parallel at the same time of day and mark their perceived soreness of the lower limbs on a 100 mm line with the left and right ends corresponding to "no soreness" and "most soreness ever experienced". Subjects were not allowed to use nonsteroidal anti-inflammatory drugs (NSAIDS) during the study to prevent any effects it may have had on soreness or muscle damage responses.

Data Analysis

A data acquisition system (Biopac MP150WSW, Biopac System Inc., Santa Barbara, CA) was used to sample the raw force signals from the Eccentron. Data were sampled at 2 KHz and processed offline with custom written software (LabVIEW 2018, National Instruments, Austin, TX). The signal was scaled to N and filtered with a fourth-order, zero phase shift, Butterworth filter with a 50 Hz cutoff. For the isometric peak force, the highest 500 ms epoch was computed and the highest repetition was used for subsequent analysis. For isokinetic eccentric peak force, the single highest data point for the highest repetition of either leg was used for subsequent analysis. Note the baseline value used to determine the training intensity was taken from the Eccentron's software output, and not from the extracted signals.

Force platform data was sampled at 1,000 Hz and the raw data was filtered using a 4^{th} order zero-phase shift Butterworth filter with 300 Hz cut-off. Ground reaction force (GRF) data was converted to acceleration and integrated to estimate take-off velocity. Take-off velocity was then used to estimate jump height for both the depth jump and countermovement jump using an equation of constant acceleration and projectile motion. All data processing was done with MATLAB (MATLAB 2010, The MathWorks Inc., Natick, MA).

An average VAS score was determined for each group and each week by taking the average of three days each week for each participant including the last three days of the five days recorded after the pretest. Then an average was calculated for each week and each group so that both groups had seven VAS scores (Baseline to Week 6). Note that baseline here refers to the week after the pretest and before training began.

Statistical Analyses

Independent t-tests were used to compare group baseline demographics and baseline eccentric strength. A chi-squared test was used to assess group differences in sex. Mixed factorial ANOVAs (trial [baseline vs. posttest] × training condition [ECC vs. AQP]) were used to examine differences in the dependent variables. If appropriate, significant effects were further decomposed with t-tests. Cohen's effect size (d) (ES) statistic was used to evaluate meaningfulness of the differences between groups and trials with the values 0.2, 0.5, and 0.8 representing small, medium, and large effect sizes respectively. An alpha level of 0.05 was used to determine statistical significance and all statistical analyses were performed in R Studio (RStudio Team (2020). RStudio: Integrated Development for R. RStudio, PBC, Boston, MA URL http://www.rstudio.com).

Results

A total of 25 participants out of 33 volunteers completed the study (24% attrition), 8 participants were unable to complete 80% of the training sessions and were therefore withdrawn. Because of the ongoing COVID pandemic individuals who were quarantined and missed a week of training had to be withdrawn. Five participants, one from the ECC group and four from the AQP group, exceeded the Eccentron’s load tolerance (set at 3336) levels at posttest making the sample size for eccentric maximal strength n = 11 in the ECC group and n = 9 in the AQP group (note these subjects’ data were included for all other measures). The ECC and AQP groups were not significantly different at baseline for age (p = .13), mass (p = .68), height (p = .99), or sex (p = .32). Baseline isokinetic eccentric strength was also found to not be significantly different (p = .15) although the isometric MVC variable was significantly different between the groups at baseline (p = .009).

The means and SDs are presented for all variables in Table 2. For the isokinetic eccentric strength variable, there was no significant group × trial interaction ($p = .23$), however, a significant main effect was observed for trial ($p <.001$) such that the posttest was higher than the pretest with the Cohen's ES showing a large effect for the ECC (ES = 1.33) and AQP (ES = .86) groups. For depth jump height there was no significant group × trial interaction ($p = .65$), however, a significant main effect was observed for trial ($p = .001$) such that the posttest was higher than the pretest with the Cohen's ES showing a medium effect for the ECC (ES = .47) but small-medium for the AQP (ES = .38) (Figure 2). For isometric MVC there was no significant group × trial interaction ($p = .73$), however, a significant main effect was observed for trial ($p = .04$) such that the posttest was higher than the pretest with Cohen's ES showing a medium effect for the ECC (ES = .53) and AQP (ES = .45) groups. There was no significant group × trial or significant main effect for trial in either 5-m sprint time ($p = .55$, $p = .16$, respectively), 15-m sprint time, ($p =.86$; $p = .7$) or countermovement jump height ($p = .46$; $p = .49$) and Cohen's ES showed a small to medium effect for ECC (ES = .52, .05, .17) and AQP (ES = .26, .14, .01).

Only the VAS muscle soreness data violated Mauchly's test for sphericity ($p <. 001$), therefore a Greenhouse-Geisser correction was utilized. For the VAS scores, there was no significant group × trial interaction for the muscle soreness data ($p = .43$) but a significant main effect was observed for trial ($p <.001$) when collapsed across the ECC (10.8 ± 5.7) and AQP (8.1 ± 3.9) groups (Figure 3).

Discussion

The primary findings of this investigation were: 1) low dose multi-joint isokinetic eccentric overload training was significantly effective for increasing muscular strength, 2) combining aquatic plyometric training with multi-joint isokinetic eccentric overload training did not increase jumping performance more than eccentric training alone, 3) depth jump and isometric peak force improved regardless of training condition; countermovement jump, 5-m sprint, and 15-m sprint did not significantly improve in either group, and 4) muscle soreness was lower than previous studies and did not differ significantly between groups.

The eccentric training protocol used in both training groups significantly improved muscular strength after 6 weeks. Although there was no significant interaction, further analysis shows that the ECC training condition had a slightly larger effect and percent change (ES = 1.33, 27%) than the AQP group (ES = .86, 17%) with an overall change of 23% across both groups. The volume of eccentric training in this investigation was 3 minutes at target workload once a week for 6 weeks resulting in a total of 18 minutes. This dose of training is half that of previous studies done on the Eccentron in our lab (Crane et al., 2020; Gordon et al., 2019). Although the eccentric training was lower dose the strength gains were similarly large. Crane et al. (2020) found a 32% increase in strength following a training volume of 6 minutes per week for 4 weeks (total of 24 minutes) with an effect size of .69. These results indicate that multi-joint isokinetic eccentric overload training can be exceptionally low dose and still significantly effective at increasing muscular strength providing further evidence that this type of eccentric training is time and energy efficient making it desirable for populations that may not handle traditional resistance training.

No significant group × trial interactions were observed for any of the outcome measures indicating that the addition of aquatic plyometric training to eccentric overload training did not increase muscle function measures, including muscular strength and jumping performance, more than eccentric training alone. This is likely due to the low dose nature of the aquatic training program. Compared to other studies where aquatic plyometric training was successful at increasing vertical jump height and sprint speed (Arazi et al., 2011; Robinson et al., 2004; Miller et al., 2002) this investigation had lower volume. Robinson et al. (2004) utilized a similar training protocol; however, they implemented their program twice a week for 45 minutes as opposed to this study's 20 minute program once a week. Miller et al. (2002) also utilized a twice weekly training volume. It is also important to note that Robinson et al. (2004) and Miller et al. (2002) participants were college athletes and had significant plyometric training experience. It is possible that aquatic plyometric training could still act complementary to eccentric overload training if the aquatic training protocol was higher dose possibly occurring twice weekly instead of once. Because of the short duration required for significant gains with eccentric training more time could be dedicated to the plyometric training while still keeping the weekly total training time relatively low. The aquatic plyometric training could also be performed following a cycle of eccentric-only training, i.e., 6 weeks of eccentric-only training followed by 6 weeks of aquatic plyometric training only. This schedule of training could allow for jumping performance to improve significantly alongside muscular strength by developing the necessary eccentric strength first and then utilizing that strength in a higher dose aquatic plyometric program to develop jumping performance.

Another possible reason this study's particular aquatic training protocol did not lead to increased jumping performance more than the eccentric-only group is the depth of the water used. All plyometric exercises, with the exception of the sprints, were performed at chest depth (xiphoid process). The reasoning behind this was to further decrease the large ground reaction forces that may cause excessive muscle soreness and risk of injury as well as allow for more rapid upward velocity movements as observed by Louder et al. (2016). It is possible that performing plyometrics in water too deep decreases ground contact time and subsequently diminishes the effect on the concentric phase of jumping (Miller et al., 2001). Depth jump height significantly increased at posttest in both ECC and AQP groups ($p = .001$), however, countermovement jump height did not significantly increase posttest for either group ($p = .49$). This indicates that the eccentric portion, which is more prominent in executing a depth jump, was trained more effectively than the concentric portion of the SSC. It also illustrates the importance of specificity of training in creating training programs. Further research is needed to determine if performing higher dose plyometrics in a water depth consistent with the anterior superior iliac spine (waist deep) would elicit more increases in SSC performance than eccentric training alone and allow for more effective training of the concentric portion.

Depth jump height increased significantly in both groups, but the ECC group showed a modest larger improvement with a percent change of 13.1% and effect size of .47 compared to the AQP group with a change score and effect size of 8.8% and .38, respectively. These results further show the importance of eccentric training on depth jump performance and subsequently SSC performance. Interestingly, the countermovement jump did not improve significantly in either group. This indicates that the depth jump fits better within the definition of a true SSC (Nicol et al., 2006) than the countermovement jump. A true SSC involves pre-activation of extensor muscles before ground contact. Countermovement jumps are performed by starting in a standing position and therefore don’t allow for ample pre-activation. It is plausible that the countermovement jump is more an indicator of lower body power than SSC performance. The depth jump involves stepping off a box before ground contact giving time for the pre-activation consistent with a true SSC.

Isometric peak force also significantly increased in both groups at posttest ($p = .04$) with the ECC group showing larger, though not significantly larger, increased peak force with a

17.2% (ES = .53) change versus the AQP percent change of 9% (ES = .45) (Figure 2). These results indicate the effectiveness of the eccentric training protocol to increase muscular strength. The results also indicate that although the aquatic program did not augment SSC performance it also did not completely inhibit strength gains even though the two different training conditions were performed concurrently. Neither 5-m nor 15-m sprint speed significantly increased at posttest ($p = .16$, $p = .77$). Although at further inspection of the data, a moderate effect was observed for 5-m sprint time in the ECC group (ES = .52). This observation suggests that eccentric-only training may benefit the first 5-m of a sprint because of the high forces needed to accelerate into a sprint.

Although there was no significant difference in muscle soreness between the two groups, further inspection of the literature on Eccentron training shows a lower amount of soreness with the more minimal dose. The lower volume of training could explain the lack of a difference in soreness scores between the ECC and AQP groups. With double the volume (6-minutes/week vs. 3 minutes/week) muscle soreness averaged around 20-30 mm on the VAS (Crane et al., 2020) compared to an average of 8-10 mm found in the current study. This finding is promising for practitioners, clinicians, or trainers who work with populations who have difficulty adhering to physical activity protocols or that may not tolerate high levels of soreness or intensity.

One limitation to this study was the lack of a true control group which does not allow for comparison against a non-training condition. Another limitation was the mode of obtaining muscle soreness measures. Participants were coached on how to properly assess and record their soreness as well as reminded at each lab appointment. It is assumed that each participant correctly performed air squats to an appropriate depth and recorded their responses at the same time of day.

In conclusion, multi-joint eccentric overload training significantly improved maximal isokinetic eccentric strength, isometric peak force, and depth jump height after 6 weeks regardless of the training condition (ECC vs. AQP). The addition of aquatic plyometric training to the eccentric training did not enhance jumping performance but also did not inhibit the aforementioned improvements. Muscle soreness was not significantly different between the groups but was less than previous studies (Crane et al., 2020) likely because of the lowered volume. Low dose multi-joint isokinetic eccentric overload training may be an effective resistance training modality that could be practical for clinicians or trainers who work with sedentary, diseased, or older populations who may not tolerate traditional resistance training. Further research is needed to examine if a higher volume of aquatic plyometric training, possibly separated into two distinct 6-week training interventions would augment the low dose eccentric overload training and produce improvements in sprint speed and countermovement jump height. It is also plausible that other improvements occurred in the AQP group that were not measured. Based on the principle of specificity, testing done in the aquatic environment could indicate changes in jump performance in the water and provide more information on the impact of aquatic plyometric training. Overall calorie output and the following cardiometabolic effects could have also occurred in the AQP group compared to the ECC group. Further research is needed to include testing aquatic specific jump measurements as well as metabolic testing.

Table 1. Aquatic plyometric program progressions.

Training Week	Training Volume	Plyometric Drill	Sets x Reps	Training Intensity
1	84	Double leg hops	2 x 9	Low
		Side to side hops	2 x 9	Low
		Tuck jump	2 x 8	Med
		Alternating split squats	2 x 8	Med
		Countermovement jump	2 x 8	Med
		Sprint	3 x 15 s	6 mph, 100% jet
2	94	Double leg hops	2 x 10	Low
		Side to side hops	2 x 10	Low
		Tuck jump	3 x 6	Med
		Alternating split squats	3 x 6	Med
		Countermovement jump	3 x 6	Med
		Sprint	3 x 15 s	6 mph, 100 % jet
3	96	Single leg hops	2 x 8	Low
		Side to side hops	2 x 12	Low
		Tuck jump	2 x 10	Med
		Alternating split squats	2 x 10	Med
		CMJ repeated	2 x 8	High
		Sprint	3 x 15 s	7 mph, 100% jet
4	118	Single leg hops	2 x 10	Low
		Side to side hops	3 x 10	Low
		Tuck jump	2 x 12	Med
		Alternating split squats	2 x 12	Med
		CMJ repeated	2 x 10	High
		Sprint	3 x 15 s	**, 100% jet
5	114	Single leg hops	2 x 10	Med
		Side to side hops	3 x 10	Low
		Tuck jump	2 x 12	Med
		Alternating split squats	2 x 12	Med
		Single leg CMJ	2 x 8	High
		Sprint	3 x 15 s	**, 100% jet
6	110	Single leg hops	3 x 10	Med
		Tuck jump	3 x 10	Med
		Alternating split squats	3 x 10	Med
		Single leg CMJ	2 x 10	High
		Sprint	3 x 15 s	**, 100% jet

A rest period of 30 seconds was given between sets and 1 minute between reps. A 1 minute rest was given between each set of sprints.

** Move up 0.5 mph if: above ½ mark, Move down 0.5 mph if: below ½ mark, Keep same if: at ½ mark (during last set)

Table 2. Means (SD) and Cohen's d effect sizes for the Eccentron strength, depth jump height, CMJ jump height, isometric peak force, 5-m sprint time, and 15-m sprint time for the eccentric-only (ECC) and eccentric plus aquatic plyometric (AQP) training conditions at pretest (Pre) and posttest (Post).

		Eccentric-Only			Eccentric + Aquatic Plyometric		
Action	Variable	Pre	Post	Cohen's d	Pre	Post	Cohen's d
Eccentron	Strength (N)	1919.3 (446.4)	2482.4 (397.8) ***	1.33	2345 (506.5)	2732.2 (392.4) ***	.86
Depth Jump	Height (m)	.28 (.07)	.32 (.10) **	.47	.32 (.08)	.35 (.08) **	.38
CMJ	Height (m)	.29 (.07)	.31 (.09)	.17	.33 (.09)	.33 (.08)	.01
Isometric MVC	Peak Force (N)	1884.2 (569.6)	2208.9 (648.6) *	.53	2518.8 (553.5)	2753.4 (488.9) *	.45
5-m Sprint	Time (s)	1.54 (.46)	1.36 (.23)	.52	1.30 (.25)	1.23 (.28)	.26
15-m Sprint	Time (s)	3.01 (.42)	2.99 (.37)	.05	2.86 (.38)	2.80 (.46)	.14

Cohen's d values only compare the pretest and posttest differences in this table.
*$p < .05$
**$p \leq .01$
** $p \leq .001$

Figure 1

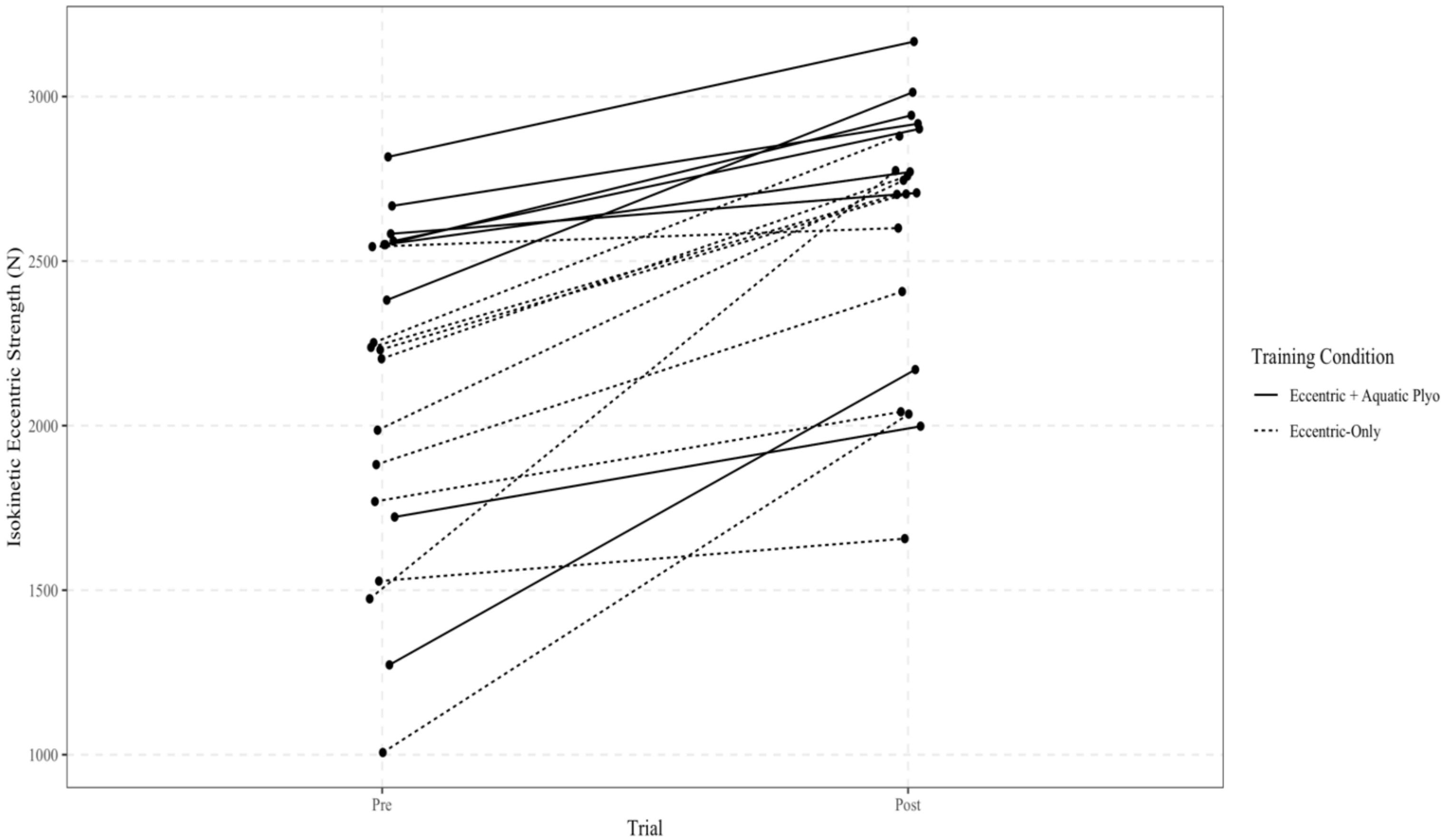

3000
2500
2000
1500
1000
Isokinetic Eccentric Strength (N)
Pre
Post
Trial
Training Condition
Eccentric + Aquatic Plyo
Eccentric-Only

Figure 2

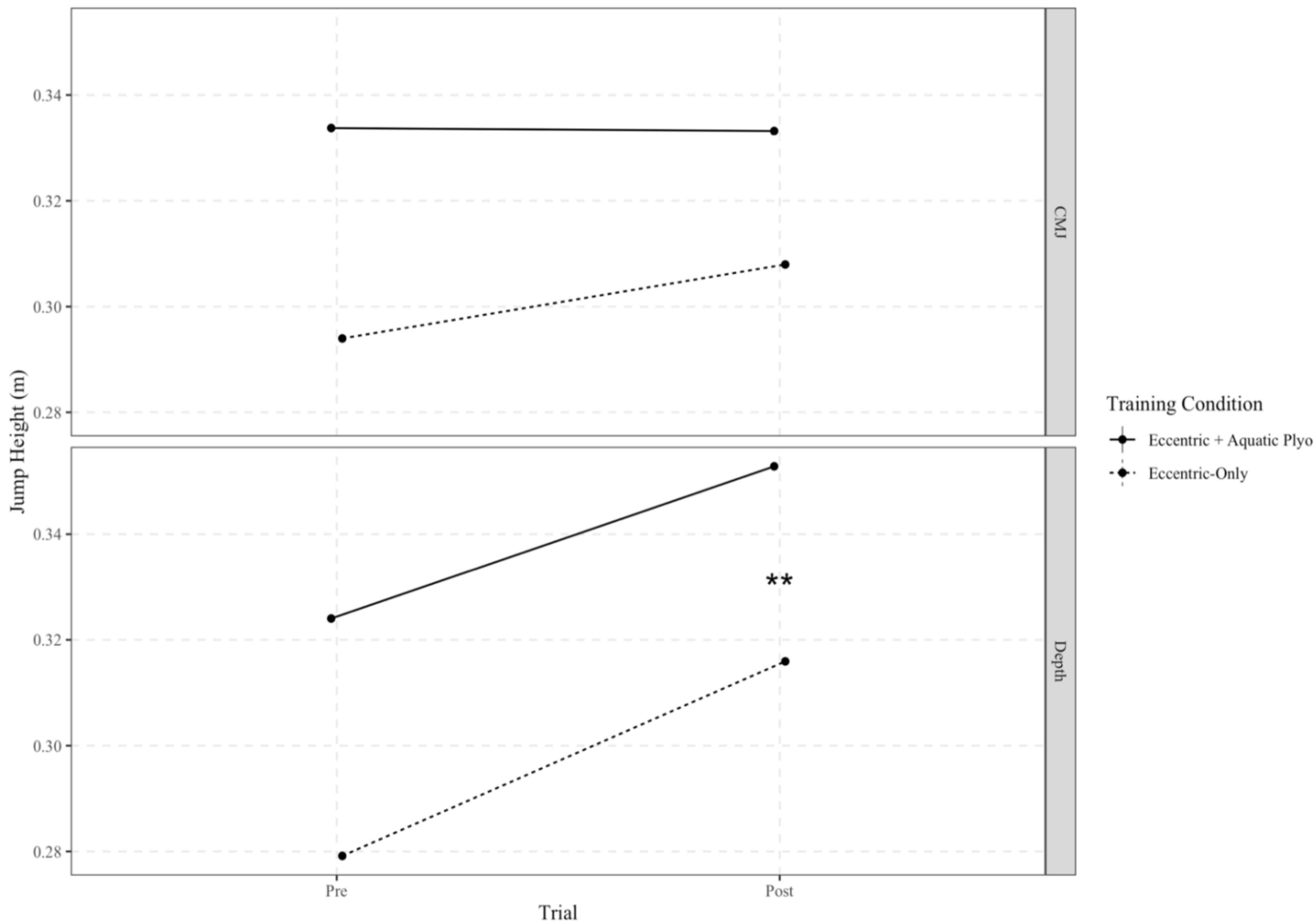
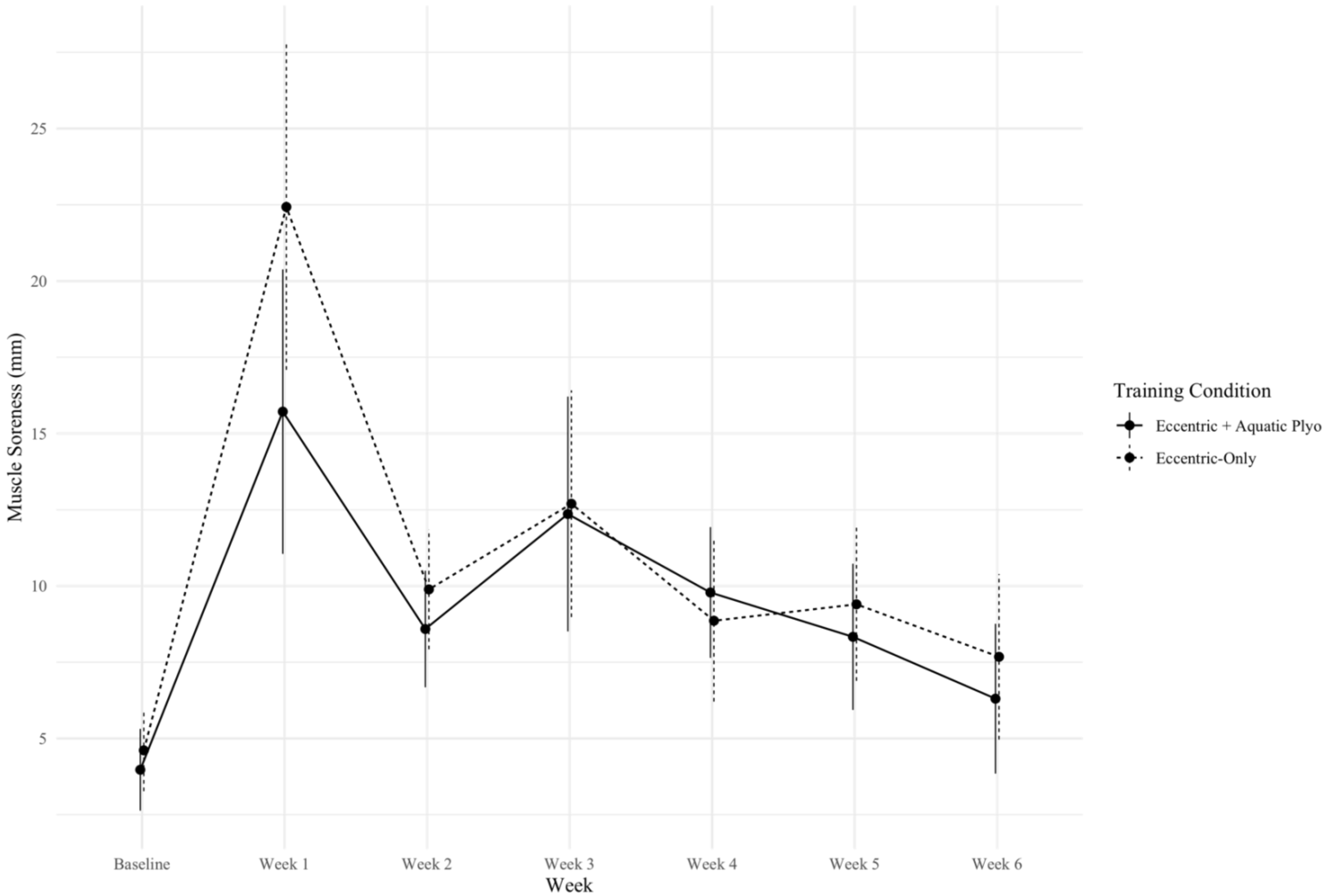

0.34
0.32
0.30
0.28
CMJ
Depth
**
Jump Height (m)
Pre
Post
Trial
Training Condition
Eccentric + Aquatic Plyo
Eccentric-Only

Figure 3


Muscle Soreness (mm)
25
20
15
10
5
Baseline
Week 1
Week 2
Week 3
Week 4
Week 5
Week 6
Week
Training Condition
Eccentric + Aquatic Plyo
Eccentric-Only

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