Massage enhances recovery following exercise-induced muscle damage in older adults

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Conflict of interest

The authors report no conflict of interest.

Abstract

To examine efficacy of cold-water immersion (CWI) and massage as recovery techniques on joint position sense, balance, and fear of falling following exercise-induced muscle damage in older adults. Seventy-eight older men and women performed a single bout of strength training on the calf muscles (3 exercises with 4 sets of 10 reps with 75% of 1RM) to induce muscle damage. After the damaging exercise, participants received either a 15-min massage on calf muscles, or a CWI of the lower limb in cold water (15±1°C) for 15 min, or passive rest. Interventions were applied immediately after the exercise protocol and at 24, 48, and 72 hours post-exercise. Muscle pain, calf muscle strength, joint position sense, dynamic balance, postural sway and fear of falling were measured at each time point. Repeated application of massage after EIMD relieved muscle pain, attenuated the loss of muscle strength and joint position senses, reduce balance impairments and fear of falling in older adults ($p \leq 0.05$). However, repeated applications of CWI, despite relieving muscle pain ($p \leq 0.05$), did not attenuate the loss of muscle strength, joint position senses, balance impairments, and fear of falling. CWI had only some modest effects on muscle pain, but massage attenuated EIMD symptoms and the related impairments in muscle strength, joint position sense, balance, and postural sway in untrained older individuals. Therefore, older exercisers who plan to participate in strength training can benefit from massage for recovery from muscle damage indices and balance to decrease falling risk during the days following strength training.

Key Words: delayed onset muscle soreness; cold water immersion; muscle strength; joint position sense; proprioception

Introduction

Reductions in muscle mass and strength are a common feature of ageing; [1] these changeable factors are more prominent in the leg muscles than other muscles groups and hence play a significant role in the increased risk of falling. [2] Previous work has suggested that after the age of 65 years, muscle mass and strength decrease by 10% and 26%-41% every decade thereafter.[3] Of particular concern is that there is a four-fold increase in the risk of falling from muscle weakness and atrophy. [1, 4, 5] Accordingly, strength training is usually used and advocated to attenuate, and even reverse, the debilitating effects of ageing on muscle characteristics and the accompanying motor function to prevent falling during locomotion. [6-8] However, one of the temporary, but somewhat debilitating musculoskeletal outcomes following exercise and physical activity, especially strength training, is the ultra-structural damage to skeletal muscle; known as exercise-induced muscle damage (EIMD).[9]

EIMD is associated with the breakdown of contractile and non-contractile proteins and leads to a loss of function and delayed onset muscle soreness (DOMS). The symptoms become evident soon after, and can last for several days post-exercise.[9, 10] The signs and symptoms of EIMD include reduced muscle strength, power, flexibility, joint range of motion, [11, 12 13, 14] and impaired proprioceptive function.[11, 12] Although not widely studied, some studies have examined the pattern of muscle damage following eccentric exercise in older adults and reported conflicting results.[15-18] For example, some studies suggested that older adults experience greater muscle damage [16] and dysfunction [19] and require a longer time for recovery [19] than younger counterparts. However, Lavender and Nosaka [17] suggested that muscle damage is not necessarily greater in older compared to younger adults.[18] Indeed, Lavender and Nosaka [17] showed that younger adults showed larger decreases in function and larger increases in DOMS than older participants.

Notwithstanding, many older adults have more confounding factors such as inadequate muscle mass, muscle strength, and joint position sense, therefore they are at risk of losing balance and increased fear of falling. [1, 3-5, 20] Therefore further decrements in those factors that occur after EIMD are more likely to impair balance and postural control, thereby increasing the risk of falling. In addition, the fear of injury and pain caused by EIMD has been a reported barrier to participating in exercise and physical activities. [21] Thus, recommendations for older adults initiating strength training programs should consider, not only long-term benefits but also the acute effects of different training regimens. Consequently, any intervention that might act as an effective recovery intervention for older adults after strength training that could reduce the negative effects associated with balance, postural control, muscle strength and joint proprioception and the risk of falling would be welcomed.

Different recovery techniques have been proposed to help reduce the impairments resulting from EIMD. Beside nutrition strategies, cold-water immersion (CWI) and massage are two of the most commonly used recovery techniques. Some studies have examined the effectiveness of these recovery techniques for muscle strength [12] and joint position sense,[11, 12] but the work almost exclusively focuses on younger athletic and non-athletic populations. It is proposed that cooling, through a reduction in muscle perfusion, can reduce infiltration of inflammatory cells and hence local swelling and oedema.[22] CWI is also proposed to minimize hypoxic secondary tissue damage, reduce pain, and ultimately help to accelerate recovery of muscle strength and power.[23-25] Massage is also purported to reduce impairments from strenuous exercise, [12, 26-28] where positive observations have been attributed to removing accumulated extracellular fluid from affected muscles and hence a reduction in swelling and pain, although this remains to be demonstrated. As such, massage might facilitate recovery after damaging exercise and help to improve muscle strength, proprioceptive, and physical performance.[26, 28] For example, applying 30-minute manual massage immediately after EIMD reduced perceived soreness and declines in muscle strength and jump performance[28]. In addition, Shin and Sung [12] suggested a 15-minute massage on the gastrocnemius after EIMD can improve muscle strength and proprioception in young participants. However, there is currently no research that has examined the efficacy of these simple recovery strategies on reducing impairments from strenuous exercise in older adults, and more specifically, on muscular strength, joint position sense, balance, and risk of falling.

Due to the fact that impaired lower extremity muscular strength and joint position sense are factors that can contribute to impaired balance and risk of falling [1, 4, 20], research into these strategies could contribute to the evidence to support athletes, coaches and the therapist's knowledge to address issues relating to EIMD. Consequently, this study aimed to examine whether CWI or massage after strength training can be used as an effective recovery method and reduce the symptoms of EIMD, namely decrements in muscle strength and joint position sense, balance, and risk of falling in the older adults. We hypothesized that CWI and massage after EIMD would be more effective than passive recovery for alleviating the symptoms of EIMD by reducing the decrements in muscle strength, and joint position sense, and reduce the imbalance and risk of falling after a session of strength training for older adults.

Materials and methods

Participants

Seventy-eight untrained healthy older adults ≥ 60 years old (age; 66±3 year, height; 1.68±0.05 m, mass; 78.8±5.7 kg), who had planned to start strength training, volunteered to participate in this study. Inclusion criteria were age ≥ 60, ability to perform the physical activity safely as assessed by the Physical-Activity Readiness Questionnaire; PAR-Q, [29] and had physician approval before participation. Exclusion criteria were that volunteers had not participated in structured strength training and/or other physical activities that involve strength training for at least 12 months preceding the study, a history of lower extremity injuries and surgeries or chronic pain, unstable cardiovascular disease, psychiatric, neurological, and/or inflammatory diseases. Also, participants were asked to refrain from any additional exercise or treatments as well as the use of supplements, any medications, caffeine, nicotine or alcohol from 72 h before baseline assessments to final evaluation. The study was approved by the Institutional Review Board and performed in accordance with the Declaration of Helsinki. All participant provided written, informed consent prior to participation.

Study procedure

This was a prospective, double-blinded parallel-group randomized controlled trial with repeated measures at baseline, 24h, 48h, and 72 h follow-up. The trial was registered with the UMIN-ICDR Clinical Trial (UMIN000036948). The chief investigator and a physician visited all the volunteers for initial screening, but were not involved in data collection and were blinded to the allocation of participants in each experimental condition. An independent, blinded colleague made a random allocation sequence using a computer-generated sequence (Random Allocation Software 2.0) to block-randomize participants to three groups of massage, cold water immersion (CWI), and passive recovery (allocation ratio 1:1:1). Group allocations were concealed from the researcher enrolling and assessing participants in sequentially numbered, opaque, sealed envelopes. The envelope number was noted by an independent researcher. Corresponding envelopes were opened by a research assistant (FG) after an enrolled participant completed all baseline assessments in order to allocate the intervention. The participants then attended the laboratory for baseline measurements. A laboratory specialist, not directly involved in the study and blinded to the interventions, performed the clinical assessments. On the following day, they performed the strength exercise protocol designed to induce muscle damage that incorporated standing calf raising with dumbbell and standing and seated calf raising with a weight machine. Then massage group received 15 minutes of standardized massage on the gastrocnemius muscle area; the CWI group received the intervention at a temperature of 15±1°C for 15 minutes; the passive group received no treatment and underwent a passive recovery for 15 minutes. Participants were instructed not to reveal or discuss the intervention with the evaluator and were unaware of the intervention provided to other participants. All measurements and interventions were replicated 24, 48 and 72 hours after the exercise intervention; each set of assessment measures took approximately 40-50 mins to administer. The order of measurements and interventions was such that the measurements were followed by interventions. Finally, analyses were completed by a data analyst that was blinded to the group allocation. The experimental procedure is summarized in Figure 1.

(INSERT FIGURE 1 ABOUT HERE)

Exercise protocol

Three weeks before baseline assessments, a 10-repetition maximum (10-RM) lift was determined for each of the three exercises including; standing calf raising with dumbbell, standing calf rising with machine, and seated calf rising with machine. This was used to calculate predicted 1RM using the Wathen prediction equation.[30] The 10-RM represents the heaviest weight that an individual can successfully lift 10 times for a given exercise. If there were more than 10 successive repetitions, the participants would rest for a 15 minute before attempting the exercise with a heavier mass.

The main exercise protocol was preceded by a 5-min warm-up, including brisk walking on a treadmill followed by 12 repetitions of calf exercise at 50% of the predicted 1RM. After 2 minutes rest, the participants performed supervised exercise with moderate intensity (75% of 1RM). The intensity was based on recommendations (60 to 85% of 1RM) for older adults to increase muscle mass and strength.[31] The training session consisted of four sets of 10 reps of each exercise that represented a total volume of 120 repetitions. A 120 s rest interval was applied between sets. Rate of perceived exertion was assessed using 6-20 version of the Borg scale, where 6 means “no exertion at all” and 20 means “maximal exertion”.[32] Participants were asked to verbally rate their exertion within 5 minutes upon exercise session, with particular reference to their perceived exertion at the moment right before the end of the exercise.

Laboratory measurements

Perceived muscle soreness: Participants rated their perceived muscle soreness on a 10-cm visual analog scale, with 0 indicating no pain and 10 indicating extreme pain. Participants indicated their muscle pain during application of a 5-kg pressure by an algometer probe (Algometer Commander; J Tech Medical Industries Inc, Midvale, UT) with a 1.0-cm^2 area on the midline of the calf muscles, approximately 1/4 of the distance from the popliteus cavity to the calcaneal tubercle in the prone lying position. This method has been used successfully in previous studies to monitor changes in perceptions of pain following exercise. [33]

Fear of falling: Falls Efficacy Scale International (FES-I) is a 16-item self-report questionnaire providing information on level of concern about falls for a range of daily living activities.[34] Participants were asked to rate on a four-point Likert scale (1 = not at all; to 4 = very concerned) their concerns about the possibility of falling when performing these activities “how concerned you are about the possibility of falling”. Total score ranges from 16 to 64 points; higher values indicate less fall-related self-efficacy. Good validity and reliability were reported for FES-I in the older adults population.[34]

Balance: We used Timed Up and Go (TUG) test as a measure of dynamic balance. The TUG measures the total time (seconds) that a participant takes to rise from a chair, walk 3-m at a fast pace, turn around, walk back to the chair and sit down. Good reliability (inter-rater ICC =0.99 and intra-rater ICC=0.99) and validity (r=0.72) were reported for TUG test. [35] Static balance was measured by center of pressure (COP) oscillations using a force platform (Kistler type 9284, Kistler Instrumente AG, Winterthur, Switzerland). The participants stood barefoot with their heels aligned at a reference line under open eyes conditions while focusing on a target placed 2 m ahead and their arms on their sides. COP data were recorded at a rate of 100 Hz for 30 seconds. COP data were filtered using a zero-lag, fourth-order low-pass Butterworth filter with a cut-off frequency of 10 Hz (MATLAB R2009b; The MathWorks Inc, Natick, MA, USA). To assess body sway, we used 95% COP confidence ellipse area (mm^2).[36] For this parameter, a good test-retest reliability was reported (ICC=0.79) and coefficient of variation was 16.6%. Three trials were performed; the mean of these trials was calculated as COP sway and used for statistical analysis.

Joint position sense: An isokinetic dynamometer (Biodex System 4 pro; Biodex Medical Systems Inc, Shirley, New York, USA) was used to evaluate joint position sense (JPS) [33]. Participant seated on the chair with calf support, the hip in 90° flexion, the knee in 30° flexion, and talocrural joint in a neutral position (0°). Limb support pad was placed under distal femur of tested limb and secured with a strap. The participant's hands were placed on the armrests. First, the participant ankle joint was passively positioned at a 15° plantar flexion with a $10°\cdot s^{-1}$ angular speed. Target position was maintained for approximately 10 s to memorize. The participant was then asked to actively reproduce this target angle started from maximal dorsiflexion. Reposition error was defined as the difference between the target angle and the reposition angle. Participants were blindfolded to prevent visual feedback influencing test results. Three trials were performed and the mean of these trials, as a repositioning error, was used for statistical analysis. The dynamometer was considered a reliable (ICC = 0.99) and valid (ICC = 0.99) instrument for the measurement of angular position and peak torque.[37]

Muscle strength: To evaluate calf muscle strength, participants were positioned in the same manner in the aforementioned dynamometer. Prior to testing, the participants performed 3 submaximal contractions to become familiar with the isokinetic device. The maximal voluntary force was measured during a set of 3 isokinetic concentric contractions at $60°\cdot s^{-1}$ with 120 s rest between contractions This velocity was chosen because it approximates the average ankle joint velocity during walking.[38] A neutral ankle position of 0° (anatomical zero) was used as the starting point and the range of motion was defined as 20° of dorsiflexion to 30° of plantarflexion. Participants received verbal encouragement and visual feedback to reach the maximum torque. The peak torque from the 3 trials was used for data analysis.

Recovery interventions

All interventions were conducted within 5 minutes of variables being measured (Figure 1). CWI was applied at a temperature of 15±1° C controlled using a glass thermometer in water for a continuous time period of 15 minutes.[39, 40] During the immersion, participants sat on the chair immersing their lower legs (to the level of the knee) in the cold water; ice was added to the water if necessary. Participants were also asked to do circular movements with their legs every 2 minutes to prevent the formation of a warmer border layer around their skin.

Participants in the massage group received a 15-minutes standardized massage on the calf muscles area immediately after exercise protocol. [12, 41, 42] The same massage therapist, with five years' experience, performed the massage protocols. Western massage techniques such as effleurage, petrissage, and vibration were used.[42, 43] Each participant began massage protocol with 4 minutes of effleurage techniques including light stroking with the palm around the popliteal cavity, Achilles tendon, and over the calf muscles. Then, participants received 6 minutes petrissage techniques including kneading, circular two-handed lifting, and pressing of the calf muscles. Between the petrissage techniques, a 2-minute vibration was added and then finished with a 3-minute effleurage over the calf muscles. Participants in passive recovery group remained seated for 15 minutes and refrained from performing any additional exercises or stretches.

Statistical analysis

A priori power analysis with ANOVA repeated measures, within and between interactions (groups=3, assessment times = 4, and correlation among repeated measures = 0.5) was performed to determine appropriate sample sizes using G * Power (version 3.1.2). With an effect size (f) of 0.18, a 2-tailed significance level (α) of 0.05, and the desired power (1-β) of 0.90, a sample size of 63 with 21 participants in each group was needed. With an expected drop-out rate of 20%, we enrolled 26 participants in each group. The effect size (f) of 0.18 was set to detect 'small' differences.[40] We used SPSS software (version 18; SPSS Inc, Chicago, IL) for the statistical analyses. The Shapiro-Wilk test showed that data were normally distributed. A 3 group (massage, CWI and passive) ×4 time (baseline, 24 h, 48 h, and 72 h) mixed-model ANOVA was used to evaluate the main and interaction effects of variables. Post-hoc Bonferroni paired comparisons were conducted where appropriate. The effect size of the interventions was expressed using partial eta squared (ηp^2), with values of 0.01 to 0.059, 0.06 to 0.139, and $\geq$ 0.14 represented small, moderate, and large effects, respectively. To better understand the magnitude of between interventions comparisons Cohen's d_z was calculated with values of $\leq$ 0.19, 0.2-0.49, 0.50-0.80, and $\geq$ 0.81 representing trivial, small, medium, and large effects, respectively. The alpha-level was set at 0.05.

Results

All three groups were similar regarding age, height, body mass, and BMI after randomization and there was no difference in the training load and baseline measurements between groups (Table 1). Results showed main effects of time ($F_{1,75}$ = 800, p = 0.001, np^2 = 0.92), group ($F_{1,75}$ = 13, p = 0.001, np^2 = 0.26), and time × group interaction ($F_{1,75}$ = 7.5, p = 0.001, np^2 = 0.17) for DOMS. Follow-up comparisons showed that muscle pain was lower in the massage and CWI groups compared with the passive group at 48 h (42.4% versus 49.5%, d = 1.03, P = 0.001 and 41.4% versus 49.5%, d = 1.1, P = 0.001; respectively) and 72 h (19.9%

versus 30.3%, d = 1.47, P = 0.001 and 21.6% versus 30.3%, d = 1.18, P = 0.001; respectively) post-exercise (Figure 2A).

(INSERT TABLE 1 ABOUT HERE)

For fear of falling, there were main effects of time ($F_{1,75}$ = 128.5; *P* = 0.001; np^2 = 0.63) and group ($F_{1,75}$ = 8.9; *P* = 0.001; np^2 = 0.19) and time × group interactions ($F_{1,75}$ = 3.2; *P* = 0.01; np^2 = 0.08). Follow-up comparisons showed that fear of falling was higher in the passive group than the massage group at 24 h (18.2% versus 10.8%, d = 1.12, *P* = 0.001) and at 48 h (26.6% versus 24.1%, d = 0.83, *P* = 0.01). Also, fear of falling was higher in the passive group than the massage and CWI groups at 72 h (14.5% versus 5.2%, d = 1.37, *P* = 0.001 and 14.5% versus 4.8%, d = 0.81, *P* = 0.01, respectively) after the exercise protocol (Figure 2B).

There were main effects of time ($F_{1,75}$ = 399.8; *P* = 0.001; np^2 = 0.84) and time × group interactions ($F_{1,75}$ = 15.7; *P* = 0.001; np^2 = 0.29) for 95% COP confidence ellipse area. Follow-up comparisons showed that the sway area of COP was higher in the passive group than the massage group at 48 h (44.96 % versus 49.7%, d = 0.65, *P* = 0.04) and 72 h (42.3% versus 18.3%, d = 0.74, *P* = 0.02) after exercise protocol (Figure 2C). For TUG, there were main effects of time ($F_{1,75}$ = 346.8; *P* = 0.001; np^2 = 0.82) and group ($F_{1,75}$ = 3.6; *P* = 0.03; np^2 = 0.09) and time × group interactions ($F_{1,75}$ = 5.2; *P* = 0.004; np^2 = 0.12). Follow-up comparisons showed that the mean time score on the TUG test was higher in the passive group than the massage and CWI group at 48 h (18.2% versus 12.8%, d = 0.88, *P* = 0.01 and 18.2% versus 13.9%, d = 0.80, *P* = 0.01; respectively). However, at 24 h (13.6% versus 8.1%, d = 0.84, *P* = 0.01 and 72 h (5.5% versus 1.0%, d = 0.68, *P* = 0.01), it was only significant between passive group and massage group (Figure 2D).

Regarding ankle joint position sense, there were main effects of time ($F_{1,75}$ = 64.7; *P* = 0.001; np^2 = 0.46), group ($F_{1,78}$ = 5.3; *P* = 0.01; np^2 = 0.12), and time × group interactions ($F_{1,78}$ = 2.2; *P* = 0.04; np^2 = 0.06). Follow-up comparisons showed that passive recovery group had higher joint-position error at 24 h (40.0% versus 21.7%, d = 0.63, *P* = 0.02), 48 h (80.6 % versus 53.7%, d = 0.79, *P* = 0.01) and at 72 h (56.4% versus 29.1%, d = 0.74, *P* = 0.02) than massage group after the exercise. In addition, joint-position error was also higher for CWI participants than massage group at 24 h (45.3% versus 21.7%, d = 0.73, *P* = 0.04) and at 72 h (50.1% versus 29.1 %, d = 0.72, *P* = 0.03) (Figure 2E). For muscle strength at 60°·s^{-1}, there were significant main effects of time ($F_{1,78}$ = 89.5; *P* = 0.001; np^2 = 0.54) and time × group interactions ($F_{1,78}$ =

3.5; $P = 0.01$; $\eta p^2 = 0.08$). Follow-up comparisons for muscle strength showed that it was lower in the passive recovery than massage group at 48 h (36.1% versus 18.7%, d = 0.74, $P = 0.03$) and at 72 h (19.4 % versus 4.6%, d = 0.71, $P = 0.04$) after eccentric exercise (Figure 2F).

(INSERT FIGURE 2 ABOUT HERE)

Discussion

The aim of this study was to investigate the effects of massage and CWI on symptoms of EIMD, joint position sense, balance, and fear of falling following a damaging bout of calf muscle strengthening exercise in untrained older adults. Our study showed that muscle strength, joint position sense, and dynamic and static balance reduced and fear of falling increased immediately following a session calf muscle strengthening exercise in untrained older adults. The decreased muscular strength and increased soreness after the exercise protocol showed evidence that the protocol successfully induced muscle damage.

Proprioceptive input from the mechanoreceptors and fast low-force muscle contractions are required to maintain the center of gravity over the base of support by controlling static sway.[20] Our study showed that 24 h after EIMD there was joint position error, COP sway, and fear of falling for passive recovery group increased 40%, 35.7%, and 18.2%; respectively. The alterations of the proprioceptive afferents could disrupt postural reflexes, impair normal muscle coordination and timing and consequently lead to reduced balance and an increased fear of falling.[20] It has been proposed that after EIMD, the increased muscle stiffness and pain mechanically unload muscle spindles.[44] This can reduce passive discharge rates and lead to a mismatch in the targeted and adapted joint position. It has been suggested that a decrease in the ability to generate force in the lower-extremity muscles causes balance impairments and postural disturbances, risk factors for falling in older people.[2, 4] Therefore, a 21% reduction in plantar flexor muscles strength for passive recovery group 24 h after EIMD has relevance because of the importance of lower extremity muscle strength in joint position sense and balance in older adults. Therefore, reducing these negative effects could reduce the risk of falling and possible injuries that might ensue during daily activities.

This study results showed that the repeated massage attenuated muscle soreness, loss of proprioception, facilitated the recovery muscle strength, and alleviated the fear of falling, and balance impairments caused by EIMD in older individuals. Despite massage being a very popular intervention to help support exercise recovery, there is limited evidence for its use. However, in support of our data, a systematic review and meta-analysis suggested that massage after strenuous exercise could be effective for alleviating DOMS and improving muscle performance.[42] In addition, Kargarfard, Lam, Shariat, Shaw, Shaw and Tamrin [26] showed that a 30-min post-exercise massage increased perceived recovery, lowered soreness, and improved knee torque and vertical jump performance. In addition, some other findings demonstrate that massage for EIMD can improve ankle proprioceptive accuracy and muscle strength because of changes in the structural properties in superficial layer of the gastrocnemius.[12] Conversely, Zainuddin, Newton, Sacco and Nosaka [41] did not report any therapeutic effect of massage on the loss of muscle strength after EIMD, despite reducing muscle pain. The timing, duration, frequency, and type of message could have an important role in determining its effectiveness.[43] In the current study, we evaluated the effect of a 15- min repeat-bout massage protocol on the gastrocnemius muscle, while Zainuddin, Newton, Sacco and Nosaka [41] evaluated a single bout of 10- min massage on arm muscles. The longer duration and greater frequency of massage might explain the positive findings in the current study. Massage has been suggested to provide exercise-induced pain relief by reducing interstitial inflammatory mediators, edema, and muscle tension.[26, 27] Neural changes purportedly caused by massage are also believed to reduce muscular tension and the potential for spasm and pain.[45] The mechanical action of massage have been proposed to help restore the normal muscle fiber organization of the gastrocnemius, facilitate muscle function recovery, and improve muscle strength, [12] but the evidence to support this idea is not present. Massage might increase muscle compliance (less muscle stiffness)[27] and thereby improve the capacity of the musculotendinous unit to store elastic energy over a longer period,[46] which can improve physical performance of our study participants. In addition, decreased muscle stiffness after massage might alter the responses of proprioceptive receptors such as muscle spindles, and thus the joint position sense.[12] Pain relief and nociceptor activation after massage[12, 45] might promote communication from afferent receptors in the connective tissue and enhance the ankle joint proprioception. We speculate that these massage-mediated positive effects facilitate the recovery of post-exercise muscle strength and ankle joint proprioception thereby improving balance and postural control.

Regeneration of damaged muscle tissue can be affected by inflammatory responses to exercise.[47] It was hypothesized that the application of CWI could be beneficial for the recovery process through reducing and/or optimizing the swelling and inflammatory response.[22] However, in the current study repeated applications of CWI, despite relieving muscle pain, did not attenuate the loss of muscle strength, joint position senses, balance impairments, and fear of falling. This result is consistent with results from young athletes that showed CWI can only attenuate muscle pain and does not have an effect on the other measured variables.[25, 39, 40]

However, some studies have shown that CWI can accelerate recovery of strength loss after EIMD in younger, more athletic populations,[23, 24] which is inconsistent with our results. This discrepancy might be due to the repeated bout effect, whereby skeletal muscle in trained individuals is protected from prior exercise bouts, and hence the damage response is less; [48] conversely the current study examined the responses in untrained older adults that were more likely to experience a greater decrease in muscle strength and joint position sense than younger more athletic volunteers. Speculatively, these might be related to the age differences in muscle cytoskeletal integration or the age-related decrease in the number of motor units resulting in greater force per motor unit in older muscle. For example, there is some limited evidence that showed conditioned mice muscle display a lower proportion of damaged fibers than the unconditioned muscle. [49] However this study was conducted in rodents and it is not clear whether these figures translate to humans.

This is the first study investigating the effects of CWI on the measures of postural control and recovery from EIMD in older adults. Studies reported that CWI has the potential to diminish DOMS, which has be associated with reduced inflammatory response, oxidative damage, and enzymatic reactions.[39] An increase in hydrostatic pressure could help reduce edema and the formation of hematomas, muscle spasm and pain.[50] In addition, tissue cooling is associated with reduced nerve transmission, which could reduce the release of acetylcholine and possibly stimulate inhibitory surface cells to increase the pain threshold.[51] Lower body CWI can also lead to a clinically relevant reduction in muscle perfusion which is also thought to play a role in the recovery process.[39, 50] Collectively, it can be concluded that CWI is beneficial in alleviating perceptions of muscle pain following EIMD, although there is little other functional benefit for older adults.

Limitations

There are several limitations in the present study which should be acknowledged. Despite the request and confirmation that participants abstained from any supplements or medications, specific diet information was not collected, therefore recovery from exercise might have been influenced by diet. Although, the free-living nature of these participants provides greater external validity and applicability of the results to a wider population. In addition, participants were provided with a list of supplements and medicines with antioxidant and anti-inflammatory effects, but the compliance to this requirement could not be formally assessed beyond verbal confirmation, although non-steroidal anti-inflammatory drugs seem to have little or no effect on EIMD indices.[52] It is possible that a placebo effect occurred during the massage recovery and might explain the superiority of the massage in the alleviation of DOMS when compared to passive and CWI groups. Practically, people expect to have some effects of massage when they receive it, and psychological belief of a positive effect could help recovery. We did not include a placebo treatment, but sham treatments might be a good inclusion for future work.

Future directions

Lower extremity proprioceptive input and muscle strength are required to maintain the balance and redact the falling risk, especially in older adults.[20] Moderated mediation of this input could allow further understanding of the mechanisms involved in the increase in postural sway, reduce balance, and increased fear of falling after EIMD in older adults. Moderated mediation can provide a good test of this theory by determining if impaired lower extremity proprioceptive input and muscle strength influence the postural sway, balance, and fear of falling in a predictive way. Likewise a greater understanding of the proposed mechanisms of massage is warranted along with the potential of efficacy of placebo/sham treatments in abating signs and symptoms of EIMD.

Conclusion

Untrained older adults, after a session of plantar flexor muscle strength training that results to EIMD, experience decreased muscle strength, joint position sense, balance, and postural control and increased fear of falling. Repeated using of CWI after EIMD has some modest effects on muscle pain and had no effect on muscle strength, joint position sense, balance, and fear of falling. However, massage attenuated EIMD symptoms and the related impairments in muscle strength and joint position sense and be more effective for improving balance, reducing fear of falling in older adults.

Perspectives

Strength training is systematically used to attenuate and even reverse the debilitating effects of ageing on muscle characteristics and accompanying motor disorders. EIMD is one of the acute and temporary musculoskeletal outcomes following strength training that results in reduced muscle strength, power, flexibility [11, 12] and joint range of motion,[13] and impaired proprioceptive function.[11, 12] Since many older adults people have more potentially confounding factors than younger adults, [2, 5, 20] they are at greater risk of losing balance and postural control, thereby increasing the risk of falling. Thus, recommendations for older adults initiating strength training programs should consider those acute effects of different training regimens. This study showed that untrained older individuals experience decreased muscle strength, joint position sense, balance, and postural control and increased fear of falling after a session of plantar flexor muscle strength training. Although CWI has some modest effects on muscle pain, massage attenuated EIMD symptoms and the related impairments joint position sense. Thus, this research provides the basis for therapists and other practitioners to use massage, as part of their evidence-based armamentarium to accelerate recovery and critically, reduce exercise-induced balance loss and postural sway following damaging resistance exercise in older adults. Therefore, older exercisers who plan to participate in strength training can benefit from massage for recovery of balance to decrease falling risk during the days following strength training.

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Table and Figure Captions

Table 1. Demographic characteristics, training load and baseline measures for participants

Variables		**Massage Group (n=26)**	**CWI Group (n=26)**	**Passive Group (n=26)**	**p-value**
		Mean ± SD	**Mean ± SD**	**Mean ± SD**	
Age (y)		67 ± 4	67 ± 4	65 ± 3	0.10
Body mass (kg)		77.8 ± 6.1	79.5 ± 5.3	79.4 ± 6.3	0.49
Height (m)		1.69 ± 0.05	1.69 ± 0.05	1.70 ± 0.06	0.64
Body mass index (kg·m^{-2})		27.1 ± 2.0	27.9 ± 1.6	27.4 ± 2.1	0.31
Rating of perceived exertion		14.5 ± 1.3	14.4 ± 1.3	14.2 ± 1.2	0.62
Training load (kg)	**Standing calf raising with dumbbell**	11 ± 3	12 ± 3	12 ± 3	0.69
	Standing calf rising with machine	11 ± 2	12 ± 3	13 ± 3	0.11
	Seated calf rising with machine	15 ± 3	16 ± 2	16 ± 3	0.62

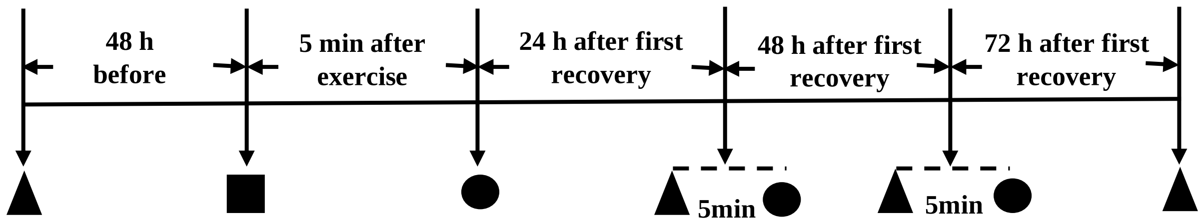

Figure 1. Timeline of study over 72 hours. Filled triangles (▲) represent assessments of outcomes including fear of falling, balance, joint position sense, and muscle strength. Filled squares (■) represent conduct of exercise protocol including 3 exercises with 4 sets of 10 reps with 75% of 1RM. Filled circle (●) represents application of recovery interventions (cold-water immersion, massage, or passive recovery).

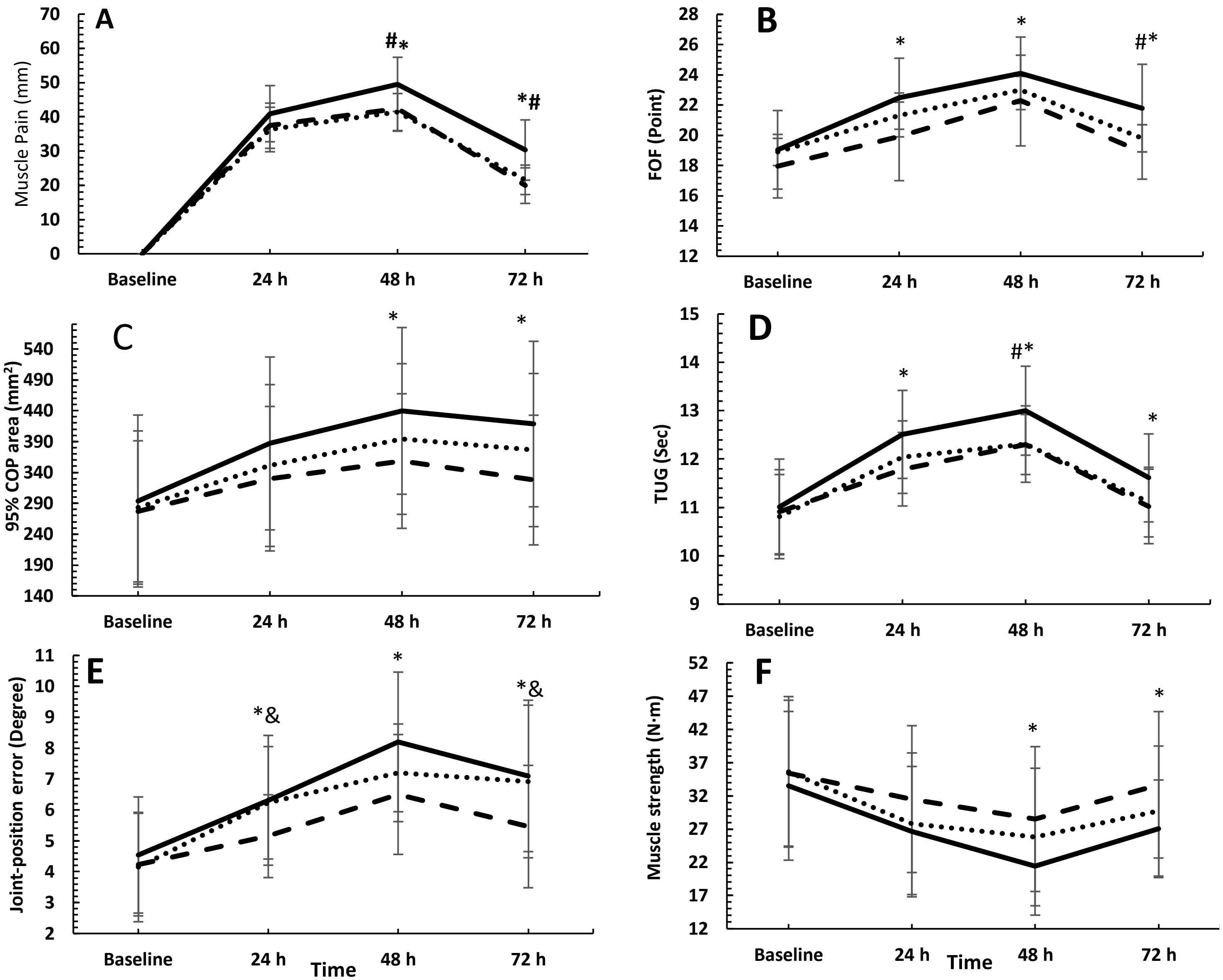
A
Muscle Pain (mm)
70
60
50
40
30
20
10
0
#*
*#
Baseline
24 h
48 h
72 h
B
FOF (Point)
28
26
24
22
20
18
16
14
12
*
*
#*
Baseline
24 h
48 h
72 h
C
95% COP area (mm2)
540
490
440
390
340
290
240
190
140
*
*
Baseline
24 h
48 h
72 h
D
TUG (Sec)
15
14
13
12
11
10
9
*
#*
*
Baseline
24 h
48 h
72 h
E
Joint-position error (Degree)
11
10
9
8
7
6
5
4
3
2
*&
*
*&
Baseline
24 h
48 h
72 h
Time
F
Muscle strength (N·m)
52
47
42
37
32
27
22
17
12
*
*
Baseline
24 h
48 h
72 h
Time

Figure 2. Changes in A) Muscle pain; B) Fear of falling; C) 95% COP confidence ellipse area; D) Time score of TUG; E) Joint-position error; and F) Muscle strength from baseline to 72 h after calf muscle strengthening exercise for – – – – Massage, · · · · · CWI, and —— Passive groups. These data are presented as the mean ± SD. * Significant difference between massage and passive groups at $P < 0.05$ and, $^{\#}$ Significant difference between CWI and passive groups at $P < 0.05$. $^{\$}$ Significant difference between CWI and massage groups at $P < 0.05$. **Abbreviations**: CWI; cold water immersion, FOF; Fear of falling, TUG; timed UP and GO, COP; center of pressure.