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Effect of Large Versus Small Range of Motion in the Various Intensities of Eccentric Exercise-Induced Muscle Pain and Strength

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ABSTRACT

International Journal of Exercise Science 14(7): 1-18, 2021. The purpose was to investigate eccentric (ECC) exercise with full range of motion (FROM) induce a greater magnitude of delayed onset muscle soreness (DOMS), pain, functional limitations compared to partial range of motion (PROM; outer 60° of ROM). Thirty-four participants (men and women) aged between 18 and 30 years performed ECC exercise protocol on elbow and knee muscles (5 × 10 repetitions each session) using their 15%/25%/35% of maximal voluntary isometric contraction (MVIC) with PROM (week 2-4) and FROM (week 6-8). Two days a week, ECC exercises and remaining days the subjective and objective assessments were carried out (activities of daily living (ADL), pain (visual analogue scale (VAS), pain pressure threshold (PPT)), and MVIC. The ECC exercise with FROM showed moderate pain (0-3.5) in ADL (pulling a heavy object and descending stairs), VAS, and PPT for elbow extensors and knee flexors and showed a statistically significant difference ($p \leq 0.05$) compared to PROM ECC protocol. The muscle strength was increased in FROM ECC exercise than PROM ECC exercise and ranged between 23.16% and 28.22%. ECC exercise performed with FROM induced a higher degree of DOMS, pain, ADL limitations than PROM. The study outcomes can be used for beginner sedentary older adults as well as young athletes.

KEY WORDS: Functional limitation, low intensity training, delayed onset of muscle soreness, maximal voluntary isometric contraction

INTRODUCTION

Exercise training (ET) is the most effective method for long-term increases in muscle strength and mass. However, acute effects of ET should be considered because individuals experience ET-induced muscle damage, that impairs activities of daily living (ADL) for a few days after exercise (27). Individuals can experience delayed onset of muscle soreness (DOMS) in varying degrees depending upon their level of fitness and type of exercise performed. Irrespective of the severity of DOMS, during the peak period of muscle soreness one may have pain when completing their regular activities.

The extent of muscle soreness may be due to many factors, such as repetition, exercise intensity, and type of muscle contraction (24). DOMS can occur from as few as 15 repetitions or gentle eccentric (ECC) loads for the untrained subjects (1, 11) and Madeleine et al. (20), on younger individuals, performed series of ECC muscle contractions of the elbow flexors and upper trapezius at high and low intensities and confirmed that greater intensity leads to greater soreness and pain. Lin et al. (19) investigated the magnitude and duration of the protective effect of low-intensity ECC contractions against damage. The results showed that low-intensity ECC contractions provided 30%-66% protection against damage induced by maximal ECC contractions of the knee flexors and extensors. The literature search confirms that ECC exercises performed at a greater intensity leads to greater muscle swelling, damage, pain, and soreness (3, 6, 36).

Several factors can affect the magnitude of ECC exercise-induced DOMS, but little is known regarding the effect of the range of motion (ROM) in ECC exercise-induced DOMS and pain (9). In the published literature search, we could find very few studies showed greater muscle soreness and pain after the ECC exercise with greater ROM compared to the ECC exercise with lesser ROM. The evidence suggests that joint ROM used during ECC exercise may also affect the muscle damage response (5, 10, 26, 28, 33). The available DOMS studies on a range of motion were performed on one or two groups of muscles (7, 25, 27, 34).

Older adults will have reduced ROM at the joints and have trouble performing ECC exercise on the full range of motion (FROM). A study by Fochi et at. (10) demonstrated that ECC of the elbow flexors with large ROM promoted a greater magnitude of muscle damage compared with a protocol with smaller ROM. The study's rationale is to create a safe exercise module for older individuals and individuals with some disabilities using younger individuals as a model. We hypothesize that individuals who complete lower intensity ECC exercise with partial range of motion (PROM) (60° of total ROM) will experience less DOMS, pain, and functional limitation compare to the individuals who complete moderate-intensity ECC exercise with full range of motion (FROM).

The present study was aimed to compare the effect of PROM and FROM in the low to moderate intensity ECC exercise induced DOMS, pain, functional limitations, and muscle strength (MVIC) on elbow and knee joints.

METHODS

Participants

Untrained, active, healthy, fourteen men and twenty women aged between 18 and 30 years were recruited from the University of New England (UNE) students (total of thirty-four). A power analysis conducted with Creative Research Systems (California, USA) determined that 34 participants were needed in the present study for the power of 0.80, with effect size of 0.5 and an $\alpha \leq 0.05$. Screening: To determine the eligibility of the research participants, health screening (height, weight, body mass index, blood pressure, and heart rate) was carried out and participant demographics are presented in Table 1. Inclusion criteria: (Participants were): An

untrained, active, healthy, man or woman (not involved in any kind of physical exercise protocols; involved in day to day regular activities), Between 18-30 years of age, and free of pain in the arms and legs. Exclusion criteria: Have had an injury in the arms and/or legs that caused a visit to a medical provider, high blood pressure (systolic > 130 or diastolic > 90), pregnant, diabetes (type 1 or type 2) and any nerve, muscle, or joint disorder**.** Participants performed their normal ADL during the testing period and refrained from consuming any anti-inflammatory drugs and nutritional supplements two hours before the exercise protocol and alcohol 12 hours before the exercise protocol. This study was conducted in the School of Biological Sciences Research lab 247 at Alfond Center for Health Sciences (ACHS) building and Campus Center Gym, University of New England (UNE), Maine, USA. Participants provided informed consent, the University of New England Institutional Review Board (IRB-20180508-004) approved the study, and research was carried out fully in accordance with the ethical standards of the International Journal of Exercise Science (23).

Table 1. Demographic characteristics of the participants.

Participants	Mean ± SD (standard deviation)
Age (years)	24.5 ±1.36
Height (cm)	176.4 ±6.46
Body weight (Kg)	66.30 ±7.37
Body mass index (BMI)	21.56 ± 2.23
Blood pressure (BP)	118/78 ± 4/3
Heart rate (HR)	85/min ± 10

Protocol

This study was carried out for the period of 8 weeks. Each week, research participants were called for six days where only two days (day 1 and day 4) performed ECC exercises and remaining days 2, 3, 5 and 6, the subjective and objective assessments were carried out by the investigators. Week 1 - pre-test screening, the familiarization session, and MVIC calculations were performed. Research participants performed ECC exercise protocol (5 ×10 Repetitions) with PROM (60° of total ROM) on elbow flexors, elbow extensors, knee flexors and knee extensors using 15% of MVIC in the first and fourth days of week 2, 25% of MVIC in the first and fourth days of week 3 and 35% of MVIC in the first and fourth days of week 4, whereas the research participants performed ECC exercise protocol with FROM using 15% of MVIC in the first and fourth days of week 6, 25% of MVIC in the first and fourth days of week 7 and 35% of MVIC in the first and fourth days of week 8. The subjective and objective assessments were performed to see the effect of ECC exercise protocol with PROM and FROM on the tested muscles and joints (ADLs, pain, and muscle strength) (Figure 1).

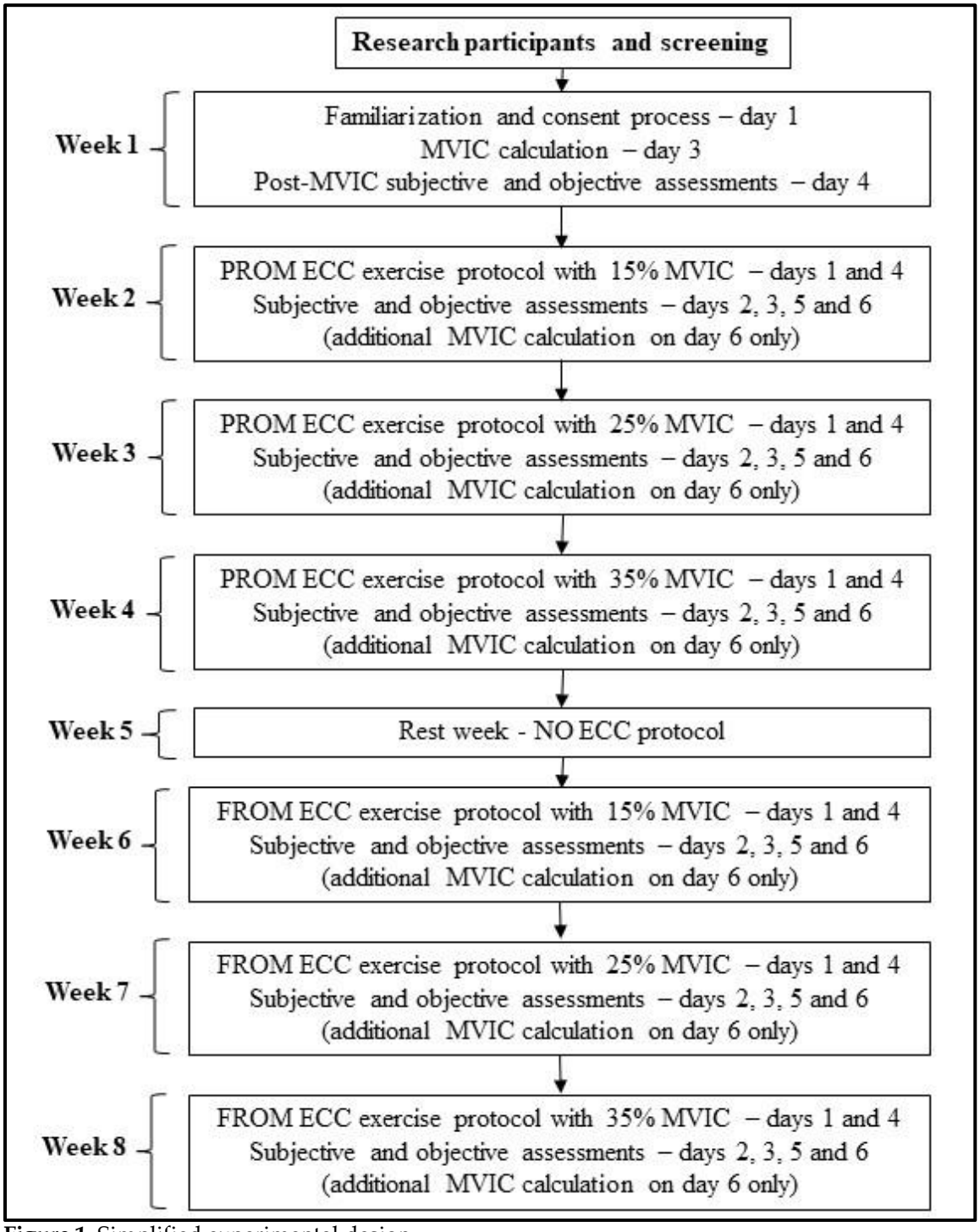

Figure 1. Simplified experimental design.

Familiarization: (week 1 – day 1 (visit 1)): The study procedure, associated risks that may arise due to their participation, and the benefit of this research project were explained to the research participants before obtaining written consent. The blood pressure (BP) was checked for every research participant at the beginning of each exercise session. Participants were instructed step by step to do MVIC and eccentric (ECC) strengthening exercises in four of their muscle groups

(elbow flexors, elbow extensors, knee flexors, and knee extensors). The participants completed a strength testing protocol (MVIC) in all four selected muscles in pounds (lbs.) using a hand-held dynamometer (Lafayette Instrument, Manual Muscle Testing (MMT) Device, Pro-Health Care, USA) for four positions: 1) Elbow flexion at 90 degrees; 2) Elbow extension at 90 degrees; 3) Knee flexion at 90 degrees; and 4) Knee extension at 90 degrees (Figure 2). Proper physical education, positioning, and support were given to all the research participants. MVICs were carried out during familiarization session for the week 2 PROM ECC exercise protocol with 15% MVIC and first day of every week in weeks 3, 4, 6, 7, and 8 for the remaining weeks ECC exercise protocol. Since there is no ECC exercise protocol for week 5, there is no MVIC calculation. Depending on the visit, 25% or 35% of MVICs were calculated for each muscle group. The dynamic adjustable ROM controlled elbow and knee joint splints (T Scope® Elbow Premier (07254) and T Scope® Premier Post-Op Knee Brace (08814), BREG, USA) were used to limit the partial ROM (60° of total ROM – the outer range of motion) while performing ECC protocols with PROM. We did not use any splint or external devices while performing ECC protocols with FROM.

Figure 2. The MVIC testing positions of elbow flexors, elbow extensors, knee flexors and knee extensors. MVIC - maximal voluntary isometric contraction

The research participants performed ECC exercises using all four limbs (right and left elbows and right and left knees), the four muscle groups selected for this study. The research participants performed eccentric exercise on one muscle group per limb at a time and each limb individually with set rest time. The participants were divided into two groups. The first group performed ECC exercises on the dominant upper limb and non-dominant lower limb. The

second group performed ECC exercises on the non-dominant upper limb and the dominant lower limb Ultimately Fit Adjustable Ankle Weights (Hayneedle Company, USA) and dumbbells were used for resistance during the ECC exercise protocols with PROM and FROM. Baseline DOMS assessment after MVIC testing: (week 1 – day 4 (visit 3)) After 24 hours of familiarization, the assessment of the ADL, active range of motion (ROM) at elbow and knee, DOMS, and pain were carried out. Subjective assessments:

a. Health activities of daily living (ADL) difficulty scale - The following questions were asked. The pain scale ranged from 0 (no pain) to 10 (worst pain). For elbow: 1. Combing hair, 2. Eating with a fork or spoon, 3. Pulling a heavy object, 4. Using arm to rise from a chair, 5. Carrying an object above the shoulder, 6. Putting on shirt/coat, 7. Washing opposite armpit and back For knee**:** 1. Getting in and out of car, 2. Walking on the flat ground, 3. Ascending stairs, 4. Descending stairs, 5. Getting in and out of bed, 6. Bending to pick up from the floor.

b. Visual Analog Scale (VAS): The level of muscle soreness was quantified using an 11 points VAS in which 0 indicated "no pain" and 10 represented "extreme pain". The participants were asked to mark the level of perceived soreness on the VAS when the elbow flexors, elbow extensors, knee flexors, and knee extensors are palpated in a circular motion by the investigator. The palpating points are mid-belly of the biceps brachii, mid-belly of triceps brachii, mid-upper anterior thigh and mid-upper posterior thigh. Each site was palpated twice, slowly, in 5 circular movements by the same investigator using his/her index and middle fingers for approximately 3 seconds. One measurement was taken from each site with 10-second intervals between measurements. All measurements were taken by the same investigator throughout the experiment.

c. The DOMS was assessed by asking the participants to perform the movements at the elbow and knee joints (flexion for extensors and extensors for flexors) and pain level was recorded based on the verbal response of the participants. Both VAS and DOMS were recorded.

Objective assessment: a. Pressure Pain Threshold (PPT): PPT is the minimum amount of force that can be applied to induce pain, that was measured using an electronic algometer (Baseline 60-pound Dolorimeter/Algometer Pain Threshold Meter, Pro-Health Care, USA). The probe head of the algometer [area of 1.0 cm^2] was placed [the same sites as the palpation muscle soreness measures by VAS] and pressed against the tester in a vertical direction while increasing the force at a constant rate of 1 kg/cm^2 until the research participant reports the first feeling of noticeable pain of the muscle.

Eccentric (ECC) Exercise Protocol with PROM and FROM: ECC exercise protocol for the elbow flexors and extensors – At comfortable position (Figure 3 and 4), **f**or the ECC exercise protocol with PROM (weeks 2-4), the dynamic adjustable ROM controlled elbow and knee joint splints were used whereas ECC exercise protocol with FROM (weeks 6-8) was performed without using splints. The calculated elbow and knee flexors or extensors, 15%, 25% or 35% of MVIC was attached to the research participant's wrist and ankle using adjustable ankle weights and facilitated the PROM and FROM ECC exercise protocols (Figure 3 and 4).

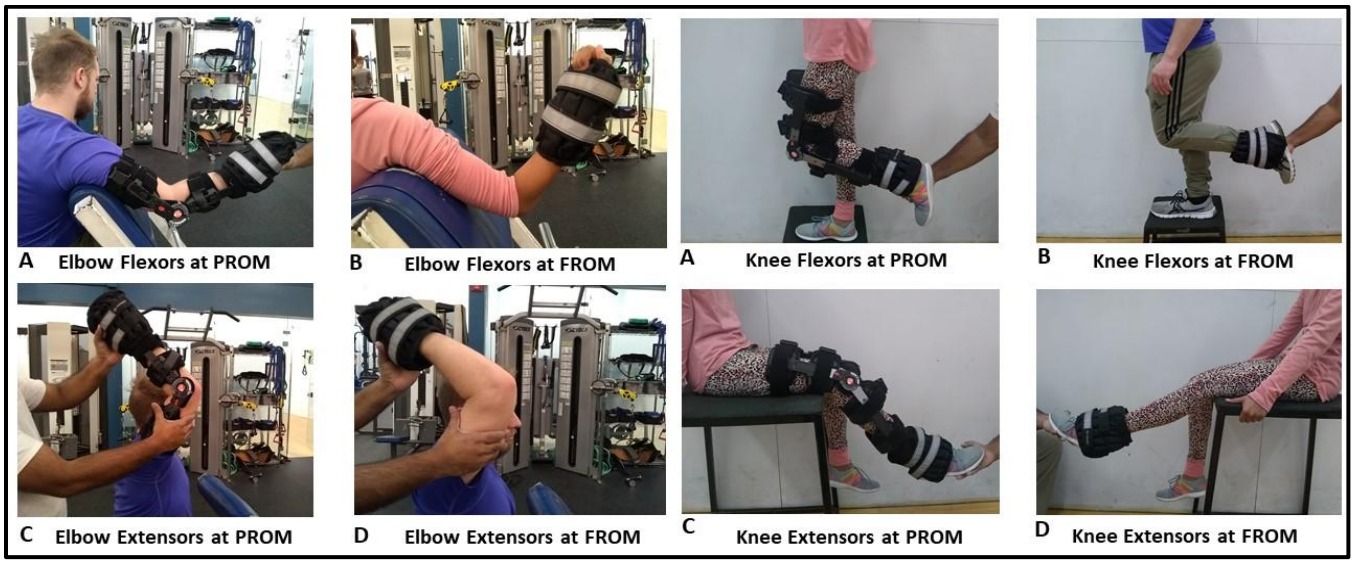

Figure 3. PROM and FROM elbow eccentric exercise positions. PROM – partial range of motion, FROM – full range of motion.

Figure 4. PROM and FROM knee eccentric exercise positions. PROM – partial range of motion, FROM – full range of motion.

ECC Exercise Protocol: week 2 – day 1 and 4 (visits 4 and 7) - After 72 hours of baseline DOMS assessment, participants were introduced to ECC exercise on day 1 and 4 (5 sets of 10 repetitions for all four muscle groups) at PROM (60° of total ROM - outer range of motion) with calculated 15% of MVIC. Post- ECC Exercise assessment: week 2 – day 2, 3, 5 and 6 (Visits 5, 6, 8 and 9) After every ECC exercise protocol, the subjective and the objective assessments were carried out for 48 hours to see the functional impairment involving elbow and knee joints. Immediately after visit 9, the muscle strength (MVIC) was calculated for all four muscle groups and 25% MVIC was calculated for the week 3 ECC exercise protocol.

ECC Exercise Protocol: week 3 (visits 10-15) – After 24 hours of MVIC testing and calculation, week 3 ECC exercise protocol with PROM was performed which was like week 2 except for the change in the percentage of MVIC (25%). MVIC was calculated for the week 4 ECC exercise protocol (35% of MVIC).

ECC Exercise Protocol: week 4 (visits 16-21) – After 24 hours of visit 15, week 4 ECC exercise protocol with PROM was performed which was like week 2 or 3 ECC protocol except for the change in the percentage of MVIC (35%).

Week 5: Participants did not perform ECC exercise protocol (resting week).

ECC Exercise Protocol: week 6 – day 1 and 4 (visits 22 and 25) – Before 24 hours of week 6-day 1 ECC exercise protocol, the muscle strength (MVIC) was calculated and 15% MVIC was calculated for the week 6 ECC exercise protocol. The elbow and knee splits were not used. participants were introduced to ECC exercise on day 1 and 4 (5 sets of 10 repetitions for all four

muscle groups) at FROM with calculated 15% of MVIC. Post- ECC Exercise assessment: week 6 – day 2, 3, 5 and 6 (Visits 23, 24, 27 and 28) After every ECC exercise protocol, the subjective and the objective assessments were carried out for 48 hours. Immediately after visit 27, MVIC was calculated for the week 7 ECC exercise protocol (25% of MVIC).

ECC Exercise Protocol: week 7 (visits 28-33) – After 24 hours of MVIC testing and calculation, week 7 ECC exercise protocol with FROM was performed which was like week 6 ECC protocol except for the change in the percentage of MVIC (25%). MVIC was calculated for the week 8 ECC exercise protocol (35% of MVIC).

ECC Exercise Protocol: week 8 (visits 34-39) – After 24 hours of visit 33, week 8 ECC exercise protocol with FROM was performed which was like week 6 or 7 ECC protocol except for the change in the percentage of MVIC (35%). Along with the post ECC exercise assessment, the MVIC was calculated for all four muscle groups.

All the above ECCs were performed with slow speed. For an ECC at FROM, the participant can take up to 3 sec. The same procedure can be repeated 50 times. After every 10 ECC repetitions, there was a 60 sec rest period given to all the participants.

Statistical Analysis

Statistical analysis was carried out using GraphPad Prism software (version 8.2.0), San Diego, CA. The repeated measures one-way ANOVA with Tukey's multiple comparison tests were carried out to compare the mean PPT, VAS and ADL pain between the PROM and FROM ECC protocols. Statistical significance was set an alpha level at $p \leq 0.05$.

RESULTS

The baseline DOMS assessment after MVIC testing (week 1) did not show any notable pain in the subjective (health activities of daily living (ADL) difficulty scale and VAS and objective (PPT), and MVIC assessments. We compared PROM ECC protocol (weeks 2-4) pain with FROM ECC protocol (weeks 6-8) pain. The level of muscle pain was quantified using 11 points in which 0 indicated "no pain" and 10 represented "extreme pain".

The mean pain level of each week's ADL is shown (Figure 5). Among all eight weeks of ECC exercise protocol, the maximum of moderate pain (pain level 3.5) was felt at week 8 (FROM ECC exercise). Pulling a heavy object, and descending stairs activities pain level was mild (pain level 1) at week 4 of 35% of MVIC PROM ECC exercise and moderate (pain level 3.5) at week 8 of 35% of MVIC FROM ECC exercise and did show a statistically significant difference [mean difference (95% CI) of 2.4 (1.5, 3.31), P = 0.0156] between them (Figure 5). Mean values of other ADL activities pain level did not show any statistically significant difference between PROM and FROM ECC exercise weeks.

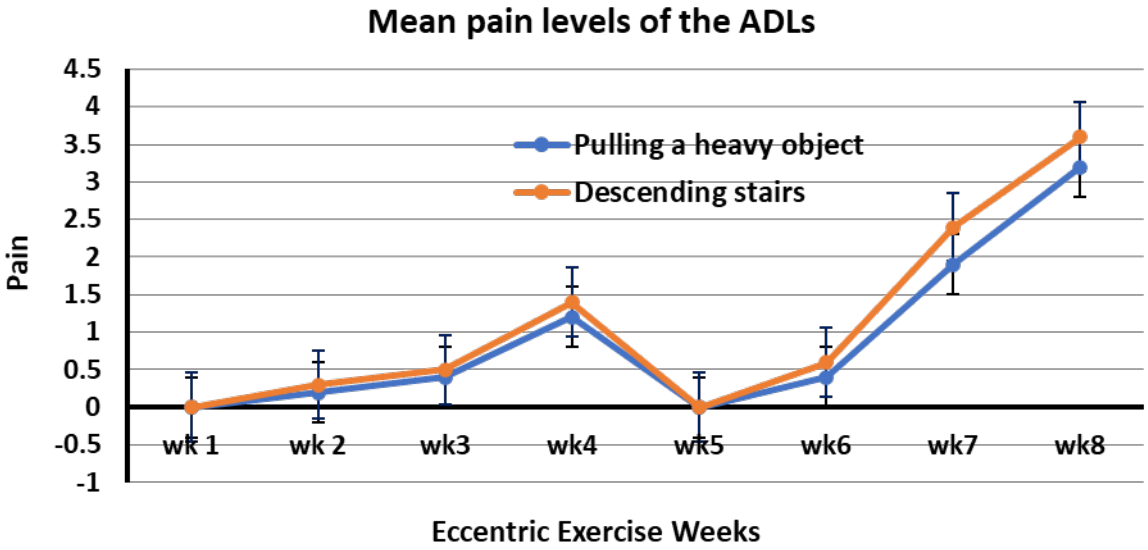

Figure 5. Mean pain level report on assessment of activities of daily living (ADLs) questionnaires.

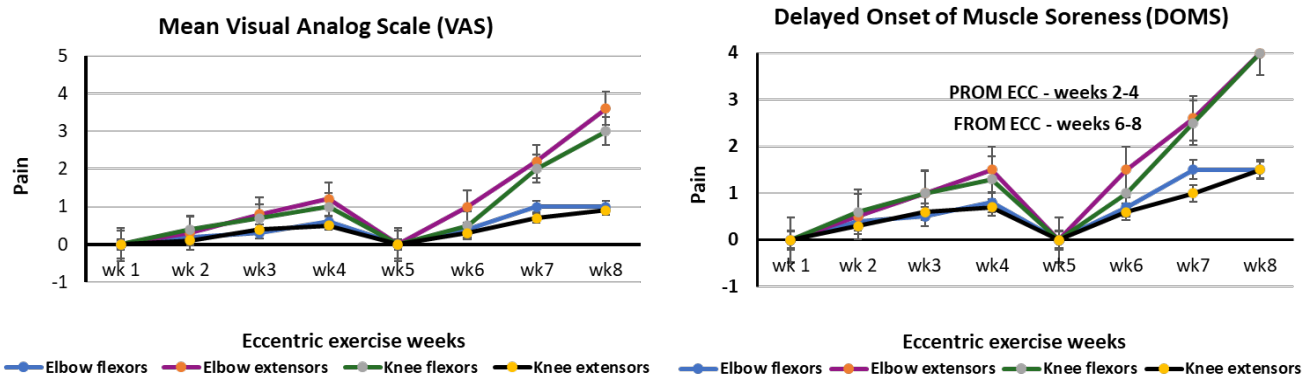

Figure 6. Mean visual analog scale (VAS) and delayed onset of muscle soreness (DOMS) (A-B) at PROM (week 2-4) and FROM (week 6-8) eccentric exercise protocol. PROM – partial range of motion, FROM – full range of motion.

The mean VAS and DOMS are shown (Figure 6). The muscle soreness was assessed by asking the participants to perform the movements at elbow and knee joints. Elbow flexion movement for elbow extensors [mean difference (95% CI) of 0.9 (0.49, 1.28), P = 0.126] and knee extension [mean difference (95% CI) of 0.75 (0.35, 1.15), P = 0.131] movement of knee flexors showed slightly higher pain than VAS palpation values and did not show any statistically significant difference. Elbow extensors (mid-point of triceps) pain level was mild (pain level 1) at week 4 of 35% of MVIC PROM ECC exercise and moderate (pain level 3.5) at week 8 of 35% of MVIC FROM ECC exercise and did show a statistically significant difference [mean difference (95% CI) of 2.2 (1.3, 3.1, P = 0.0091] between them. Knee flexors (mid-posterior thigh) pain level was mild (pain level 0.75) at week 3 of 25% of MVIC PROM ECC exercise and moderate (pain level 3) at week 7 of 25% of MVIC FROM ECC exercise and did show a statistically significant difference [mean difference (95% CI) of 1.6 (1.10, 2.10), P = 0.0157] between them. Elbow extensors did show a maximum pain (pain level 3.5) at week 8 of FROM ECC protocol. Mean

values of elbow flexors [mean difference (95% CI) of 0.6 (0.25, 0.94), P = 0.092] and knee extensors [mean difference (95% CI) of 0.5 (0.3, 0.7), P = 0.104] pain levels did not show any statistically significant difference between PROM and FROM ECC exercise weeks (Figure 6).

The highest mean PPT for the mid-belly of triceps brachii (pain level 1.7) was measured in FROM ECC exercise (35% of MVIC) at week 8 and lowest mean PPT (pain level 4.7) was in PROM ECC exercise (35% of MVIC) at week 4. The moderate mean PPT was experienced on mid-belly of the triceps brachii for the FROM ECC exercise (35% of MVIC) at week 8 when compared with PROM ECC exercise (35% of MVIC) at week 4 and did show a statistically significant difference [mean difference (95% CI) of 2.03 (1.13, 2.93), P = 0.0305] (Figure 7A). The moderate mean PPT (pain level 2) was also experienced on mid-upper posterior thigh for the FROM ECC exercise (35% of MVIC) at week 8 when compared with PROM ECC exercise (35% of MVIC) at week 4 (pain level 7) and did show a statistically significant difference [mean difference (95% CI) of 3.67 (1.47, 5.87), P = 0.0253] between them (Figure 7B). PPT of mid-belly of the biceps brachii [mean difference (95% CI) of 4.8 (3.1, 6.5), P = 1.245] and mid-upper anterior thigh [mean difference (95% CI) of 4.9 (3.2, 6.6), P = 1.642) mean values showed minimal pain and did not show any statistically significant difference between PROM and FROM ECC exercise weeks. Both VAS and PPT results showed that elbow extensors with FROM ECC protocol at week 8 had moderate pain compared to elbow flexors, knee flexors, and knee extensors.

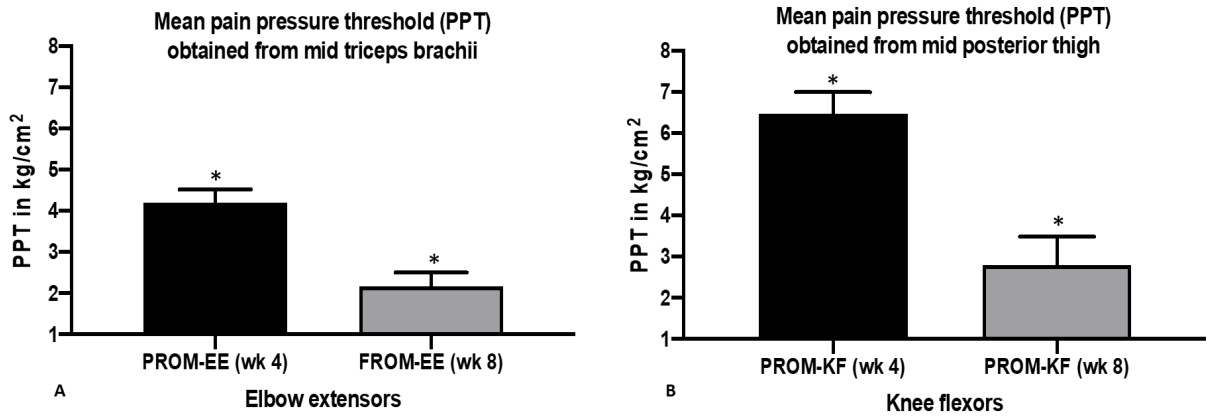

Figure 7. Mean pain pressure threshold (PPT) of mid triceps brachii (A) and mid posterior thigh (B) comparison between PROM and FROM eccentric exercise protocols. PROM – partial range of motion.; FROM – full range of motion.

Elbow flexors, elbow extensors, knee flexors, and knee extensors MVICs were calculated to all the participants before starting the ECC exercise protocol (pre-ECC protocol; after week 1), after completing PROM ECC exercise protocol (after week 4) and, after completing entire study i.e. FROM ECC exercise protocol (after week 8) and were compared using repeated measures one-way ANOVA with Tukey's multiple comparison test (Figure 8). The MVIC mean values, mean difference (MD), mean percentage increase for each muscle group and p-value are presented (Table 2). This comparison was to quantify the overall improvement of muscle strength at the end of the study. After completing the PROM ECC exercise protocol (after week 4) and FROM ECC exercise protocol (after week 8), the MVIC values were high in all four muscle groups. After

three weeks of PROM ECC exercise protocol (after week 4), the mean MVIC values were high when compared with pre-ECC MVIC values (week 1) and showed statistically significant differences [mean difference (95% CI) of 8.02 (3.72, 12.32) lbs, P = 0.0053] between them in all four muscle groups. After completing entire study i.e. FROM ECC exercise protocol (after week 8), the mean MVIC values were high when compared to both pre-ECC (week 1) and PROM ECC (after week 4) MVIC values and showed statistically significant differences [mean difference (95% CI) of 12.32 (7.71, 16.93) lbs, P = 0.0084] between them in all four muscle groups.

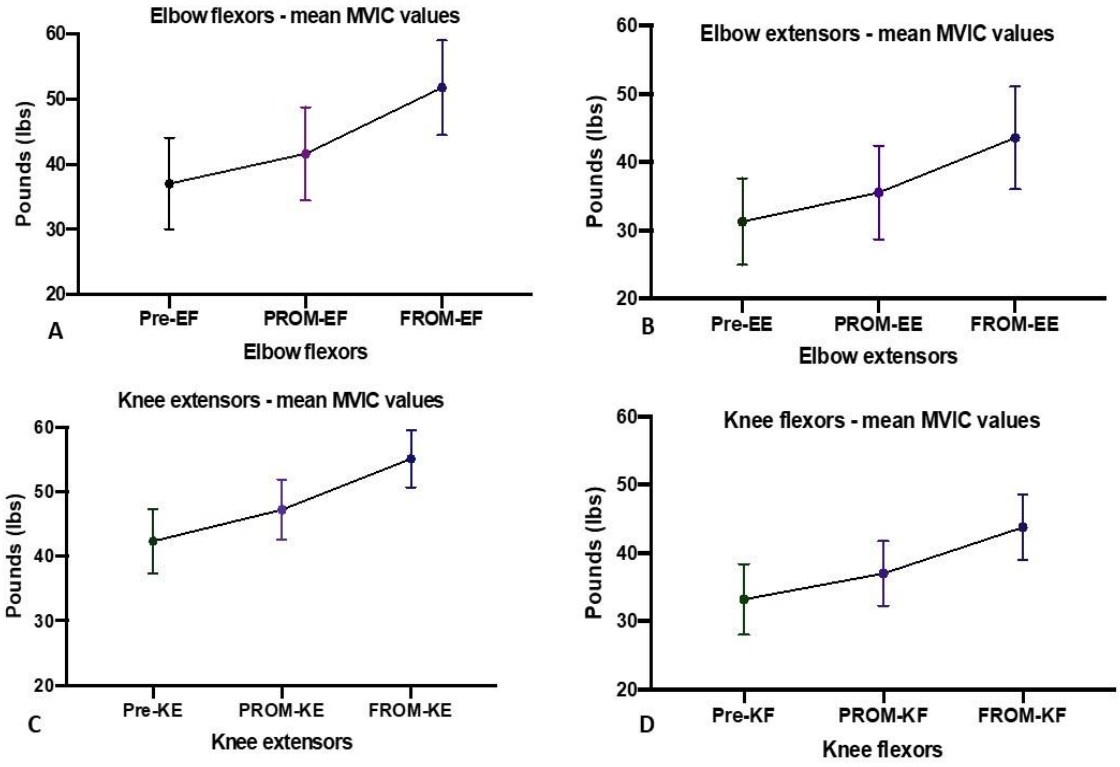

Figure 8. Pre, PROM and FROM MVIC mean values comparison in the elbow flexors, elbow extensors, knee flexors and knee extensors. Pre – MVIC value before starting the exercise protocol; PROM – MVIC value after completing partial range of motion exercise protocol (after 4th week); FROM – MVIC value after completing full range of motion exercise protocol (after 8th week). MVIC - maximal voluntary isometric contraction, PROM – partial range of motion, FROM – full range of motion.

After the PROM ECC protocol (weeks 2-4), MVIC values were increased between 11.43 and 13.65% whereas after FROM ECC protocol (weeks 6- 8), MVIC values were increased between 16.67 and 23.80%. The MVIC values were increased in FROM ECC protocol when compared with PROM ECC protocol. The overall percentage of increased MVIC value at the end of the study was between 23.16 and 28.22%.

Table 2. MVIC comparison between Pre-ECC Protocol, PROM ECC Protocol and FROM ECC Protocol using repeated measures one-way ANOVA with Tukey's multiple comparison test.

	Pre-ECC MVIC mean (lbs)	Pre-ECC MVIC vs PROM ECC MVIC			PROM-ECC MVIC mean (lbs)	PROM-ECC MVIC vs FROM ECC MVIC			FROM-ECC MVIC mean (lbs)	Pre-ECC MVIC vs FROM ECC MVIC		
		MD	Mean percentage increase in MVIC	p value		MD	Mean percentage increase in MVIC	p value		MD	Mean percentage increase in MVIC	p value
Elbow flexors (EF)	37.03	4.58	12.36 %	0.008	42	10	23.80 %	0.011	52	14.77	28.04 %	0.040
Elbow extensors (EE)	31.28	4.27	13.65 %	0.010	35.55	8.02	22.55 %	0.004	43.58	12.3	28.22 %	0.023
Knee flexors (KF)	42.33	4.88	11.52 %	0.007	47.21	7.87	16.67 %	0.010	55.09	12.76	23.16 %	0.013
Knee extensors (KE)	33.22	3.8	11.43 %	0.014	37.02	6.75	18.23 %	0.009	43.77	10.55	24.10 %	0.008

PROM – partial range of motion, FROM- full range of motion, MVIC - maximal voluntary isometric contraction, MD – mean difference, ECC – eccentric contraction

DISCUSSION

To the best of our knowledge, this is the first study designed to compare the effect of PROM (outer 60° of total ROM) and FROM in the low to moderate intensity ECC exercise-induced DOMS, pain, functional limitations and muscle strength (MVIC) on elbow flexors, elbow extensors, knee flexors, and knee extensors. In summary, our findings confirmed the initial hypothesis that individuals who completed moderate-intensity ECC exercise with FROM experienced higher DOMS, pain, muscle strength and functional limitation compared to lower intensity ECC exercise with PROM.

Participants' characteristics, like gender, age, physical fitness, exercised muscle group (lower vs. upper limb), type of exercise (e.g., single joint vs. multi-joint exercises), type of muscle contraction (e.g., concentric vs. eccentric), contraction velocity, exercise intensity or load, and number of repetitions are variables that can affect the magnitude of DOMS, pain, and muscle strength (5, 7, 8, 12, 14, 16, 25, 27, 30, 31). In our study, each subject performed a similar ECC exercise for the upper limb (elbow flexors and extensors) and lower limb (knee flexors and extensors), with a controlled ROM (PROM for the weeks 2-4 and FROM for the weeks 6-8), exercise intensity (15%/25%/35% of MVIC) and a standard training volume (5 sets of 10 repetitions; weekly 2 days) for the period of 8 weeks.

Previously published study showed that the higher intensity (ranged from 50% to 140% of MVIC) ECC exercise caused more muscle damage and, more pain they feel (11). The lower intensity ECC exercise group did 30 reps at 10% MVC 48 hours before the eccentric training bout. Meaning that light ECC not only grows the muscle but keeps it from hurting as well (22). The published studies suggested that lower intensity, longer-term exercise may reduce the effect of DOMS and pain on the muscles and protective effect on the muscle (19, 22, 35). Our study's ECC intensities ranged between mild to moderate (15%/25%/35% of MVIC). The PROM ECC exercise protocol with 15% (week 2) and 25% (week 3) of MVIC load did not show DOMS and pain in all tested (elbow and knee) four muscle groups whereas, FROM ECC exercise protocol with 25% (week 7) and 35% (week 8) of MVIC load did show DOMS and pain on the elbow extensors and knee flexors only.

VAS and PPT can be used as pain level measuring tools that can help to limit the exercise without feeling extreme pain while performing exercise protocol (17, 18). Lau et al. (17, 18) studies induced DOMS by performing sets of 6 maximal eccentric contractions of the elbow flexors and measured for muscle pain using VAS) and PPT and claimed that both VAS and PPT should be used when attempting to pain map DOMS, and determine a pain threshold. Our study results showed that ECC exercise with FROM (35% of MVIC; week 8) showed moderate pain (3+) in the VAS, DOMS, PPT and ADL assessments (pull a heavy objects and descending stairs) on elbow extensors and knee flexors whereas, ECC exercise with PROM (35% of MVIC; week 4) showed minimal or no pain in the assessments. Results of the upper and lower limb ADL questionnaire showed that elbow extensors and knee flexors perceived mild pain (0-1.4) at PROM ECC exercise whereas moderate pain (3.2-3.6) at FROM ECC exercise. In our study, DOMS was assessed by asking the participants to perform the movements at the elbow and knee joints (flexion for extensors and extensors for flexors) and pain level was higher than VAS. Our results reported here agree with Nosaka and Sakamoto (28), who reported that extension triggers greater muscle soreness in the flexors than local palpation (VAS), and soreness response is high for muscles ECC exercised with FROM. The current study is in the agreement of the previously published report on FROM induces high DOMS and pain compared to PROM.

Talbot and Morgan (32) observed a strong correlation between exercise through greater ROM and greater muscle damage in the animals. In humans, limited studies have investigated the effect of PROM and FROM on the magnitude of muscle pain and DOMS (10, 26, 28, 33). Kachanathu et al. (15) conducted a study on knee extensors with ECC contractions at 75% ROM, 50% ROM and 25% ROMs. This study result showed that in a group of men age approximately 25 years who performed ECC exercise with 25% of ROM did not feel DOMS and pain. Vaczi et al. (33) studied at two different total ROMs (20-80° vs 10- 130°) using 6 sets of 15 knee ECC exercises and their results showed high-intensity, ECC exercise training at large ROM may induce greater muscle damage and force deficit, than training at small ROM. The final phase (outer part) of ROM developed in the ECC is reported to be very important for inducing muscle damage in DOMS (28). Vaczi et al. (33) study did not conduct the ECC exercise protocol at the final phase of ROM at the knee. In Nosaka and Sakamoto (28) study, students performed 24 maximal ECC of the elbow flexors at the elbow joint angle from 50-130 degrees (inner ROM of 80°) and the other arm at the elbow joint angle from 100-180 degrees (outer ROM of 80°). The

results showed that greater muscle damage in the elbow joint angle from 100-180 degrees (outer ROM of 80°) compared with the angle from 50-130 degrees (inner ROM of 80°). The same authors also demonstrated with a ROM of 50° greater magnitude of muscle damage for the large angle condition (100° to 180°) compared to the small angle condition (50° to 130°) (Nosaka et al., 26). Although muscle damage is greater when ECC begins with elbow flexors more stretched (i.e., large angle, 130-180°), little is known about whether a larger ROM of ECC promotes an even greater magnitude of muscle damage in humans. Fochi et al. (10) performed an ECC exercise study of the elbow flexors on twelve healthy young men. His study concluded that participants performed with 120° of ROM (from 60° of elbow flexion until elbow full extension – 180°; long outer ROM) had a greater magnitude of muscle pain and DOMS compared with 60° of ROM ((120-180° of elbow flexion; short outer ROM) even when both protocols were performed at long muscle lengths. So, smaller ROM ECC exercise protocol reduced the level of muscle soreness and pain. In the published literature, DOMS and pain studies with PROM and FROM were performed on one group of muscles (elbow flexors, or knee extensors) (10, 13, 17, 28, 33). The DOMS studies with PROM and FROM on one or two muscle groups and evaluating pain levels and ADL activities may not be enough to draw the conclusion. Because different types of muscle fibers are present in the upper and lower limbs. Our study participants performed the final phase of PROM and FROM ECC exercise protocols on upper limbs (flexors and extensors of the elbow) and lower limbs (flexors and extensors of the knee) muscle groups that are prone for the DOMS. Our results agree with previous reports, FROM exercise seems to promote higher muscle pain and DOMS, even though with similar intensity compared with PROM exercise in both elbow and knee joints.

Studies have reported that ECC exercise with ROM (partial and full) can cause strength falls in the post-exercise days due to pain and soreness (2, 27). Baroni et al. (2) study showed that muscle strength during FROM ECC exercise falls around 23–29% throughout post-exercise days (24-72 h), whereas the PROM ECC exercise presented falls ranging between 9 and 22% in the same period. Baroni et al. (2) concluded that elbow flexion exercise with FROM seems to induce greater muscle damage than PROM exercises. Bloomquist et al. (4) compared the effects of squat training with a short vs. a long range of motion and concluded that training with long ROM squats elicited favorable adaptations on knee extensor muscle strength and function compared to training with short ROM shallow squats. McMahon et al. (21) study on resistance training results showed that greater morphological and adaptations in the long ROM exercise result in a more significant increase in strength compared with that of the low ROM. Pinto et al. (29) compared partial range-of-motion vs. full range-of-motion upper-body resistance training on strength in young men and suggested that muscle strength was improved with both FROM and PROM resistance training, but FROM lead to greater strength gains. In our study, elbow flexors, elbow extensors, knee flexors, and knee extensors MVICs were calculated after week 1, week 4, and week 8 and compared to see the difference between PROM and FROM ECC protocols. We did not calculate muscle strengths (MVICs) on post-ECC exercise assessment days. The PROM ECC exercise (weeks 2- 4) increased the muscle strength (MVIC) between 11.43 - 13.65% and the FROM ECC exercise (weeks 6- 8) increased the muscle strength between 16.67 - 24.16% with overall muscle strength gain at the end of the study (after 8 weeks) was 23.16 - 28.22%. Our study results show that FROM ECC exercise with 35% of MVIC increased the muscle strength

compared to PROM ECC exercise with 35% MVIC and supported by the previous studies (4, 21, 29).

This study design is limited to two upper limb and two lower limb muscle groups only. In the future studies, we will try to perform more muscle groups involving back and neck muscles with more sample size.

Both PROM and FROM ECC exercise protocol increased muscle strength in elbow flexors, elbow extensors, knee flexors, and knee extensors. The muscle strengths were increased by the FROM ECC exercise compared to the PROM ECC exercise. During ECC exercise with FROM, moderate DOMS, pain, ADL limitations were noted on elbow extensors, and knee flexors than elbow flexors and knee extensors. Elbow flexors and knee extensors were not much affected by the DOMS and pain. This may be due to the type of skeletal muscle fibers present in it and strong upper limb flexors and lower limb extensors. Low-intensity ECC exercise with PROM (outer ROM) may have a protective and preventive effect on muscle damage to cause mild or no DOMS, pain and ADL limitations. FROM ECC exercise induce greater muscle strength with damage that requires a larger recovery period for muscle regeneration compared with the PROM ECC exercise. Sedentary older adults if they start ECC exercise protocol with FROM may cause greater DOMS, pain, ADL limitations that may need more recovery period or may lead to permanent injury or disability. PROM ECC exercises can be used for the individuals who should avoid high levels of muscle damage like soreness, pain and ADL limitations (especially older adults). Low-intensity ECC exercise protocol with FROM can be recommended for beginner athletes and younger individuals who are in a plan to start an exercise regimen. Therefore, practitioners should be careful with large ROM exercises with a high load in the early stages of the training protocol.

This study is performed on younger individuals to create an exercise model that can induce less pain, DOMS and ADL limitation. The study can be used as a guide for future research and applied to the older adults who are in chronic conditions with co-morbidities to improve their muscle strength, and ROM to fulfill their ADL and healthy independent life. Having said that, we realized that the study has some limitations such as using isokinetic machines and targeting several types of muscle groups. However, it clearly justifies that low intensity exercise would benefit older adults without any impact. Furthermore, the beginner athletes and younger individuals who are in a plan to start an exercise regimen would also get benefits.

In summary, ECC exercise performed with FROM induces a higher degree of DOMS, pain, ADL limitations than ECC exercise with PROM (outer 60° of ROM), even when the protocols are performed to the same end-point of ROM.

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