Localized Pain and Fatigue During Recovery From Submaximal Resistance Exercise in People With Fibromyalgia

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Localized Pain and Fatigue During Recovery from Submaximal Resistance Exercise in People with Fibromyalgia

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Abstract

Objective  
Exercise is recommended as a main treatment in fibromyalgia. However, many people have limited exercise tolerance and report exacerbated pain and fatigue during and following a bout of exercise.
This study examined the local and systemic changes in perceived pain and fatigue during exercise and through the 3-day recovery following isometric and concentric exercises in people with and without fibromyalgia.

Methods
Forty-seven participants with a physician diagnosis of fibromyalgia (44 women; mean age [SD] = 51.3 [12.3] years; mean body mass index [SD] = 30.2 [6.9]) and 47 controls (44 women; mean age [SD] = 52.5 [14.7] years; mean body mass index [SD] = 27.7 [5.6]) completed this prospective, observational cohort study. A bout of submaximal resistance exercise (isometric and concentric) was performed localized to the right elbow flexors on 2 separate days. Baseline attributes (pain, fatigue, physical function, physical activity, and body composition) were assessed prior to exercise. Primary outcomes were: change in perceived pain and fatigue (0 to 10 on the visual analog scale) in the exercising limb and whole body during recovery with movement (immediately, 1 day following exercise, and 3 days following exercise). Secondary outcomes were perceived pain and exertion during exercise performance and pain and fatigue at rest during recovery.

Results
Following a single bout of isometric or concentric exercise, there was increased perceived pain ($\eta_p^2 = 0.315$) and fatigue ($\eta_p^2 = 0.426$) in the exercising limb, which was greater in people with fibromyalgia (pain: $\eta_p^2 = 0.198$; fatigue: $\eta_p^2 = 0.211$). Clinically, relevant increases in pain and fatigue during exercise and through the 3-day recovery occurred in individuals with fibromyalgia only. Concentric contractions led to greater perceived pain, exertion, and fatigue during exercise compared with isometric exercise for both groups.

Conclusions
People with fibromyalgia experienced significant pain and fatigue in the exercising muscle during recovery from low-intensity and short-duration resistance exercise, with greater pain during concentric contractions.

Impact
These findings highlight a critical need to assess and manage pain and fatigue in the exercising muscles of people with fibromyalgia up to 3 days following a single bout of submaximal resistance exercise.

Lay Summary
If you have fibromyalgia, you might have significant pain and fatigue up to 3 days following an exercise bout, with the pain and fatigue localized to the exercising muscles and no changes in whole-body pain.

Introduction
Fibromyalgia is characterized by symptoms of widespread body pain and fatigue at rest and with activity,1–3 which has been attributed to alterations in pain processing by the central and peripheral nervous systems.4,5 Exercise training has been shown to reduce pain and fatigue in fibromyalgia,6 which may be mediated by mechanisms of the nervous system.7,8 Aerobic and resistance exercises are recommended as primary treatments in this population, particularly the use of resistance exercise to improve muscle strength and pain tolerance.6,9–11 Many people with fibromyalgia, however,
have limited exercise tolerance\textsuperscript{12,13} and report exacerbated pain and fatigue during and immediately following a bout of exercise.\textsuperscript{14,15} Despite these reports, there has been limited investigation into the changes in perceived pain and fatigue with validated self-report scales during and through recovery from a single bout of exercise in people with fibromyalgia, especially beyond 24 hours. We have shown that people with fibromyalgia experience greater performance fatigability (exercise-induced decreases in muscle force) in the exercising limb and similar changes in experimental pain (increases in pressure pain thresholds) following isometric and concentric exercises compared to control participants.\textsuperscript{16} This paper will focus on the changes in self-reported or perceived pain and fatigue during the 3-day recovery from exercise.

There is minimal understanding of whether changes in perceived pain and fatigue are localized to the exercising muscles or occur throughout the body. Healthy adults commonly report muscle pain and fatigue specific to the exercising muscle, which resolve following a bout of unaccustomed exercise.\textsuperscript{17,18} Understanding whether acute changes in perceived pain and fatigue following a single exercise session in people with fibromyalgia parallel transient symptoms experienced by healthy adults or lead to widespread symptom exacerbation is fundamental to improving exercise tolerance.

The American College of Sports Medicine acknowledges limited research exists to formulate an evidence-based guideline for exercise prescription in fibromyalgia.\textsuperscript{19} Of the limited exercise guidelines, international consensus recommends initiating with preferred or light intensity exercise to avoid symptom aggravation.\textsuperscript{15,20–22} The type of muscle contraction (isometric or concentric) may also influence the symptoms and performance,\textsuperscript{10,23–26} as isometric and concentric contractions lead to differences in blood flow. Greater ischemia occurs during isometric contractions, resulting in a buildup of fatigue metabolites peripherally, which differentially activate small-diameter afferents (metaboreceptor and nociceptor) and contribute to centrally mediated pain and fatigue.\textsuperscript{24,27–30} Additional characteristics associated with fibromyalgia may also affect recovery from exercise, including kinesiophobia and catastrophizing,\textsuperscript{31–34} limited participation with physical activity,\textsuperscript{35,36} and poor body composition.\textsuperscript{37–39}

The primary aim of this study was to examine the local and systemic changes in perceived pain and fatigue with movement during the 3-day recovery period following 2 separate submaximal resistance exercise sessions (isometric and concentric) in people with and without fibromyalgia. Pain and exertion during performance of the exercise task and pain and fatigue at rest during recovery were evaluated as a secondary outcome. We hypothesized that, during exercise and recovery, people with fibromyalgia would report greater changes in perceived pain, exertion, and fatigue locally in the exercising muscle and systemically compared to control participants.

Methods

Participants
Forty-seven participants with fibromyalgia (44 women; mean age of 51.3 years [SD = 12.3]; mean body mass index of 30.2 [SD = 6.9]) and 47 controls (44 women; mean age of 52.5 years [SD = 14.7]; mean body mass index of 27.7 [SD = 14.7]) completed 3 sessions: 1 familiarization and 2 randomized submaximal exercise sessions (isometric or concentric contractions of the right elbow flexors). English-speaking participants, 18 to 75 years of age, with a physician diagnosis of fibromyalgia confirmed by
the 2010 Fibromyalgia Survey Diagnostic Criteria and individuals without chronic pain were recruited from the Milwaukee metropolitan area via flyers in community centers and clinics, social media posts through local support groups, and newspaper ads. Control participants and participants with fibromyalgia were enrolled in tandem, matching for age, sex, and body mass index. Exclusion criteria included known orthopedic, cardiopulmonary, neurological, and unstable medical conditions that preclude exercise, or responding yes to any item on Physical Activity Readiness Questionnaire. Informed consent was acquired prior to study enrollment, and the protocol was approved by the Marquette University Institutional Review Board (HR-3035) according to principles of the Declaration of Helsinki.

Study Design and Protocol
This research was part of a larger prospective, observational cohort study (NCT03778385) investigating exercise specificity in people with fibromyalgia. All participants completed 3 sessions separated by approximately 1 week. Session 1 (Fig. 1a) included baseline assessments, familiarization to maximal voluntary isometric contractions (MVIC), and isometric and concentric exercise with the right elbow flexors.

Figure 1 Experimental session design; (a) familiarization session (session 1), (b) exercise sessions (sessions 2 and 3), and (c) days 1 and 3 recovery assessments. \( \| \parallel = \) arm and whole-body pain and fatigue (VAS); \( \downarrow = \) arm pain (numerical pain rating scale) and RPE; ACR = American College of Rheumatology Diagnostic Criteria for Fibromyalgia; DXA = dual-energy X-ray absorptiometry; FIQ-R = Fibromyalgia Impact Questionnaire—Revised; MVIC = maximal voluntary isometric contraction; PAAT = Physical Activity Assessment Tool; PCS = Pain Catastrophizing Scale; PROMIS—Fatigue = PROMIS Short Form v1.0—Fatigue 7a; RPE = rating of perceived exertion; SF-MPQ = Short-Form McGill Pain Questionnaire; TSK-11 = Tampa Scale for Kinesiophobia-11; VAS = visual analog scale.

Session 2 initiated with additional baseline assessments and performance of MVICs to determine the submaximal intensity (20% MVIC) of isometric or concentric exercise (Fig. 1b). Participants were randomly allocated via a random number generator to begin with concentric or isometric exercise during session 2, and the other exercise type was performed during session 3 approximately 1 week
later. Concentric and isometric sessions were matched for intensity (20% of MVIC), duration (10 minutes), and duty cycle (2-second contraction:1-second relaxation) (description of the setup is described below). The primary outcome was change in perceived pain and fatigue intensity in the exercising arm and whole body with movement immediately following and at 1 and 3 days following exercise compared to preexercise values measured with a 0- to 10-cm visual analog scale. Secondary outcomes included perceived arm pain and rating of perceived exertion (RPE) during each exercise bout and the change in perceived pain and fatigue intensity in the exercising arm and whole body at rest during the recovery period.

Baseline Assessments
Baseline pain intensity (visual analog scale) and quality (pain rating index) were evaluated with the Short-Form McGill Pain Questionnaire.42 Fibromyalgia symptom severity and impact were evaluated with the modified 2010 American College of Rheumatology Diagnostic Criteria for Fibromyalgia (ACR)40,43 and Revised Fibromyalgia Impact Questionnaire.44,45 Self-reported fatigue impact was measured with the PROMIS Short Form v1.0–Fatigue 7a (PROMIS Fatigue).46,47 The Pain Catastrophizing Scale measured negative thoughts and feelings directed toward pain and fear of movement/(re)-injury was evaluated with the Tampa Scale for Kinesiophobia-11.49,50 Further detail of baseline measures can be found in Supplementary Table S1.

Self-reported moderate-to-vigorous physical activity over a 7-day period was measured with the Physical Activity Assessment Tool51 (Suppl. Tab. S1). During the same 7-day reference period as the Physical Activity Assessment Tool, all participants wore an activity monitor (ActiGraph wGT3X-BT, ActiGraph LLC, Pensacola, FL, USA) on the nondominant wrist for 7 days. Data from 4 validated days52 were analyzed using ActiLife software (ActiLife 6.13.1; ActiGraph LLC, Pensacola, FL, USA); nonwear and sleep time were removed using daily logs and Troiano algorithm;53 and the worn-on the wrist option was selected.54,55 Freedson algorithm54,55 cut points were used to estimate the percent of time spent in sedentary, light, and moderate-to-vigorous activity. Body composition (total lean mass [kg], total fat mass [kg], right arm lean mass [kg], right arm fat mass [kg], and visceral adipose tissue [in³]) was quantified using GE Lunar iDXA and Encore software (GE, Madison, WI, USA).

Isometric and Concentric Exercise Setup
Two MVICs were performed with the right elbow flexors at the start of each exercise session while seated in a Biodex System 3 PRO (Biodex Medical Systems Inc, Shirley, NY, USA), and the average peak torque was used to individualize exercise intensity (20% MVIC) to each participant. Participants were seated with their hips and knees in 90 degrees of flexion, right shoulder in 40 degrees of flexion, and right elbow in 90 degrees of flexion. The forearm was placed in neutral position in a modified forearm orthosis attached to the dynamometer. Setup and positioning were maintained during all sessions. Torque recordings from the dynamometer were recorded online and were digitized using a Power 1401 analog-to-digital converter and Spike 2 software (Cambridge Electronics Design, Cambridge, UK) at 500 samples per second.

Submaximal isometric or concentric muscle contractions were performed with an intermittent duty cycle (2-second contraction:1-second relaxation) at the same relative intensity (20% MVIC) and duration (10 minutes) with the right elbow flexors. Positioning during exercise was maintained similar
to the performance of MVICs with the right elbow fixed at 90 degrees of flexion during isometric contractions and with 50 to 120 degrees of flexion range of motion for concentric contractions. Participants were provided verbal encouragement and with a visual display of target force indicating 20% MVIC.

Self-Reported Pain and Fatigue During and Following Exercise

Self-reported pain and fatigue intensity in the exercising arm and whole body were rated upon arrival to each session, immediately after exercise, and at 1 and 3 days following each exercise bout with a 0 to 10 cm visual analog scale with anchors of “no pain” to “worst pain,” and “no weakness/fatigue” to “worst weakness/fatigue” (Suppl. Tab. S1). Participants rated exercising arm pain and perceived exertion every minute during the 10-minute bout of exercise with a 0 to 10 numerical pain rating scale (0 = no pain, 10 = worst pain) and Modified Borg Rating of Perceived Exertion (RPE: 0 = nothing at all, 10 = very very hard/maximal exertion). Participants were provided with standardized instruction to differentiate localized pain and fatigue in the exercising arm versus whole body and to assess pain and fatigue while seated at rest and while mimicking functional limb and whole-body movement, such as picking up a cup or squatting to pick up an object from the floor, respectively. The primary outcomes were the change in arm and whole-body pain and fatigue with movement following exercise. Secondary outcomes include the change in arm and whole-body pain and fatigue at rest following exercise and the change in pain and exertion during exercise. Further detail of self-reported pain and fatigue measures can be found in Supplementary Table S1.

Statistical Analysis

Data were analyzed using IBM SPSS (Version 26, IBM, Armonk, NY, USA). Normality and linearity were evaluated with the Shapiro–Wilk test and visual inspection via Q–Q plots. Data are reported as mean (SD) in the text and tables and are displayed as mean (SEM) in the figures. Differences between means were tested with paired samples and independent samples t-test. For the primary and secondary outcomes, changes over time were analyzed with repeated measures analysis of variance, and the Greenhouse–Geisser adjustment was used when sphericity was not met. Post hoc tests were applied where appropriate with paired t-test, and partial eta-squared ($\eta^2$) was applied as a measure of effect size to indicate the proportion of variance in the dependent variable explained by the independent variable, excluding variance from other independent variables. Based on power analysis with an expected medium effect size of 0.5, $\alpha = 5\%$, and nonsphericity correction, the desired sample size for the primary outcome of change in perceived pain and fatigue across 4 timepoints in 2 groups was 12 participants per group. A more stringent $\alpha$ level, $P \leq .02$ was used for statistical significance to minimize type I and II errors. Results from repeated measures analysis of covariance with baseline pain and fatigue as covariates are not presented since neither significantly influenced the change in pain and fatigue during recovery, thus baseline pain and fatigue were not controlled for with the primary analyses in this study.

Role of Funding Source

The funders played no role in the design, conduct, or reporting of this study.
Results

Participant Characteristics and Baseline Assessments

Group characteristics and baseline differences between groups are presented in Tables 1 and 2. The order of exercise exposure (isometric vs concentric) did not influence baseline pain and fatigue, as the preexercise pain and fatigue in the arm and whole body were similar across sessions (Tab. 2).

**Table 1 Participant Characteristics: Baseline Values of Clinical Pain, Perceived Fatigue, Psychosocial Assessments, Physical Activity, and Body Composition**

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<tr>
<th></th>
<th>Controls</th>
<th>Fibromyalgia</th>
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<tr>
<td>Number of participants</td>
<td>47</td>
<td>47</td>
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<tr>
<td>Age, y, mean (SD)</td>
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<td>51.3 (12.3)</td>
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<tr>
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<td>44 F, 3 M</td>
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<tr>
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<td>45/2</td>
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<tr>
<td>Race (White/African American)</td>
<td>37/10/0</td>
<td>39/8/2</td>
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<tr>
<td>FIQ-R total summed score</td>
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<td>SF-MPQ</td>
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<td>-</td>
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<tr>
<td>Pain rating index</td>
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<td>8.8 (7.3)b</td>
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<tr>
<td>Visual analog scale (cm)</td>
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<td>24.5 (7.2)b</td>
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<td>Pain catastrophizing scale</td>
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<td>Physical activity, mean (SD)</td>
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<td>ActiGraph light PA (%)</td>
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<td>ActiGraph moderate-to-vigorous PA (%)</td>
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<td>19.0 (8.5)</td>
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<td>PAAT total moderate-to-vigorous PA (min/wk)</td>
<td>420.2 (424.0)</td>
<td>413.9 (591.2)</td>
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<td>Body composition, mean (SD)</td>
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<td>Total fat mass (kg)</td>
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<td>Total lean mass (kg)</td>
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<td>Right arm fat mass (kg)</td>
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<td>Right elbow flexor MVIC (Nm)</td>
<td>41.2 (13.5)</td>
<td>39.3 (12.0)</td>
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*ACR = American College of Rheumatology Diagnostic Criteria for Fibromyalgia; FIQ-R = Fibromyalgia Impact Questionnaire—Revised; MVIC = maximal voluntary isometric contractions; PA = physical activity; PAAT = Physical Activity Assessment Tool; SF-MPQ = Short-Form McGill Pain Questionnaire

b P ≤ .001.
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**Whole-body fatigue—rest**

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**Whole-body fatigue—mvm**

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\(^a\)CON = control; FM = fibromyalgia; MVIC = maximal voluntary isometric contraction; mvm = movement; RPE = rating of perceived exertion; SF-MPQ = Short-Form McGill Pain Questionnaire.

\(^b\)Group difference.

\(^c\)Significant from preexercise.

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**Self-Reported Arm and Whole-Body Pain With Movement During Recovery (Primary Outcome)**

All participants reported immediate postexercise assessments, whereas 41 control participants and 37 participants with fibromyalgia reported pain and fatigue at 1 and 3 days following exercise. Arm pain with movement (mimicking picking up a cup) increased following exercise (time: \( F_{2.15,165.34} = 35.40, P < .001, \eta^2_p = 0.315 \)), and the change was different between groups (time × group: \( F_{2.15,165.34} = 19.02, P < .001, \eta^2_p = 0.198 \)) (Fig. 2b, Tab. 2). Arm pain with movement increased for both groups immediately following exercise (control: \( t_{46} = -3.75, P < .001 \); fibromyalgia: \( t_{46} = -8.68, P < .001 \)) and remained elevated only in fibromyalgia on days 1 (\( t_{38} = -6.52, P < .001 \)) and 3 (\( t_{46} = -5.86, P < .001 \)). Post hoc analysis revealed the increase in arm pain was greater in fibromyalgia immediately after exercise (\( t_{71.7} = -5.78, P < .001 \)) and at 1 (\( t_{81.12} = -6.44, P < .001 \)) and 3 days (\( t_{37.06} = -5.80, P < .001 \)) following exercise. There was no influence of contraction type for arm pain with movement during recovery.
Whole-body pain with movement (mimicking squatting to pick up object on floor) increased following exercise (time: $F_{2.31,175.27} = 8.19$, $P < .001$, $\eta^2 = 0.097$) and was different between groups (time × group: $F_{2.31,175.27} = 5.30$, $P = .004$, $\eta^2 = 0.065$) (Fig. 2d, Tab. 2); there was an increase for both groups immediately following exercise (control: $t_{46} = -2.50$, $P = .02$, fibromyalgia: $t_{46} = -2.80$, $P = .007$) and at day 1 (control: $t_{41} = -2.54$, $P = .02$; fibromyalgia: $t_{38} = -3.71$, $P = .001$), and it remained elevated for fibromyalgia only on day 3 ($t_{36} = -4.30$, $P < .001$). Post hoc analysis revealed the increase was not different between groups immediately following exercise ($t_{49.85} = -2.24$, $P = .03$); however, those with fibromyalgia experienced elevated whole-body pain on days 1 ($t_{42.10} = -3.04$, $P = .004$) and 3 ($t_{42.50} = -3.66$, $P = .001$). There was no influence of contraction type on whole-body pain with movement during recovery (no main effect or interaction with session).

Self-Reported Arm and Whole-Body Fatigue With Movement During Recovery (Primary Outcome)

Perceived arm fatigue with movement increased following exercise (time: $F_{2.16,164.39} = 56.49$, $P < .001$, $\eta^2 = 0.426$) and the change was different between groups (time × group: $F_{2.16,164.39} = 20.36$, $P < .001$, $\eta^2 = 0.211$) (Fig. 3b, Tab. 2); there was an increase for both groups immediately following exercise (control: $t_{46} = -4.73$, $P < .001$; fibromyalgia: $t_{46} = -10.95$, $P < .001$), which remained elevated in fibromyalgia only on days 1 ($t_{37} = -5.23$, $P < .001$) and 3 ($t_{37} = -5.29$, $P < .001$). Post hoc analysis revealed that the increase was greater in fibromyalgia immediately ($t_{79.29} = -6.57$, $P < .001$), 1 day ($t_{37.82} = -5.03$, $P < .001$), and 3 days ($t_{38.63} = -5.06$, $P < .001$) following exercise. Contraction type did not influence the change in arm fatigue with movement.
Figure 3 Perceived arm fatigue (0 to 10 VAS) (a) at rest and (b) with movement, and whole-body fatigue (c) at rest and (d) with movement at preexercise, immediately postexercise, days 1 and 3 following exercise. a = group difference at baseline; b = time; c = time × group; d = contraction × time; e = significant from preexercise; FM = fibromyalgia; HC = healthy control; Mvm = movement; VAS = visual analog scale.

Whole-body fatigue with movement increased following exercise (time: $F_{2.55,190.90} = 4.76$, $P = .005$, $\eta^2 = 0.060$) (Fig. 3d, Tab. 2), with an increase in both groups immediately following exercise ($t_{93} = −4.17$, $P < .001$) and on day 3 ($t_{76} = −3.12$, $P = .003$). The change in whole-body fatigue assessed with movement was not different between groups or the exercise type.

Self-Reported Arm and Whole-Body Pain at Rest During Recovery (Secondary Outcome)

Arm pain at rest had similar results as arm pain with movement (contraction × time: $F_{1.63,125.83} = 10.81$, $P = .001$, $\eta^2 = 0.123$) with 1 exception. Post hoc analysis revealed that both groups reported greater increases immediately following concentric exercise compared to isometric ($t_{93} = −3.91$, $P < .001$). ([Fig. 2a, Tab. 2]). Whole-body pain at rest had similar results compared to movement (Fig. 2c, Tab. 2).

Self-Reported Arm and Whole-Body Fatigue at Rest During Recovery (Secondary Outcome)

Arm fatigue at rest had similar results as arm fatigue with movement (Fig. 3a, Tab. 2); arm fatigue at rest was influenced by the exercise type (contraction × time: $F_{1.64,126.30} = 6.89$, $P = .003$, $\eta^2 = 0.082$). The change in arm fatigue at rest was greater immediately following concentric exercise ($t_{93} = −2.80$, $P = .006$), while no difference occurred at days 1 and 3.

Whole-body fatigue at rest increased following exercise (time: $F_{2.68,203.94} = 8.76$, $P < .001$, $\eta^2 = 0.103$), and the change was different among groups (time × group: $F_{2.68,203.94} = 4.38$, $P = .007$, $\eta^2 = 0.055$) (Fig. 3c, Tab. 2). Whole-body fatigue at rest increased for both groups immediately following exercise (control: $t_{46} = −2.67$, $P = .011$; fibromyalgia: $t_{46} = −4.61$, $P < .001$) and remained elevated for
fibromyalgia only on days 1 \((t_{38} = -2.57, P = .014)\) and 3 \((t_{36} = -3.56, P = .001)\). The fibromyalgia group reported a greater increase in whole-body fatigue at rest immediately \((t_{62.16} = -2.20, P = .002)\), 1 day \((t_{39.58} = -2.36, P = .02)\), and 3 days \((t_{37.62} = -3.44, P = .001)\) following exercise.

Self-Reported Arm Pain and Perceived Exertion During Exercise (Secondary Outcome)
Participants with fibromyalgia reported greater mean pain intensity \((t_{84.47} = -6.24, P < .001)\), peak pain \((t_{91.75} = -6.15, P < .001)\), mean RPE \((t_{92} = 2.80, P = .006)\), and peak RPE \((t_{92} = -3.14, P = .002)\) during exercise compared to controls (Tab. 2). Mean pain \((F_{1,92} = 64.02, P < .001, \eta^{2} = 0.410)\), peak pain \((F_{1,92} = 52.09, P < .001, \eta^{2} = 0.362)\), mean RPE \((F_{1,92} = 13.43, P < .001, \eta^{2} = 0.127)\), and peak RPE \((F_{1,92} = 15.46, P < .001, \eta^{2} = 0.144)\) were greater during concentric exercise compared to isometric for both groups.

Discussion
The novel findings of this study were people with fibromyalgia who reported clinically relevant worsening of perceived pain and fatigue localized to the exercising limb during a 3-day recovery period from low-intensity, short-duration isometric and concentric exercises. By contrast, the increase in pain and fatigue for control participants was less compared to fibromyalgia and returned to the baseline levels by day 1 following exercise. In addition to group differences, the contraction type influenced the pain experienced during exercise, with greater pain and fatigue reported with concentric than isometric contractions. Control participants and participants with fibromyalgia were matched for age, sex, and body mass index and had similar baseline strength and physical activity; thus, differences between groups may be attributed to the clinical features of fibromyalgia. Additionally, this cohort of participants with fibromyalgia reported similar functional impact (FIQR), kinesiophobia, and catastrophizing compared to prior studies.

Even though this study used an exercise protocol according to clinical recommendations, people with fibromyalgia reported moderate-to-severe pain in the exercising arm, whereas control participants reported minimal-to-moderate pain. Similarly, perceived exertion during submaximal exercise was greater in fibromyalgia (moderate to very hard) compared to controls (fairly moderate to hard). While prior studies have reported differences in the symptom response to resistance and aerobic exercise in fibromyalgia, we show that the mode of resistance exercise may also influence perceived pain as concentric contractions induced greater pain during exercise. Potential explanations for differences among concentric and isometric exercises include using MVIC to determine 20% intensity. Using MVIC may have resulted in greater intensity for the concentric protocol because of greater force demands related to the mechanical disadvantage with changing moment arm and velocity of muscle shortening. Additionally, the greater force requirements for concentric exercise likely leads to greater accumulation of fatigue-induced metabolites. Isometric-based forces are commonly used clinically to establish load intensity when prescribing resistance exercise, which may impact the perceived pain and fatigue.

During recovery, control participants and participants with fibromyalgia reported elevated pain and fatigue with movement and at rest in the exercising limb immediately following both exercise conditions. This finding is in line with prior studies showing elevated pain and fatigue during and up to
24 hours following an exposure to exercise.\textsuperscript{6,70–79} However, we show that symptoms remained elevated only for fibromyalgia 1 and 3 days following exercise with clinically important differences (>2 point change on the 0 to 10 visual analog scale).\textsuperscript{80,81} By contrast, whole-body pain and fatigue with movement and at rest did not reach clinically important differences at any timepoint following both exercise types in participants with fibromyalgia or control participants. These findings suggest that the evaluation of perceived pain and fatigue following exercise should include context pertaining to spatial aspects relative to the exercising body part. Adjunct pain management techniques (electrophysical modalities, manual therapy, and medications) may be successful in reducing the intensity and duration of localized symptoms with exercise.\textsuperscript{82}

Limitations
Future research should incorporate assessment of pain and fatigue over a longer recovery duration and should include people with fibromyalgia of varying intensities of baseline pain and fatigue, which was not controlled for with the primary analysis and may impact symptom exacerbation during recovery. The results from this study have limited generalizability to men and individuals from varying ethnic and racial groups with fibromyalgia due to limited recruitment of these respective cohorts, and it was not powered to address all secondary aims. It is possible that some participants may not have been able to distinguish between the local (exercising arm) and systemic (whole body) pain and fatigue; however, these methods have been recommended and implemented in the literature to differentiate the pain intensity of various body regions in cohorts with multisite pain.\textsuperscript{57,60,61,83–86}

Conclusion
People with fibromyalgia experienced clinically relevant increases in perceived pain and fatigue localized to the exercising muscle during the 3-day recovery from isometric and concentric exercises, with greater symptoms following concentric exercise. Patients with fibromyalgia should not be deterred from exercise intervention because we found no clinically relevant changes in widespread body pain and fatigue. Clinical decision-making in the management of pain and fatigue during recovery from exercise should include assessment of the location and duration of the symptom response, patient education in expected postexercise symptoms, and exercise prescription that gradually incorporates multiple body regions to avoid exacerbation of widespread pain and fatigue.

Author Contributions
Study conception and design: G. Berardi, M.H. Bement, S.K. Hunter

Material preparation and data collection and analysis: G. Berardi, C. Eble, M.H. Bement

Writing of the first draft of the manuscript: G. Berardi, M.H. Bement

Comments and edits to the manuscript: S.K. Hunter

Approval of the final manuscript: G. Berardi, M.H. Bement, S.K. Hunter

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Ethics Approval
Approval was granted by the Institutional Review Board of Marquette University (September 17, 2015; HR-3035).

Clinical Trial Registration
The larger study was registered at ClinicalTrials.gov (December 19, 2018; NCT03778385).

Data Availability Statement
The data that support the findings of this study are available on request from the corresponding author, G.B.

Disclosures and Presentations
The authors completed the ICMJE Form for Disclosure of Potential Conflicts of Interest and reported no conflicts of interest. A portion of this manuscript was presented as a platform presentation at: APTA CSM, January 25, 2019, Washington, DC.

References


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