



# Can mat Pilates intervention increase lower limb rate of force development in overweight physically active older women?

Josefina Bertoli<sup>1</sup> · Fernando Diefenthaler<sup>1</sup> · Daniele Detanico<sup>1</sup> · Juliano Dal Pupo<sup>1</sup> · Marco Aurélio Vaz<sup>2</sup> · Cíntia de la Rocha Freitas<sup>1</sup>

Received: 30 April 2018 / Accepted: 31 January 2019 / Published online: 13 March 2019  
© Springer-Verlag Italia S.r.l., part of Springer Nature 2019

## Abstract

**Purpose** This study investigated the effect of 12 weeks of mat Pilates intervention (60 min sessions, three times per week) on lower limb rate of force development (RFD) parameters (absolute and relative values and contractile impulse) in physically active and overweight elderly women.

**Methods** Fourteen elderly women (age  $62 \pm 3$  years) participated in this study. Workouts were performed in three sets; repetitions increased every 4 weeks, and exercise difficulty increased from beginner to intermediate and advanced levels. Knee extensor and hip extensor–flexor RTD parameters were measured at different time intervals (0–30, 0–50, 0–100, 0–150, 0–200, and 0–250 ms) before (weeks –4 and 0, control period) and after 6 and 12 weeks of mat Pilates intervention.

**Results** No statistical difference ( $p > 0.05$ ) was observed between weeks –4 and 0 (control period). However, significant increments were observed after week 12 for most time intervals for absolute and relative knee extensor and hip extensor–flexor RFD, as well as for contractile impulse for the same muscle groups.

**Conclusions** We conclude that the mat Pilates causes significant increments in knee extensor and hip extensor–flexor RFD and contractile impulse using an incremental structure of training in physically active elderly women.

**Keywords** Aging · Physical activity · Rapid force · Muscle contraction

## Introduction

Aging is associated with neuromuscular changes, such as deterioration of intrinsic force production (i.e., alterations in muscle fiber contractile properties and metabolic properties) [1, 2], changes in muscle architecture (i.e., serial and parallel sarcomere loss, and pennation angle reduction), and tendon stiffness reduction [3, 4]. In addition to the aforementioned changes due to aging, increasing body mass index (BMI) seems to be a trend among older adults as a consequence

of overweight and obesity [5, 6]. Some studies have shown that there is an increment in body fat mass and a reduction in musculoskeletal tissues with the aging process [5, 7]. More specifically, there is a large fat infiltration in the muscles, which has a negative effect on muscle strength and, consequently, on daily living activities' (ADLs) performance [8, 9].

Those neuromuscular changes, including the muscular fat infiltration, produce a progressive loss of explosive force, which is important in balance recovery after a sudden perturbation [10]. Explosive force can be assessed through the rate of force development (RFD) and contractile impulse at the early onset of a muscle or muscle group during a maximal isometric voluntary contraction (MIVC) [11]. Therefore, RFD parameters have an important functional significance during ADLs and movements that require fast contractions to recover balance to avoid the risk of falling in older adults [6–10].

Traditionally, power training and strength training have been adopted as the main strategy to improve the capacity to produce rapid force in older adults [11–13]. However,

**Electronic supplementary material** The online version of this article (<https://doi.org/10.1007/s11332-019-00533-5>) contains supplementary material, which is available to authorized users.

✉ Josefina Bertoli  
josefinabv85@gmail.com

<sup>1</sup> Laboratório de Biomecânica, Centro de Desportos, Universidade Federal de Santa Catarina, Campus, Trindade, Florianópolis, SC 88040900, Brazil

<sup>2</sup> Laboratório de Pesquisa do Exercício, Universidade Federal de Rio Grande do Sul, Porto Alegre, RS, Brazil

some studies [14–16] have shown an increment in RFD parameters after the traditional strength training performed at slow or moderate velocities. Tiggemann et al. [15] have shown significant increments in knee extensor absolute RFD after power training and traditional strength training in older women, without significant differences between training modalities.

In addition to the traditional strength training, the Pilates method has been widely practiced among older adults to improve physical fitness [17, 18]. It has been shown that Pilates is able to enhance joint range of motion [19, 20] and muscular strength in older adults [21, 22]. These adaptations may be related to the Pilates exercise characteristics that involve dynamic and isometric contractions (i.e., sustaining body weight) [23]. Although the Pilates method is not characterized by rapid contractions, the coordination and balance requirements challenge the nervous system, with the possibility of impacting RFD [24].

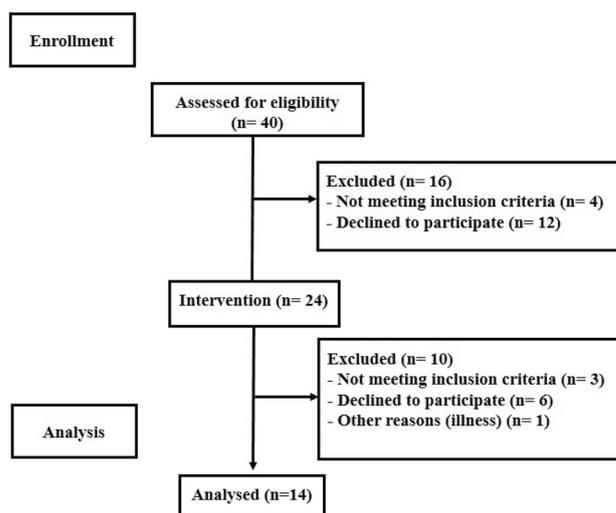
Most of the studies investigating strength training effects on older adults' muscle structure/function have focused on knee extensor adaptations [15, 16, 25, 26], while hip extensors-flexors have been ignored, despite their importance in ADLs performance [27, 28]. Similarly, there is no available evidence on the effect of a mat Pilates incremental overload model on lower limb RFD, which emphasizes the need for studies evaluating the effects of mat Pilates training in this population. Functional disabilities associated with explosive force impairments are more pronounced among older women than men [29], which justifies special attention to this population.

Due to the loss of explosive force production associated with aging, and due to the evidence of some training strategies improving this parameter, our study aimed to analyze the effects of a mat Pilates intervention with progressive overload on the hip RFD and contractile impulse in overweight physically active older women. We hypothesized that mat Pilates will induce increments in RFD and impulse after our mat Pilates intervention.

## Materials and methods

### Participants

Fourteen older women (age =  $62 \pm 3$  years; height =  $1.59 \pm 0.05$  m; weight =  $68.9 \pm 7.6$  kg; body mass index =  $27.3 \text{ kg/m}^2$ —overweight) volunteered to participate and completed our study (Fig. 1). Participants were recruited from the physical activity programs for older adults at the university where this study was conducted. All participants were physically active and attended hydrogymnastics, aquaerobics, or gymnastics classes for older adults, with a mean of  $2.28 \pm 0.26$  years of practice. The sample size was



**Fig. 1** Consort flow diagram showing the enrollment (eligibility, exclusion), the intervention (exclusions), and the analysis phase of the mat Pilates intervention

calculated using statistical software (G-power 3.1 Düsseldorf, Germany), which revealed that ten participants were needed to achieve an effect size of 0.5,  $\alpha$  error probability of 0.05, power ( $1-\beta$  error probability) of 0.8, and correlation among repeated measures of 0.5 [30].

To be included in the study, participants had to be aged  $\geq 60$  years and available to participate in the data collection and in the mat Pilates intervention with a minimum adherence of 75% per month. Participants were excluded if they (a) scored less than 19 points in the Mini-Mental Examination [31, 32]; (b) were diagnosed with depression by the 9/Geriatric Depression Scale (GDS) [33]; had Alzheimer's, Parkinson's, and/or multiple sclerosis; (c) presented skeletal muscle illnesses (osteoarthritis, arthrosis, rheumatoid arthritis, or disc hernia); or (d) had been practicing Pilates (on either equipment or mat Pilates) and/or strength training in the 6 months prior to the study.

The local Human Research Ethics Committee approved the study (Protocol No. 44972915.9.0000.0110), and procedures were conducted in accordance with the Declaration of Helsinki. Thereafter, participants signed an informed consent form, and groups were established according to the gym's and participants' availability. Before the study began, participants answered a questionnaire concerning their age, address, health insurance, personal and familial coronary medical history, neurological illnesses, skeletal muscle diseases, and history of falls, fractures, and physical activity practice and frequency.

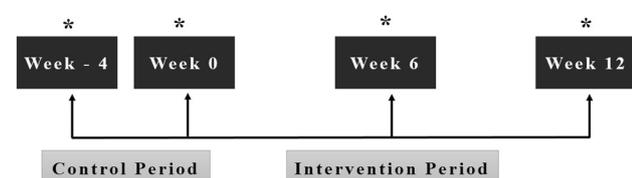
## Study design

This study was part of a major project, in which the first part analyzed the effects of mat Pilates on the hip and knee isokinetic torque parameters [22], whereas the present study analyzed the effects of mat Pilates on the RFD and contractile impulse variables. The study consisted of a within-subject controlled design, aimed at looking at the effects of 12 weeks of mat Pilates intervention (independent variable) on absolute and relative RFD and contractile impulse (dependent variables) in older overweight women. The study was divided into two periods: a control period and an intervention period. The control period consisted of 4 weeks (between week -4 and 0) [34, 35], where participants continued to perform their normal ADLs and no mat Pilates exercises were performed. The aforementioned variables were assessed at the beginning (week -4) and at the end of the control period (week 0) and after week 6 and week 12 of the training period (Fig. 2). Week 0 was considered the baseline, and hence, intervention periods were compared with week 0. Participants were asked to refrain from practicing any other physical activity (i.e., running, cycling, strength training, and/or Pilates) throughout the intervention period.

## Pilates intervention program

Mat Pilates sessions were 60 min long, three times per week for 12 weeks. The training sessions were divided into three sections: warm-up, main component, and cool down. Mats and equipment were used throughout the sessions (i.e., small balls, Swiss balls, gym sticks, and resistance bands). Participants were divided into three groups, with no more than six participants per group, to guarantee more control over the exercise movement quality. The Pilates intervention was conducted by a physical education teacher trained in the Pilates method, who was also in charge of the assessments with another researcher. In the first session, the principles of Pilates were taught as well as the neutral posture of the scapular and pelvic belt in the sitting, lying, and standing positions, which were reinforced throughout each training session.

Pilates method emphasizes movement quality, with repetitions ranging from 6 to 10, and the level of exercise



**Fig. 2** Study design showing the control and intervention periods (\*RFD and impulse assessments)

difficulty (beginner, intermediate, and advance level) is used to determine the exercise intensity [22, 36]. Mat Pilates is also characterized as a group activity. Therefore, the overload followed an incremental progression by increasing the number of repetitions (which progressed from 6 repetitions at weeks 0–4, up to 8 repetitions for weeks 5–8, and 10 repetitions for weeks 9–12). As participants acquired ease in performing the exercises over the time course of the training program, the exercise difficulty was increased. For the exercises that involved body weight sustaining in isometric contractions, the time that the participants remained in the exercise was increased during the course of the intervention according to each participant’s capability. All the main exercises were performed in three sets. For more details about mat Pilates intervention, see Bertoli et al. [22] and the supplemental file.

## Rate of force development assessment

Knee extensors and hip flexor–extensor peak torque of the preferred lower limb were assessed using an isokinetic dynamometer (Biodex Medical System 4, Shirley, NY, USA). The participants came to the laboratory on two different days separated by no more than 48 h. The first visit consisted of a familiarization in which submaximal contractions were performed in the isokinetic dynamometer. On the second day, participants performed three MIVCs of 5 s each, separated by 2 min rest. A fourth attempt was performed in case the coefficient of variation was higher than 5% between each MIVC [37]. A light stimulus was used to indicate the beginning of the contraction and the light off to indicate the contraction end. The “fast and hard as possible” command [38] was adopted for all evaluated muscle groups. Participants completed a 5-min warm-up on a cycle ergometer at 50 Watts (Ergo-fit 167 Cycle, Pirmasens, Germany) before testing.

To assess the knee extensor muscles, the participant sat on the dynamometer’s chair following the manufacturer’s recommendation. The tested limb was weighted at 45° of knee flexion according to the manufacturer’s instructions. Thereafter, the knee extensor and flexor muscles’ warm-up was performed at 120° s<sup>-1</sup> during ten concentric contractions. RFD parameters were evaluated at 70° of knee flexion [11]. For the hip flexor–extensor muscles assessment, participants were positioned in the dorsal decubitus position on the dynamometer following the manufacturer’s recommendation. The tested knee remained flexed to avoid compensations and was weighted at 45° of hip flexion. Hip flexor–extensor muscles’ warm-up was performed at 120° s<sup>-1</sup> during ten concentric contractions before testing. RFD parameters were assessed at 15° of hip flexion for hip flexor muscles, and at 100° of hip flexion for hip extensor muscles.

Torque signal was recorded using a four-channel Miotoool 400 device (Miotec Equipamentos Biomédicos Ltda., Porto Alegre, Brazil) at a sampling frequency of 2000 Hz. The absolute RFD was calculated as the average slope of the torque–time curve ( $\Delta\text{torque}/\Delta\text{time}$ ) at different time intervals (0–30, 0–50, 0–150, 0–200, and 0–250 ms) relative to the contraction beginning [11]. Similarly, the relative RFD was determined as the slope of the moment–time curve relative to the MIVC and expressed in the percentage of the MIVC (%MIVC). The contractile impulse was calculated as the area under the moment–time ( $t$ ) curve ( $\int\text{moment } dt$ ) in the aforementioned time intervals [11].

## Statistical analysis

Descriptive statistics were calculated. Data normality was verified through the Shapiro–Wilk test. A one-way ANOVA, with a Bonferroni post hoc test, was used to check between-groups heterogeneity at baseline. Subjects were stratified into three physical activity groups (Group 1: hydrogymnastics, Group 2: aquaerobics, and Group 3: gymnastics). After homogeneity determination, one-way repeated-measures ANOVA ( $f$  Greenhouse–Geisser) and Bonferroni post hoc test were used to compare absolute and relative RFD, as well as contractile impulse means, among the different weeks. Weeks –4 and 0 were

compared to determine possible differences in the control period. If no differences were observed for the control period measures, then week 0 was used as the pre-intervention measure that was compared to data obtained postintervention (i.e., weeks 6 and 12). PASW software SPSS 18.0 was used for the statistical analysis (SPSS Inc., Chicago, IL, USA). Statistical difference was considered when  $p < 0.05$ . The Cohen's  $d$  effect size [39] between weeks 0–6, weeks 0–12, and weeks 6–12 was also assessed, which is presented in the supplemental file.

## Results

No statistical difference was verified at baseline between the three physical activity (Group 1: hydrogymnastics, Group 2: aquaerobics, and Group 3: gymnastics) groups ( $p > 0.05$ ). Therefore, participants were allocated into a single group for the intervention.

Absolute and relative RFD and impulse of knee extensor and hip flexor–extensor muscles are presented in Tables 1, 2 and 3, respectively. No significant differences were observed during the control period (between weeks –4 and 0) for all the parameters ( $p > 0.05$ ); thus, the results obtained at weeks 6 and 12 were compared just to baseline (week 0).

**Table 1** Mean, standard deviation, and 95% CI for absolute rate of force development (RFD) of the knee extensor and hip extensor–flexor muscles at different periods and time intervals

	Time intervals (ms)	Week 0	Week 6	Week 12	$f$	$p$
Knee extensors (N·m·s <sup>-1</sup> )	0–30	424 ± 115 (358; 490)	529 ± 153 <sup>a</sup> (441; 617)	575 ± 183 <sup>a</sup> (469; 681)	8.97	0.001
	0–50	470 ± 132 (394; 546)	584 ± 172 (485; 683)	623 ± 205 (505; 741) <sup>a</sup>	7.54	0.002
	0–100	478 ± 136 (399; 557)	564 ± 156 (465; 663)	587 ± 174 (487; 687) <sup>a</sup>	4.87	0.014
	0–150	398 ± 94 (344; 452)	462 ± 119 (393; 531)	484 ± 118 (416; 552) <sup>a</sup>	5.03	0.015
	0–200	345 ± 75 (302; 388)	420 ± 113 (355; 485)	437 ± 103 (378; 496) <sup>a</sup>	7.88	0.004
	0–250	318 ± 68 (279; 357)	380 ± 103 (321; 439)	398 ± 85 (349; 447) <sup>a</sup>	7.26	0.005
Hip extensors (N·m·s <sup>-1</sup> )	0–30	291 ± 111 (227; 355)	412 ± 134 (335; 489) <sup>a</sup>	378 ± 98 (321; 434) <sup>a</sup>	9.22	0.004
	0–50	328 ± 132 (252; 404)	468 ± 152 (380; 556) <sup>a</sup>	435 ± 114 (369; 500) <sup>a</sup>	9.31	0.004
	0–100	361 ± 150 (274; 448)	496 ± 118 (428; 564) <sup>a</sup>	486 ± 124 (414; 557) <sup>a</sup>	9.13	0.002
	0–150	326 ± 130 (251; 401)	426 ± 85 (337; 475)	446 ± 111 (382; 510) <sup>a</sup>	9.42	0.001
	0–200	272 ± 102 (213; 331)	356 ± 78 (311; 401)	395 ± 95 (340; 449) <sup>a</sup>	13.77	0.001
	0–250	241 ± 90 (189; 293)	312 ± 85 (263; 361)	354 ± 92 (301; 407) <sup>a</sup>	15.34	0.001
Hip flexors (N·m·s <sup>-1</sup> )	0–30	353 ± 162 (259; 447)	527 ± 167 (431; 623) <sup>a</sup>	620 ± 212 (498; 742) <sup>a</sup>	13.37	0.001
	0–50	376 ± 182 (271; 481)	562 ± 184 (456; 668) <sup>a</sup>	615 ± 190 (505; 724) <sup>a</sup>	10.36	0.002
	0–100	310 ± 146 (226; 394)	431 ± 143 (348; 514)	428 ± 116 (361; 494) <sup>a</sup>	5.95	0.009
	0–150	231 ± 95 (176; 286)	292 ± 80 (246; 338)	308 ± 87 (258; 358)	4.71	0.011
	0–200	206 ± 83 (158; 254)	241 ± 68 (202; 280)	257 ± 67 (218; 617)	2.70	0.069
	0–250	176 ± 71 (135; 217)	200 ± 62 (164; 236)	213 ± 50 (184; 241)	2.08	0.120

$f$  experimental effect ratio,  $p$   $p$  value of main effect showed by ANOVA's Greenhouse–Geisser

<sup>a</sup>Significant difference from week 0, while <sup>b</sup> significant difference from week 6

**Table 2** Mean, standard deviation, and 95% CI for rate of force development (RFD) relative to the maximal isometric voluntary contraction (%MIVC) of the knee extensor and hip extensor–flexor muscles at different periods and time intervals

	Time inter- vals (ms)	Week 0	Week 6	Week 12	<i>f</i>	<i>p</i>
Knee extensors (%MIVC)	0–30	258 ± 94 (204; 302)	353 ± 105 (292; 414) <sup>a</sup>	373 ± 117 (362; 384) <sup>a</sup>	10.17	0.001
	0–50	317 ± 111 (253; 381)	414 ± 109 (351; 477) <sup>a</sup>	425 ± 129 (413; 437) <sup>a</sup>	7.71	0.001
	0–100	384 ± 114 (318; 450)	447 ± 93 (393; 501)	434 ± 107 (424; 444)	2.66	0.071
	0–150	346 ± 82 (299; 393)	382 ± 68 (343; 421)	366 ± 69 (359; 373)	1.81	0.176
	0–200	301 ± 55 (269; 333)	340 ± 51 (311; 369) <sup>a</sup>	330 ± 51 (325; 335)	4.20	0.015
	0–250	282 ± 46 (255; 309)	311 ± 39 (288; 334)	300 ± 35 (297; 303)	3.72	0.023
Hip extensors (%MIVC)	0–30	171 ± 75 (164; 178)	241 ± 101 (231; 251) <sup>a</sup>	224 ± 60 (218; 230) <sup>a</sup>	6.38	0.013
	0–50	203 ± 87 (195; 211)	288 ± 139 (275; 301)	258 ± 71 (218; 230) <sup>a</sup>	5.16	0.028
	0–100	249 ± 86 (241; 257)	338 ± 170 (322; 354)	290 ± 69 (251; 265)	3.23	0.084
	0–150	241 ± 58 (235; 247)	299 ± 92 (290; 308)	264 ± 49 (283; 297)	3.06	0.083
	0–200	210 ± 39 (206; 214)	254 ± 50 (249; 259) <sup>a</sup>	231 ± 36 (259; 269)	4.25	0.033
	0–250	185 ± 29 (183; 187)	224 ± 45 (220; 228) <sup>a</sup>	206 ± 30 (228; 234)	4.90	0.026
Hip Flexors (%MIVC)	0–30	261 ± 215 (241; 281)	429 ± 198 (410; 448)	662 ± 335 (630; 694) <sup>ab</sup>	17.40	0.001
	0–50	338 ± 261 (313; 363)	547 ± 218 (526; 568)	715 ± 310 (685; 745) <sup>ab</sup>	16.14	0.001
	0–100	417 ± 233 (395; 439)	612 ± 154 (597; 627) <sup>a</sup>	589 ± 201 (570; 608)	7.32	0.003
	0–150	340 ± 139 (327; 353)	463 ± 86 (455; 471) <sup>a</sup>	429 ± 122 (417; 441)	5.18	0.008
	0–200	296 ± 106 (286; 306)	369 ± 56 (364; 374)	364 ± 83 (356; 372)	3.86	0.029
	0–250	269 ± 85 (261; 277)	309 ± 50 (304; 314)	306 ± 64 (300; 312)	1.71	0.190

*f* experimental effect ratio, *p* *p* value of main effect showed by ANOVA'S Greenhouse–Geisser

<sup>a</sup>Significantly different from week 0

<sup>b</sup>Significantly different from week 6

## Absolute RFD

There was a significant increase in the knee extensor absolute RFD for the time interval 0–30 ms at week 6 compared to week 0 ( $p=0.040$ ). Considering time intervals 0–30, 0–50, 0–100, 0–150, 0–200, and 0–250 ms, there was a significant increase in the knee extensors absolute RFD after week 12 compared to week 0 ( $p=0.002$ ;  $p=0.003$ ;  $p=0.015$ ;  $p=0.014$ ;  $p=0.002$ ;  $p=0.004$ , respectively). Absolute RFD increased significantly for time intervals 0–30, 0–50, and 0–100 ms after week 6 compared to week 0 ( $p=0.026$ ;  $p=0.033$ ;  $p=0.041$ , respectively) for hip extensor muscles. There was a significant increase after week 12 compared to week 0 ( $p=0.005$ ;  $p=0.004$ ;  $p=0.007$ ;  $p=0.005$ ;  $p=0.001$ ;  $p=0.001$ , respectively) for time intervals 0–30, 0–50, 0–100, 0–150, 0–200, and 0–250 ms. Absolute RFD increased significantly for time interval 0–30 ms after week 6 compared to week 0 ( $p=0.047$ ) for hip flexor muscles. There was a significant increase in the hip flexor's absolute RFD for time intervals 0–30, 0–50, and 0–100 ms after week 12 compared to week 0 ( $p=0.003$ ;  $p=0.004$ ;  $p=0.041$ , respectively).

## Relative RFD

There was a significant increase in the knee extensor's relative RFD for the time intervals 0–30, 0–50, and 0–200 ms after week 6 compared to week 0 ( $p=0.017$ ;  $p=0.024$ ;  $p=0.040$ , respectively). In addition, there was a significant increase in the knee extensors relative RFD after week 12 compared to week 0 ( $p=0.006$ ;  $p=0.005$ , respectively) in the intervals 0–30 and 0–50 ms. A significant increase was found for the hip extensors relative RFD for time intervals 0–30, 0–200, and 0–250 ms after week 6 compared to week 0 ( $p=0.045$ ;  $p=0.011$ ;  $p=0.018$ , respectively). There was a significant increase in the hip extensors relative RFD after week 12 compared to week 0 ( $p=0.011$ ;  $p=0.023$ , respectively) in the intervals 0–30 and 0–50 ms. A significant increase was observed in the hip flexors relative RFD for the time intervals 0–100 and 0–150 ms after week 6 compared to week 0 ( $p=0.033$ ;  $p=0.015$ , respectively). Finally, there was a significant increase after week 12 compared to week 0 ( $p=0.005$ ;  $p=0.006$ ) and compared to week 6 ( $p=0.007$ ;  $p=0.024$ ) for intervals 0–30 and 0–50 ms for the hip flexors relative RFD.

**Table 3** Mean, standard deviation and 95% CI for contractile impulse of the knee extensor and hip extensor–flexor muscles at different periods and time intervals

	Time intervals (ms)	Week 0	Week 6	Week 12	<i>f</i>	<i>p</i>
Knee extensors (N·m·s)	0–30	0.40±0.04 (0.39; 0.40)	0.44±0.60 (0.38; 0.50) <sup>a</sup>	0.46±0.07 (0.42; 0.50) <sup>a</sup>	8.23	0.001
	0–50	0.91±0.14 (0.90; 0.92)	1.04±0.19 (1.02; 1.06) <sup>a</sup>	1.10±0.23 (0.97; 1.23) <sup>a</sup>	8.24	0.001
	0–100	3.10±0.61 (3.48; 3.16)	3.62±0.83 (3.54; 3.70)	3.82±0.94 (3.28; 4.36) <sup>a</sup>	6.68	0.004
	0–150	6.21±1.35 (6.08; 6.34)	7.15±1.65 (6.99; 7.31)	7.53±1.80 (6.49; 8.57) <sup>a</sup>	5.89	0.008
	0–200	9.80±1.86 (9.62; 9.98)	11.32±2.64 (11.0; 11.5)	11.93±2.71 (10.3; 13.4) <sup>a</sup>	6.40	0.007
	0–250	13.96±2.55 (13.7; 14.2)	16.18±3.85 (15.8; 16.5)	17.09±3.75 (14.9; 19.2) <sup>a</sup>	6.88	0.006
Hip extensors (N·m·s)	0–30	0.35±0.04 (0.33; 0.37)	0.39±0.05 (0.36; 0.42)	0.038±0.03 (0.02; 0.06) <sup>a</sup>	6.97	0.012
	0–50	0.75±0.14 (0.67; 0.83)	0.89±0.17 (0.79; 0.99)	0.86±0.12 (0.79; 0.93) <sup>a</sup>	5.16	0.028
	0–100	2.45±0.68 (2.06; 2.83)	3.10±0.72 (2.68; 3.52)	3.02±0.57 (2.69; 3.35) <sup>a</sup>	8.58	0.005
	0–150	4.99±1.54 (4.10; 5.88)	6.30±1.23 (5.59; 7.01) <sup>a</sup>	6.32±1.24 (5.60; 7.04) <sup>a</sup>	9.48	0.002
	0–200	7.97±2.51 (6.52; 9.42)	10.06±1.71 (9.07; 11.05) <sup>a</sup>	10.37±2.01 (9.2; 11.5) <sup>a</sup>	11.11	0.001
	0–250	11.20±3.55 (9.1; 13.2)	14.25±2.42 (12.8; 15.6) <sup>a</sup>	14.95±2.94 (13.2; 16.6) <sup>a</sup>	12.72	0.001
Hip flexors (N·m·s)	0–30	0.37±0.06 (0.34; 0.40)	0.44±0.06 (0.70; 0.40) <sup>a</sup>	0.49±0.09 (0.44; 0.54) <sup>ab</sup>	14.67	0.001
	0–50	0.82±0.20 (0.70; 0.94)	1.04±0.21 (0.92; 1.16) <sup>a</sup>	1.14±0.25 (1.00; 1.28) <sup>a</sup>	12.83	0.001
	0–100	2.51±0.83 (2.03; 2.99)	3.22±0.81 (2.75; 3.69) <sup>a</sup>	3.47±0.77 (3.03; 3.91) <sup>a</sup>	9.43	0.003
	0–150	4.52±1.51 (3.65; 5.39)	5.87±1.42 (5.05; 6.69) <sup>a</sup>	6.06±1.32 (5.30; 6.82) <sup>a</sup>	8.37	0.003
	0–200	6.81±2.23 (5.52; 8.10)	8.56±2.01 (7.40; 9.72)	8.90±1.97 (7.76; 10.4) <sup>a</sup>	7.35	0.004
	0–250	9.34±3.01 (7.60; 11.0)	11.40±2.72 (9.83; 12.97)	11.91±2.55 (10.4; 13.3) <sup>a</sup>	6.42	0.005

*f* experimental effect ratio, *p* *p* value of main effect showed by ANOVA's Greenhouse–Geisser

<sup>a</sup>Significantly different from week 0

<sup>b</sup>Significantly different from week 6

## Contractile impulse

There was a significant increase in the knee extensors contractile impulse in the time intervals 0–30 and 0–50 ms after week 6 compared to week 0 ( $p=0.029$ ;  $p=0.026$ , respectively). A significant increase in the knee extensors' contractile impulse was verified after week 12 compared to week 0 ( $p=0.007$ ;  $p=0.005$ ;  $p=0.005$ ;  $p=0.005$ ;  $p=0.003$ ;  $p=0.002$ , respectively) in the time intervals 0–30, 0–50, 0–100, 0–150, 0–200, and 0–250 ms. There was a significant increase in the hip extensor contractile impulse in the time intervals 0–150, 0–200, and 0–250 ms after week 6 compared to week 0 ( $p=0.044$ ;  $p=0.038$ ;  $p=0.035$ , respectively). There was a significant increase in the hip extensors contractile impulse after week 12 compared to week 0 ( $p=0.009$ ;  $p=0.006$ ;  $p=0.004$ ;  $p=0.004$ ;  $p=0.002$ ;  $p=0.001$ , respectively) in the time intervals 0–30, 0–50, 0–100, 0–150, 0–200, and 0–250 ms. In the time intervals 0–30, 0–50, 0–100, and 0–150 ms of the hip flexors contractile impulse, there was a significant increase after week 6 compared to week 0 ( $p=0.045$ ;  $p=0.047$ ;  $p=0.048$ ;  $p=0.047$ , respectively), while, in the intervals 0–30, 0–50, 0–100, 0–150, 0–200 and 0–250 ms, there was a significant increase after week 12 compared to week 0 ( $p=0.003$ ;  $p=0.003$ ;  $p=0.006$ ;  $p=0.012$ ;  $p=0.022$ ;  $p=0.032$ ,

respectively). There was a significant increase in the hip flexor contractile impulse after week 12 compared to week 6 for time interval 0–30 ms ( $p=0.020$ ).

## Discussion

The present study investigated the effect of 12 weeks of mat Pilates intervention on RFD parameters and contractile impulse in overweight physically active older women. Considering the positive effects in most RFD and contractile impulse time intervals for the three muscle groups tested, our hypothesis was accepted. The main finding of this study was that mat Pilates intervention using an incremental overload model was able to significantly increase absolute and relative RFD, as well as contractile impulse for the knee extensors and hip flexor-extensors.

Moreover, the differences in variables after 12 weeks were significantly different compared to a pre-intervention control period indicating within-subject changes attributed to the Pilates intervention. To the best of our knowledge, this is the first study to assess the effect of mat Pilates on hip flexor–extensor RFD and contractile impulse in overweight physically active older women.

Although the Pilates method is not characterized by rapid contractions, the exercises both dynamic and isometric components with refinements in coordination and balance reactions potentially contributing to the changes noted in this study. Furthermore, Avelar et al. [26] demonstrated that a training program of balance exercises was able to significantly improve knee extensors RFD in a group of older women compared to a control group at time intervals of 0–50, 0–100, 0–200, and 0–300 ms.

It has been shown that the aging process affects the capacity to produce rapid force [29, 40–42]. For instance, Thompson et al. [40] demonstrated that older men produce significantly less absolute RFD and contractile impulse for time intervals 0–30, 0–50, 0–100, and 0–200 ms in the knee extensor muscles compared to young- and middle-aged men. Although aging has a negative impact on these parameters for both older men and women, it appears that older women are more affected than men [29]. The decrease in RFD with aging is affected by different and complex mechanisms, such as slower muscle contractile properties [43, 44], impaired voluntary activation, less motor unit recruitment, and a decrease in the rate at which the active motor action potential units are discharged [10, 43].

On the other hand, aging is associated with the increase of BMI due to overweight and obesity [6, 45]. In this context, LaRoche et al. [46] compared the knee flexor and extensor RFD, as well as the ankle plantarflexor and dorsiflexor muscles in 25 older women, classified in normal weight ( $BMI < 25 \text{ kg/m}^2$ ) and overweight ( $BMI \geq 25 \text{ kg/m}^2$ ). To compare results, LaRoche et al. [46] normalized the RFD dividing this variable by the fat-free mass and body mass. When normalizing by fat-free mass, there were no significant differences between-groups for all muscular groups, while when normalized by body mass, the overweight group showed a significant lower RFD for all muscle groups except for ankle dorsiflexors. Absolute RFD was also significantly lower in the overweight group compared to the normal-weight group for knee flexor and extensor muscles. Different from our study, LaRoche et al. [46] analyzed the first 200 ms of the contraction. It is worth mentioning that the early phase of the RFD ( $< 75 \text{ ms}$ ) is more related to neural factors [11, 47], and it is extremely important to avoid falls during a perturbation [48], while the late phases of the RFD ( $> 100 \text{ ms}$ ) are more influenced by contractile properties and maximal voluntary contraction [47, 49].

According to Aagaard [24], strength training is able to induce changes in neural properties, such as increasing firing rates and motor units' excitability, down regulating neural pathways, and central descending motor drive. Although we did not investigate neural properties and effort type, strength training and Pilates method are quite different. From the RFD results observed at the early phases of the torque–time curve (0–30 and 0–50 ms), for both knee and hip joints, we

might speculate that 12 weeks of Pilates intervention can induce neuromuscular adaptations. However, further investigations are necessary to ratify this hypothesis.

Aging, higher body mass and sedentary lifestyles might impact the capacity to produce rapid force [50]. Furthermore, the ability to produce rapid contractions and force has been reported to decrease to a greater extent than muscle strength in older individuals [29, 40]. In our study, we found a significant increase at most time intervals in absolute and relative RFD and contractile impulse after week 6 of mat Pilates training for all the muscle groups assessed. After 12 weeks of intervention, most of the time intervals showed greater increments than week 6, which may be related to the augmentations in the number of exercise repetitions and higher difficulty level.

As previously mentioned, hip RFD has not been explored before, during, and after a training program in older adults. Even though the hip joint has an important role during ADLs (i.e., going up and down stairs, rising from a chair, transposing obstacles, and avoiding falls), this joint's extensor and flexor muscles' force production is less studied compared to the knee and the ankle joints [27, 28]. In the present study, the absolute and relative RFD and contractile impulse increased significantly for hip extensor–flexor muscles, parameters that have relevance due to the association with older adults' functionality [42, 51] added to the hip role during ADLs. It is also worth mentioning that the Pilates method emphasizes the CORE workout, which includes the abdominal and hip muscles [52] involved in body stabilization.

We verified positive effects after mat Pilates intervention on RFD parameters for all muscle groups assessed. However, among the limitations of this study, we highlight the following: (a) small sample size, (b) the lack of physical activity level data, (c) lack of randomized design, and (d) lack of blinded assessment. Further studies should be carried out using a randomized and blinded designs, mainly in sedentary older men and women, as well as in individuals with skeletal muscle illnesses (i.e., osteoarthritis, arthrosis, rheumatoid arthritis, or disc hernia) for longer intervention periods in mat Pilates and in Pilates practiced with apparatus. In addition, studies comparing the effects of Pilates with a different number of sets (e.g., 1, 2, and 3) and repetitions (e.g., 6–15) should be conducted to identify the best overload throughout the training intervention.

## Conclusions

In summary, mat Pilates intervention using an incremental overload model was able to induce improvements in absolute and relative RFD and contractile impulse for lower limb

muscle groups after 6 weeks of training, with further increments after 12 weeks.

**Acknowledgements** The authors wish to thank the study participants, CAPES for the scholarship for JB, and CNPq for the fellowship for FD and MAV.

### Compliance with ethical standards

**Conflict of interest** The authors of this manuscript declare no conflict of interest.

**Ethical approval** The local Human Research Ethics Committee approved the study (Protocol No. 44972915.9.0000.0110), procedures were conducted in accordance with the Declaration of Helsinki, and the participants signed an informed consent form.

### References

- Yu F, Hedström M, Cristea A et al (2007) Effects of ageing and gender on contractile properties in human skeletal muscle and single fibres. *Acta Physiol* 190:229–241. <https://doi.org/10.1111/j.1748-1716.2007.01699.x>
- Mitchell WK, Williams J, Atherton P et al (2012) Sarcopenia, dynapenia, and the impact of advancing age on human skeletal muscle size and strength; a quantitative review. *Front Physiol* 3:1–18. <https://doi.org/10.3389/fphys.2012.00260>
- Narici MV, Maffulli N, Maganaris CN (2008) Ageing of human muscles and tendons. *Disabil Rehabil* 30:1548–1554. <https://doi.org/10.1080/09638280701831058>
- Narici MV, Maganaris CN, Reeves ND, Capodaglio P (2003) Effect of aging on human muscle architecture. *J Appl Physiol* 95:2229–2234. <https://doi.org/10.1152/jappphysiol.00433.2003>
- Newman AB, Lee JS, Visser M et al (2005) Weight change and the conservation of lean mass in old age: the health, aging and body composition study. *Am J Clin Nutr* 82:872–878. <https://doi.org/10.1093/ajcn/82.4.872>
- Kuk JL, Saunders TJ, Davidson LE, Ross R (2009) Age-related changes in total and regional fat distribution. *Ageing Res Rev* 8:339–348. <https://doi.org/10.1016/j.ARR.2009.06.001>
- Santanasto AJ, Glynn NW, Newman MA et al (2011) Impact of weight loss on physical function with changes in strength, muscle mass, and muscle fat infiltration in overweight to moderately obese older adults: a randomized clinical trial. *J Obes*. <https://doi.org/10.1155/2011/516576>
- LaRoche DP, Cremin KA, Greenleaf B, Croce RV (2010) Rapid torque development in older female fallers and nonfallers: a comparison across lower-extremity muscles. *J Electromyogr Kinesiol* 20:482–488. <https://doi.org/10.1016/J.JELEKIN.2009.08.004>
- Doherty TJ (2003) Invited review: aging and sarcopenia. *J Appl Physiol* 95:1717–1727. <https://doi.org/10.1152/jappphysiol.00347.2003>
- Thompson BJ, Ryan ED, Herda TJ et al (2014) Age-related changes in the rate of muscle activation and rapid force characteristics. *Age (Dordr)* 36:839–849. <https://doi.org/10.1007/s11357-013-9605-0>
- Aagaard P, Simonsen EB, Andersen JL et al (2002) Increased rate of force development and neural drive of human skeletal muscle following resistance training. *J Appl Physiol* 93:1318–1326. <https://doi.org/10.1152/jappphysiol.00283.2002>
- Caserotti P, Aagaard P, Larsen JB, Puggaard L (2008) Explosive heavy-resistance training in old and very old adults: changes in rapid muscle force, strength and power. *Scand J Med Sci Sports* 18:773–782. <https://doi.org/10.1111/j.1600-0838.2007.00732.x>
- Barboza BHV, Gurjão ALD, Jambassi Filho JC et al (2008) Age-related decline on rate of force development and the effect of resistance training in older women. *Acta Fisiátrica* 16:4–9
- Moura BM de, Sakugawa RL, Orssatto LBR da et al (2017) Functional capacity improves in-line with neuromuscular performance after 12 weeks of non-linear periodization strength training in the elderly. *Aging Clin Exp Res* 1–10. <https://doi.org/10.1007/s40520-017-0873-x>
- Tiggemann CL, Dias CP, Radaelli R et al (2016) Effect of traditional resistance and power training using rated perceived exertion for enhancement of muscle strength, power, and functional performance. *Age (Dordr)* 38:42. <https://doi.org/10.1007/s11357-016-9904-3>
- Blazevich AJ, Horne S, Cannavan D et al (2008) Effect of contraction mode of slow-speed resistance training on the maximum rate of force development in the human quadriceps. *Muscle Nerv* 38:1133–1146. <https://doi.org/10.1002/mus.21021>
- Souza MS, Vieira BC, C (2006) Who are the people looking for the Pilates method? *J Bodyw Mov Ther* 10:328–334. <https://doi.org/10.1016/J.JBMT.2005.10.005>
- Wells C, Kolt GS, Bialocerkowski A (2012) Defining Pilates exercise: a systematic review. *Complement Ther Med* 20:253–262. <https://doi.org/10.1016/j.ctim.2012.02.005>
- Oliveira LC, Oliveira RG, Pires-Oliveira DAA (2016) Comparison between static stretching and the Pilates method on the flexibility of older women. *J Bodyw Mov Ther* 1–7. <https://doi.org/10.1016/j.jbmt.2016.01.008>
- Rogers K, Gibson AL (2009) Eight-week traditional mat Pilates training-program effects on adult fitness characteristics. *Res Q Exerc Sport* 80:569–574
- Oliveira LC, Pires-Oliveira DAA, Abucarub AC, Oliveira RG De et al (2017) Pilates increases isokinetic muscular strength of the elbow flexor and extensor muscles of older women: a randomized controlled clinical trial. *J Bodyw Mov Ther* 21:2–10. <https://doi.org/10.1016/j.jbmt.2016.03.002>
- Bertoli J, Dal Pupo J, Vaz MA et al (2018) Effects of mat Pilates on hip and knee isokinetic torque parameters in elderly women. *J Bodyw Mov Ther* 22:798–804. <https://doi.org/10.1016/J.JBMT.2017.08.006>
- Kloubec J (2011) Pilates: how does it work and who needs it? *Muscles Ligament Tendons J* 1:61–66
- Aagaard P (2003) Training-induced changes in neural function. *Exerc Sport Sci Rev* 31:61–67
- Higbie EJ, Cureton KJ, Warren GL, Prior BM (1996) Effects of concentric and eccentric training on muscle strength, cross-sectional area, and neural activation. *J Appl Physiol* 81:2173–2181. <https://doi.org/10.1152/jappl.1996.81.5.2173>
- Avelar BP, Costa JNA de, Safons MP et al (2016) Balance exercises circuit improves muscle strength, balance, and functional performance in older women. *Age (Dordr)* 38:14. <https://doi.org/10.1007/s11357-016-9872-7>
- Dvir Z (2002) Isokinetic of the hip muscles. In: *Isokinetics: muscle testing, interpretation, and clinical applications*, pp 91–100
- Neumann D (2010) Kinesiology of the hip: a focus on muscular actions. *J Orthop Sports Phys Ther* 40:82–94. <https://doi.org/10.2519/jospt.2010.3025>
- Skelton DA, Greig CA, Davies JM, Young A (1994) Strength, power and related functional ability of healthy people aged 65–89 years. *Age Ageing* 23:371–377
- Cohen J (1992) A power primer. *Psychol Bull* 112:155–159
- Brucki SMD, Nitri R, Caramelli P et al (2003) Sugestões para o uso do mini-exame do estado mental no Brasil. *Arq Neuropsiquiatr* 61:777–781. <https://doi.org/10.1590/S0004-282X2003005000014>

32. Folstein MF, Robins LN, Helzer JE (1983) The mini-mental state examination. *Arch Gen Psychiatry* 40:812. [https://doi.org/10.1016/0022-3956\(75\)90026-6](https://doi.org/10.1016/0022-3956(75)90026-6)
33. Yesavage JA, Sheikh JI (1986) 9/ Geriatric Depression Scale (GDS) sigeriatric depression recent evidence and development of a shorter version. *Clin Gerontol* ISSN 5:165–173. <https://doi.org/10.1300/J018v05n01>
34. Häkkinen K, Newton RU, Gordon SE et al (1998) Changes in muscle morphology, electromyographic activity, and force production characteristics during progressive strength training in young and older men. *J Gerontol A Biol Sci Med Sci* 53:415–423
35. Häkkinen K, Kallinen M, Izquierdo M et al (1998) Changes in agonist-antagonist EMG, muscle CSA, and force during strength training in middle-aged and older people Changes in agonist-antagonist EMG, muscle CSA, and force during strength training in middle-aged and older people. *J Appl Physiol* 84:1341–1349
36. Latey P (2002) Updating the principles of the Pilates method—part 2. *J Bodyw Mov Ther* 6:94–101. <https://doi.org/10.1054/jbmt.2002.0289>
37. Walker S, Peltonen H, Sautel J et al (2014) Neuromuscular adaptations to constant vs. variable resistance training in older men. *Int J Sports Med* 35:69–74. <https://doi.org/10.1055/s-0033-1343404>
38. Maffiuletti NA, Aagaard P, Blazevich AJ et al (2016) Rate of force development: physiological and methodological considerations. *Eur J Appl Physiol* 116:1091–1116. <https://doi.org/10.1007/s00421-016-3346-6>
39. Cohen J (1988) *Statistical power analysis for the behavioral sciences*, 2nd edn. Lawrence Erlbaum Associates, New York
40. Thompson BJ, Ryan ED, Sobolewski EJ et al (2013) Age related differences in maximal and rapid torque characteristics of the leg extensors and flexors in young, middle-aged and old men. *Exp Gerontol* 48:277–282. <https://doi.org/10.1016/j.exger.2012.10.009>
41. Izquierdo M, Aguado X, Gonzalez R et al (1999) Maximal and explosive force production capacity and balance performance in men of different ages. *Eur J Appl Physiol Occup Physiol* 79:260–267. <https://doi.org/10.1007/s004210050504>
42. Bellumori M, Jaric S, Knight CA (2013) Age-related decline in the rate of force development scaling factor. *Mot Control* 17:370–381
43. Klass M, Baudry S, Duchateau J (2008) Age-related decline in rate of torque development is accompanied by lower maximal motor unit discharge frequency during fast contractions. *J Appl Physiol* 104:739–746. <https://doi.org/10.1152/jappphysiol.00550.2007>
44. Thelen DG, Muriuki M, James J et al (2000) Muscle activities used by young and old adults when stepping to regain balance during a forward fall. *J Electromyogr Kinesiol* 10:93–101
45. Reinders I, Murphy RA, Koster A et al (2015) Muscle quality and muscle fat infiltration in relation to incident mobility disability and gait speed decline: the age, gene/environment susceptibility-Reykjavik study. *J Gerontol A Biol Sci Med Sci* 70:1030–1036. <https://doi.org/10.1093/gerona/glv016>
46. LaRoche DP, Kralian RJ, Millett ED (2011) Fat mass limits lower-extremity relative strength and maximal walking performance in older women. *J Electromyogr Kinesiol* 21:754–761. <https://doi.org/10.1016/j.jelekin.2011.07.006>
47. Folland JP, Buckthorpe MW, Hannah R (2014) Human capacity for explosive force production: neural and contractile determinants. *Scand J Med Sci Sports* 24:894–906. <https://doi.org/10.1111/sms.12131>
48. Bassey EJ, Fiatarone MA, O’Neill EF et al (1992) Leg extensor power and functional performance in very old men and women. *Clin Sci* 82:321–327
49. Andersen LL, Aagaard P (2006) Influence of maximal muscle strength and intrinsic muscle contractile properties on contractile rate of force development. *Eur J Appl Physiol* 96:46–52. <https://doi.org/10.1007/s00421-005-0070-z>
50. D’Antona G (2003) The effect of ageing and immobilization on structure and function of human skeletal muscle fibres. *J Physiol* 552:499–511. <https://doi.org/10.1113/jphysiol.2003.046276>
51. Foldvari M, Clark M, Laviolette LC et al (2000) Association of muscle power with functional status in community-dwelling elderly women. *J Gerontol A Biol Sci Med Sci* 55:M192–M199
52. Behm DG, Drinkwater EJ, Willardson JM, Cowley PM (2010) The use of instability to train the core musculature. *Appl Physiol Nutr Metab* 35:91–108. <https://doi.org/10.1139/H09-127>

**Publisher’s Note** Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.