Effect of Different Load Intensity Transition Schemes on Muscular Strength and Physical Performance in Postmenopausal Women

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ABSTRACT

CARNEIRO, M. A. S., W. KASSIANO, G. OLIVEIRA-JÚNIOR, J. F. R. SOUSA, E. S. CYRINO, and F. L. ORSATTI. Effect of Different Load Intensity Transition Schemes on Muscular Strength and Physical Performance in Postmenopausal Women. *Med. Sci. Sports Exerc.*, Vol. 55, No. 8, pp. 1507–1523, 2023. **Purpose:** In postmenopausal women, optimizing muscular strength and physical performance through proper resistance training (RT) is crucial in achieving optimal functional reserve later in life. This study aimed to compare if a higher-load-to-lower-load (HL-to-LL) scheme is more effective than a lower-load-to-higher-load (LL-to-HL) scheme on muscular strength and physical performance in postmenopausal women after 12 and 24 wk of RT. **Methods:** Twenty-four postmenopausal women were randomized into two groups: LL-to-HL (n = 12, 27–31 repetitions maximum (RM) in the first 12 wk, and 8–12RM in the last 12 wk) or HL-to-LL (n = 12, 8–12RM during the first 12 wk, and 27–31RM in the last 12 wk). Muscular dynamic (1RM test) and isometric strength (MIVC) and functional tests (sit-to-stand power, 400-m walking, and 6-min walking) were analyzed at baseline, after 12 and 24 wk. **Results:** Different load intensity transition schemes resulted in enhancements ($P < 0.05$) in dynamic (45° leg press: LL-to-HL = 21.98% vs HL-to-LL = 16.07%; leg extension: LL-to-HL = 23.25% vs HL-to-LL = 16.28%; leg curl: LL-to-HL = 23.89% vs HL-to-LL = 13.34%) and isometric strength (LL-to-HL = 14.63% vs HL-to-LL = 19.42%), sit-to-stand power (LL-to-HL = 7.32% vs HL-to-LL = 0%), and walking speed (400-m test: LL-to-HL = 3.30% vs HL-to-LL = 5.52%; 6-min test: LL-to-HL = 4.44% vs HL-to-LL = 5.55%) after 24 wk of RT, without differences between groups ($P > 0.05$). However, only the HL increased the dynamic strength in 45° leg press and leg extension and sit-to-stand power. Moreover, walking speed changes were more strongly correlated with the changes in MIVC ($P < 0.05$). **Conclusions:** Our results indicate that both load intensity transition schemes produce similar improvements in muscular strength and physical performance in postmenopausal women after 24 wk of RT. However, the HL was more effective in increasing 45° leg press and leg extension strength, as well as power (mainly when performed after the LL), whereas having little effect on leg curl strength, isometric strength, and walking speed. Our findings suggest that although an HL makes a muscle isotonically stronger, it may have limited impact on isometric strength and walking speed in postmenopausal women.

Key Words: STRENGTH TRAINING, PERIODIZATION, VARIATION, FORCE, OLD ADULTS

The increase in life expectancy has resulted in women spending one-third of their lives in the postmenopausal period, older than 50 yr. The menopause transition is characterized by a rapid decline in muscular strength, particularly in the lower limbs (1–3). This decline contributes to a decline in physical performance, which can be defined as "an objectively measured whole body function related with mobility," such as walking speed (4). Impaired muscular strength and physical performance may precede sarcopenia (5), falls, disability, loss of independence, and premature death (6). This leads to increased healthcare costs for community-dwelling older adults (7,8), in which older women face a greater burden than older men (9). The cost difference can range from $5684 for those with low muscular strength to $2271 for those with normal muscular strength (7,8).

Resistance training (RT) has been established as a means of mitigating the negative impacts of women aging on muscular strength and physical performance (10). However, the most appropriate RT scheme for optimizing muscular strength and physical performance gains remains elusive. Among several possible RT variables to be manipulated (11), the order of load intensity (light, moderate or heavy weights) has been identified as a key factor in optimizing RT-induced adaptations (11–16). However, there is limited published research on the effect of the order of load intensity, particularly among older adults. The available evidence on the topic is inconsistent. Some studies suggest that starting RT with a lower load (LL, >25 repetitions)

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and gradually increasing to a higher load (HL, 8–12 repetitions) results in improved muscular strength and physical performance gains (11–13), whereas others argue that starting with an HL and transitioning to an LL is more effective (14–16).

For postmenopausal and older women with comorbidities (e.g., musculoskeletal disease, coronary artery disease, and diabetes), the suggested RT approach is to start with LL and transit to HL (11,17,18). Starting with HL may cause joint pain, due to high compressive forces, in novice exercisers, particularly postmenopausal women who are at risk of osteoarthritis (19,20). In addition, RT with HL can cause skeletal muscle damage in novice exercisers, leading to an acute inflammatory response that removes damaged tissue and triggers repair mechanisms. However, postmenopausal women lack estrogen's protective effect on muscle damage and inflammation from exercise, leading to slower recovery and repair after muscle damage (21–23). As a result, repeated HL sessions may not align with the muscle damage (24) and the recovery process in novice postmenopausal women (21,22), potentially hindering the growth of myosin heavy chain II fibers (25) and impacting muscular strength and physical performance gains (26). Indeed, previous evidence has suggested that this approach is more effective to improve muscular strength and physical performance than starting with HL and transiting to LL (11–13).

However, recent findings in young men suggest that starting with HL followed by LL may lead to greater gains in muscular strength, hypertrophy, and endurance (14–16). It is suggested that HL leads to greater muscular strength gains than LL (27) and the increase in muscular strength obtained in the first weeks of RT (during the HL phase) enables postmenopausal women to use heavier weights later in the training program (during the LL phase) (15), leading to increased stress on skeletal muscle (28). The mechanical stress applied to each fiber has regulatory effects, via mechanotransduction and activation of force sensors, on the mechanisms involved in RT adaptations (28). This stress plays a role in enhancing muscle growth (28), which can result in increased muscle strength (29). However, while literature suggests that transitioning from higher-load-to-lower-load (HL-to-LL) can enhance muscle performance in men, there is a dearth of studies examining the effectiveness of this approach in women, particularly in postmenopausal women. Thus, this study aimed to compare if an HL-to-LL transition scheme is more effective than a lower-load-to-higher-load (LL-to-HL) transition scheme on muscular strength and physical performance in postmenopausal women after 12 and 24 wk of RT. We hypothesized that the HL-to-LL transition scheme would result in superior gains in muscular strength and physical performance gains than LL-to-HL.

METHODS

Study overview. This crossover study was conducted over 28 wk. Initially, an anamnesis was performed to delimit the sample from the inclusion criteria, and a total of 24 postmenopausal women were included in this study. All participants performed three sessions of familiarization of execution techniques in week 1 (45° leg press, leg extension, leg curl, and calf raise). Muscular strength assessment and functional tests were performed in weeks 2, 15, and 28. In the study's first 12 wk of RT (weeks 3–14), the 24 participants were randomly assigned to HL or LL intensities and performed the RT for 12 wk. After this period, a crossover of the load intensity (transition) was adopted (HL-to-LL or LL-to-HL), and the participants performed another 12 wk of RT (weeks 16 to 27). Thus, two parallel groups of 12 individuals each were trained for 24 wk (HL-to-LL or LL-to-HL). In this study, however, the 24 participants trained at high and low intensities for 12 wk due to the crossover design. All assessments and RT sessions were performed at the same time of day to minimize the effects of daytime biological variation. In addition, all muscular strength and functional tests were performed 48 to 72 h after the last RT session to avoid residual effects of training.

Participants. Recruitment was carried out in residential neighborhoods. Interested postmenopausal women completed detailed anamnesis (age, labor situation, health indicators, history of past and present illnesses, therapeutic and physical activities). Of the 39 volunteers who were screened for participation, 24 postmenopausal women met the inclusion criteria, which were: (i) >50 yr or older (characterized by spontaneous amenorrhea for at least 12 months); (ii) no use of hormone therapy or dietary supplements; (iii) controlled blood pressure and glycemia; (iv) absence of myopathies, arthropathies, and neuropathies; (v) lack of muscle, thromboembolic, and gastrointestinal disorders; (vi) absence of cardiovascular and infectious diseases; (vii) nondrinkers (no alcohol intake whatsoever in their diet); (viii) nonsmokers; (ix) they had resistance exercise experience, but had not practiced regular physical activity more than once every week in the last 6 months, and (x) performed the 24 wk of RT. The study conducted at Federal University of Triangulo Miniero (UFTM) adhered to the ethical standards set by the institutional and national research committee, as well as the Helsinki Declaration. Furthermore, all participants provided informed consent prior to their involvement in the study. The local ethical committee (CAAD: 5052218.0.0000.5154 and number: 2.654.326) approved the study, ensuring its compliance with all necessary regulations.

Muscular strength (dynamic and isometric) and functional tests. A combination of muscular strength measures (dynamic and isometric) and functional tests (physical performance) represents a global function of individuals, mainly in older adults (including postmenopausal women) (4,5).

Dynamic muscular strength was measured using the 1RM tests in 45° leg press, leg extension, and leg curl exercises. Test–retest reliability of the 1RM test is good to excellent regardless of exercise selection, familiarization sessions, RT experience, body parts tested (upper vs lower body), sex, or age (30).

Previously, participants completed three RT sessions (Monday, Wednesday, and Friday) to become familiarized with the exercise technique. The 1RM tests were preceded by a general warm-up (walking for 5 min) at their usual speed and a specific warm-up of 15 to 20 repetitions using LL. After 90 s of rest, the load intensity was increased by ~20%, and the participants performed between 8 and 12 repetitions. Again, after 90 s of rest, the load intensity was increased by ~20%, and the participants performed between three to five repetitions. Posteriorly, after 3 to 5 min of rest, the load intensity was considerably increased, and the participants were encouraged to overcome resistance using the full range of motion. When the load intensity was overestimated or underestimated, the participants rested for 3 to 5 min before a new attempt was performed with a lower or higher load intensity (~5% to 10%), respectively. This last procedure was performed to find the equivalent 1RM load intensity, ranging between two and five attempts. The load intensity performed with no more than one repetition by the participant was adopted as 1RM for each exercise.

In the sit-to-stand test (STS) using a chair (42 cm height), the participants performed five repetitions as fast as possible from the sitting position with their buttocks touching the chair to the full standing position, and their arms crossed over the chest. Then, the STS power was calculated using the subject's body mass and height, chair height and the time needed to complete five STS repetitions, according to Alcazar et al (31). The 400-m walking and 6-min walking test (6MWT) were performed on a flat floor around the sports court. The walking course was 103 m (32 m + 19.5 m + 32 m + 19.5 m of length marked every 3 m). Participants performed a warm-up (walking for 5 min) at their usual speed before the physical performance tests. All participants were advised to walk as fast as possible with no interruptions and no running during the trial. Verbal cues were used to encourage participants to stay motivated during the testing (i.e., "you are doing great," "walk as fast as you can"). After completing the 400-m walk, the time was recorded. Distance performed by participants was recorded at the end of the 6MWT. All functional tests were performed three times during the study: baseline, after 12 and 24 wk of training. These functional tests have shown excellent test–retest reliability (4,31,32). The rest intervals between each functional test lasted 3 min.

In addition, the knee extension maximal isometric voluntary contraction (MIVC) was performed in a climate-controlled (21–25°C) laboratory. A S-beam load cell (Miotec Equipamentos Biomédicos, Porto Alegre, RS, Brazil) with maximum tension-compression = 200 kgf, precision of 0.1 kgf, maximum error of measurement = 0.33% was attached just above the malleolus without static fixation of the ankle joint. The participants were placed in a sitting position and securely strapped into the test chair, with the hip and knee joints at angles of 100° and 70°, respectively. The load cell axis was aligned with the knee flexion-extension axis and positioned perpendicular to the individual's lower leg axis. Trunk movement was limited by two cross-shoulder harnesses and an abdomen belt. The hands were positioned over (holding) cross-shoulder harnesses. Initially, a warm-up was performed with 24 contractions (3 s of contraction and 2 s of rest). The effort level of the warm-up exercise was auto-selected as comfortable. After the warm-up exercise, a 3-min pause was allowed, and then three MIVC with a duration of 3 s were performed. A 1-min pause was allowed between the MIVC. Contractions and rest time were controlled by a metronome and preceded by verbal commands "go and stop," respectively. The signal was captured with an analogic-to-digital converter (Miotec Equipamentos Biomédicos, Porto Alegre, RS, Brazil) using a sampling frequency of 2000 Hz, and analyzed in a specific software MioGraph (Miotec Equipamentos Biomédicos, Porto Alegre, RS, Brazil). The torque was calculated by multiplying the MIVC by the leg length (distance between the medial malleolus and the knee intra-articular space). Afterward, the MIVC was the maximum peak value recorded by the equipment (33).

Regarding 12 and 24 wk postintervention, the muscular strength and functional test data were determined after 48 to 72 h of the last RT session. Moreover, we standardized the same hour of the day to perform all the assessments, according to each participant.

RT program. The RT program was performed $3 \cdot d \cdot wk^{-1}$ (Mondays, Wednesdays, and Fridays) over 24 wk. Two fitness professionals supervised all RT sessions to ensure consistent and safe exercise techniques. Before beginning each RT session, participants performed a warm-up (walking for 5 min) at their usual speed. Afterward, both the HL-to-LL and LL-to-HL groups performed three sets in four single- and multiple-joint dynamic exercise machine (Moldmac Live Fitness, Franca, SP, Brazil): 45° leg press, leg extension, leg curl, and calf raise. The rest of the interval between sets and exercises was 90 s. The execution velocity was 1 to 2 s for each muscle action. The participants performed the maximal of repetitions until, or close to, voluntary concentric failure in each set. The load intensity used in the first set of each exercise allowed individuals to perform between 27 (minimal) and 31 (maximum) repetitions (LL) or 8 (minimal) and 12 (maximum) repetitions (HL). The weight in each exercise was adjusted by 5% to 10% when the upper limit of the repetition zone was reached in the first set (LL = 31 repetitions and HL = 12 repetitions) (34–36).

Moreover, in both load intensity transition schemes, participants were oriented to perform the maximum repetitions possible in the second and third sets (until, or close to, voluntary concentric failure) with the same load used in the first set. The duration of RT sessions in the LL was ~40 min, whereas in the HL, it was ~30 min.

Statistical analyses. Data distributions were examined using the Shapiro–Wilk test. The Levene test was used to verify the variance homogeneity. The data showed normal distribution and variance homogeneity between groups. The box-plot analysis identified outliers within the groups in some variables. To test the sensitivity of the outliers, the outliers were moved to the closest value in the dataset (5th–10th or 90th–95th percentiles). Then, we compared groups without outliers (see Supplemental Tables 1 and 2, Supplemental Digital Content, http://links.lww.com/MSS/C833). The original values were used for statistical analysis as the outliers did not impact the results. Data are presented as means and a confidence interval of 95%. Score changes (deltas), which represent the average change in a variable between two time points, were calculated for all individuals between the pre and 12th week, the pre and 24th week, and the 12th and 24th weeks (Tables 1 and 2).

The Student *t* test (independent) was used to compare the general characteristics of the groups at baseline. Furthermore, the Student *t* test was used to compare training characteristics between groups. ANCOVA adjusted for the baseline value as a covariate to eliminate any possible influence of initial variances on different load intensity scheme results and regression to the mean (37–39) was used to compare deltas between the groups. The deltas between pre and the 12th week and between the pre and 24th week were adjusted for the prevalue, and the delta between the 12th and 24th week was adjusted for the 12th week value (Table 1). The different phases were combined (crossover study) and a *t* test (matched pairs) was used to compare the load intensities (Table 2). The unadjusted comparison of the deltas of the groups are shown in Figures 2A, 2D, 2G, 3A, 3D, 3G, 3J, 4A, 4C, 4E, and 4G.

The effect size (d) was calculated by subtracting the delta means (delta HL-to-LL minus LL-to-HL or HL minus LL, Tables 1 and 2, respectively) and dividing the result by the pooled standard deviation. We also calculated the probability of superiority (PS) or common language effect size indicator (40), which is the likelihood that a randomly selected case from one sample has a higher mean value than a randomly selected case from the other sample. For PS, we take the higher group mean as the point of reference. Therefore, all PS values are positive. Moreover, we calculated the *post hoc* power analysis (G*Power, version 3.1.9.7).

Because of the nature of the study (load intensity crossover and older adults), the duration of the intervention (6 months), and inclusion criteria, the sample size was limited (*n* = 24,

TABLE 1. Muscular strength and power and physical performance at baseline, after 12 and 24 wk of lower-limb RT at different load intensity transition schemes in postmenopausal women.

Variables	**LL-to-HL (*n* = 12)**	**HL-to-LL (*n* = 12)**	**ES (*d*)**	**PS (%)**	***P***
Leg press (kg)					
Pre	162.9 (140.7 to 185.1)	147.5 (128.4 to 166.6)			
12 wk	170.4 (139.9 to 200.9)	172.5 (149.4 to 195.5)			
24 wk	198.7 (168.5 to 229.0)	171.2 (148.3 to 194.2)			
Δ Pre to 12 wk	7.5 (−5.4 to 20.4)	25.7 (16.8 to 33.2)	1.31	82	0.005
Δ 12 to 24 wk	28.3 (10.6 to 46.0)	−1.2 (−15.8 to 13.3)	−1.18	80	0.009
Δ Pre to 24 wk	35.8 (19.5 to 52.2)	23.7 (10.1 to 37.4)	−0.45	62	0.294
Leg extension (kg)					
Pre	31.4 (27.6 to 35.2)	30.1 (26.1 to 34.1)			
12 wk	33.8 (30.1 to 37.5)	34.5 (29.9 to 39.0)			
24 wk	38.7 (34.9 to 42.4)	35.0 (30.2 to 39.7)			
Δ Pre to 12 wk	2.4 (0.6 to 4.2)	4.4 (2.9 to 5.8)	0.75	70	0.084
Δ 12 to 24 wk	4.9 (3.1 to 6.6)	0.5 (−0.8 to 1.8)	−1.76	89	<0.001
Δ Pre to 24 wk	7.2 (4.3 to 10.1)	4.9 (2.8 to 7.0)	−0.62	67	0.144
Leg curl (kg)					
Pre	18.0 (14.5 to 21.5)	18.7 (16.1 to 21.4)			
12 wk	20.7 (17.4 to 24.0)	20.3 (17.8 to 22.8)			
24 wk	22.3 (18.5 to 26.1)	21.2 (18.2 to 24.3)			
Δ Pre to 12 wk	2.7 (0.4 to 5.0)	1.5 (0.6 to 2.4)	−0.38	61	0.360
Δ 12 to 24 wk	1.6 (0.1 to 3.1)	1.0 (−0.1 to 2.0)	−0.31	59	0.460
Δ Pre to 24 wk	4.3 (1.2 to 7.5)	2.5 (1.1 to 3.8)	−0.44	62	0.291
MIVC (N·m)					
Pre	123.0 (104.4 to 141.6)	107.1 (96.3 to 117.9)			
12 wk	137.1 (116.5 to 157.8)	127.1 (113.7 to 140.5)			
24 wk	141.0 (118.7 to 163.2)	127.9 (114.5 to 141.3)			
Δ Pre to 12 wk	14.1 (6.6 to 14.7)	20.0 (13.7 to 26.3)	0.60	66	0.179
Δ 12 to 24 wk	3.9 (−6.1 to 13.7)	0.8 (−6.6 to 8.2)	−0.27	58	0.528
Δ Pre to 24 wk	18.0 (8.2 to 27.7)	20.8 (11.7 to 30.0)	0.23	57	0.606
STS power (w·kg^{-1})					
Pre	4.1 (3.7 to 4.5)	4.0 (3.5 to 4.4)			
12 wk	4.1 (3.8 to 4.4)	4.1 (3.7 to 4.5)			
24 wk	4.4 (4.1 to 4.7)	4.0 (3.7 to 4.3)			
Δ Pre to 12 wk	0.0 (−0.3 to 0.3)	0.1 (−0.2 to 0.5)	0.23	57	0.586
Δ 12 to 24 wk	0.3 (0.0 to 0.6)	−0.1 (−0.3 to 0.1)	−1.14	79	0.011
Δ Pre to 24 wk	0.3 (−0.1 to 0.7)	0.0 (−0.4 to 0.5)	−0.74	70	0.087
400 m (m·s^{-1})					
Pre	1.82 (1.74 to 1.90)	1.81 (1.73 to 1.89)			
12 wk	1.87 (1.79 to 1.95)	1.88 (1.80 to 1.96)			
24 wk	1.88 (1.80 to 1.97)	1.91 (1.83 to 2.00)			
Δ Pre to 12 wk	0.05 (0.01 to 0.09)	0.07 (0.03 to 0.11)	0.41	61	0.330
Δ 12 to 24 wk	0.02 (−0.02 to 0.05)	0.03 (−0.01 to 0.07)	0.20	56	0.628
Δ Pre to 24 wk	0.07 (0.01 to 0.12)	0.10 (0.05 to 0.16)	0.43	62	0.308
6MWT (m·s^{-1})					
Pre	1.80 (1.73 to 1.88)	1.80 (1.72 to 1.87)			
12 wk	1.86 (1.79 to 1.94)	1.87 (1.80 to 1.95)			
24 wk	1.88 (1.80 to 1.96)	1.90 (1.82 to 1.98)			
Δ Pre to 12 wk	0.06 (0.02 to 0.10)	0.08 (0.04 to 0.11)	0.29	58	0.488
Δ 12 to 24 wk	0.01 (−0.02 to 0.05)	0.03 (−0.01 to 0.06)	0.23	57	0.575
Δ Pre to 24 wk	0.07 (0.02 to 0.12)	0.10 (0.05 to 0.15)	0.38	61	0.366

ANCOVA, adjusted for baseline value and age as the covariates, was used to compare the changes between groups. Data are presented in means and confidence interval of 95%.

TABLE 2. Effect of load intensity on muscular strength, sit-to-stand power test, and walking speed tests after 12 wk (crossover) of RT in postmenopausal women.

Variables	LL ($n = 24$)	HL ($n = 24$)	*ES* (d)	PS (%)	P
Leg press (kg)					
Pre	167.7 (152.9 to 182.6)	159.0 (141.7 to 176.2)			
12 wk	170.8 (153.2 to 188.4)	185.6 (167.2 to 204.0)			
Δ Pre to 12 wk	3.1 (−6.0 to 12.3)	26.7 (17.7 to 35.7)	0.66	68	0.004
Leg extension (kg)					
Pre	32.9 (30.1 to 35.7)	31.9 (29.3 to 34.6)			
12 wk	34.4 (31.6 to 37.2)	36.6 (33.7 to 39.4)			
Δ Pre to 12 wk	1.4 (0.4 to 2.5)	4.6 (3.56 to 5.7)	1.00	76	<0.001
Leg curl (kg)					
Pre	19.1 (17.2 to 21.2)	19.7 (17.8 to 21.7)			
12 wk	21.0 (18.9 to 23.0)	21.3 (19.2 to 23.4)			
Δ Pre to 12 wk	1.8 (0.6 to 3.1)	1.6 (0.8 to 2.4)	0.10	52	0.692
MIVC (N·m)					
Pre	125.1 (114.5 to 135.6)	122.1 (109.6 to 134.6)			
12 wk	134.0 (121.7 to 146.3)	132.5 (121.0 to 144.0)			
Δ Pre to 12 wk	7.5 (1.8 to 13.1)	11.9 (5.5 to 18.3)	−0.20	55	0.385
STS power (W·kg^{-1})					
Pre	4.1 (3.8 to 4.4)	4.0 (3.8 to 4.3)			
12 wk	4.0 (3.8 to 4.2)	4.3 (4.0 to 4.5)			
Δ Pre to 12 wk	−0.1 (−0.2 to 0.1)	0.2 (0.0 to 0.4)	0.45	63	0.040
400 m (m·s^{-1})					
Pre	1.85 (1.80 to 1.90)	1.84 (1.78 to 1.89)			
12 wk	1.89 (1.83 to 1.94)	1.88 (1.83 to 1.84)			
Δ Pre to 12 wk	0.04 (0.01 to 0.06)	0.05 (0.02 to 0.07)	0.09	53	0.550
6MWT (m·s^{-1})					
Pre	1.84 (1.79 to 1.89)	1.83 (1.78 to 1.88)			
12 wk	1.88 (1.83 to 1.93)	1.87 (1.82 to 1.93)			
Δ Pre to 12 wk	0.04 (0.02 to 0.06)	0.05 (0.02 to 0.07)	0.04	51	0.858

t Test (matched pairs) was used to compare the intensities. Data are presented in mean and confidence interval of 95%.

convenience sample). Hence, we conducted a sensitivity power analysis (G*Power, version 3.1.9.7). Therefore, the effects that our study may detect with a desired power (i.e., 80%) when performing a hypothesis test are $d = 1.19$ for the difference between two independent means (two groups; Table 1) and $d = 0.59$ for the difference between two dependent means (Table 2).

When the null hypothesis cannot be rejected ($P > 0.05$), no effect can be established, particularly in small samples. Then, it is possible to use equivalence tests as an alternative (41). A range of values considered practically equivalent to the absence of an effect is known as an equivalence boundary (41). In the current study, the equivalence boundaries between the score changes of two interventions (LL-to-HL vs HL-to-LL) or two load intensities (LL vs HL) were determined using the minimal clinically significant difference. From a clinical standpoint, a minimal clinically important difference refers to a change in functional status that is so valuable that the patient would choose the same intervention again if given a chance (42). Differences between two interventions (when both interventions are considered efficient) that are smaller than the minimal clinically significant differences are not considered clinically relevant or meaningful and may be considered equivalent. In this regard, it has been observed that the minimal clinically significant difference is equivalent to a difference of 0.5 standard deviation from a change score ($d = 0.5$) (42). Thus, the minimal clinically significant difference in muscular strength (1RM and MIVC) and STS power was calculated using distribution-based calculations (standard deviation) (42). The equivalence boundaries for muscular strength and STS power deltas were set at effect size $d = 0.5$. For walking speed tests, differences of 0.05 and 0.1 m·s^{-1} have been established as clinically significant (4,43).

The two 1-sided test (TOST) independent or paired sample *t* test was used to test the equivalence boundaries (41). For change scores by transition, the magnitude direction in TOST was the delta of the HL-to-LL minus the delta of the LL-to-HL (Figs. 2 and 3, values indicating equivalence between HL-to-LL and LL-to-HL). Therefore, Figure 2 (B, C, E, F, H and I) and Figure 3 (B, C, E, F, H, I, K and L) show the difference between the deltas (pre to 12 wk and pre to 24 wk, respectively) of the HL-to-LL and LL-to-HL. Positive mean values indicate that the HL-to-LL transition scheme was superior to the LL-to-LL and negative mean values indicate that the HL-to-LL transition scheme was inferior to the LL-to-LL. The dotted lines indicate the equivalence boundaries (TOST). For change scores by load intensity, the magnitude direction in TOST was the delta of the LL minus the delta of the HL (Fig. 4, values indicating equivalence between LL and HL). Therefore, Figure 4 (B, D, F, and H) shows the difference between the deltas (pre to 12 wk and pre to 24 wk, respectively) of HL and LL. Positive mean values indicate that the LL was superior to the HL and negative mean values indicate that the LL was inferior to the HL. The dotted lines indicate the equivalence boundaries (TOST).

We used a multiple regression adopting an in-subject model, as recommended by Bland and Altman (44), to determine whether the changes caused by RT in the variables were associated with each other. The associations are presented as the coefficient of correlation (Tables 3 and 4). Furthermore, we used the Pearson correlation coefficient to determine whether muscular strength was associated with functional tests at

TABLE 3. Correlation in-subject model between muscular strength and physical performance markers at baseline to 12 wk in the postmenopausal women.

	400-m (s)			6MWT (m)			MIVC (N·m)		
Muscular Strength	**All (N = 24)**	**LL-to-HL (n = 12)**	**HL-to-LL (n = 12)**	**All (N = 24)**	**LL-to-HL (n = 12)**	**HL-to-LL (n = 12)**	**All (N = 24)**	**LL-to-HL (n = 12)**	**HL-to-LL (n = 12)**
Leg press (kg)									
R^2	25% (P = 0.011)	13% (P = 0.231)	32% (P = 0.043)	23% (P = 0.016)	8% (P = 0.351)	34% (P = 0.036)	49% (P < 0.001)	21% (P = 0.116)	73% (P < 0.001)
Estimate B (95% CI)	−0.2 (−0.4 to −0.1)	−0.1 (−0.4 to 0.1)	−0.3 (−0.5 to −0.0)	0.6 (0.1 to 1.2)	0.3 (−0.5 to 1.2)	0.8 (0.1 to 1.5)	0.6 (0.3 to 0.8)	0.4 (−0.1 to 0.9)	0.7 (0.4 to 1.0)
Leg extension (kg)									
R^2	19% (P = 0.030)	16% (P = 0.178)	21% (P = 0.118)	26% (P = 0.009)	26% (P = 0.077)	26% (P = 0.073)	41% (P < 0.001)	6% (P = 0.405)	76% (P < 0.001)
Estimate B (95% CI)	−1.1 (−2.0 to −0.1)	−0.8 (−2.1 to 0.4)	−1.2 (−2.7 to 0.4)	3.9 (1.1 to 6.8)	3.8 (−0.5 to 8.2)	4.0 (−0.4 to 8.4)	3.0 (1.4 to 4.6)	1.3 (−2.0 to 4.5)	3.9 (2.5 to 5.4)
Leg curl (kg)									
R^2	17% (P = 0.043)	24% (P = 0.086)	25% (P = 0.081)	25% (P = 0.011)	33% (P = 0.039)	32% (P = 0.044)	10% (P = 0.126)	3% (P = 0.562)	42% (P = 0.016)
Estimate B (95% CI)	−1.2 (−2.4 to −0.1)	−0.8 (−1.8 to 0.1)	−3.1 (−6.7 to 0.5)	4.8 (1.2 to 8.8)	3.6 (0.2 to 7.0)	10.4 (0.4 to 20.1)	1.8 (−0.6 to 4.3)	0.7 (−2.0 to 3.4)	7.0 (1.5 to 12.4)
MIVC (N·m)									
R^2	38% (P < 0.001)	49% (P = 0.008)	34% (P = 0.035)	37% (P = 0.001)	44% (P = 0.013)	33% (P = 0.040)	—	—	—
Estimate B (95% CI)	−0.3 (−0.5 to −0.1)	−0.3 (−0.5 to −0.1)	−0.3 (−0.7 to -0.0)	1.0 (0.4 to 1.6)	1.0 (0.3 to 1.8)	1.0 (0.1 to 1.9)	—	—	—
STS power (W·kg^{-1})									
R^2	5% (P = 0.292)	0% (P = 0.844)	9% (P = 0.316)	4% (P = 0.336)	0% (P = 0.871)	9% (P = 0.331)	2% (P = 0.500)	3% (P = 0.576)	13% (P = 0.236)
Estimate B (95% CI)	−4.7 (−13.8 to 4.3)	−1.0 (−12.1 to 10.1)	−7.0 (−22.7 to 8.0)	13.7 (−15.1 to 42.5)	3.1 (−38.0 to 44.2)	21.1 (−24.6 to 66.9)	5.9 (−11.8 to 23.6)	−7.0 (−33.8 to 19.8)	15.0 (−11.0 to 41.0)

baseline. The significance level was $P < 0.05$. All analyses were performed using JAMOVI software (version 1.8).

RESULTS

General Characteristics between Different Load Intensity Transition Schemes

For general characteristics at baseline, there was no significant difference ($P > 0.05$) between groups for age (LL-to-HL = 58.8 ± 8.8 yr and HL-to-LL = 59.6 ± 8.6 yr, $P = 0.835$), time of menopause (LL-to-HL = 12.0 ± 7.5 yr and HL-to-LL = 14.8 ± 10.7 yr, $P = 0.610$), and body mass index (LL-to-HL = 27.3 ± 3.8 kg·m^{-2} and HL-to-LL = 27.0 ± 5.0 kg·m^{-2}, $P = 0.480$).

Medication Intake between Different Load Intensity Transition Schemes

In the LL-to-HL group, 1 of 12 participants used antihypertensive, 1 of 12 participants used antihyperglycemic, and 1 of 12 participants used cholesterol-lowering medication. In the HL-to-LL group, we observed similar medication intake compared with the LL-to-HL group—1 of 12 participants used antihypertensive, 1 of 12 participants used antihyperglycemic, and 1 of twelve participants used a cholesterol-lowering drug.

Adherence and Dropouts between Different Load Intensity Transition Schemes

Regarding the LL-to-HL group, in the first 12 wk of intervention, three postmenopausal women dropped out of the study due to [sciatic nerve problem (n = 1), problems of arriving at the training site (n = 1), and anemia (n = 1)]. In addition, after the first 12 wk of training, five postmenopausal women dropped out of the study due to personal reasons. Then, 12 postmenopausal women completed the study in the LL-to-HL group. Concerning the HL-to-LL group, in the first 12 wk of intervention, six postmenopausal women dropped out of the study (osteoarticular problems [n = 2], problems to move to the training site [n = 1], and family problems [n = 3]). Moreover, after the first 12 wk of training, one postmenopausal woman dropped out of the study due to travel reasons. In both the HL-to-LL and LL-to-HL groups, all remaining participants completed >80% of RT sessions.

In addition, the HL phase had a higher dropout rate (11 participants) than the LL phase (4 participants), with the HL phase having a dropout rate 2.75 times higher than the LL phase. It should be noted that personal and family issues, as well as difficulty attending the training site, were reported reasons for dropping out.

Training Characteristics between Different Load Intensity Transition Schemes

The absolute load (kg) lifted in all dynamic exercises increased ($P < 0.01$) from 49 ± 11 to 91 ± 24 kg in LL-to-HL and 118 ± 24 to 133 ± 28 kg in HL-to-LL of the 1st to 12th week (Fig. 1B). Therefore, the relative load (% of 1RM) for

TABLE 4. Correlation in-subject model between muscular strength and physical performance markers at baseline to 24 wk in the postmenopausal women.

	400-m (s)			6MWT (m)			MIVC (N·m)		
Muscular Strength	**All (*N* = 24)**	**LL-to-HL (*n* = 12)**	**HL-to-LL (*n* = 12)**	**All (*N* = 24)**	**LL-to-HL (*n* = 12)**	**HL-to-LL (*n* = 12)**	**All (*N* = 24)**	**LL-to-HL (*n* = 12)**	**HL-to-LL (*n* = 12)**
Leg press (kg)									
R^2	21% ($P = 0.001$)	29% ($P = 0.005$)	20% ($P = 0.024$)	22% ($P < 0.001$)	25% ($P = 0.011$)	22% ($P = 0.018$)	45% ($P < 0.001$)	42% ($P < 0.001$)	51% ($P < 0.001$)
Estimate B (95% CI)	−0.2 (−0.3 to −0.1)	−0.1 (−0.2 to −0.0)	−0.2 (−0.4 to −0.0)	0.5 (0.2 to 0.8)	0.4 (0.1 to 0.7)	0.7 (0.1 to 1.2)	0.4 (0.3 to 0.6)	0.4 (0.2 to 0.5)	0.5 (0.3 to 0.8)
Leg extension (kg)									
R^2	15% ($P = 0.006$)	18% ($P = 0.037$)	18% ($P = 0.034$)	21% ($P < 0.001$)	20% ($P = 0.024$)	27% ($P = 0.008$)	44% ($P < 0.001$)	34% ($P = 0.002$)	63% ($P < 0.001$)
Estimate B (95% CI)	−0.8 (−1.3 to −0.2)	−0.5 (−1.0 - -0.0)	1.2 (−2.4 to −0.1)	2.8 (1.2 to 4.4)	2.0 (0.3 to 3.7)	4.4 (1.3 to 7.5)	2.4 (1.6 to 3.2)	1.8 (0.7 to 2.9)	3.6 (2.4 to 4.7)
Leg curl (kg)									
R^2	20% ($P = 0.001$)	22% ($P = 0.019$)	36% ($P = 0.002$)	26% ($P < 0.001$)	26% ($P = 0.009$)	46% ($P < 0.001$)	26% ($P < 0.001$)	19% ($P = 0.027$)	54% ($P < 0.001$)
Estimate B (95% CI)	−1.3 (−2.1 to −0.5)	−0.8 (−1.4 to −0.1)	−3.2 (−5.1 to −1.4)	4.5 (2.2 to 6.7)	3.0 (0.8 to 5.1)	10.1 (5.1 to 15.2)	2.7 (1.4 to 4.0)	1.8 (0.2 to 3.3)	6.0 (3.7 to 8.5)
MIVC (N·m)									
R^2	33% ($P < 0.001$)	31% ($P = 0.004$)	36% ($P = 0.002$)	35% ($P < 0.001$)	30% ($P = 0.005$)	40% ($P < 0.001$)	—	—	—
Estimate B (95% CI)	−0.3 (−0.5 to −0.2)	−0.2 (−0.4 to −0.1)	−0.4 (−0.6 to 0.2)	1.0 (0.6 to 1.4)	0.8 (0.3 to 1.3)	1.2 (0.6 to 1.8)	—	—	—
STS power ($W \cdot kg^{-1}$)									
R^2	3% ($P = 0.230$)	10% ($P = 0.128$)	1% ($P = 0.643$)	2% ($P = 0.291$)	3% ($P = 0.377$)	2% ($P = 0.519$)	3% ($P = 0.250$)	1% ($P = 0.625$)	5% ($P = 0.263$)
Estimate B (95% CI)	−3.6 (−9.5 to 2.4)	−4.6 (−10.5 to 1.4)	−2.5 (−13.6 to 8.6)	9.7 (−8.5 to 27.9)	9.4 (−12.1 to 30.8)	10.0 (−21.7 to 41.7)	6.2 (−4.5 to 17.0)	3.6 (−11.5 to 18.7)	9.2 (−7.4 to 25.7)

all dynamic exercises was increased by 90% and 12.5% for LL-to-HL and HL-to-LL groups, respectively ($P < 0.01$), of the 1st to 12th week (Fig. 1A).

In contrast, the absolute load (kg) lifted in all dynamic exercises increased ($P < 0.01$) from 122 ± 31 to 143 ± 30 kg in LL-to-HL and 52 ± 10 and 83 ± 10 kg in HL-to-LL of the 13th to 24th week (Fig. 1D). Therefore, the relative load (% of 1RM) for all dynamic exercises was increased by 19.4% and 63.3% for LL-to-HL and HL-to-LL groups, respectively ($P < 0.01$), of the 13th to 24th week (Fig. 1C).

Change Scores by Transition Schemes

Leg press. The results of the study on the 45° leg press exercise after the first 12 wk of training showed that only the HL-to-LL group had an increase in muscle strength (1RM) (Fig. 2A). The comparison between the groups showed a significant difference in leg press strength gains ($P = 0.020$, Fig. 2A) in which the HL-to-LL group outperformed the LL-to-HL group (d = 1.0, 17.5 kg). However, the confidence interval (TOST) for this superiority did not surpass the minimal clinically significant difference ($d = 0.5$) indicated by the upper limit of equivalence (Fig. 2B), meaning that the superiority was not deemed clinically meaningful. After adjusting the change scores for muscular strength to their prevalues (Table 1), the HL-to-LL group still had superior 45° leg press strength compared with the LL-to-HL group (d = 1.3, 95% confidence interval [CI] 0.3–2.3), with 82% PS ($P = 0.005$, power = 86%). Hence, while the HL-to-LL group produced greater 45° leg press strength gains compared with the LL-to-HL group, this difference was not considered to be clinically meaningful.

After the load intensity crossover (from 12 to 24 wk), only the LL-to-HL group showed an increase in muscular strength in the 45° leg press exercise (Table 1). The muscular strength gains, adjusted by the 12-wk values, were superior in the LL-to-HL group compared with the HL-to-LL group, with a difference of $d = -1.2$ (PS = 80%, $P = 0.009$ and power = 80%, Table 1). Thus, only the LL-to-HL group demonstrated an improvement in muscular strength in the 45° leg press exercise after the final 12 wk of intervention compared with the HL-to-LL group.

An analysis of the results after 24 wk of training showed that both groups had similar gains in 45° leg press strength (as indicated by a P value of 0.225 in Fig. 2A). The confidence interval for the difference in strength gains between the groups crossed the lower limit of equivalence, indicating that the groups were not equivalent (as shown in Fig. 2C). However, this confidence interval (TOST) did not reach the upper limit of equivalence, which would indicate a minimally clinically significant difference in favor of the HL-to-LL group. This means that there was no clinically meaningful superiority of the HL-to-LL group and that the LL-to-HL group was noninferior in terms of 45° leg press strength gains. Even when the change scores of 45° leg press strength were adjusted to their prevalue, there was no significant difference between the groups (as indicated by a d-value of −0.45, PS of 62%, P

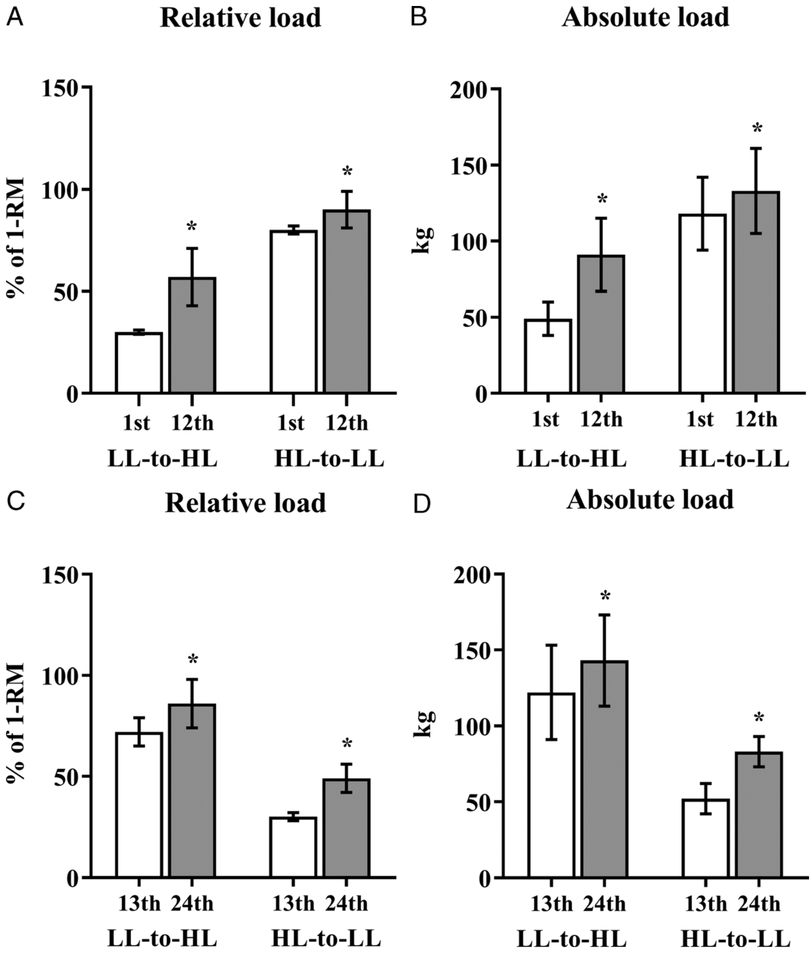

FIGURE 1—Figures 1A and 1B show relative and absolute load (% of 1RM and kg) for RT programs (LL-to-HL and HL-to-LL) at 1st to 12th week, respectively. Figures 1C and 1D show the same data for the 12th to 24th week. The mean and standard deviation are presented, and statistical significance was tested using Student t test (* indicates significant difference).

value of 0.294, and power of 18%, as shown in Table 1). Therefore, after 24 wk of training, both the HL-to-LL and LL-to-HL groups showed similar increases in muscular strength in the 45° leg press exercise.

Leg extension. After 12 wk, both the HL-to-LL and LL-to-HL groups showed an increase in muscular strength in the leg extension exercise, according to the 95% CI (Fig. 2D). The comparison between the groups indicated that the HL-to-LL group was slightly better than the LL-to-HL group in terms of leg extension strength gains (P = 0.073, Fig. 2D). The TOST test showed that the superiority of the HL-to-LL was at $d = 0.77$ (2.0 kg). However, the confidence interval (TOST) for this superiority did not reach the upper limit of equivalence (the minimal clinically significant difference in $d = 0.5$) (Fig. 2E). This indicates that the superiority of the HL-to-LL was not greater than the minimal clinically significant difference. In addition, when the leg extension strength gains were adjusted to their prevalues (Table 1), the analysis showed only weak evidence of superiority for the HL-to-LL group over the LL-to-HL group (d = 0.75, PS = 70%, P = 0.084, and power = 42%). Thus, although the HL-to-LL group showed a small advantage in leg extension strength gains compared with the LL-to-HL group during the first 12 wk (before the protocol crossover), this difference between the groups was not considered to be clinically meaningful.

After the load intensity crossover (from 12 to 24 wk), only the LL-to-HL group experienced an increase in leg extension strength. The strength gain was found to be greater in the LL-to-HL group compared with the HL-to-LL group, with a $d = -1.76$ (PS = 89%, $P < 0.001$, and 98% power; Table 1). Thus, only the LL-to-HL group produced gains in leg extension strength when compared with the HL-to-LL group in the last 12 wk of the intervention.

The analysis of the 24 wk (from preintervention to 24 wk) revealed a similar increase in leg extension strength between the groups (P = 0.158, Fig. 2D), even after adjusting for the prevalue (d = 0.7, PS = 69%, P = 0.110, and power = 37%; Table 1). Although there was a difference (because confidence intervals crossed the lower limit of equivalence), the difference in leg extension strength improvements between groups did not reach the upper limit of equivalence (Fig. 2F). Hence, there was no clinically meaningful superiority of the HL-to-LL, showing that LL-to-HL was not inferior to HL-to-LL in leg extension strength gains. Therefore, both the HL-to-LL and LL-to-HL groups experienced comparable increases in muscular strength in leg extension exercise after 24 wk of intervention (the complete training period).

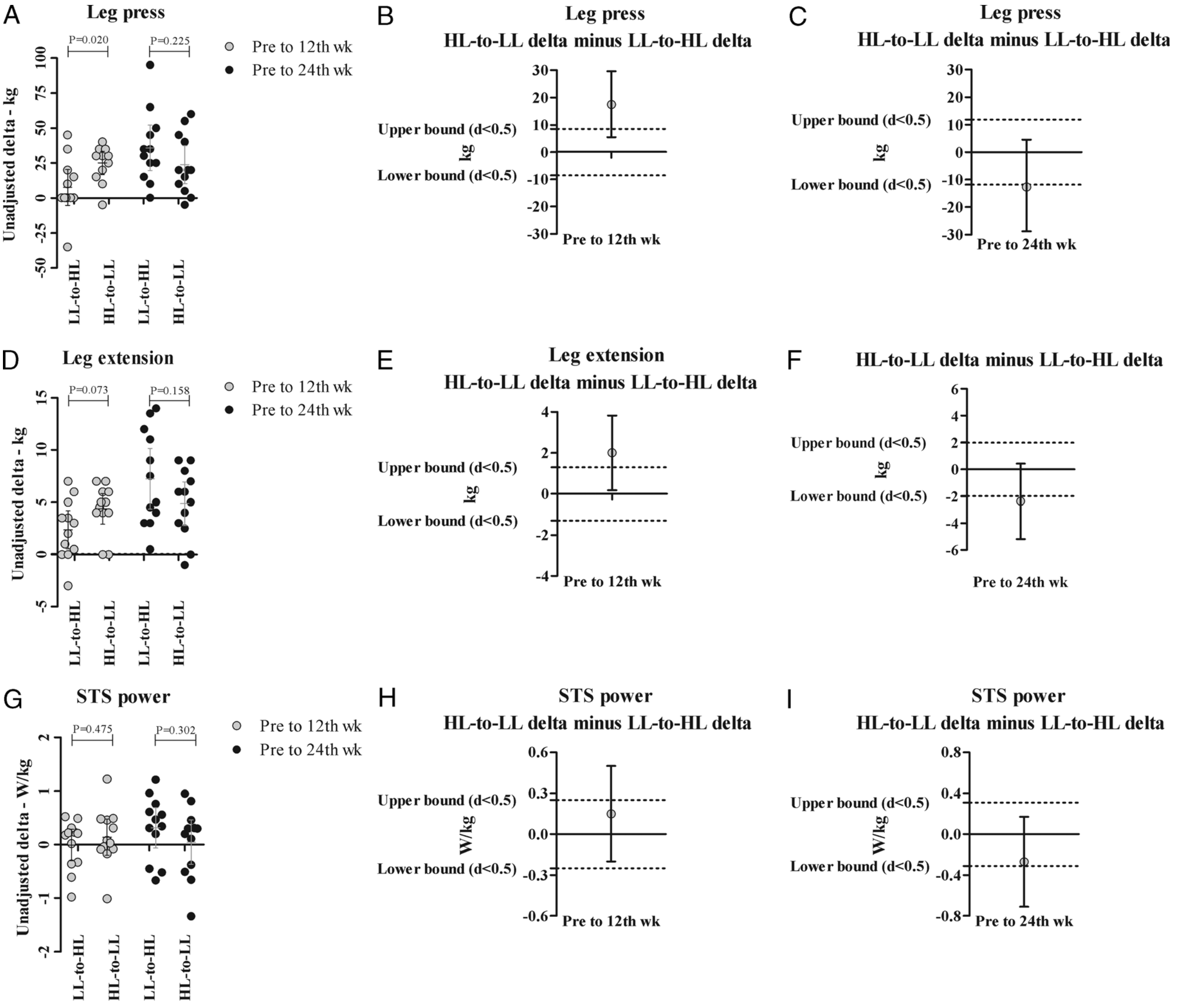

FIGURE 2—Change score by load transition in the 45° leg press at baseline to 12 wk of training and at baseline to 24 wk of training (panel A), TOST in the 45° leg press at baseline to 12 wk of training (panel B, positive values favor HL-to-LL compared with LL-to-HL), TOST in the 45° leg press at baseline to 24 wk of training (panel C, values indicating equivalence between HL-to-LL and LL-to-HL), the change score by load transition in leg extension at baseline to 12 wk of training and at baseline to 24 wk of training (panel D), TOST in the leg extension at baseline to 12 wk of training (panel E, positive values favor HL-to-LL compared with LL-to-HL), TOST in the leg extension at baseline to 24 wk of training (panel F, values indicating equivalence between HL-to-LL and LL-to-HL), the change score by load transition in the sit-to-stand test power at baseline to 12 wk of training and at baseline to 24 wk of training (panel G), TOST in sit-to-stand test power at baseline to 12 wk of training (panel H, values indicating equivalence between HL-to-LL and LL-to-HL) and TOST in sit-to-stand test power at baseline to 24 wk of training (panel I, values indicating equivalence between HL-to-LL and LL-to-HL).

Leg curl. The 95% CI showed that both the HL-to-LL and LL-to-HL groups increased their leg curl strength after 12 wk (Fig. 3A). Despite the fact that there was no significant difference in strength gains between the groups (P = 0.314, Fig. 3A), nonequivalence was demonstrated (Fig. 3B). However, the confidence interval (TOST) for the difference in leg curl strength gains between the groups did not exceed the upper limit of equivalence (Fig. 3B). This means that any superiority of the HL-to-LL group in leg curl strength gains was not greater than the minimal clinically significant difference during the first 12 wk of intervention. In addition, when the leg curl strength changes were adjusted by their prevalues, the analysis showed no difference between the groups (d = −0.38, PS = 61%, P = 0.360, and power = 15%; Table 1). Therefore, both the HL-to-LL and LL-to-HL groups experienced similar increases in leg curl strength after the first 12 wk of intervention (before the load intensity crossover).

After the load intensity crossover (from 12 to 24 wk), only the LL-to-HL group showed an increase in leg curl strength, as indicated by the 95% CI (Table 1). However, there was no statistically significant difference in the changes of leg curl strength between the two groups (d = −0.3, PS = 58%, P = 0.460, and power = 11%; Table 1). Thus, both the HL-to-LL and LL-to-HL groups demonstrated a similar response in terms of changes in leg curl strength after the protocol crossover.

The results of the 24-wk analysis (from preintervention to 24 wk) showed a similar increase in leg curl strength between the two groups (P = 0.254, Fig. 3A). This remained unchanged even after the change scores were adjusted for their prevalues (d = 0.44, PS = 62%, P = 0.291, and power = 18%; Table 1). Although nonequivalence was demonstrated, the difference in leg curl strength gains between the groups did not exceed the upper limit of equivalence (Fig. 3C). This indicates that the

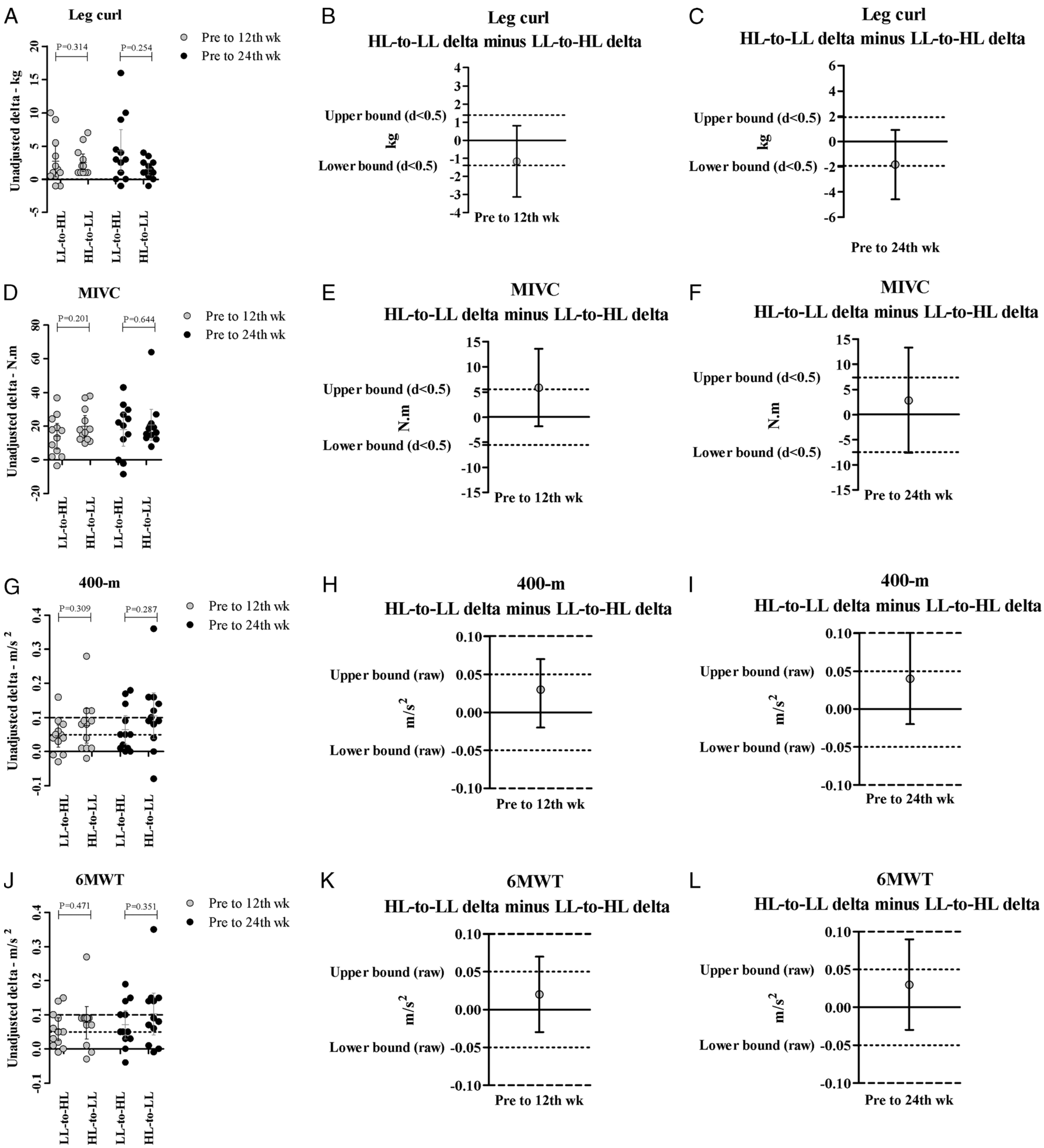

FIGURE 3—Change score by load transition in the leg curl at baseline to 12 wk of training and at baseline to 24 wk of training (panel A), TOST in the leg curl at baseline to 12 wk of training (panel B, values indicating equivalence between HL-to-LL and LL-to-HL), TOST in the 45° leg curl at baseline to 24 wk of training (panel C, values indicating equivalence between HL-to-LL and LL-to-HL), the change score by load transition in maximal isometric voluntary contraction at baseline to 12 wk of training and at baseline to 24 wk of training (panel D), TOST in maximal isometric voluntary contraction at baseline to 12 wk of training (panel E, values indicating equivalence between HL-to-LL and LL-to-HL), TOST in the maximal isometric voluntary contraction at baseline to 24 wk of training (panel F, values indicating equivalence between HL-to-LL and LL-to-HL), the change score by load transition in the 400-m walking test at baseline to 12 wk of training and at baseline to 24 wk of training (panel G), TOST in the 400-m walking test at baseline to 12 wk of training (panel H, values indicating equivalence between HL-to-LL and LL-to-HL), and TOST in the 400-m walking test at baseline to 24 wk of training (panel I, values indicating equivalence between HL-to-LL and LL-to-HL), the change score by load transition in the 6MWT at baseline to 12 wk of training and at baseline to 24 wk of training (panel J), TOST in the 6MWT at baseline to 12 wk of training (panel K, values indicating equivalence between HL-to-LL and LL-to-HL), and TOST in the 6MWT at baseline to 24 wk of training (panel L, values indicating equivalence between HL-to-LL and LL-to-HL). The *dotted lines* indicate the equivalence boundaries (TOST).

LL-to-HL group was not inferior to the HL-to-LL group in terms of leg curl strength gains. As a result, both the HL-to-LL and LL-to-HL groups experienced similar increases in leg curl strength after the 24-wk intervention period.

MIVC. After the first 12 wk of intervention, the 95% CI indicated that both the HL-to-LL and LL-to-HL groups increased MIVC strength (Fig. 3D). There was no significant difference between the groups in terms of MIVC strength gains ($P = 0.201$, Fig. 3A). Although nonequivalence was indicated (Fig. 3E), the confidence interval (TOST) of the difference between the groups did not exceed the upper limit of equivalence (Fig. 3E). Furthermore, the analysis showed that there was no difference between the groups in terms of MIVC strength gains, even when the change scores were adjusted to their prevalues ($d = 0.60$, PS = 66%, $P = 0.179$, and power = 29%) (Table 1). Hence, both the HL-to-LL and LL-to-HL groups experienced similar increases in MIVC strength before the load intensity crossover.

After the load intensity crossover, neither the HL-to-LL nor the LL-to-HL groups showed an increase in MIVC strength, according to results indicated by 95% CI ($P > 0.05$; Table 1). Therefore, both groups did not experience an increase in MIVC strength during the last 12 wk of the intervention.

The analysis of the 24-wk period (pre to 24 wk) showed a similar increase in MIVC strength between the groups ($P = 0.644$, Fig. 3D). This result was confirmed after adjusting the change scores of MIVC strength to their prevalues ($d = 0.23$, PS = 57%, $P = 0.606$, and power = 8%; Table 1). Nonequivalence was demonstrated (Fig. 3F), as the confidence interval (TOST) for the difference between the groups crossed the upper limit of equivalence but did not exceed it. Hence, both the LL-to-HL and HL-to-LL groups had comparable increases in MIVC strength after the full 24 wk of intervention.

STS power. After 12 wk of training, neither group showed an increase in STS power compared with pretraining levels (Fig. 2G). There was no difference between the groups ($P = 0.201$, Fig. 3A) in the changes in STS power. Nonequivalence was indicated (Fig. 2H) because the confidence interval (TOST) of the difference in STS power changes between the groups crossed the upper limit of equivalence but did not exceed it. Despite adjusting the change scores in STS power to their prevalues (Table 1), statistical analysis showed no difference between the groups ($d = 0.22$, PS = 57%, $P = 0.586$, and power = 8%). Therefore, both the HL-to-LL and LL-to-HL groups did not experience an increase in STS power during the first 12 wk of intervention (before the load intensity crossover)

After the load intensity crossover, only the LL-to-HL group showed an increase in STS power from the 12th to 24th week. The LL-to-HL group also demonstrated superior gains in STS power compared with the HL-to-LL group, as observed by a larger magnitude of increase ($d = -1.14$, PS = 79%, $P = 0.011$, and power = 76%; Table 1). As a result, the LL-to-HL group exhibited a greater advantage in STS power gains compared with the HL-to-LL group during the last 12 wk of intervention.

The 95% CI indicated that neither group showed an increase in STS power after 24 wk of intervention. There was no difference between the groups in the gains in STS power ($P = 0.302$, Fig. 2G). After adjusting the change scores in STS power to their prevalues (Table 1), there was weak evidence of superiority for the LL-to-HL group over the HL-to-LL group ($d = -0.74$, PS = 70%, $P = 0.087$, and power = 41%). Although nonequivalence was shown, the confidence interval of the difference between the groups did not exceed the upper limit of equivalence (Fig. 2I). This result indicated that the LL-to-HL group was not inferior to the HL-to-LL group in the changes in STS power after 24 wk of intervention. As such, both the HL-to-LL and LL-to-HL groups demonstrated similar changes in STS power after the complete 24-wk training period.

400-m walking speed. After 12 wk of training, both the HL-to-LL and LL-to-HL groups showed an increase in 400-m walking speed, as indicated by the 95% CI (Fig. 3G). There was no difference between the groups in the improvement of walking speed ($P = 0.309$, Fig. 3G). Equivalence was shown between the groups, with a ± 0.1 $m \cdot s^{-1}$ difference (Fig. 3H). When the change scores of 400-m walking speed were adjusted to their prevalues (Table 1), the statistical analysis showed no difference between the groups ($d = 0.41$; PS = 61%, $P = 0.330$, and power = 16%). Therefore, both groups similarly improved 400-m walking speed during the first 12 wk of the intervention (before the crossover of load intensities)

After the load intensity crossover, neither the HL-to-LL or the LL-to-HL group showed an increase in 400-m walking speed (Table 1). Therefore, both groups did not show improvement in 400-m walking speed during the last 12 wk of the intervention.

The 95% CI indicated that both the HL-to-LL and LL-to-HL groups increased 400-m walking speed after 24 wk of intervention. There was no difference between the groups in the improvement of 400-m walking speed ($P = 0.287$, Fig. 2G). When the change scores of 400-m walking speed were adjusted to their prevalues (Table 1), the statistical analysis showed no difference between the groups ($d = 0.43$, PS = 62%, $P = 0.308$, power = 17%; Table 1). Equivalence between the groups was maintained, with a ± 0.1 $m \cdot s^{-1}$ difference (Fig. 3I). Therefore, both load intensity transition schemes showed a similar improvement in 400-m walking speed after 24 wk of intervention (the complete training period).

6MWT. The 95% CI indicated that both the HL-to-LL and LL-to-HL groups increased their walking speed in 6MWT after the first 12 wk of training (Fig. 3J). There was no significant difference between the groups in the gains in 6MWT ($P = 0.471$, Fig. 3J) and equivalence was demonstrated between the groups with a margin of ±0.1 $m \cdot s^{-1}$ (Fig. 3K). In addition, when the change scores of 6MWT were adjusted to their preintervention values (Table 1), there was still no difference between the groups ($d = 0.29$, PS = 58%, $P = 0.488$, and power = 10%). As a result, both the HL-to-LL and LL-to-HL groups showed similar improvement in 6MWT after the first 12 wk of intervention (before the crossover of load intensity).

Following the crossover of load intensities, no increase in 6MWT was observed for either the HL-to-LL or LL-to-HL groups (Table 1). Thus, neither group showed improvement in walking speed during the last 12 wk of intervention (from 12 to 24 wk).

When considering the results over the entire 24 wk of intervention, statistical analysis indicated a similar increase in 6MWT between the groups ($P = 0.351$, Fig. 3J). The equivalence between groups was still maintained with a margin of $\pm 0.1\ \text{m·s}^{-1}$ (Fig. 3L) even when the change scores of 6MWT were adjusted to their preintervention values ($d = 0.38$, PS = 61%, $P = 0.366$, power = 14%, Table 1). Therefore, both the HL-to-LL and LL-to-HL groups showed similar improvement in 6MWT after 24 wk of intervention (the complete training period).

Change Scores by Load Intensity

Leg press. The 95% CI indicated that only the HL phase increased muscular strength in 45° leg press (1RM) (Table 2). The magnitude of muscular strength gain (adjusted) was superior in the HL phase when compared with the LL phase in $d = 0.66$ (PS = 68%, $P = 0.004$ and power = 87%) (Table 2). Therefore, only the HL phase led to an increase in muscular strength in the 45° leg press exercise when compared with the LL phase.

Leg extension. Both the LL and HL phases increased muscular strength in leg extension (Table 2). However, the magnitude of muscular strength gain (adjusted) was superior in the HL phase when compared with the LL phase in $d = 1.0$ (PS = 76%, $P < 0.001$, and power = 100%; Table 2). Therefore, although both load intensities caused muscular strength gains in leg extension exercise, the HL phase induced greater strength gains when compared with the LL phase.

Leg curl and MIVC. Both the LL and HL phases increased muscular strength in the leg curl exercise and MIVC (Fig. 4C and D and Table 2). Statistical analysis showed no difference between the groups (leg curl: $d = 0.10$, PS = 58%, $P = 0.692$, and power = 8%; and MIVC: $d = -0.20$, PS = 55%, $P = 0.385$, and power = 14%). Equivalence between the groups of $d \pm 0.5$ was shown for the leg curl (Fig. 4D) but not for MIVC (Fig. 4E). However, the confidence interval (TOST) of the difference between the phases in MIVC strength gains did not exceed the lower limit of equivalence (Fig. 4E). Lower limit of equivalence indicates a minimally clinically important difference in favor of HL. Hence, the difference between the phases in MIVC strength gains was not clinically a meaningful difference, indicating that the LL phase was not inferior to the HL phase (noninferiority) in MIVC strength gains. Thus, both HL and LL phases increased muscular strength in the leg curl exercise and MIVC.

STS power. The 95% CI indicated that only the HL phase increased STS power (Table 2). The STS power gain was slightly greater in the HL phase when compared with the LL phase in $d = 0.45$ (PS = 63%, $P = 0.040$, and power = 56%; Table 2). Thus, only the HL phase improved STS power when compared with the LL phase.

400-m and 6MWT. Both the LL and HL phases increased walking speed in 400-m and 6MWT (Fig. 4F and G and Table 2). There was no difference between the LL and HL phases in walking speed gains (400-m: $d = 0.09$, PS = 53%, $P = 0.550$, and power = 7%; and 6MWT: $d = 0.04$, PS = 51%, $P = 0.858$, and power = 5%). Equivalence of $\pm 0.5\ \text{m·s}^{-1}$ was shown between the LL and HL phases for 400-m (Fig. 4H) and 6MWT (Fig. 4I). Thus, both the HL and LL phases increased the walking speed in 400-m and 6MWT.

Correlation. A baseline, walking speed tests were associated with leg curl strength (400-m: $r = 0.47$, $P = 0.019$, and 6MWT: $r = 0.58$, $P = 0.003$). STS power was correlated with leg extension and leg curl strength at baseline (leg extension: $r = 0.45$, $P = 0.029$, leg curl: $r = 0.42$, $P = 0.040$).

Table 3 shows correlation coefficients with repeated observations (correlation within subjects) between muscular strength changes and physical performance changes from baseline to post 12 wk of intervention. When the associations were made independently of the intervention group ($n = 24$), the changes in 400-m and 6MWT were significantly associated with the changes in dynamic (all exercises) and isometric muscular strength, but not with STS power. Moreover, changes in 45° leg press and leg extension were significantly associated with the changes in isometric muscular strength. When the associations were made separately by intervention groups ($n = 12$), changes in 400-m and 6MWT were significantly associated with changes in isometric muscular strength in both the HL-to-LL and LL-to-HL groups. Changes in leg curl were significantly associated with the changes in 6MWT in both the HL-to-LL and LL-to-HL groups. In addition, changes in dynamic muscular strength (all exercises) were significantly associated with changes in isometric muscular strength only in the HL-to-LL group.

Table 4 shows correlation coefficients with repeated observations (correlation within subjects) between muscular strength change and physical performance change from baseline to post 24 wk of intervention. When the associations were made independently of the interventions group ($n = 24$) or separately by intervention groups ($n = 12$), the changes in 400-m and 6MWT were significantly associated with the changes in dynamic (all exercises) and isometric muscular strength, but not with STS power. Moreover, changes in dynamic muscular strength (all exercises) were significantly associated with the changes in isometric muscular strength.

The changes in leg extension ($R^2 = 16\%$, B = $0.04\ \text{w·kg}^{-1}$ [0.01–$0.06\ \text{w·kg}^{-1}$], $P = 0.005$) and the changes in leg curl ($R^2 = 13\%$, B = $0.05\ \text{w·kg}^{-1}$ [0.01–$0.09\ \text{w·kg}^{-1}$], $P = 0.011$), but not the changes in 45° leg press ($R^2 = 2\%$, B = $0.00\ \text{w·kg}^{-1}$ [-0.00–$0.01\ \text{w·kg}^{-1}$], $P = 0.120$) and the changes in MIVC ($R^2 = 3\%$, B = $0.00\ \text{w·kg}^{-1}$ [-0.00–$0.01\ \text{w·kg}^{-1}$], $P = 0.250$), were associated with the changes in STS power after 24 wk.

DISCUSSION

The main findings of this study were that different load intensity transition schemes (from LL-to-HL vs from HL-to-LL)

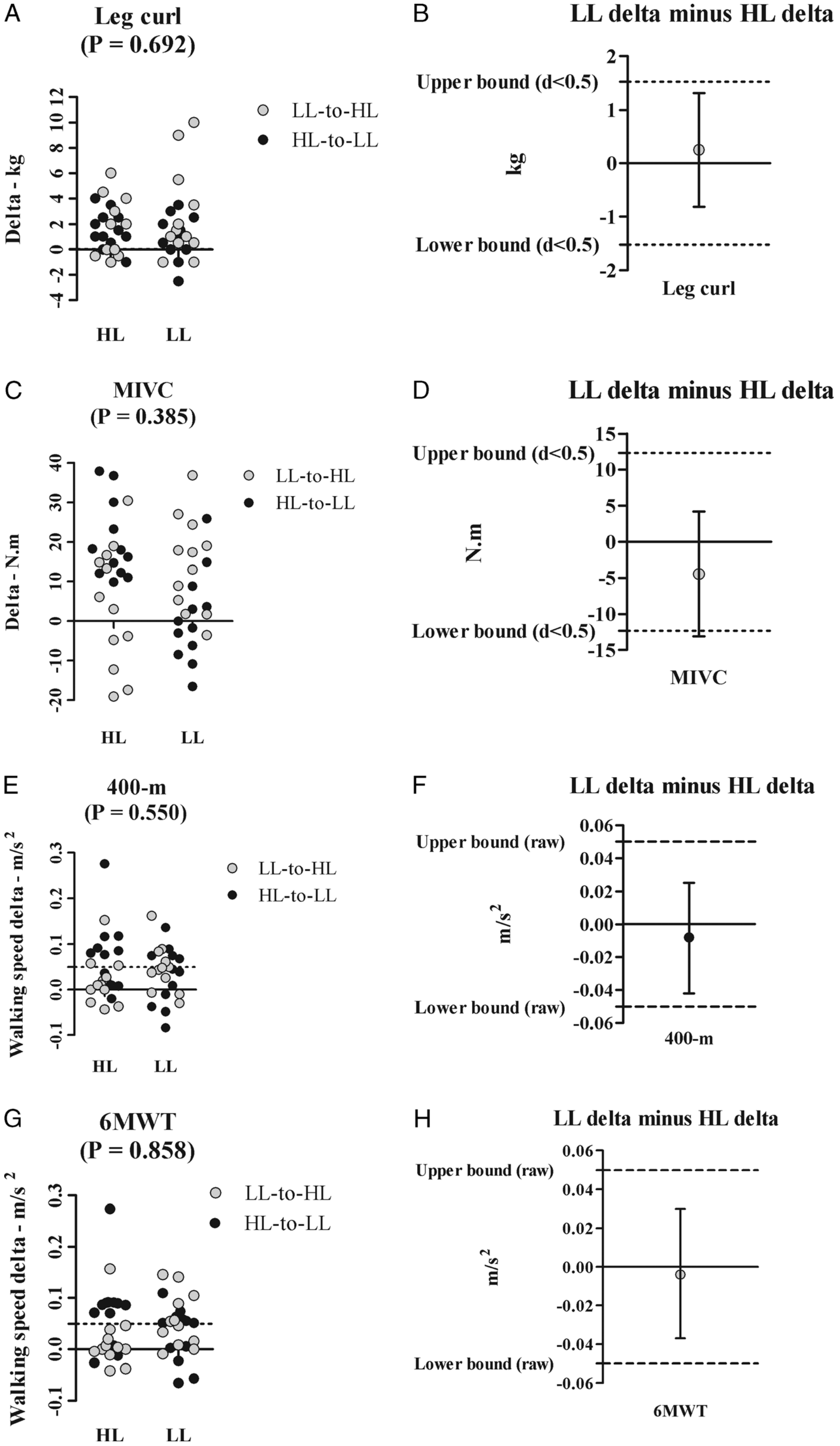

FIGURE 4—Change score by intensity in the leg curl at baseline to 24 wk of training (panel A), TOST in the leg curl at baseline to 24 wk of training (panel B, values indicating equivalence between LL and HL), the change score by intensity in maximal isometric voluntary contraction at baseline to 24 wk of training (panel C), TOST in maximal isometric voluntary contraction at baseline to 24 wk of training (panel D, values indicating equivalence between LL and HL), the change score by intensity in 400-m walking test at baseline to 24 wk of training (panel E), TOST in the 400-m walking test at baseline to 24 wk of training (panel F, values indicating equivalence between LL and HL), the change score by intensity in the 6MWT at baseline to 24 wk of training (panel G), TOST in the 6MWT at baseline to 24 wk of training (panel H, values indicating equivalence between LL and HL). The *dotted lines* indicate the equivalence boundaries (TOST).

resulted in similar changes in muscular strength, STS power, and walking speed in postmenopausal women after 24 wk of RT. However, the HL phase was determinant to increase the 45° leg press and leg extension strength, as well as STS power (mainly when performed after the LL phase), but it was not necessary to increase leg curl strength, MIVC, or walking speed. In addition, changes in walking speed were more strongly related to changes in MIVC.

Change scores by load intensity transition schemes for dynamic muscular strength and STS power. The results of the comparison between groups showed no evidence that the HL-to-LL transition was superior to the LL-to-HL transition in terms of dynamic muscular strength and power gains after 24 wk of training (as seen in Table 1 and Figs. 2 and 3). Our initial hypothesis was that the HL-to-LL transition would enable postmenopausal women to lift heavier loads during the low-load phase (15), thus increasing mechanical stress and promoting muscle adaptation (28). However, it appears that starting with a higher load does not result in postmenopausal women using heavier loads in the later low-load phase. In this study, the first 12 wk of LL-to-HL training involved loads of 46% (95% CI, 43%–52%) of 1RM and 70 kg (95% CI, 55–85 kg), which were comparable to the HL-to-LL training loads of 41% (95% CI, 37%–45%) of 1RM and 69 kg (95% CI, 60–77 kg) used in the last 12 wk (as seen in Fig. 1). This suggests that starting with an HL does not result in postmenopausal women lifting heavier loads in the later LL phase.

Contrary to our original hypothesis, the HL-to-LL transition did not have a positive impact on muscular strength and power gains in postmenopausal women. The increase in muscular strength and power was observed more in the HL phase (Table 1), regardless of the transition scheme for load intensity. Therefore, the load intensity used during RT, not the load transition, is crucial for the improvement of dynamic muscular strength and power.

Our findings suggest that starting with LL and gradually increasing to HL may benefit untrained postmenopausal women in terms of muscular power gains. Interestingly, our results showed that only when the HL was used after the LL, did STS power increase (Table 1). According to research by Straight et al. (25), load intensity in RT is inversely related to the hypertrophy of fast-twitch MHC II fibers in older adults, which are characterized by high contraction velocity (26). This inverse relationship may be due to the fact that starting with consecutive HL sessions in the early weeks of training may not align with the progression of muscle damage and recovery in novice postmenopausal women (21–23). This is because postmenopausal women lose the protective effect of estrogen on exercise-induced muscle damage and inflammation, leading to slower strength recovery and tissue repair (21–23). On the other hand, starting with an LL in the first few weeks can increase muscle mass and muscular strength (34–36), making the muscle better adapted to handle HL.

Change scores by load intensity for dynamic muscular strength and STS power. The results of the intervention, grouped by load intensity, revealed that HL was more effective than LL in increasing the 45° leg press, leg extension, and STS power. This finding aligns with previous research which suggests that HL programs are better at increasing muscular strength compared with LL programs (27). However, the same effect was not observed in the leg curl, which could be due to intermuscle differences in the ability to fully activate muscle fibers. Neural factors, such as maximal voluntary activation level, can be used to explain these discrepancies between exercises and muscle groups. For instance, the knee extensors display relatively lower levels of voluntary activation (~84.5%) (45), making it more challenging to activate the quadriceps fully (46).

Conversely, the results showed that hamstrings have higher levels of voluntary activation, estimated to be around 98.5% (46), and are capable of activating most or all muscle fibers (44). Increasing voluntary activation is one of the strategies to improve muscle performance, and one way to achieve this is by using HL (47). This means that quadriceps muscles may benefit more from HL than hamstrings, as they display relatively lower voluntary activation levels (~84.5%) (45) and are therefore more challenging to fully activate (44). Jenkins et al. (47) found that voluntary activation increased only when using HL (80% of 1RM) compared with LL (30% of 1RM), thus explaining the greater gains in quadriceps strength. On the other hand, Carneiro et al. (33,34) did not observe any differences in leg curl muscular strength gains between HL and LL for hamstrings. The current and previous findings suggest that HL promotes greater gains in dynamic exercises that specifically involve the quadriceps, such as 45° leg press, leg extension, and STS power. Further studies are necessary to confirm the mechanisms proposed in this study.

Change scores by load intensity transition schemes for isometric strength. The results of the study showed that there was no significant difference in the improvement of MIVC (isometric muscular strength) between the HL-to-LL group and the LL-to-HL group after 24 wk of intervention (as seen in Table 1 and Fig. 3). The difference between the two groups, as shown in Figure 3F, was only 2.8 N, which was less than the minimal clinically relevant difference of 7.75 N or 3.3 kg (47). This suggests that transitioning from HL-to-LL does not provide additional benefits in terms of isometric strength compared with transitioning from LL-to-HL in postmenopausal women.

Both the HL-to-LL and the LL-to-HL groups showed similar improvements in isometric strength after 12 wk of intervention. However, there was no further improvement in isometric strength observed between 12 and 24 wk for either group (as seen in Table 1). This is in line with previous studies that have reported gains in isometric strength after 8 to 12 wk of RT, regardless of training volume (48), sex (49), and age (49). Some studies have even found that the gains in isometric strength achieved at 8 wk are maintained, rather than increased, after 24 wk of RT (49). The initial improvements in isometric strength in untrained individuals may be due to neural adjustments, such as increased firing rate, signal size, and improved intramuscular and intermuscular coordination (49–51).

It is worth noting that there are differences between dynamic and isometric strength of the quadriceps. Dynamic strength is dependent on load intensity (as discussed earlier), whereas isometric strength does not vary with load intensity (as seen in Table 2). The improvement in isometric strength may represent a general strength adaptation, whereas the improvement in dynamic strength indicates a specificity of RT (52). Although there is a correlation between isometric and dynamic strength (as seen in Tables 3 and 4), it may not represent the full extent of the general strength adaptation (52). The general strength adaptation appears to be relatively low, even between strength skills that use the same muscle in related movements. Thus, a single strength assessment may not capture all of the strength adaptations that occur after a RT program (52).

Change scores by load intensity for isometric strength. Our results indicate that there is no significant difference in isometric muscular strength gains between HL and LL (as seen in Table 2). Previous studies have shown that when resistance-trained individuals are tested on an unfamiliar exercise such as isometric tests, the differences in muscular strength gains between different load intensities tend to diminish (52,53). For instance, HL is known to be more effective than LL on the 1RM test. However, changes in isometric muscular strength are often similar between both load intensities (52,53). This could be explained by the principle of training specificity, which states that the gains in muscular strength from different load intensities are largely dependent on the type of test used.

Change scores by load intensity transition schemes for walking speed. The results from the study showed that both the HL-to-LL and LL-to-HL groups improved their walking speed after the first 12 wk of intervention, but there was no further improvement after the load intensity transition (from 12 to 24 wk) (Table 1). The difference in walking speed between the two groups was equivalent at ±0.1 $m\cdot s^{-1}$ (Fig. 3). It is noteworthy that changes in walking speed of 0.05 $m\cdot s^{-1}$ are considered to be a small but clinically meaningful improvement, while changes of 0.1 $m\cdot s^{-1}$ are considered to be a substantial and significant improvement (4,43). These results suggest that the type of load intensity transition scheme does not significantly impact the walking speed in postmenopausal women.

Change scores by load intensity for walking speed. The results of the study indicate that both HL and LL similarly improve walking speed (400-m and 6MWT) in postmenopausal women (Table 3). The difference in walking speed changes between the two load intensities was not clinically meaningful at ±0.05 $m\cdot s^{-1}$ (Fig. 4), as per the criteria established by previous research (4,43). This suggests that different load intensities have similar effects on walking speed in postmenopausal women.

In line with previous research, changes in muscle function play a crucial role in changes in physical performance (4,54). However, our findings showed that dynamic muscular strength differences between the groups had no effect on walking speed. On the other hand, both the HL-to-LL and LL-to-HL groups experienced similar improvements in isometric muscular strength and walking speed. This suggests that walking speed changes are more strongly correlated with improvements in isometric strength than with improvements in dynamic strength as measured by the 45° leg press and leg extension exercises (Tables 3 and 4). Isometric muscular strength gains are more likely to represent a general strength adaptation and may better explain the improvement in walking speed (52). Therefore, our findings indicate that load intensity seems to have little impact on isometric muscular strength and walking speed in postmenopausal women.

Dropouts. There was a higher rate of dropouts in the HL phase (11 participants) compared with the LL phase (4 participants). Despite the reported reasons for dropping out, such as personal and family issues and difficulty getting to the training site, the dropout rate was 2.75 times higher in the HL phase. Research has suggested that a higher intensity of RT can contribute to exercise dropout, especially in individuals who are overweight and less fit at the start of the program (55). Therefore, it is important for coaches and physical therapists to carefully plan HL RT programs to avoid high dropout rates in postmenopausal women. Future studies may explore the relationship between dropout rates and the use of HL in RT programs, especially in older adults such as postmenopausal women, after both short-term and long-term interventions.

Future perspectives. The rapid decline in muscular strength experienced by women during menopause makes them highly susceptible to sarcopenia and its associated consequences (1–7,9,56). A recent systematic review has shown that RT can bring positive benefits to muscular strength and physical performance in postmenopausal women (10). However, it is crucial to recognize the importance of optimizing muscular strength and physical performance through an appropriate exercise program in determining an individual's functional reserve later in life and reducing the impact on healthcare costs. To this end, it is believed that load intensity transition schemes such as variation, progression or physiological stress are necessary to optimize muscular strength gains and increase physical performance over longer training periods (11–13).

Our study found that, after 24 wk of RT, muscular strength and physical performance improved regardless of the load intensity transition scheme used, and the expected greater gains from HL-to-LL transition were not observed. Except for STS power, it appears that varying the load intensity does not bring significant benefits to muscular strength and physical performance in middle-age and older women. Further research is needed to understand how RT can be optimized to bring these benefits to older adults. In addition, more research is needed to determine the relationship between the utilization period of HL and its impact on muscular power adaptation in older adults.

Although the increased load intensity had an effect on the dynamic quadriceps strength in the exercises of 45° leg press and leg extension, and STS power, it had no impact on isometric strength and walking speed. Despite our expectation that the improvement in dynamic muscular strength and power would lead to improved physical performance (4), this was not observed in the current study. Instead, the relationship between isometric strength and physical performance was evident.

Further research is needed to determine the generality of dynamic muscle strength to physical performance adaptations.

Load intensity had minimal impact on isometric strength and physical performance in our study. In addition, HL, as well as excessive weight and low physical activity, are associated with a higher risk of dropout (55). Although a simpler approach to RT may increase adherence, it is still unclear if manipulating RT variables can bring additional benefits beyond a protocol with a more straightforward approach (e.g., RT with self-selected loads).

Limitations. The study has a few limitations that should be considered. First, the small sample size is a result of the intervention's nature. Despite this, we still demonstrated the significant impact of RT on muscular strength and physical performance. Secondly, a higher dropout rate was observed in the HL phase compared with the LL phase. This may have led to an imbalance between the groups, as participants who dropped out of the study generally had higher body mass indices and lower baseline fitness levels (55). However, we found no differences between groups in baseline measurements. Finally, we did not assess the participants' diets, which may have impacted the results between the groups. Nonetheless, the inclusion criteria (nonconsumption of nutritional supplements) and the randomized design used in the study likely minimized any potential difference in protein intake between the groups.

Moreover, it is essential to highlight the strengths of the current study. Firstly, it used a 24-wk crossover design, which allowed for the comparison of the two groups. Secondly, variables such as load intensity, frequency, and exercise proficiency were controlled to minimize bias. In addition, two skilled fitness professionals closely monitored all participants during each RT session, ensuring high compliance and proper techniques.

CONCLUSIONS

Our findings suggest that both load intensity transition schemes (HL-to-LL and LL-to-HL) result in similar changes in muscular strength and power, and walking speed in postmenopausal women after 24 wk of training. However, HL is a determining factor in increasing 45° leg press and leg extension strength, as well as power, particularly when performed after LL. In addition, although HL results in an increase in isotonic strength, it had a minimal effect on isometric strength and walking speed in postmenopausal women. These results provide valuable insights into the effects of load intensity on muscular strength, power, and physical performance in postmenopausal women.

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The results of the study are presented clearly, honestly, and without fabrication, falsification, or inappropriate data manipulation. The results of the present study do not constitute an endorsement by the American College of Sports Medicine. This study has no conflicts of interest to declare.

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