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Does Taking a Break Matter—Adaptations in Muscle Strength and Size Between Continuous and Periodic Resistance Training

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ABSTRACT

We aimed to compare the effects of periodic resistance training (RT) and continuous RT on muscle strength and size. Fifty-five healthy, untrained participants (age 32 ± 5 years) were randomized to periodic (PRT, $n = 20$ completed the study, 45% females) or continuous (CRT, $n = 22$ completed the study, 45% females) groups. PRT completed a 10-week RT, a 10-week detraining, and a second identical 10-week RT. CRT began with a 10-week non-RT, followed by a 20-week RT. RT included twice-weekly supervised whole-body RT sessions. Leg press (LP) and biceps curl (BC) one repetition maximum (1RM), countermovement jump (CMJ) height, muscle cross-sectional area (CSA) of vastus lateralis (VL), and biceps brachii (BB) using ultrasound imaging were measured twice at the beginning and every fifth week during the intervention. Both groups increased ($p < 0.001$) 1RM in LP and BC, CSA in VL and BB, and CMJ height with no differences between the groups. In PRT, 1RM in LP and BC, CSA in VL and BB, and CMJ height decreased during detraining ($p < 0.05$). During the first 5 weeks of retraining in PRT, increases in LP 1RM, and VL and BB CSA were greater than in CRT during Weeks 10–15 of their CRT ($p < 0.01$). PRT and CTR ended up in similar postintervention adaptations, as decreased muscle strength and size during detraining in PRT regained rapidly during retraining. Our results therefore suggest that trainees should not be too concerned about occasional short-term training breaks in their daily lives when it comes to lifelong strength training.

Trial Registration: ClinicalTrials.gov identifier: NCT05553769

1 | Introduction

Skeletal muscle and its maintenance are essential for health and function and have a remarkable ability to adapt to environmental demands [1]. For example, in response to chronic resistance training (RT), skeletal muscles increase their size and strength as well as induce various positive effects on health by improving insulin sensitivity, body composition, immune function, markers of inflammation, and quality of life by improving functional capacity [2, 3].

Unfortunately, skeletal muscle plasticity is also shown after a training break. If RT is discontinued, the adaptations in muscle strength and size will start to decline and, depending on the

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length of the detraining period, can even be fully diminished. After short-term (<4 weeks) detraining periods, muscle strength and size are typically well maintained [4–6], but after longer-term (>4 weeks) detraining periods, decrements are typically reported, with the effects being greater on muscle size than on muscle strength [7–9]. Fortunately, several studies have shown that RT adaptations in muscle size and strength, once achieved with RT, can be obtained faster with subsequent retraining if the initial adaptations were lost after detraining [10–16]. However, it is uncertain whether the retraining effect on muscular adaptations is so significant that RT practitioners should not be concerned about intermittent detraining periods.

Previously, Ogasawara et al. conducted two studies comparing upper-body adaptations to continuous RT (CRT) and periodic RT (PRT) in young men with no prior experience in RT. In the first one, they [4] reported no differences between the groups in muscle cross-sectional area (CSA) and one repetition maximum (1RM) adaptations after 15 weeks of CRT when compared to 6 weeks of RT, 3 weeks of detraining, and 6 weeks of RT. In the second study [17], no differences in muscle CSA, 1RM, and maximum voluntary isometric contraction (MVC) were reported between 24 weeks of CRT when compared to PRT, which consisted of three 6-week RT periods separated by 3-week detraining periods. The lack of differences between the groups, despite CRT group performing more training sessions, was explained by the decreased rate of development in muscle hypertrophy and strength in the CRT group, whereas the PRT group maintained their rate of development in strength and hypertrophy after the detraining period(s). In 2015, Gentil et al. [18] did a similar study in untrained women where they compared upper and lower body adaptations in muscle strength and size between a group performing CRT for 10 weeks and a group performing two 5-week RT periods separated by a 2-week detraining period. After the intervention, they found no significant differences between the groups for any measures of muscle strength or size. These studies suggest that short-term (<4 weeks) detraining periods may not compromise muscular adaptations to RT compared to CRT. This may be explained by the fact that short detraining periods do not have major effects on muscle size and strength, unlike longer detraining periods, which can reverse the adaptations from the previous RT [8, 19]. For example, Tavares et al. [19] showed that quadricep CSA reduced back to pretraining values after 8 weeks of detraining preceded by 8 weeks of RT in previously untrained males. It is therefore important to study the effects of retraining following extended periods of detraining and compare these effects of periodic training with the outcomes of an equivalent duration of continuous training. This is essential information as different reasons can cause breaks from RT in healthy individuals, such as lack of motivation, work commitments, or even pandemics.

Hence, this study aimed to compare the effects of a 20-week CRT period to two 10-week RT periods separated by a 10-week detraining period. We hypothesized that a CRT would be more effective than PRT in increasing maximal strength, muscle CSA, and vertical jump height. The hypothesis is based on the assumption that after 10 weeks of detraining, a greater deterioration in RT adaptation is observed than in previous studies comparing CRT and PRT with a shorter (<8 weeks) detraining period.

2 | Materials and Methods

2.1 | Participants

Participants were recruited via advertisements published around the University of Jyväskylä campus, on university websites, on social media, and distributed to the university staff and students via e-mail lists. All interested applicants were sent a link to an online questionnaire to assess their suitability for participating in the study. The health status of suitable applicants' according to the questionnaire was then assessed by a physician to ensure that clinical inclusion criteria were met. After this, the applicants were informed of all potential risks and discomforts of the study and the possibility of dropping out from the research project at any time before they were asked to sign an informed consent document.

Fifty-five eligible males and females volunteered to participate in the study. Inclusion criteria were age within the range 18–40 years, no regular RT history (<10 RT sessions a year), not participating in systematic endurance-type training (<2 endurance exercise sessions lasting <30 min per week for the last 6 months), body mass index (BMI) within the range 18.5–30 kg/m^2, and not currently consuming any anti-inflammatory drug(s). Exclusion criteria were a history of medication that could affect exercise responses, use of creatine, any acute or chronic illness affecting cardiovascular, respiratory, musculoskeletal, and/or endocrine function, any other condition that may limit the ability to perform RT and testing (e.g., uncontrolled hypertension, diabetes, arthritic conditions, and neuromuscular complications), or blood-borne diseases, diseases, and medication affecting blood clotting, allergies to anesthetic drugs, and severe psychological disorders.

The study received ethical approval from the ethics committee at the University of Jyväskylä (857/13.00.04.00/2021). The study was conducted according to the declaration of Helsinki. Personal data were stored and handled according to the ethical and GDPR guidelines of the University of Jyväskylä.

2.2 | Study Design and Setting

This study was a randomized, parallel-group repeated-measures design, and the purpose of the study was to compare the effects of PRT and CRT on adaptations in muscle strength and size in untrained young male and female adults. Participants were randomly assigned in a 1:1 ratio to PRT or CRT. This study design included a randomized controlled trial (RCT) between 10 weeks of RT (10RT) and 10 weeks of non-RT control to investigate whether 10-week RT increases maximal strength, muscle size, and countermovement jump (CMJ) height before the comparisons between PRT and CRT will be made. Homogeneity between groups at baseline was aimed to achieve by separately dividing male and female participants into matched pairs by the combined Z score for BMI and age. Before the RCT started, muscle strength and size measurements were conducted twice every 2 weeks without any training intervention to determine the measurement error size. The first testing session was also conducted to familiarize participants with the tests. Then, the effectiveness of a 10-week RT (10RT) period on muscle strength and size was determined by comparing it to a 10-week control period. To compare adaptations achieved by PRT and CRT, the intervention of 10-week RT, 10-week detraining, 10-week re-RT (PRT), and 20-week CRT period (CRT) was implemented.

Once the intervention started, measurements for muscle strength and size were performed every fifth week, excluding a 10-week control and 10-week detraining periods to avoid any RT stimulus during those periods. The study design is illustrated in Figure 1.

In the first 10-week intervention period, four participants dropped out from the 10RT group, whereas all the participants in the control group completed the control period. In the second part of the study, four and five participants dropped out from the PRT and CRT groups, respectively (Figure 2). The compliance rate with the training program was ≥ 92.5% (≥ 37/40 sessions) for the rest of the participants. One participant from the PRT group was excluded from the VL CSA analysis due to poor image quality, and one participant from the CRT group was excluded from the biceps curl 1RM analysis due to forearm pain. The aforementioned participants were included in all the other analyses.

2.3 | Muscle Strength

Dynamic muscle strength from the lower and upper body was assessed by leg press and barbell biceps curl one repetition maximum tests (1RM), respectively. The leg press 1RM was performed in horizontal leg press (David, F210, Finland) from a 180° (knee straight) to ~65° knee angle in an eccentric–concentric movement. The load in the leg press was first assisted up so the movement could be started with eccentric motion with straight legs. From there, the eccentric phase had to be performed with controlled motion, the movement had to stop at the bottom to avoid bouncing, and the concentric phase had to be started from the researcher's command. If the concentric phase was performed before the researcher's command or the load bounced at the bottom of the movement, the trial was disqualified. The biceps curl was performed with a barbell on custom-made equipment where adjustable paddings supported the lumbar spine and upper back, and the participants were attached to the equipment by a leather belt. The movement had to be started with straight arms and both elbow joints had to be fully flexed at the end of the movement. The movement was performed in a concentric–eccentric motion, and the lower and upper back had to remain in contact with the paddings for accepted repetition. If the upper back came off the padding at any point or there was bending of the knees to assist the lift, the trial was disqualified. One familiarization session was performed 1 week before the control measurement (−2 week) where correct techniques were instructed, and individual equipment settings were recorded for leg press and

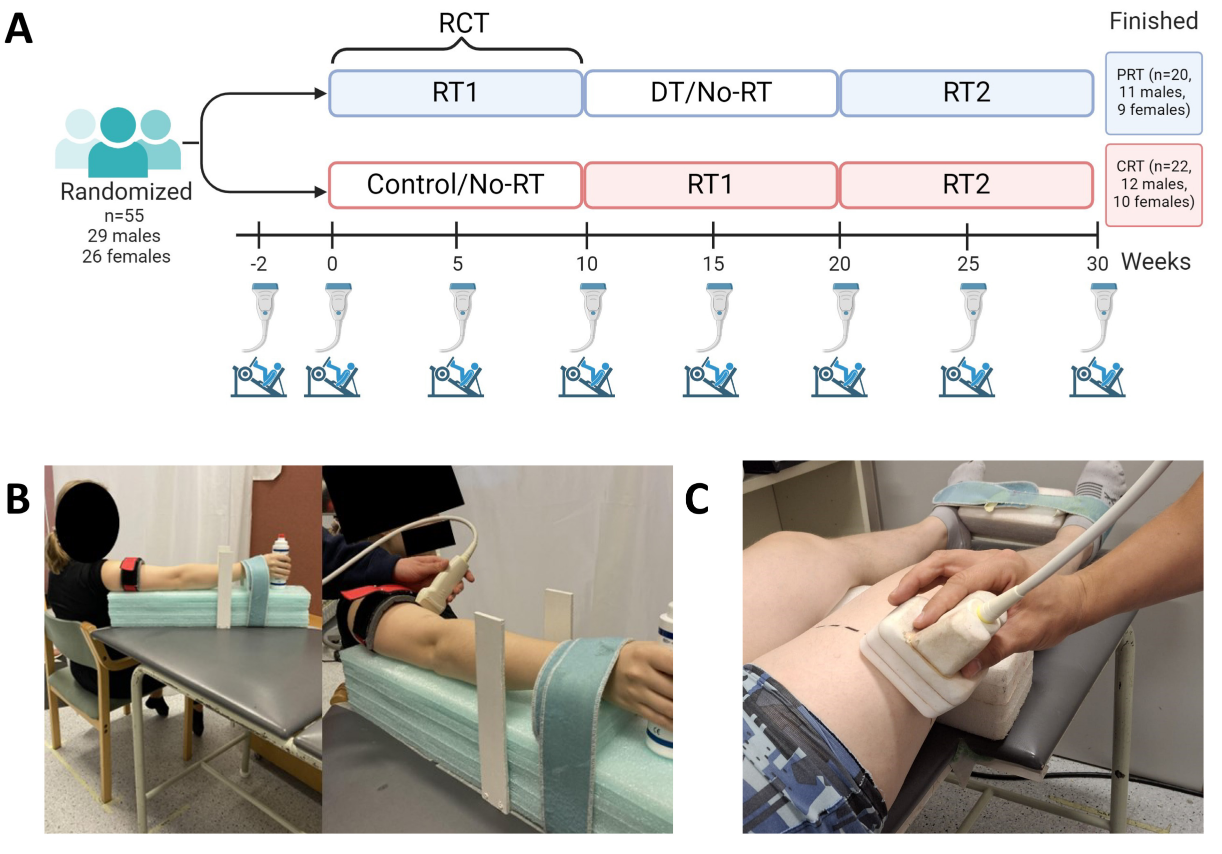

FIGURE 1 | (A) Experimental design. The ultrasound probe and leg press icons represent muscle size and strength measurement time points (1RM tests for the leg press and biceps curl as well as CMJ). Muscle strength and size were not measured from the continuous resistance training (CRT) group at Week 5 and from the periodic resistance training (PRT) group at Week 15. RCT, randomized controlled trial; RT, resistance training. (B) CSA assessment of the biceps brachii muscle with axial plane ultrasound. (C) CSA assessment of the VL muscle with axial plane ultrasound with custom-made probe support. Gap in the examination table enabled for full imaging of the vastus lateralis muscle starting from the lateral intermuscular septum of the thigh. Note that image was taken only for illustrative purposes and therefore no transmission gel is applied between the probe and the skin.

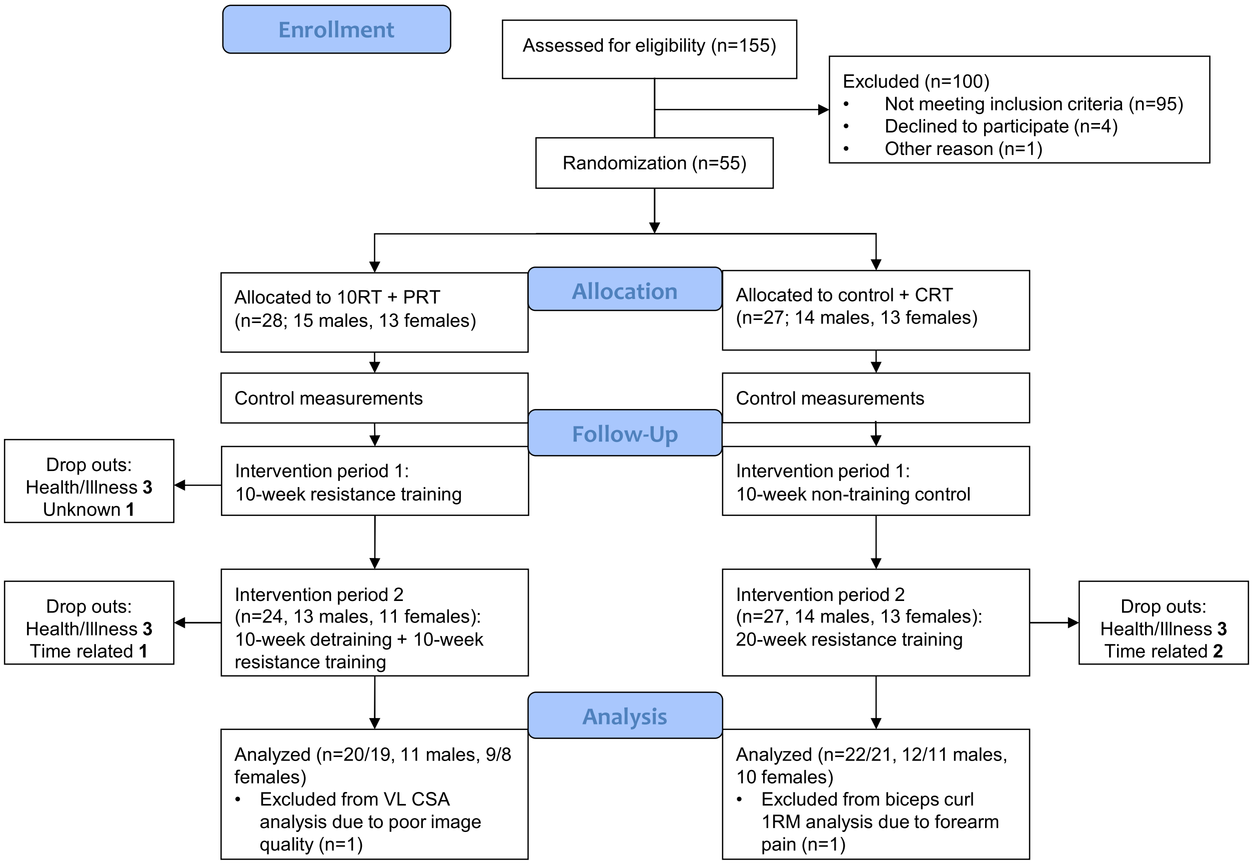

FIGURE 2 | Enrollment, randomization, and follow-up of participants. 10RT, 10-week resistance training; CRT, continuous resistance training group; CSA, cross-sectional area; PRT, periodic resistance training group; VL, vastus lateralis.

barbell biceps curl exercises. Before 1RM tests, participants performed a standardized general warm-up lasting approximately 10 min. The warm-up included 3-min indoor cycling at self-selected intensity, 10 bodyweight squats, five bodyweight lunges for both legs, five times standing forward bend to plank position and back, and five standing knee tucks with calf raises for both legs and depending on learning the correct technique, one to three submaximal CMJ followed by three maximal effort CMJ. CMJ flight time (t) was measured from the maximal effort jumps using custom-made IR sensors, and CMJ height (h) was calculated using the formula $h = t^2g/8$, where g is the gravity acceleration (9.81 m/s^2). Only trials with correct technique (hands remained on hips, knees remained straight during the jump, and landing was done with the balls of the foot) were recorded, and the highest value from the three jumps was used as the result. The coefficient of variation (CV%) for CMJ from test to retest was 4.0%.

After the warm-up, the participants first performed the leg press 1RM test, followed by the biceps curl 1RM test. Before the 1RM tests, participants performed an exercise-specific warm-up with 10 reps at ~50%, five reps at ~75%, and finally, one rep with 90%–95% of the participants' predicted 1RM (estimated from the previous familiarization session), with 1–2 min of rest between sets. The load was then progressively increased by 2.5–10 kg in leg press and by 0.5–2.5 kg in biceps curl for each attempt until the 1RM was reached. The rest period between each attempt was 3 min. If the load was increased more than the minimum amount (2.5 kg in the leg press and 0.5 kg in the biceps curl) after the successful lift and the next attempt failed, the load was then decreased to the minimum amount above the previous successful lift. From there, minimum increases were used until 1RM was reached. On average, 3–5 attempts were required to complete the 1RM tests. The CV% for leg press and biceps curl 1RM from test to retest was 3.1% and 4.2%, respectively.

2.4 | Muscle Size

Vastus lateralis (VL) and biceps brachii (BB) muscle CSA (cm^2) were measured using a B-mode axial plane ultrasound (model SSD-α10; Aloka, Tokyo, Japan) with a 10 MHz linear-array probe (60 mm width) in extended-field-of-view mode (23 Hz sampling frequency). Measuring muscle hypertrophy and atrophy by B-mode ultrasound imaging has been reported to have a high correlation with MRI, which is considered the reference standard for measuring changes in muscle size [20, 21]. The ultrasound measurements were always taken by the same research group member with US imaging experience. The US measurements were performed at least 48 h after any exercise sessions and always before the 1RM measurements. Before imaging, the participants had to lie supine for at least 10 min to stabilize fluid shifts. VL CSA images were taken in a standardized supine position where a sculptured support was placed under the participants' knees as earlier [20]. Any movement of the legs during the measurement was avoided by placing a 20-cm-wide block between the participants' ankles, and an elastic band was strapped around the feet (Figure 1). The distance from the greater trochanter to the proximal edge of the patella was measured, the mid-point was marked with a permanent pen, and an axial line was drawn on the skin along which the measurements were taken. The participants were positioned on the examination table so that the marked line was aligned with the gap on the table to ensure complete panoramic imaging of the VL muscle starting from the lateral intermuscular septum of the thigh (Figure 1).

Next, for the BB CSA measurements, the participants were seated with their arms resting at a supported 45° angle to the torso on the examination table. To maintain a stable arm position during the measurement, a sculptured support (4.5 cm) was placed below the wrist, and an elastic strap was placed around it (Figure 1). The distance from the acromion process to the central point of the elbow joint was measured from which a point was marked on the skin at one-third of the length from the elbow joint toward the acromion. At this point, one axial line was marked on the skin, and a strap was placed around the arm above the marked line so that the probe could be moved against the strap to reduce the risk of probe tilt during the measurement. Care was taken to ensure that the strap did not compress the arm.

The CSA images were taken with a generous amount of transmission gel on top of the skin to aid acoustic coupling and with consistent and minimal pressure to avoid compression of the muscle. The probe was moved along the marked axial lines from the lateral aspect medially at a slow and steady pace. After each image, the probe was removed from the skin and returned to the starting position. For VL CSA images, a custom-made probe support (Figure 1) was used to keep the probe perpendicular to the thigh. To ensure the repeatability of the measurement, all the distances of the marks made to the skin were documented and photographed. The sites were reassessed at each measurement point to ensure that the marks had not moved.

The US images were analyzed using ImageJ software (version 1.54). For VL CSA, three images were analyzed, and the mean of the two closest values was taken as the result. Because measuring the BB CSA with US imaging was a novel method at our laboratory, we took three to six representative images from the participants at each time point and analyzed all of them. If the CV% was < 5% between all the images from the same time point, we used the average of all the images to minimize the measurement error. In a few cases, when the CV% was more than 5%, we excluded the image furthest from the mean so that the CV% was < 5% and used the average from the rest of the images as the result. The CV% for VL CSA and BB CSA from test to retest were 1.6% and 2.3%, respectively.

2.5 | Interventions

Both groups underwent the two identical 10-week RT periods, but the difference between the groups was that the CRT group performed the first and second 10-week RT periods continuously, and the PRT group had a 10-week detraining period between the two RT periods. The training consisted of two whole-body RT sessions a week with at least 48 h between the sessions. The same general warm-up protocol was performed before every training session as before the 1RM tests. The training protocol was designed based on the literature to promote gains in both hypertrophy and strength (e.g., 16 sets a week for the measured muscle groups, frequency of two sessions a week, ≥ 2 min rests between the sets, use of moderate-to-high loads, and combining different exercises for the measured muscle groups) [22–27]. In more detail, the exercises were conducted in the following order: leg press (4 × 8–10 reps), knee extension (4 × 8–10 reps), Smith machine bench press (3 × 8–10 reps), barbell biceps curl (4 × 8–10 reps), and chest supported seated row (4 × 8–10 reps). All sets in each exercise were performed consecutively before moving on to the next exercise. Participants were instructed to conduct the concentric phase of the lifts as fast as possible (i.e., with maximal effort) and the eccentric phase under muscular control and to last approximately 2 s. All the exercises were done with 2-min rest periods between the sets. In the first training session of both 10-week RT periods, a 3–5RM test was performed for knee extension, Smith machine bench press, and chest-supported seated row exercises to prescribe training loads. Before each 3–5RM test, two warm-up sets were conducted: 10 repetitions with 40%–60% of 1RM, followed by five repetitions with 60%–80%, with a 1-min rest between sets. The load was then increased based on the participants' perceived repetitions in reserve. If five repetitions were completed, the load was increased for the next trial until the participants could not perform five repetitions with a full range of motion. The rest periods between trials were 3 min. The pretest 1RM results were used for training load prescription for leg press and biceps curl exercises. The participants started the training with loads corresponding to 70% 1RM in leg press, Smith machine bench press, and chest-supported seated row exercises, and 50% 1RM in biceps curl and knee extension exercises. The participants were instructed to perform 8–10 reps in each set with approximately 1–2 repetitions in reserve, except in the final set of each exercise in the second training session of every week, when the last set was performed until volitional failure. The number of repetitions was then used to adjust the training loads for the following week. If the number of performed repetitions was more than 10, the loads were increased, and if the repetitions were less than eight, the load was decreased. A more detailed description of the training load adjustments is shown in Table 1. Every fifth week, the second training session was replaced with the 1RM tests, which resulted in a decreased total volume load during those weeks and, therefore, also served as a small volume deload. All training sessions were conducted at the faculty laboratory, and the sessions were instructed and supervised by a trainer to ensure correct training techniques.

2.6 | Detraining

After the first 10-week RT period, the participants in the PRT group were instructed to resume their habitual lifestyle but to avoid any form of resistance or endurance-type training or any other unaccustomed exercise for the next 10-week period. A detraining period of 10 weeks was chosen as muscle size has been reported to decline close to pretraining values in the untrained

TABLE 1 | Weekly load adjustments (kg) according to the repetitions performed in the repetition maximum sets for each exercise.

Repetitions performed	Leg press	Knee extension	Smith machine bench press	Biceps curl	Chest-supported seated row
<5	−7.5	−7.5	−5	−2.5	−5
6–7	−5	−5	−2.5	−1	−2.5
8–10	0	0	0	0	0
11–12	2.5	2.5	2.5	1	2.5
13–15	5	5	5	2.5	5
16–20	7.5	7.5	7.5	3.5	10
>20	10	10	10	5	15

subjects after 8 weeks of detraining [19]. Physical activity and other lifestyle changes during the detraining period were assessed with a survey, and the participants were also contacted via email in the middle of the detraining period to ensure that they did not participate in any form of RT.

2.7 | Statistical Analysis

Our sample size calculations are based on earlier studies in our laboratory indicating that 10–20 participants per group are sufficient for between-group comparison of 10RT and control in both muscle size and strength [28, 29] with the power of 80% and two-tailed $p<0.05$, thus allowing a potential detraining effect to be investigated. To limit possible problems with statistical power, a large sample size as feasible for the current study setting was adopted to account for potential missing data. Normality of the data was tested using Shapiro–Wilk test. Between-group differences were examined with a two-way repeated measures analysis of variance (ANOVA) using sex and baseline values as a covariate. Within-group comparisons were examined with repeated measures ANOVA. In post hoc analysis, *t*-tests were used with correction for multiple testing by Holm–Bonferroni method [30]. Within-group effect sizes (ES) were calculated by the following formula: mean change divided by the sum of pre- and postvalues divided by 2. Percentage changes were calculated by the following formula: (postvalue minus prevalue) divided by prevalue and multiplied by 100. Between-group differences from the physical activity questionnaires were examined with independent-samples Mann–Whitney *U* test and within-group comparisons were examined with related-samples Wilcoxon signed rank test. Statistical analyses were performed using the SPSS software (version 28.0, IBM Corp) and Microsoft Excel (version 2406), and figures were made with GraphPad Prism software (version 10.0, GraphPad Software Inc).

3 | Results

3.1 | Ten Weeks of RT Increases Muscle Size and Strength

To first understand whether the present 10 weeks of RT increases performance and muscle size, we compared 10-week RT to a similar length control period (see Figure 1). We found a significant group-by-time interaction favoring 10 weeks of RT ($p<0.001$) in leg press 1RM, biceps curl 1RM, VL CSA, BB CSA, and CMJ height (Table 2). No significant sex-by-time interactions ($p \geq 0.192$) were observed for the leg press and biceps curl 1RM, VL and BB CSA, or CMJ.

3.2 | No Differences in the Adaptations Between PRT and CRT

3.2.1 | Training Load

The total training volume load (Sets × Repetitions Per Set × Loads) during the 20 weeks of RT did not differ between the groups (PRT: 862 275 ± 187 295 kg vs. CRT: 891 115 ± 183 946 kg, $p=0.618$) (Figure 3). Both groups increased the training volume load from the first 10-week training block to the second 10-week training block ($p<0.001$), and there was no significant difference between the groups in the volume load in the first ($p=0.893$) or in the second 10-week training block ($p=0.424$) or increases from the first to second 10-week block (PRT, 18% ± 10% vs. CRT, 23% ± 11%, $p=0.116$). Every 5 weeks, we also calculated the relative training loads from the 1RM tests. There was no difference between the groups in the average relative training load for the 20 weeks of RT in leg press (PRT, 81.1% ± 3.9% vs. CRT, 82.6% ± 3.7%, $p=0.220$) or biceps curl (PRT, 62.7% ± 5.3% vs. CRT, 63.7 ± 3.9, $p=0.464$).

3.2.2 | Muscle Strength and Muscle Size

Both groups significantly increased ($p<0.001$) their 1RM in leg press (ES; PRT: 0.90, CRT: 1.01) and biceps curl (ES; PRT: 1.01, CRT: 0.86), muscle CSA in VL (ES; PRT: 0.79, CRT: 0.76) and BB (ES; PRT: 0.66, CRT: 0.71), and CMJ height (ES; PRT: 0.60, CRT: 0.50) (Table 3). When comparing PRT and CRT during their 20 weeks of RT (i.e., PRT from Week 0 to Week 30 and CRT from Week 10 to Week 30), no statistically significant ($p \leq 0.150$) Group × Time differences were observed (Figure 4). To examine whether the effect of different intervention lengths (30 weeks of PRT and 20 weeks of CRT) explained the results, we also conducted the group-by-time analysis from 0 to 30 weeks in CRT, and the results remained unchanged (Table S1).

TABLE 2 | Muscle strength and size, and CMJ height at baseline and after 10 weeks of intervention, in 10-week resistance training (10RT) and nontraining control groups.

	10RT ($n = 24/23$[a])		Control group ($n = 27$)		Group × Time interaction	
Outcomes	**Mean ± SD**	**Difference (95% CI)**	**Mean ± SD**	**Difference (95% CI)**	**Difference (95% CI)**	***p***
Leg press 1RM (kg)						
Baseline	161.9 ± 44.8		162.7 ± 41.6			
Week 10	192.8 ± 46.0*	30.9 (24.3–37.5)	167.2 ± 42.7*	4.5 (1.3–7.7)	26.4 (19.2–33.7)	< 0.001
Δ%	21.1 ± 12.3		3.0 ± 4.6			
Biceps curl 1RM (kg)						
Baseline	27.6 ± 8.5		28.0 ± 8.9			
Week 10	33.7 ± 8.7*	6.1 (4.9–7.3)	29.0 ± 8.7*	1.1 (0.4–1.7)	5.0 (3.7–6.4)	< 0.001
Δ%	25.0 ± 17.5		4.5 ± 6.2			
VL CSA (cm^2)						
Baseline	25.4 ± 5.8		26.5 ± 5.8			
Week 10	29.6 ± 7.0*	4.2 (3.1–5.2)	26.9 ± 5.8	0.4 (−0.1–0.8)	3.8 (2.8–4.9)	< 0.001
Δ%	16.6 ± 8.8		1.5 ± 4.1			
BB CSA (cm^2)						
Baseline	9.2 ± 3.1		8.8 ± 3.2			
Week 10	10.7 ± 3.6*	1.6 (1.2–1.9)	9.1 ± 3.3*	0.3 (0.2–0.4)	1.3 (1.0–1.6)	< 0.001
Δ%	17.1 ± 6.1		3.1 ± 2.8			
CMJ height (cm)						
Baseline	25.4 ± 7.2		27.1 ± 6.8			
Week 10	29.8 ± 8.5*	4.4 (3.2–5.6)	27.6 ± 6.3	0.4 (−0.5–1.4)	3.8 (2.3–5.4)	< 0.001
Δ%	17.9 ± 10.7		2.3 ± 8.1			

Abbreviations: 10RT, 10-week resistance training group; 1RM, one repetition maximum; BB, biceps brachii; CI, confidence interval; CMJ, countermovement jump; CSA, cross-sectional area; SD, standard deviation; VL, vastus lateralis.
[a]One participant from the 10RT group was excluded from the VL CSA analysis due to poor image quality.
*$p < 0.05$ versus baseline.

When pretraining values or sex were analyzed as a covariate, the results of no differences between PRT and CRT remained (Table S1). Moreover, when females and males were analyzed separately, there was no difference after 20 weeks of RT between the PRT and CRT groups in any muscle size or strength variable examined (data not shown). Therefore, sex does not appear to explain the results.

3.3 | Decrease in Muscle Size and Strength During Detraining

We next conducted more thorough within-group comparisons in the PRT group. After the 10-week detraining period, there was a significant decrease from the first RT period in leg press 1RM (−5.4% ± 4.4%, $p < 0.001$), biceps curl 1RM (−3.6% ± 6.8%, $p = 0.023$), VL CSA (−9.9% ± 4.1%, $p < 0.001$), BB CSA (−7.3% ± 3.9%, $p < 0.001$), and CMJ height (−6.9% ± 5.3%, $p < 0.001$) (Figure 4). Although especially VL CSA was already close to the baseline, it remained significantly ($p = 0.03$) above pretraining values, as did the other variables measured ($p < 0.01$, Table 3). Decreases were significantly greater for muscle CSA compared to 1RM in the lower limbs ($p = 0.01$), and a trend for greater decreases was found in the upper limbs ($p = 0.07$). No difference was observed in 1RM decreases between leg press and biceps curl ($p = 0.745$), or CSA decreases between VL and BB ($p = 0.171$) after detraining.

3.4 | Regained Muscle Strength and Size During the First Weeks of Retraining

Five weeks of retraining reached the previous levels of the first 10-week RT in muscle strength and size, and CMJ height. This was shown as a lack of significant differences ($p > 0.05$) compared to the first RT week 10 values in leg press or biceps curl 1RM, in VL or BB CSA, and CMJ height. After 10 weeks of retraining, muscle strength and size had increased significantly ($p < 0.001$) above the first RT week 10 values, whereas no significant difference was observed in CMJ height.

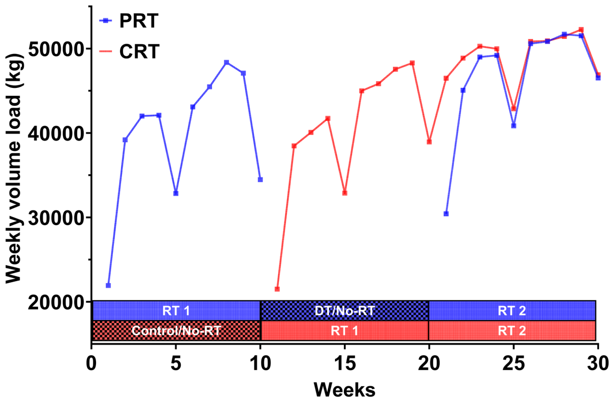

FIGURE 3 | Total weekly training volume load in kilograms for periodic resistance training (PRT) and continuous resistance training (CRT) groups. The volume load decreases every 5 weeks due to the strength tests replacing the second training session of the week. RT1, first 10-week resistance training period; RT2, second 10-week resistance training period; DT, detraining period.

Unlike in the first 10-week RT, during the second 10-week RT period, the changes were significantly greater ($p<0.001$) in PRT than in CRT in leg press 1RM (PRT 12.2% ± 5.4% vs. CRT 5.9% ± 3.5%) and VL (PRT 15.1% ± 4.8% vs. CRT 3.3% ± 4.0%) and BB CSA (PRT 15.1% ± 6.1% vs. CRT 6.8% ± 4.1%), but not in biceps curl 1RM (PRT 12.2% ± 6.2% vs. CRT 9.3% ± 4.6%, $p=0.11$). Further analysis showed that the greater gains were explained by the first 5 weeks of the second 10-week RT period in the PRT group (leg press 1RM, VL CSA, and BB CSA: $p \leq 0.004$) (Figure 5).

4 | Discussion

In this study, we showed that 10 weeks of detraining did not compromise RT adaptations in hypertrophy, maximal strength, or vertical jump performance when PRT was compared to an equal amount of CRT in young untrained males and females. This is explained by our observation that muscle strength and size lost during detraining were rapidly regained, especially during the first weeks of retraining. As a secondary finding, we observed that detraining had a more pronounced effect on muscle size than strength.

The observation that PRT and CRT similarly improved muscle strength and size aligns with previous findings on the topic [4, 17, 18]. However, in the previous studies, the length of the detraining periods was short (3–2 weeks), which makes the previous findings somewhat expected, as short-term detraining (<4 weeks) does not have as deleterious effects as long-term detraining (>4 weeks) on RT adaptations [5, 6]. In the study by Ogasawara et al. [17], in young untrained men, triceps brachii CSA decreased by 2.6% and 2.9%, and upper body dynamic strength decreased by 2.0% and 3.3% during the first and second 3-week detraining periods, respectively. In this study, muscle CSA decreased by about 7%–10% in VL and BB, and 1RM by about 3%–6% in leg press and biceps curl during 10 weeks of detraining. Despite longer detraining and, thus, greater detraining effects in the present study, no significant differences between PRT and CRT were observed by the end of the intervention. However, due to differences in research designs and methodologies, comparisons between studies should be made with caution. Nevertheless, our study complements the previous work by showing that a detraining period of up to 10 weeks appears not to compromise RT adaptations in muscle strength and size compared to volume-matched CRT in untrained females and males. This is an important finding as RT cessation can occur due to, for example, holidays, traveling, and lack of motivation. Most recently, limited access and fear of training at gyms during the SARS-Cov-2 outbreak has also likely imposed discontinuity on RT. Therefore, while continuity of training is an important fundamental principle in physical activity, our results suggest that recreational RT practitioners should not be too concerned about an occasional 10-week training break, for example, once a year, as long as the RT performed is effective and regular.

The fact that muscle strength and size showed a rapid regain back to levels of the previous RT period only after 5 weeks of retraining without differences between continuous and periodic groups may support the intriguing theory of muscle memory. Skeletal muscle memory has been defined as "The capacity of skeletal muscle to respond differently to environmental stimuli in adaptive (positive) or maladaptive (negative) manner if the stimuli have been encountered previously" [31]. Proposed underlying mechanisms for skeletal muscle memory have been an increased number of myonuclei and epigenetic modifications that are perceived after training breaks [32]. Also, perceived neural adaptations, motor learning ability of the central nervous system, and the resensitization of hypertrophic signaling in myofibers are plausible candidates contributing to this phenomenon [33, 34]. This phenomenon of rapid regain of previously attained RT adaptations has been observed in several studies [10–14, 16]. However, this is the first time that retraining following a prolonged detraining period with losses in muscle size and strength is directly compared to equivalent CRT. When previously untrained persons first engage in RT, rapid increases in muscle strength and hypertrophy occur during the first couple of weeks. Still, the rate of increases typically plateaus after approximately 10 weeks of RT [11, 17, 28, 29], which was also observed in the CRT group in the present study. After 10 weeks of RT followed by detraining, the PRT group experienced greater gains during the first 5 weeks of the second 10-week RT period than the CRT group during its second RT period immediately after 10 weeks of RT. This suggests that the early weeks of retraining are especially effective at reattaining the prior RT adaptations, after which the rate of improvements starts to slow down to levels similar to continuous training. However, the changes during the first 5 weeks of retraining were not greater compared to the initial 5 weeks of RT and, thus, it remains unclear if the greater rate of gains in PRT compared to the CRT group was due to muscle memory or just resensitization of muscle after the training break [34]. In addition, the perceived neural adaptations and motor learning ability of the central nervous system from the initial RT period may have also allowed for the use of higher loads in relation to muscle size at the beginning of retraining compared to initial training, which could also explain fast regain during the first 5 weeks. However, at this point, the mechanisms of the rapid regaining of RT adaptations in the present study remain speculative, and more cellular and molecular research, also perhaps with longer detraining periods, is needed to better

TABLE 3 | Participant characteristics and their absolute values for muscle strength and size outcomes, and CMJ height before, during, and after the 20 weeks of RT for PRT and CRT groups.

	PRT (n = 20/19[a])		CRT (n = 22/21[b])	
	Mean ± SD	**Difference (95% CI)**	**Mean ± SD**	**Difference (95% CI)**
Characteristics				
Age (years)	32.9 ± 5.8		31.5 ± 4.0	
Height (cm)	174.2 ± 9.5		172.6 ± 10.3	
Body mass (kg)	78.2 ± 14.9		73.2 ± 14.0	
Leg press 1RM (kg)				
Week 0	165.5 ± 46.9	Pretraining value		
Week 5	187.6 ± 47.3*	22.1 (17.2–27.0)		
Week 10	197.6 ± 47.5*	32.1 (24.7–39.6)	165.1 ± 38.5	Pretraining value
Week 15			182.4 ± 41.1*	17.3 (13.6–21.0)
Week 20	187.5 ± 48.0*	22.0 (15.4–28.6)	195.7 ± 42.3*	30.6 (26.1–35.1)
Week 25	201.5 ± 50.0*	36.0 (27.3–44.7)	202.4 ± 44.2*	37.3 (32.1–42.5)
Week 30	209.3 ± 50.7*	43.8 (33.8–53.7)	207.0 ± 44.5*	41.9 (36.4–47.4)
Biceps curl 1RM (kg)				
Week 0	28.0 ± 8.6	Pretraining value		
Week 5	32.3 ± 9.4*	4.3 (3.0–5.7)		
Week 10	34.2 ± 8.7*	6.2 (4.7–7.7)	28.9 ± 7.8	Pretraining value
Week 15			31.2 ± 8.2*	2.4 (1.4–3.3)
Week 20	32.8 ± 8.5*	5.0 (3.4–6.6)	33.5 ± 8.5*	4.6 (3.6–5.7)
Week 25	35.1 ± 8.4*	7.1 (5.3–8.9)	35.3 ± 8.9*	6.4 (5.2–7.6)
Week 30	36.7 ± 8.8*	8.8 (7.1–10.4)	36.2 ± 9.4*	7.7 (6.3–9.1)
VL CSA (cm^2)				
Week 0	26.2 ± 5.9	Pretraining value		
Week 5	28.9 ± 6.7*	2.8 (1.9–3.6)		
Week 10	30.3 ± 7.2*	4.2 (2.9–5.4)	27.2 ± 5.7	Pretraining value
Week 15			30.1 ± 6.2*	2.9 (2.2–3.6)
Week 20#	27.2 ± 6.0*	1.1 (0.1–2.0)	32.6 ± 6.7*	5.4 (4.5–6.3)
Week 25	30.2 ± 7.4*	4.0 (2.7–5.3)	32.9 ± 6.7*	5.7 (4.8–6.7)
Week 30	31.3 ± 7.3*	5.2 (3.8–6.5)	33.6 ± 6.8*	6.4 (5.4–7.4)
BB CSA (cm^2)				
Week 0	9.1 ± 3.1	Pretraining value		
Week 5	10.2 ± 3.3*	1.2 (1.0–1.4)		
Week 10	10.6 ± 3.5*	1.6 (1.2–1.9)	9.0 ± 3.0	Pretraining value
Week 15			10.1 ± 3.3*	1.1 (0.9–1.3)
Week 20	9.8 ± 3.3*	0.8 (0.6–1.0)	10.7 ± 3.6*	1.7 (1.4–2.0)
Week 25	10.7 ± 3.5*	1.7 (1.3–2.1)	11.1 ± 3.6*	2.0 (1.7–2.4)
Week 30	11.3 ± 3.6*	2.2 (1.8–2.7)	11.4 ± 3.7*	2.4 (2.0–2.8)

(Continues)

	PRT (n = 20/19[a])		CRT (n = 22/21[b])	
	Mean ± SD	Difference (95% CI)	Mean ± SD	Difference (95% CI)
CMJ height (cm)				
Baseline	25.7 ± 7.3	Pretraining value		
Week 5	29.1 ± 8.4*	3.3 (2.2–4.5)		
Week 10	30.4 ± 8.8*	4.7 (3.2–6.1)	27.6 ± 6.6	Pretraining value
Week 15			29.6 ± 7.0*	2.0 (1.0–3.0)
Week 20	28.4 ± 8.5*	2.6 (1.4–3.9)	30.2 ± 7.1*	2.6 (1.7–3.5)
Week 25	29.8 ± 8.3*	4.1 (2.8–5.3)	30.5 ± 7.2*	3.0 (1.9–4.1)
Week 30	30.5 ± 8.4*	4.8 (3.4–6.1)	31.2 ± 8.0*	3.7 (2.2–5.1)

Abbreviations: 1RM, one repetition maximum; BB, biceps brachii; CI, confidence interval; CMJ, countermovement jump; CRT, continuous resistance training group; CSA, cross-sectional area; PRT, periodic resistance training group; SD, standard deviation; VL, vastus lateralis.
[a]One participant from the PRT group was excluded from the VL CSA analysis due to poor image quality.
[b]One participant from the CRT group was excluded from the biceps curl 1RM analysis due to forearm pain.
*$p < 0.05$ versus pretraining value. Holm–Bonferroni correction was used for selected within-group comparisons (PRT: pretraining value vs. Weeks 5, 10, 20, 25, and 30, CRT: pretraining value vs. Weeks 15, 20, 25, and 30).
#$p < 0.05$ difference between groups. Holm–Bonferroni correction was used for selected between-group comparisons (Weeks 10, 20, 25, and 30).

understand the effects of skeletal muscle memory on RT adaptations, as most of the studied variables did not yet decrease back to baseline after 10 weeks of detraining.

The difference in detraining effect between muscle strength and size observed in the present study is also supported by previous research [7, 11, 35]. As stated previously, muscle strength and size decreases are related to the duration of the detraining period, and no changes or minimal decreases are generally reported after short-term detraining periods [6, 7, 36]. However, after prolonged detraining, muscle size typically declines faster than maximal strength. We observed that after detraining, 1RM in leg press and biceps curl remained approximately at the training Week 5 values, whereas CSA in VL and BB decreased below training Week 5 values. In previously untrained males, 7–12 weeks of detraining have been reported to diminish RT-induced increases in quadriceps femoris muscle CSA back to pretraining values [8, 14, 19], whereas knee extension dynamic muscle strength decreased only modestly and remained above pretraining values [11, 16]. In addition, dynamic muscle strength measured in machine-based exercises has been reported to remain elevated even after 5–12 months of detraining [9, 12, 15], whereas 1RM in squats using free weights returned to pretraining values after 8 weeks of detraining in previously untrained males [19]. Also, in studies where RT has been done with dynamic exercises and maximal strength has been measured as MVC, strength adaptations have been reported to decrease back to pretraining values after detraining [14, 37]. Therefore, it seems that the principle of specificity and the skill component of the exercises (e.g., machine-based exercises vs. free-weight exercises) might affect the detraining responses in maximal strength, suggesting that neural adaptations rather than muscle size plausibly explain the long-lasting gains in dynamic muscle strength [7]. However, as we did not measure any neural adaptations in the present study, the mechanism by which dynamic muscle strength was better maintained than muscle size after the detraining remains speculative.

4.1 | Strengths and Limitations

The study strengths included long intervention period with multiple measurement time points of both lower and upper body muscle CSA and strength and a relatively large number of participants including both females and males. Moreover, the training load was individually programmed and supervised for every RT session, which ensured proper training effort. Study limitations were lack of nutrition control, CMJ height was used to evaluate lower body power production, but a similar test for the upper body was not conducted, and no other test was used to measure functional capacity in daily activities. We evaluated physical activity and found no significant changes, but it is based on subjective questionnaires (Table S2) and not more accurate objective methods (e.g., accelerometers). Maximal dynamic strength was measured from the lower body using a machine in a multijoint movement and from the upper body using free weights in a single-joint movement, which makes it difficult to compare strength adaptations between the upper and lower body. Also, it should be noted that the 20 weeks of RT might have been too monotonous for the CRT group, as their progress started to slow down after the first 10 weeks of RT. This might have contributed to similar effectiveness of PRT and CRT, as it has been shown that already after 6 weeks of training, periodized RT is more effective in increasing muscle strength and size than nonperiodized RT, even in untrained males [38]. Moreover, the effects were only evaluated in leg press and biceps curl 1RM and VL and BB CSA, and may not, therefore, be directly applied to other exercises and muscles.

4.2 | Perspectives

The results of this study show that 10 weeks of detraining did not impair 20-week RT adaptation compared to CRT in young untrained females or males. Rapid increases in muscle strength and size were observed during the first 5 weeks of retraining, which explained the similar effectiveness of PRT and CRT.

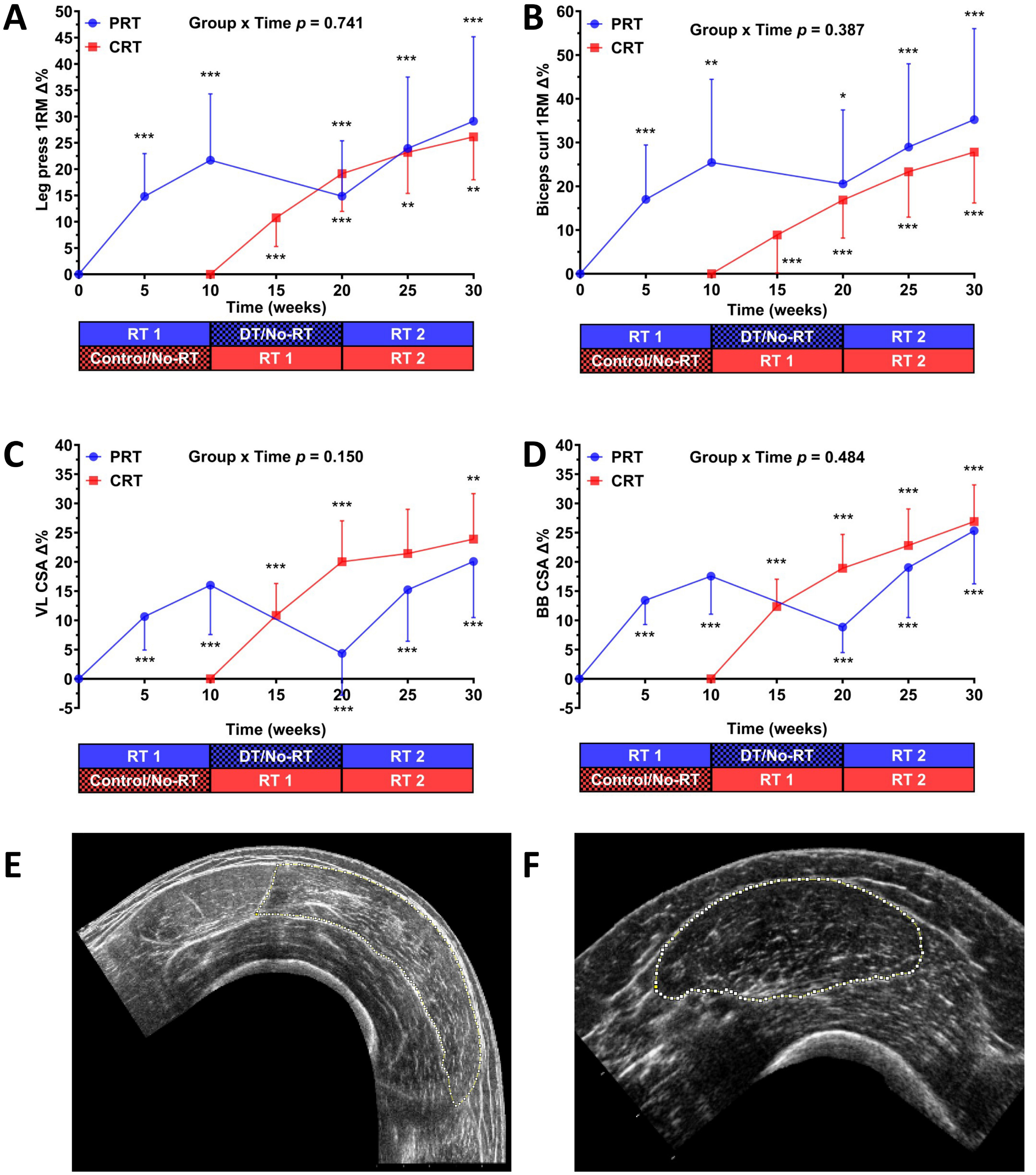

FIGURE 4 | Effect of periodic resistance training (PRT, weeks 0–30) or continuous resistance training (CRT, weeks 10–30) on muscle strength and cross-sectional area (CSA). (A, B) Muscle strength measured as one repetition maximum (1RM) (mean ± SD) in relation to pretraining values in leg press and biceps curl, respectively. (C, D) Muscle CSA (mean ± SD) in relation to pretraining values for vastus lateralis (VL) and biceps brachii (BB) muscles, respectively. (E, F) Representative ultrasound images illustrating VL and BB muscle CSA, respectively. Blue lines represent PRT group ($n = 20$), and red lines represent CRT group ($n = 22$). *$p < 0.05$, **$p < 0.01$, and ***$p < 0.001$ represent within-group differences in delta changes from previous time points for the indicated group, underneath, above, or next to the data points. Multiple testing was corrected using the Holm–Bonferroni method for selected comparisons (PRT: Weeks 0 vs. 5, 10 vs. 5, 20 vs. 10, 25 vs. 20, and 30 vs. 25; CRT: Weeks 15 vs. 10, 20 vs. 15, 25 vs. 20, and 30 vs. 25).

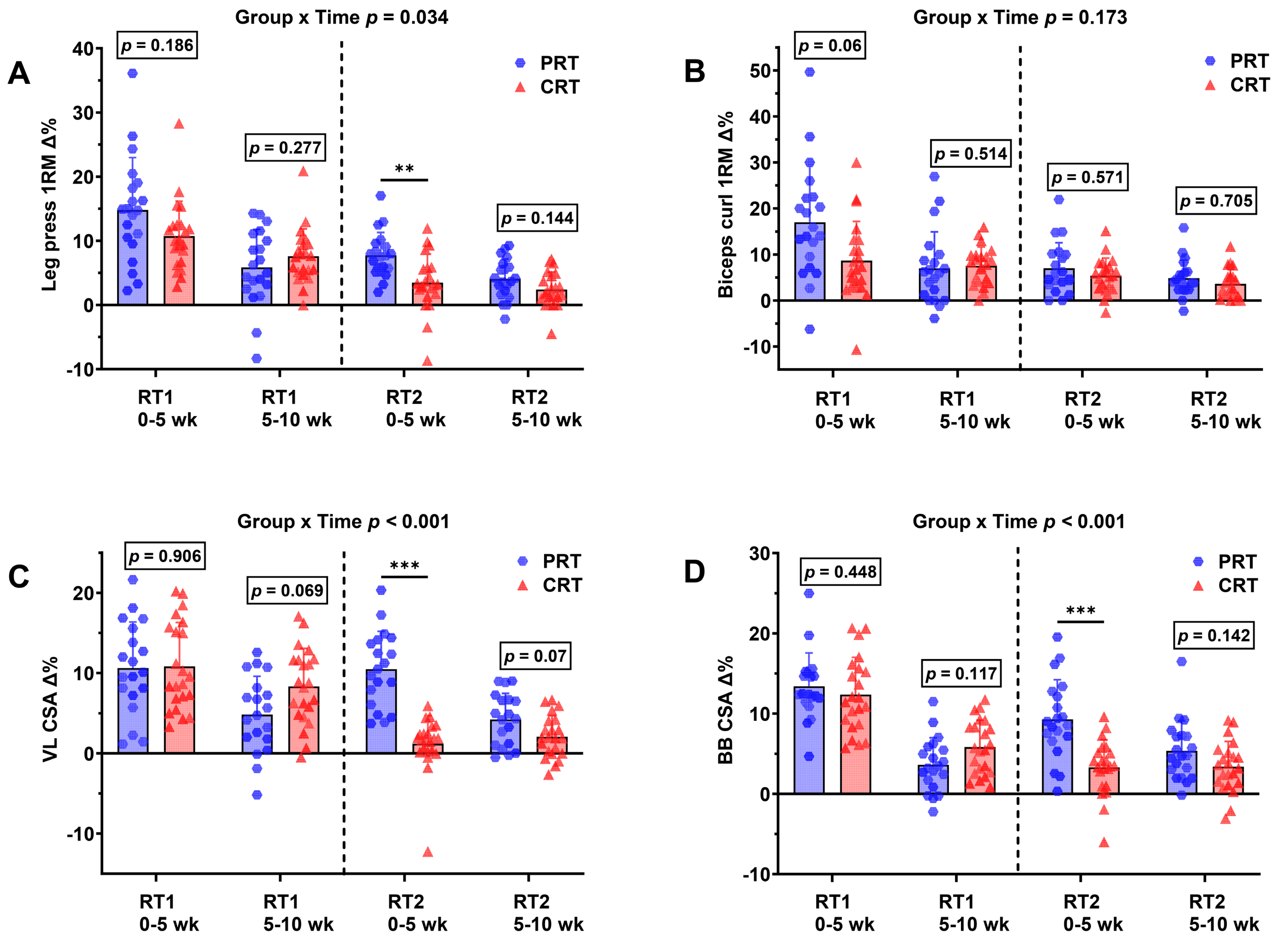

FIGURE 5 | Five-week percentage changes in relation to previous measurement time point in one repetition maximum (1RM) in (A) Leg press, and (B) biceps curl, and muscle cross-sectional area (CSA) in (C) vastus lateralis (VL), and (D) biceps brachii (BB) muscles during the first 10 weeks of resistance training (RT1) and the second 10 weeks of resistance training (RT2) in periodic resistance training (PRT) and continuous resistance training (CRT) groups. The results are shown as mean ± SD and individual values. $^{**}p < 0.01$ and $^{***}p < 0.001$ difference between groups during the indicated time interval. All time points were included in the Holm–Bonferroni method correcting for multiple comparisons.

Thus, our results suggest that occasional training breaks of up to 10 weeks may slow the emergence of muscle strength and size gains but do not impair the chronic adaptation of muscle strength and size induced by long-term RT. This is an important finding because it suggests that PRT can serve as an effective approach for improving muscle mass and strength, at least in the early phase of RT. However, more research in trained populations is needed to examine whether these results could also be applied to their training programming. Also, the results of this study cannot be directly applied to situations where training breaks are caused by illnesses or injuries.

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Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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Supporting Information

Additional supporting information can be found online in the Supporting Information section.