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Original Article

High-frequency resistance training is not more effective than low-frequency resistance training in increasing muscle mass and strength in well-trained men

Running Head: Resistance training frequency and muscle hypertrophy.

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ABSTRACT

We studied the effects of two different weekly frequency resistance training (RT) protocols over eight weeks on muscle strength and muscle hypertrophy in well-trained men. Twenty-three subjects (age: 26.2±4.2 years; RT experience: 6.9±3.1 years) were randomly allocated into the two groups: low frequency (LFRT, n = 12) or high frequency (HFRT, n = 11). The LFRT performed a split-body routine, training each specific muscle group once a week. The HFRT performed a total-body routine, training all muscle groups every session. Both groups performed the same number of sets (10-15 sets) and exercises (1-2 exercise) per week, 8-12 repetitions maximum (70-80% of 1RM), five times per week. Muscle strength (bench press and squat 1RM) and lean tissue mass (dual-energy x-ray absorptiometry) were assessed prior to and at the end of the study. Results showed that both groups improved ($p<0.001$) muscle strength [LFRT and HFRT: bench press = 5.6 kg (95% Confidence Interval (CI): 1.9 – 9.4) and 9.7 kg (95%CI: 4.6 – 14.9) and squat = 8.0 kg (95%CI: 2.7 – 13.2) and 12.0 kg (95%CI: 5.1 – 18.1), respectively] and lean tissue mass ($p = 0.007$) [LFRT and HFRT: total body lean mass = 0.5 kg (95%CI: 0.0 – 1.1) and 0.8 kg (95%CI: 0.0 – 1.6), respectively] with no difference between groups (bench press, $p = 0.168$; squat, $p = 0.312$ and total body lean mass, $p = 0.619$). Thus, HFRT and LFRT are similar overload strategies for promoting muscular adaptation in well-trained subjects when the sets and intensity are equated per week.

Key words: Training volume; Weight lifting; Strength training; Hypertrophy

INTRODUCTION

Attenuated rate of muscle growth following RT is observed in well-trained subjects when compared with their untrained state (38). About 2/3 of muscle growth occurs in the first weeks of training (5, 9, 38). It is assumed that the attenuated rate of muscle growth can be, at least in part, due to the adaptation of muscle to RT, and therefore is difficult to provide a more effective "stimulus" to increase muscle growth (1, 10-11). However, when an appropriate progressive overload stimulus is applied, well-trained subjects can obtain significant hypertrophic responses (1, 24, 31-32). Thus, manipulation of training frequency (number of times a muscle group is trained over a week) has been proposed as effective stimuli to increase muscle mass and strength in well-trained subjects (12, 34).

Muscle group split routines (individual muscle groups trained during a workout) enables individuals to train with a higher daily set number (~16 sets per muscle group and load ≥ 70 % of 1RM (17)), while also providing greater recovery (i.e. 3 – 7 days) of all involved muscle groups between sessions (1, 20). A high set number per muscle group may imply intramuscular metabolic stress (15-16, 30) and high muscle protein synthesis (6), and consequently hypertrophy after RT (1, 21, 31). Hence, a muscle group split routine has been a widely accepted approach among competitive bodybuilders (17). However, recently, more attention has been given to the effects of high-frequency resistance training (HFRT) as an overload stimulus (12, 34, 36). The hypothetical effect of HFRT on muscle hypertrophy has considered that more days of RT (i.e. more stimuli) per week would result in a higher net-positive protein balance in the week than low-frequency resistance training (LFRT) (12). For instance, some studies have suggested that a low daily set number (i.e. ≤ 3 sets) per muscle group is sufficient to achieve a maximum muscle anabolic response (3, 12, 22-23, 28). As a low daily set number allows less recovery of involved muscle groups between sessions, it is possible to train more days per week and promote greater overall muscle protein synthesis per week, and consequently hypertrophy (1, 12).

Although HFRT seems to result in more effective stimuli per week (i.e. more training days per week) (12), there is very little empirical evidence to support that HFRT provides additional stimuli to greater hypertrophic response compared to LFRT in well-trained subjects. To the best of the authors' knowledge, only two studies (34, 36) conducted in well-trained subjects and using accurate hypertrophic measures have compared muscular adaptations when the subjects performed HFRT versus LFRT (volume-equated weekly distributed). One study reported similar improvements in lean mass and strength between the conditions (36), whereas the other study reported a dose-response relationship between RT frequency and muscular adaptations (muscle mass and strength gains) in only one muscle group (elbow flexor thickness) from three muscles assessed (elbow extensors and flexors and vastus lateralis thickness) (34). The aforementioned studies have compared a low daily training volume (i.e. three sets per muscle group) in a three-day routine (i.e. HFRT) with a high daily training volume (9 sets per muscle group) in a one-day routine (i.e. LFRT). In these studies, although there were more stimuli per week with HFRT, muscle size and strength gains were similar between frequencies (one vs. three days per week) in well-trained subjects, except for elbow flexor thickness gains (34, 36). It would seem reasonable to assume that although more stimuli per week takes place in a three-day routine, three stimuli per week (three-day routine) were not sufficient for HFRT to be better than LFRT in (one-day routine) in well-trained subjects (12, 34, 36). Thus, acknowledging that HFRT may be an important stimulus for promoting muscular adaptation, more training days (stimuli) than three days per week seems to be necessary to observe a better performance of HFRT compared to LFRT considering muscle mass and strength in well-trained subjects (12). To confirm this assumption, we investigated the impact of two different frequencies, HFRT (muscle groups were trained 5 days per week) vs.

LFRT (muscle groups were trained one day per week), on muscle strength and size gains in well-trained men. The study aim was to investigate whether HFRT with low daily training volume is a more effective way than LFRT with high daily training volume to increase muscle mass and strength in well-trained subjects.

METHODS

EXPERIMENTAL APPROACH TO THE PROBLEM

The experimental and randomized (Figure 1) study was performed over eight weeks. Muscle strength, body composition, and delayed muscle soreness were assessed at the baseline and at the end of study. The sample consisted of 23 resistance-trained men (height = 1.75 ± 4.9 m; body mass = 78.5 ± 9.6 kg; age = 26.2 ± 4.2 years) divided into two groups: LFRT (n=12), and HFRT (n=11). The LFRT group performed 2 specific resistance exercises in each training session while the HFRT group performed all resistance exercises in each training session (Table 1). Both groups performed two different five–day-a-week (Monday to Friday) and volume-equated training routines (HFRT and LFRT). After the RT period (eight weeks), the assessments were performed 72 hours after the last session of training to avoid residual effects.

Table 1 and Figure 1 about here

SUBJECTS

The inclusion criteria consisted of well-trained men, aged between 18 to 32 years, having practiced RT for at least for three years without interruptions and a back squat/body mass ratio ≥ 1.5 and bench press/body mass ratio ≥ 1.0 (33). Moreover, the inclusion criteria comprised absence of (assessed by questionnaires): myopathies, arthropathies, neuropathies; muscle, thromboembolic and gastrointestinal disorders; cardiovascular and infection diseases; non-drinker (no alcohol intake whatsoever in their diet), non-smoker, non-supplements and non-pharmacological substances (e.g. anabolic steroids) or any illegal agents for muscle growth at least for one year.

All volunteers were informed about the objectives and procedures of the study and gave us their written informed consent. The study (nº 1697) was approved by the University Review Board for the Use of Human Subjects (local Ethics Committee) and was written in accordance with the standards set out by the Declaration of Helsinki.

NUTRITIONAL ASSESSMENTS

All the subjects completed three-day diet records (two days in the middle of the week and one at the weekend) (37), which (the three-day food record) was collected twice during the study, in the first and last training weeks. Energy and macronutrients (carbohydrates, proteins and fat) were quantified by a nutritionist who used the "DietSmart Professional" software, version 7.7. Macronutrients data were corrected for body mass to reduce the inter-individual differences.

To maximize muscle anabolic response, all volunteers consumed 30 g of a nutritional supplement (Whey Protein Super Bland concentrate, Spartacus Nutrition, São Paulo-Brazil) containing 24 g of whey protein and 6.4 g of carbohydrate immediately after all training sessions (2).

BODY COMPOSITION ASSESSMENTS

Total-body dual-energy x-ray absorptiometry (DXA) was performed using a densitometer plus scanner (GE/Lunar iDXA Corp., Madison, WI, EUA). To minimize interobserver variations, all scans and analyses were performed by the same evaluator at the same time of day, and the day-to-day percent coefficient of variation was 0.5% for the bone-free lean mass and fat mass. Patients were instructed to remove metal objects (e.g., snaps, belts, underwire bras, jewelry), as well as their shoes and wore only light clothes. Body composition was analyzed using the enCORE 14.0 software (GE/Lunar iDXA Corp., Madison, WI, USA) for the total body. The upper trunk was defined as the trunk region minus the android region. More details on the analysis of regional body composition were described in other study (35). The muscle mass index (MMI) was calculated dividing the appendicular muscle mass (fat-free mass of arms and legs) by the height in meters squared.

MAXIMUM STRENGTH ASSESSMENT

The lower and upper body strength was quantified by the 1RM test, which consisted of the maximum load that an individual could lift during the exercises. Before the 1RM test, all volunteers reported no exercise other than activities of daily living for at least 72 hours. The 1RM test complied with recognized guidelines as established by the American College of Sports Medicine (26). The subjects performed a specific warm-up prior to testing consisting of loads corresponding ~ 50% of the 1RM and 5–10 repetitions were performed. After the warm-up, the volunteers were allowed to rest for 1 minute. Afterwards, 3–5 repetitions were performed and the load was increased between 60 to 80% of 1RM. After doing this exercise, the volunteers rested for three minutes.

Then, the load was adjusted to find the equivalent load of one repetition maximum, which ranged between three and five attempts. The load that was adopted as the maximum load was the one used for the last part of the exercise that was performed with no more than one repetition by the volunteer. At the end of the study, only the 1RM of the back squat and the bench press exercises were reassessed and it was used to determine muscle strength gains. The 1RM back squat was conducted prior to 1RM bench press with a 20 min rest period separating tests (34). The same qualified fitness professional supervised all the 1RM tests.

DELAYED ONSET MUSCLE SORENESS

A visual numeric pain rating scale was used to detect delayed onset muscle soreness (DOMS) as recommended by The National Initiative on Pain Control (25). All volunteers self-reported the subjective delayed muscle soreness (scale 0-10) according to the body segments (chest, elbow flexors, elbow extensors, thigh and calf) the day after (24 hours) the first and the last RT session.

RESISTANCE TRAINING PROTOCOL

A five–day-a-week (Monday to Friday) regime of the RT protocol (Table 1) was performed over eight weeks. Both groups performed two different volume-equated training routines (HFRT and LFRT). Both groups performed 10 sets (except triceps extension and barbell curl, where 5 sets were performed) per exercise, 8-12 repetition maximums with 70-80 % of 1RM per set and 90 seconds rest recovery between sets and exercise in the training week. However, the LFRT group performed 2 specific resistance exercises in each training session while the HFRT group performed all resistance exercises in each training session

(Table 1). The LFRT group performed the RT (length time ~31 min) divided according to the body segments: Monday – shoulder adductors and elbow extensors, Tuesday – knee extensors and hip extensors and flexors, Wednesday – shoulder extensors and elbow flexors, Thursday – knee flexors and plantar flexors and Friday – shoulder abductors, lumbar spine flexors and extensors. The HFRT group performed the RT (length time ~32 min) for all body segments: Monday to Friday – shoulder adductors, elbow extensors, knee extensors, hip extensors and flexors, shoulder extensors, elbow flexors, knee flexors, plantar flexors, shoulder abductors, lumbar spine flexors and extensors. The exercises performed were leg press 45°, squat, bench press, seated row, hamstring curl, barbell curl, tricep extension, lateral raises, calf standing, abdominal crunch and lower back bench (Table 1). A warm up session (one set of 15 repetitions) with ~ 50% of 1RM was done in each exercise before each RT session. At the end of the RT sessions, stretching exercises were done so that participants could cool down. During RT, if the volunteer was able to perform more than 12 repetitions in the first set of each exercise, the load was adjusted between 5-10% to ensure the repetition zone between 8 to 12 repetitions and maintain the relative load of 70-80% of 1RM and a progressive overload.

STATISTICAL ANALYSES

Data distributions were assessed using the D'Agostino-Pearson test. The data are presented by mean and standard deviation or confidence interval of 95% (delta values). For the participant's age and experience, the data are presented by median and inter-quartile interval. The student's independent t-test (continuous data) or Mann – Whitney test (discrete data) was used to compare the baseline characteristics between the HFRT and LFRT groups. The Levene test was used to determine equality of variances at baseline.

The Mauchley test was used to evaluate the sphericity. Repeated measure ANOVA was used to determine the effects of the group (LFRT and HFRT), time (pre and post), and interaction of time by group. When an F-test was significant, effect size (partial eta-squared) and observed power was performed to verify the statistical power of the analysis. The student's independent t-test was used to compare the difference in training volume (at weeks 1, 4, 8 and sum of the 8 weeks, for exercise and all exercises). The statistical significance was considered at $P < 0.05$.

RESULTS

There was no difference between the groups concerning the participants´ characteristics at baseline (Table 2).

Table 2 about here

Adherences to the HFRT and the LFRT were 98% and 97%, respectively. There were no differences in dietary measure (carbohydrate, protein, fat, and energy) either within- or between-subjects over the course of the study (Table 3).

Table 3 about here

The changes in fat-free mass (total, trunk, gynoid, leg and MMI) and muscle strength (bench press and squat) and muscle soreness (DOMS) after 8 weeks of intervention (pre vs. post) were statistically compared and interpreted. The LFRT showed more DOMS than HFRT at the beginning, middle and end of the study (Table 4).

Table 4 about here

The HFRT showed a higher total volume than LFRT at the beginning, middle and end of the study (Table 5).

Table 5 about here

There were significant (P < 0.05) effects for time in fat-free mass (total, trunk, gynoid, leg and MMI) and muscle strength (bench press and squat), indicating that both the interventions increase fat-free mass and muscle strength. There was no significant interaction (time vs. groups) in fat-free mass and muscle strength, indicating that the responses were similar between the interventions (Table 6).

Table 6 about here

DISCUSSION

This study examined changes in muscle mass and maximal strength after an 8-week RT in different frequencies (LFRT and HFRT) in well-trained subjects. Our results showed that 8 weeks of HFRT (five days a week) increases muscle mass and strength similarly to LFRT (one day a week) in well-trained subjects. Thus, HFRT is not more effective than LFRT in increasing muscle mass and strength in well-trained subjects when the sets (10-15 sets per week) and intensity (8-12 RM) are equated per week.

The few existing studies concerning the RT frequency effect on muscle mass and strength in well-trained subjects have been limited to a three-day frequency as HFRT (34, 36). Evidence of different configurations of RT frequency is important to confirm previous findings or to bring new insight into RT frequency and muscle mass and strength gains interaction (12).

Hence, we investigated the impact of two different frequencies: HFRT with five days a week vs. LFRT with one day a week, on muscle strength and size gains in well-trained men. Even using higher frequency than those studies (five vs three times per week), we also did not observe significant differences between HFRT and LFRT for gains in total muscle mass, leg muscle, hip muscle, upper-trunk muscle, MMI and bench press and squat strength. Our results are congruent with those of Thomas and Burns (36), who also showed hypertrophy and strength gains following RT regardless of training frequency in well-trained subjects. In addition, our findings are also supported by other studies that examined changes in muscle mass and strength after different RT frequencies in untrained (8) and older (13) subjects. Moreover, in a pilot study, Ribeiro et al. (2015) showed that four weeks of RT over four-days (n=5) and six-day frequencies promote similar increases in muscle mass and strength in elite bodybuilders (29). In contrast, a study reported that HFRT was better when compared to LFRT (34). However, in this study the researchers measured three muscles and reported that HFRT was better in forearm flexor hypertrophy but was not in extensors and vastus lateralis (hypertrophic responses were similar between HFRT and LFRT) (34). Therefore, it seems that regardless of the days per week used, different frequencies (with sets and intensity equalized per week) respond in a positive and similar fashion regarding changes in muscle mass and strength in well-trained subjects.

It is well known that a high RT set number per week produces greater hypertrophy gains (21, 31), especially in well-trained subjects (1, 17). In a systematic review and meta-analysis, Schoenfeld et al. (2017) showed that greater muscle hypertrophy is achieved by performing at least 10 sets per week per muscle group (31). In the current study, both groups performed 10-15 sets (15 sets to biceps and triceps) per week per muscle group. Our finding showed that 10-15 sets distributed over one week (HFRT; five days a week, two-three sets per day) increase muscle mass and strength similarly to 10-15 sets performed in one day a week (LFRT one day a week, 10-15 sets per day) in well-trained subjects. These findings suggest that the total number of sets per week (i.e. ≥10 sets per muscle), but not the total volume distribution during the week, is important for muscle mass and strength gains in well-trained subjects.

We observed that the LFRT group showed more DOMS than HFRT at the beginning, middle and end of the study (Table 4). DOMS has been associated to exercise-induced muscular damage (19). Muscular damage has been attributed to mechanical stimulus (i.e. eccentric contraction), however metabolic stimuli (i.e. ischaemia or hypoxia) may exacerbate the damage from eccentric contractions (19). Although the LFRT and HFRT were performed with similar loads (at 70% of 1RM), the higher daily volume per muscle group (e.g. metabolic stimuli) observed in LFRT (~5 times higher than the HFRT) may have contributed to more DOMS (19). In a recent study, Bartolomei et al. (2017) showed that an acute bout of resistance exercise with a higher volume produces a greater increase in the metabolic markers (i.e. cytokine, hormonal and lactate response), muscle swelling (ultrasound measures) and DOMS and produces greater reduced muscle performance (counter movement jump and strength) in resistance-trained men (4). Furthermore, the protection against muscle damage and DOMS due to resistance exercise has been attributed to the repeated bout effect (19). Thus, as the HFRT group performed a higher frequency in a week of resistance exercise for all muscle groups xthan the LFRT group (5 vs 1 times/week), the repeated bout effect may have contributed to a protective effect against the DOMS in the HFRT group. Although LFRT caused more DOMS levels than HFRT, there was no difference between the groups for muscle mass and strength gains. Thus, HFRT may be an alternative strategy to LFRT, when sets and intensity are equated per week, in order to increase their muscle mass and strength without causing DOMS in well-trained subjects.

A dose-response relationship between RT set numbers per muscle group per week and hypertrophy has been reported (31). It has also been observed that a high daily set number per muscle group induces a lower repetition number (i.e. fatigue) in subsequent sets after the first sets, leading to lower total volume per muscle group per week (18). Therefore, it seems reasonable to assume that RT with a low daily set number per muscle group and high frequency (HFRT) would promote a higher total volume per muscle group per week and more muscle mass gains than RT with a high daily set number per muscle group and low frequency (LFRT). Indeed, in the present study the HFRT group performed a higher total volume (-13.9%; Table 5) than the LFRT group. This represented a small increase of ~1.4 set per week in the HFRT group when compared to the LFRT group. However, there was no significant difference between the groups in muscle mass and strength gains. These data suggest that the increased total volume (~1.4 set per week) observed in the HFRT was not sufficient to improve muscle mass and strength gains in well-trained subjects when compared to LFRT. Indeed, it has been shown that a small increase from 10 sets in RT does not cause a great change in hypertrophic gains (31). In a systematic review and meta-analysis, Schoenfeld et al. (2017) showed that each set per week only represents a very small change in muscle size of 0.37% (31). Thus, increasing the RT frequency (when the sets and intensity are equated per week) to avoid the fatigue due to high volume of LFRT do not improve muscle mass and strength gains in HFRT when compared to LFRT.

We set up the HFRT (five days a week) with two-three sets (performed to volitional failure) per day to equal the set numbers per week of the HFRT group with the set numbers per week of the LFRT group. It has been observed that when the RT volume is increased, acute post-exercise muscle protein synthesis is maximized in young men (6). An implication of this assumption for the current study is the possibility that the lack of superiority of HFRT over LFRT in muscle mass gain was due to low daily training volume (two-three sets in 5-

day-a-week routine) and, consequently, low muscle anabolic response. Although previous findings demonstrated that when given an adequate stimulus (e.g. volitional failure) during a training session, a low daily set number (i.e. ≤ 3 sets) per muscle group seems to be enough to achieve a maximum muscle anabolic response (3, 7, 12, 14, 22-23, 27-28), these studies were not performed with well-trained subjects. Thus, future research is needed to address this issue.

In conclusion, our results showed that 10-15 sets (8-12 RM) distributed over a week (HFRT; five days a week, two set per day) increased muscle mass and strength similarly to 10-15 (8-12 RM) sets performed in one day a week (LFRT one day a week, 10-15 sets per day) in well-trained subjects. Therefore, our findings suggest a set number (≥10 sets) per week performed to volitional failure (8-12 RM), instead of training frequency, is an important "stimulus" to promote muscle mass and strength gains in well-trained subjects when the sets and intensity are equated per week. Thus, HFRT and LFRT are similar overload strategies for promoting muscular adaptation in well-trained subjects when the sets and intensity are equated per week.

PRACTICAL APPLICATIONS

Our results suggest that HFRT and LFRT are similar overload strategies for promoting muscular adaptation in well-trained subjects. This allows a greater possibility of manipulation of training frequency without reducing the performance in muscle strength and mass gains. In addition, the LFRT group showed more DOMS than the HFRT group during the study. Thus, HFRT may be an alternative strategy to LFRT in order to increase their muscle mass and strength without DOMS in well-trained subjects.

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Figure Captions

Figure 1 Participant flow diagram

TABLE 1. Training protocol

GROUPS	MONDAY	Sets	TUESDAY	Sets	WEDNESDAY	Sets	THURSDAY	Sets	FRIDAY	Sets
	Bench press	10	Squat	5	Seated row	10	Hamstring curl	10	Lateral Raises	5
LFRT	Triceps extension	5	Leg press 45º	5	Barbell curl	5	Calf standing	10	Abdominal crunch solo	10
									Lower back bench	10
	Leg press 45º	1	Bench press	2	Hamstring curl	2	Lateral raises	1	Calf standing	2
	Squat	1	Seated row	2	Bench press	2	Triceps extension	1	Abdominal crunch	2
	Bench press	2	Leg press 45º	1	Seated row	2	Barbell curl	1	Lower back bench	2
	Seated row	2	Squat	1	Leg press 45º	1	Squat	1	Seated row	2
HFRT	Hamstring curl	2	Hamstring curl	2	Squat	1	Leg press 45º	1	Hamstring curl	2
	Barbell curl	1	Barbell curl	1	Barbell curl	1	Seated row	2	Barbell curl	1
	Triceps extension	1	Triceps extension	1	Triceps extension	1	Bench press	2	Triceps extension	1
	Lateral Raises	1	Lateral Raises	1	Lateral Raises	1	Hamstring curl	2	Lateral Raises	1
	Calf standing	2	Calf standing	2	Calf standing	2	Calf standing	2	Leg press 45º	1
	Abdominal crunch	2	Abdominal crunch	2	Abdominal crunch	2	Abdominal crunch	2	Squat	1
	Lower back bench	2	Lower back bench	2	Lower back bench	2	Lower back bench	2	Bench press	2

LFRT - low frequency resistance training, **HFRT** - high frequency resistance training

TABLE 2. Participant characteristics at baseline

VARIABLE	LFRT n=12	HFTR n=11	*P*
Age (years)	25.5 (24.0 – 26.5)	27.1 (25.0 – 28.7)	0.267 †
Body Mass (kg)	78.2 ± 9.8	78.8 ± 9.9	0.899 #
Height (cm)	174.0 ± 5.2	176.8 ± 4.1	0.173 #
Experience (years)	6.0 (4.5 – 7.0)	7.0 (6.0 – 8.0)	0.131 #
Training session time (min)	31.0 ± 0.5	32.0 ± 0.6	0.0002*
1RM squat (kg)	132.9 ± 28.1	123.3 ± 17.5	0.344 #
1RM squat/body weight (kg)	1.7 ± 0.3	1.6 ± 0.2	0.285 #
1RM bench press (kg)	103.5 ± 15.4	100.6 ± 14.5	0.652 #
1RM bench/body weight (kg)	1.3 ± 0.1	1.3 ± 0.2	0.567 #
Muscle mass index (kg/m^2)	9.9 ± 1.2	9.7 ± 0.9	0.624 #
Total fat free mass (kg)	61.1 ± 8.4	62.1 ± 4.4	0.722 #
Fat mass (%)	19.2 ± 6.1	16.5 ± 5.8	0.294 #
Total fat mass (kg)	14.4 ± 4.7	13.4 ± 6.2	0.722 #

LFRT - low frequency resistance training, **HFTR** - high frequency resistance training**,**
1RM – one repetition maximum **MMI** - muscle mass index,
#Test-t (accept Normality - Mean ± SD)
† Mann – Whitney Test reject normality – Mean (P_{25} – P_{75})
***** Significant differences between groups $P<0.05$

TABLE 3. Dietary intake following 8-week resistance training period

	LFRT baseline	LFRT post	HFRT baseline	HFRT post	P groups	P moment	P interaction
Protein (g)	150.6 ± 20.0	152.1 ± 17.4	150.1 ± 18.7	151.4 ± 15.8	0.979	0.640	0.838
Carbohydrate (g)	263.9 ± 23.7	270.5 ± 27.7	264.6 ± 20.3	270.2 ± 29.2	0.983	0.342	0.918
Fat (g)	86.2 ± 12.9	88.1 ± 12.8	87.8 ± 15.4	87.7 ± 12.3	0.906	0.698	0.683
Energy (kcal)	2434.6 ± 244.9	2483.4 ± 258.8	2452.5 ± 255.7	2476.4 ± 256.1	0.957	0.265	0.703

LFRT – low frequency resistance training, **HFTR** – high frequency resistance training.
Data presented in mean and standard deviation (±SD).

TABLE 4. Daley onset muscle soreness

MUSCLE GROUP	WEEK 1		WEEK 4		WEEK 8	
	LFRT	HFRT	LFRT	HFRT	LFRT	HFRT
CHEST	7.0 (4.0 – 7.5)	0.8 (0.0 – 3.0)*	5.5 (4.0 – 7.5)	0.0 (0.0 – 0.5)*	5.0 (4.5 – 7.0)	0.0 (0.0 – 0.5)*
ELBOW FLEXORS	4.5 (3.0 – 6.0)	0.2 (0.0 – 3.0)*	4.5 (3.0 – 5.0)	0.0 (0.0 – 1.5)*	3.5 (3.0 – 5.0)	0.0 (0.0 – 0.8)*
ELBOW EXTENSORS	5.0 (1.5 – 7.5)	0.0 (0.0 – 2.0)*	3.5 (2.5 – 6.5)	0.0 (0.0 – 0.0)*	4.0 (3.5 – 5.0)	0.0 (0.0 – 0.0)*
THIGH	8.0 (9.0 – 0.0)	2.0 (0.6 – 3.5)*	7.5 (5.5 – 8.0)	0.0 (0.0 – 0.6)*	7.0 (4.5 – 8.0)	0.5 (0.0 – 4.5)*
CALF	8.0 (7.0 – 9.5)	1.0 (0.0 – 3.0)*	4.5 (2.0 – 6.5)	0.0 (0.0 – 0.0)*	5.5 (1.5 – 7.0)	0.0 (0.0 – 1.0)*

LFRT – low frequency resistance training, **HFRT** – high frequency resistance training,
Data are show in Mean (P_{25} – P_{75})
*Significant difference between groups (P<0.001).

TABLE 5. Weekly volume by muscle group (kg)

Exercices	Groups	Week 1	Week 4	Week 8	Sum week 1 to 8
Barbell curl	LFRT	1428.7 ± 223.7	1546.3 ± 189.8	1568.7 ± 293.6	12135.6 ± 1733.1
	HFRT	1856.1 ± 3141*	2029.1 ± 234.9*	2068.4 ± 273.3*	16007.8 ± 1942.2*
	Δ%	23.0	23.8	24.1	24.1
Triceps extension	LFRT	1512.6 ± 202.3	1535.6 ± 251.7	1650.0 ± 331.0	12380.4 ± 1666.7
	HFRT	1740.6 ± 377.0	1970.0 ± 348.6*	1909.1 ± 505.7*	15139.6 ± 2425.7*
	Δ%	13.1	22.0	13.5	18.2
Lateral Raises	LFRT	1230.5 ± 312.8	1324.1 ± 329.0	1381.3 ± 319.4	10298.5 ± 2832.14
	HFRT	1350.5 ± 248.0	1522.9 ± 295.1	1546.9 ± 292.2	18880.0 ± 24789.7
	Δ%	8.8	13.0	10.7	12.7
Bench press	LFRT	6472.01 ± 1066.1	6628.6 ± 938.7	6733.1 ± 1064.0	52705.9 ± 7654.8
	HFRT	8014.72 ± 1321.7*	8972.6 ± 1428.6*	8639.6 ± 1089.1*	66460.2 ± 9491.7*
	Δ%	19.2	26.1	22.0	20.7
Seated row	LFRT	5948.7 ± 1006.8	6306.2 ± 838.2	6392.1 ± 1088.7	50010.4 ± 7848.8
	HFRT	6773.6 ± 909.2	7549.2 ± 814.4*	7556.3 ± 817.8*	58803.0 ± 11329.1*
	Δ%	12.1	16.4	15.4	14.9
Squat	LFRT	3739.3 ± 781.5	4091.0 ± 871.9	4344.0 ± 879.0	33263.5 ± 7587.5
	HFRT	4532.7 ± 454.4*	5319.8 ± 531.1*	5193.45 ± 1395.24	38558.09 ± 5617.9
	Δ%	17.5	23.1	16.3	13.7
Leg press 45º	LFRT	10290.0 ± 1251.8	10954.5 ± 1069.3	11257.5 ± 1683.4	84985.0 ± 11589.0
	HFRT	10853.3 ± 1681.0	12061.6 ± 1929.9	12910.0 ± 2180.2	93307.1 ± 16591.4
	Δ%	5.1	9.1	12.8	8.9
Hamstring curl	LFRT	3308.2 ± 531.9	3722.8 ± 518.2	3753.7 ± 633.4	28701.9 ± 3920.5
	HFRT	4247.2 ± 732.2*	4695.18 ± 593.4*	5082.6 ± 568.8*	37251.4 ± 4071.9*
	Δ%	22.1	20.7	26.1	22.9

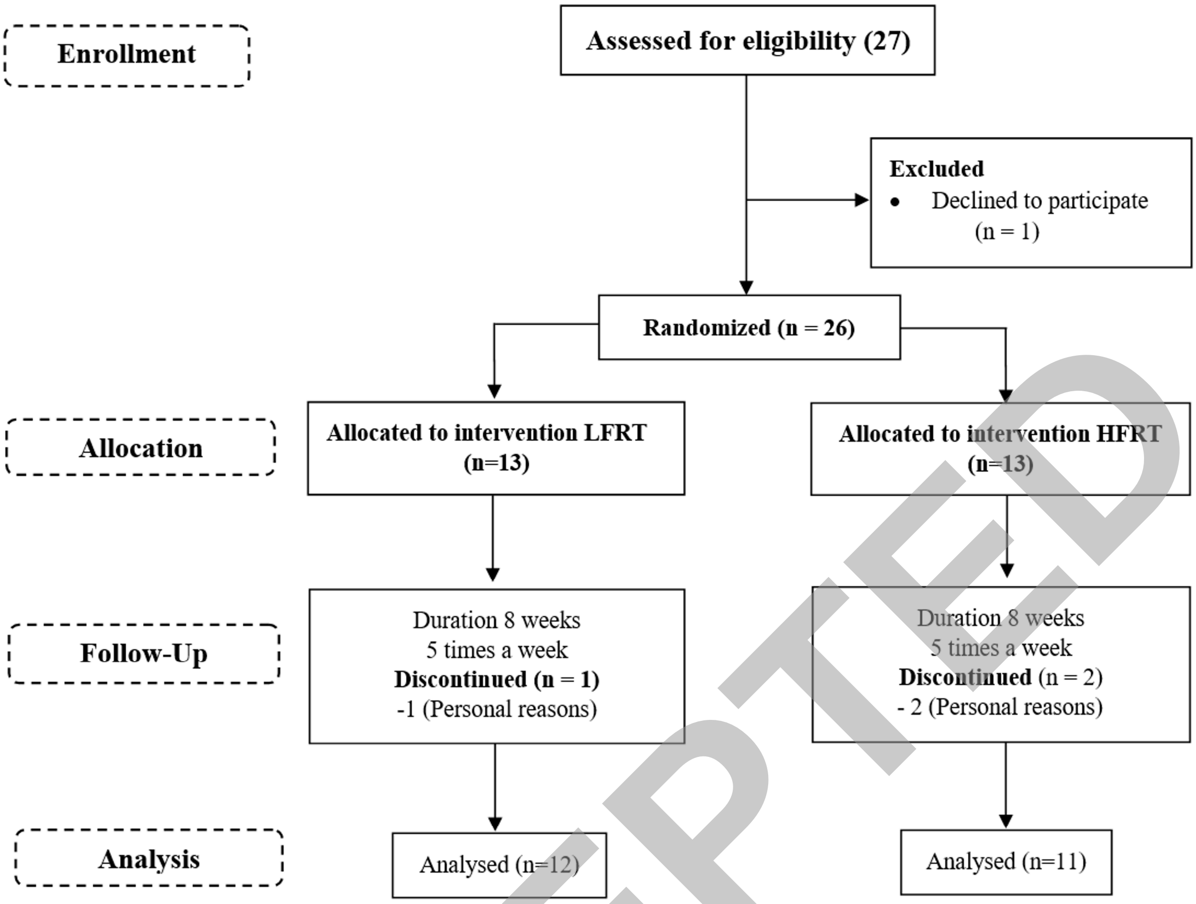
Calf standing	LFRT	6497.5 ± 2045.7	8450.8 ± 2816.6	9312.5 ± 1954.0	68762.1 ± 13908.4
	HFRT	7649.2 ± 1378.2	9393.2 ± 1613.4	9797.4 ± 1403.3	70122.7 ± 11657.5
	Δ%	15.0	10.0	4.9	11.7
Total Volume	LFRT	41168.5 ± 4067.8	45664.9 ± 6594.9	46910.1 ± 7164.9	353243.5 ± 42255.3
	HFRT	46644.5 ± 4920.0*****	52985.1 ± 3661.6*****	53194.0 ± 4659.6*****	410652.9 ±51940.5*****
	Δ%	11.7	13.8	11.8	13.9

HFRT – high frequency resistance training, **LFRT –** low frequency resistance training,
Δ **%** - post value minus baseline value/ baseline value.
Data presented in mean and standard deviation (±SD)
*Significant difference between groups (P<0.05).

TABLE 6. Body composition and muscle strength following 8-week resistance training period

VARIABLE	LFRT baseline	LFRT post	ΔLFTR	HFRT baseline	HFRT post	ΔHFRT	Δ_{HFRT}-Δ_{LFRT}	P_{groups}	P_{moment}	ETA	Power	$P_{interaction}$
FFM-total (kg)	61.1 ± 8.4	61.7 ± 8.2	0.5 (0.0 – 1.1)	62.2 ± 4.4	62.9 ± 4.25	0.8 (0.0 – 1.6)	0.2 (-1.8 – 9.9)	0.689	0.007	0.30	0.82	0.619
FFM-trunk (kg)	27.7 ± 4.2	27.8 ± 4.0	0.1 (-0.2 – 0.5)	28.3 ± 1.4	28.9 ± 1.36	0.5 (-0.1 – 1.0)	0.3 (-0.3 – 0.9)	0.521	0.067	0.16	0.48	0.301
FFM-android (kg)	3.9 ± 0.5	3.9 ± 0.6	-0.0 (-0.1 – 0.1)	4.0 ± 0.3	4.0 ± 0.25	0.0 (-0.1 – 0.1)	0.1 (-0.1 – 0.1)	0.761	0.961	0.00	0.05	0.639
FFM-upper trunk (kg)	23.7 ± 3.6	23.8 ± 3.5	0.1 (-0.2 – 0.5)	24.3 ±1.3	24.8 ± 1.3	0.4 (0.0 – 0.8)	0.2 (-0.3 – 0.8)	0.493	0.045	0.19	0.55	0.292
FFM-gynoid (kg)	9.5 ± 1.3	9.7 ± 1.5	0.2 (0.1 – 0.4)	9.6 ± 0.7	9.9 ± 0.7	0.3 (0.2 – 0.4)	0.1 (-0.1 – 0.2)	0.790	<0.001	0.63	1.00	0.586
FFM-leg (kg)	20.6 ± 2.7	21.1 ± 2.9	0.4 (0.2 – 0.7)	20.7 ± 2.5	21.1 ± 2.3	0.4 (0.0 – 0.7)	-0.1 (-0.5 – 0.3)	0.944	<0.001	0.47	0.98	0.671
FFM-arm (kg)	9.4 ± 1.6	9.3 ± 1.6	0.0 (-0.2 – 0.2)	9.5 ± 1.0	9.5 ± 1.1	0.0 (-0.2 – 0.2)	0.0 (-0.3 – 0.3)	0.787	0.710	0.00	0.05	0.890
MMI (kg/m^2)	9.9 ±1.2	10.0 ± 1.2	0.1 (0.1 – 0.2)	97.7 ± 0.9	9.8 ± 0.8	0.1 (0.0 – 0.2)	-0.1 (-0.2 – 0.1)	0.607	0.010	0.28	0.77	0.842
1RM squat (kg)	132.9 ± 28.0	140.9 ± 25.5	8.0 (2.7 – 13.2)	123.3 ± 17.5	135.3 ± 22.2	12.0 (5.1 – 18.1)	4.0 (-4.0 – 12.0)	0.448	<0.001	0.58	1.00	0.312
1RM bench press (kg)	103.5 ± 15.4	109.1 ± 18.5	5.6 (1.9 – 9.4)	100.6 ± 14.5	110.3 ± 12.1	9.7 (4.6 – 14.9)	4.1 (-1.8 – 9.9)	0.896	<0.001	0.56	1.00	0.168

HFRT – high frequency resistance training, **LFRT** – low frequency resistance training, **FFM** – fat free mass, **FFM-upper trunk** – trunk minus android,
MMI – muscle mass index, **1RM** – one maximum repetition, Δ **(delta)** – post value minus baseline value, Δ_{HFRT}-Δ_{LFRT} – Difference between delta HFRT and delta LFRT.
Data presented in mean and standard deviation (±SD) and 95% Confidence interval for mean.
*Significant difference between groups (P<0.05).


Enrollment
Assessed for eligibility (27)
Excluded
Declined to participate (n = 1)
Randomized (n = 26)
Allocation
Allocated to intervention LFRT (n=13)
Allocated to intervention HFRT (n=13)
Follow-Up
Duration 8 weeks
5 times a week
Discontinued (n = 1)
-1 (Personal reasons)
Duration 8 weeks
5 times a week
Discontinued (n = 2)
- 2 (Personal reasons)
Analysis
Analysed (n=12)
Analysed (n=11)