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Original Research

Effects of High-Intensity Resistance Training Volume on Muscle Performance and Blood-derived Markers in Recreationally Trained Subjects

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Abstract

International Journal of Exercise Science 19(6): 6006, 2026. The present study aimed to compare the effects of high-intensity resistance training (HIRT) with different training volumes on physical performance and blood-derived markers adaptations in recreationally trained subjects. Thirty subjects of both genders (21.7 ± 1.8 years old; body mass 62.4 ± 6.5 kg; height 1.7 ± 0.03 m) were randomly allocated to perform lower (G4; women = 7; men = 8) or higher (G6; women = 8; men = 7) training volume, which consisted of 4 and 6 weekly sets per muscle group, respectively. The HIRT method consisted of 2 sets of the following: 6 repetitions maximum (RM) at 85% of the 1RM followed by 20-seconds of rest, 3RM, another 20-seconds of rest, followed by 3RM, and finally, 2:30 minutes of rest. After 2:30 minutes of rest, the participants repeated the entire sequence a second time (i.e., the second series was performed). Muscle performance and blood-derived markers were assessed before and after 4 weeks of training. No significant differences in physical performance were observed between groups. However, there were significant changes in creatine kinase (p = 0.03), creatinine (p = 0.01), and lactate dehydrogenase (p = 0.01), with higher values for G6 in comparison to G4. HIRT improved muscle performance regardless of training volume. Nevertheless, the greater volume resulted in more pronounced increases in blood-derived markers of muscle damage when compared to the lower volume group. Therefore, considering the similar benefits on muscle performance, it would be recommended to perform lower volumes to prevent unnecessary physiological stress.

Keywords: Strength training, muscle fatigue, power output, countermovement jump

Introduction

High-intensity resistance training (HIRT) is defined as an advanced resistance training (RT) technique where short intra-sets rest intervals (20-seconds) are applied while lifting the same load until momentary muscle failure (MMF).[1] HIRT is considered an effective strategy to increase muscle strength, lean body mass, basal metabolic rate, reduce fasting blood glucose, and body fat.[2,3] Moreover, HIRT might promote greater adaptations in muscle performance when compared to conventional RT.[4] Optimum RT adaptations might result from the proper manipulation of

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different training variables, such as frequency, exercise selection, volume, intensity, and effort,[5,6] There is evidence that greater strength gains could be achieved by increased training volume in a dose-response relationship,[7-9] while other studies showed no additional benefits for higher training volumes.[10,11] One important aspect of calculating training volume is the stress promoted by the exercise session. Considering that physiological adaptations rely on the adequate balance between stress and recovery, one should be especially judicious with training volume when using advanced methods and training to failure.[12]

HIRT is usually characterized by the combination of higher loads with high levels of effort. While this combination may lead to increased biochemical markers of muscle damage,[13] it's noteworthy that no differences were found in creatine kinase, creatinine, and aspartate aminotransferase values after 6 weeks of HIRT[2]. However, further evidence is needed regarding the effects of different volumes of HIRT. Moreover, the latter aspect may result in prolonged changes in physiological parameters and neuromuscular function.[14] Given that HIRT can induce a more stressful condition compared to conventional RT,[15] understanding the impact of different HIRT volumes on physiologic parameters might be useful to RT prescription, since excessive exercise dose might lead to an overtraining state.

"Advanced techniques" are commonly prescribed and performed by experienced practitioners. However, HIRT is utilized across diverse populations, including older adults and recreationally trained subjects.[2,3] Therefore, this study aimed to compare the effects of HIRT with different training volumes on physical performance and blood-derived marker adaptations. The initial hypothesis is that a lower volume would induce similar physical and physiological adaptations when compared with a higher volume.

Methods

Participants

Volunteers were recruited through social media and personal invitations among college students and attendees of the University's RT facility. Initially, thirty-six individuals of both genders volunteered to participate. To be included, volunteers had to be between 18 and 30 years old, have previous RT experience, have been currently engaged in RT programs, and be free of clinical disorders that could be aggravated by the training procedures. To be included in the analyses, participants should not perform other RT or high-intensity exercises during the study period and participate in all the training and test days. Participants were oriented to not use any medications or substances that could influence physical performance and blood-derived markers (i.e., caffeine, anti-inflammatory, creatine, and alcoholic drinks).

G*Power software was used to calculate the sample size, considering two groups, two repeated measures, a correlation among repeated measures of 0.50, a statistical power of 0.80, and an effect size of 0.30. The calculation returned a total sample of 24 subjects, based on a previous study that investigated muscle strength through the test of 1-repetition maximum (1RM) in 20 participants[2]. Due to the risk of dropouts (50%), thirty-six volunteers were initially enrolled in the study. Six participants were excluded during the experimental procedures: two for not participating in the post-tests, three for not achieving the minimum attendance, and one for conflicting schedules. Thirty young adults (14 men and 16 women) were included in the final analyses. The enrolment procedures are described in Figure 1, following CONSORT recommendations (http://www.consort-statement.org).

Protocol

This study is randomized involving recreationally trained young adults of both sexes, that performed different HIRT volumes for 4 weeks. The study was approved by the local ethics committee (3.049.886) and was conducted in full compliance with the ethical standards outlined by the *International Journal of Exercise Science*. For further details regarding ethical considerations, refer to the following reference.[16] After being informed about the study procedures, all participants gave their written consent following the Declaration of Helsinki. Participants were randomized by the website (http://www.randomization.com) to perform lower (G4) or higher (G6) RT volumes, distributed on 4 and 6 weekly sets per muscle group, respectively. Each training session involved 2 sets per muscle group, therefore, G4 performed two sessions per week, while G6 performed three. This distribution was chosen because the high-intensity nature of the protocol applied in a single training session could impair performance, following previous investigations.[10,17]

Participants were familiarized with training methods and tests for two weeks before intervention. Muscle performance, including muscle strength and power, and blood-derived markers, was assessed before and after the training period. Post-tests were conducted 72 hours after the last day of training. Initially, muscle power and 1RM tests were performed, according to previous recommendations.[18] After 72 hours, blood collecting was conducted to avoid interference in the sanguine answers due to the physical test battery. Both the test battery and blood collection were performed in the same order, at the same time of day (10:00–12:00 pm), and by the same evaluator, who was blinded to group allocation. Participants were advised to maintain their dietary habits during the experimental procedures, and none of the participants reported relevant adverse events.

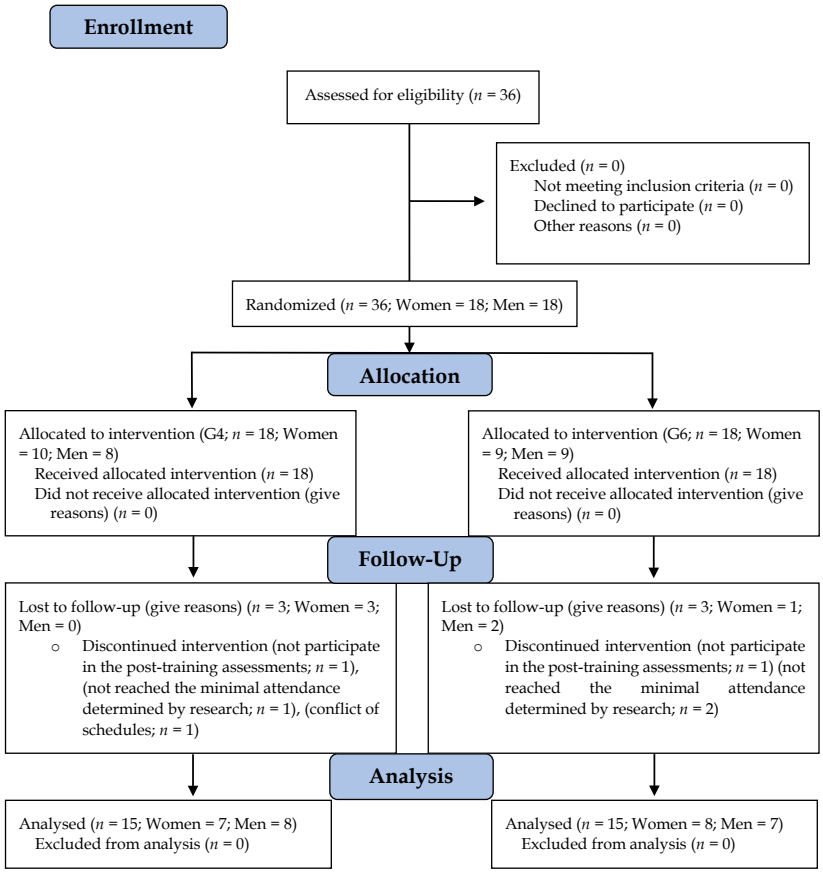

Figure 1. Consort for screening, recruitment, randomization, and intervention.

Participants performed the HIRT protocol two or three days per week, separated by a minimum of 48 hours, for 4 weeks. Before the protocols, participants completed a specific warm-up consisting of 2 sets of 12 repetitions with a load equivalent to 40% 1RM, with a 60-seconds interval between sets. Subsequently, participants realized the HIRT protocol that consisted of 2 sets of the following: 6RM at 85% 1RM, followed by 20-seconds of rest, 3RM, another 20-seconds of rest, followed by 3RM, and finally, 2:30 minutes of rest. After 2:30 minutes of rest, participants repeated the entire sequence a second time (i.e., the second series was performed). The protocol is described in Table 1.[1] All participants were instructed to perform repetitions until MMF, which eventually caused little variations in the number of repetitions performed.[1] Load progression was established by the repetitions zone, with 2–10% increments when participants were able to perform more than 6RM in the first set of each exercise.[19] The selected exercises were exclusively multiarticular (leg press 45º, bench press, and seated row) in a design similar to previous studies.[1] Volunteers were instructed to maintain a self-selected cadence for both the concentric and eccentric muscle actions, without pausing between them.[20] The total training volume (TTV) was determined from the following formula: TTV= sets x repetitions x load.[21]

Table 1. Protocol prescription.

Exercise	Sets x Reps	Rest	Intensity	Cadence
Leg press 45º	2 x 6/3/3	20″/20″/2′:30″	85% 1RM	Self-selected
Bench press	2 x 6/3/3	20″/20″/2′:30″	85% 1RM	Self-selected
Seated row	2 x 6/3/3	20″/20″/2′:30″	85% 1RM	Self-selected

The HIRT protocol consisted of 6RM, followed by 20-seconds of rest, 3RM with another 20-seconds of rest, and finally, 3RM with a 2:30 minutes rest, completing one set. After 2:30 minutes, the participants repeated the same sequence a second time. RM = repetition maximum; Reps = repetitions.

Maximum jump height was tested in the countermovement jump, squat jump, and drop jump, using a contact mat (Jump System Pro®, Cefise, Brazil), following previous recommendations.[22–24] Three attempts were made for each jump separated by 30-seconds intervals. The best performance was used in the analysis. The vertical jumps tests showed high reproducibility (intraclass correlation coefficient; [ICC = 0.95]). Three standing long jumps were performed, and the distance was evaluated using a non-elastic tape. Only the best performance was considered. For all analyses, high values of reproducibility were found (ICC = 0.97). The same tape measure was used to assess medicine ball throw performance. The participants were seated with their back's perpendicular to the wall, their hips forming a ~90º, their knees fully extended and together, and their elbows flexed. Subsequently, a 3 kg medicine ball was positioned on the upper chest region of the participants, who flexed their elbows and threw the ball as far as possible. Three attempts were permitted, and the best measure was included in the analysis.[23] High values of reproducibility were found (ICC = 0.94).

Muscle strength was tested through 1RM tests on a leg press 45º and bench press (Life Fitness, Hammer Strength, Brazil). The warm-up consisted of 12 repetitions with a comfortable self-selected load, followed by 2 minutes of rest.[25] No more than five attempts were necessary for all participants, with 3 to 5 minutes interval between each attempt. After 48–72 hours, a retest was performed for reliability (ICC = 0.97). All tests were supervised by an experienced professional.

After 72 hours of physical test battery, blood collection was performed. Blood was obtained by puncture of the brachial vein, and the participants were fasting. For blood collection, sepsis was

performed from the site with cotton soaked in alcohol 70%. For blood analysis, the samples were collected in a sterile tube for vacuum blood collection containing anticoagulant EDTA K_3 (13 x 75 mm). A volume of approximately 4 ml of blood was collected after a night of approximately 12 hours of fasting for the hematological analysis. The blood samples intended for biochemical analysis were collected. An additional approximately 8 ml of blood was collected in a sterile tube containing separator gel for serum (13 x 100 mm) for the biochemical analysis. The samples for hematological parameters were analyzed on the same day of collection. The samples for biochemical analysis were centrifuged at a velocity of 3.500 rpm per 5 minutes and stored in a refrigerator to be analyzed on the day after the collection. All samples were analyzed by the same subjects and reagent lot for each test. The coefficient of variation was < 7%, and the ICC was 0.98. Blood analysis was analyzed in the Sysmex XS-1000i (Roche® Hematological Analyzer, São Paulo, Brazil), including white blood cell count, neutrophils, lymphocytes, monocytes, eosinophils, and basophils. This device uses the following methods: (i) flow cytometry for white blood cell counts analysis; (ii) hydrodynamic focus for analysis of red blood cell count and platelets; (iii) detection of SLS-hemoglobin for hemoglobin's analysis. Biochemical analyses for creatinine, creatine kinase, creatine kinase-MB, aspartate aminotransferase, alanine aminotransferase, urea, and lactate dehydrogenase were performed in the Cobas Integra 400 Plus (Roche® Biochemical, São Paulo, Brazil) equipment using the colorimetric method.

Statistical Analysis

Normality and homoscedasticity were assessed and confirmed using the Shapiro-Wilk and Levene tests, respectively. The data on participants' characteristics and training volume after each week were presented as mean ± standard deviation (SD). Independent *t*-test was used to detect differences between participants' characteristics, and two-way ANOVA (group*weeks) for repeated measurements was used to detect differences in training volume after each week. Data for physical performance and blood-derived markers are presented as percentage change (Δ%) values, calculated using the following equation: Δ% = ([Post-test – Pre-test]/ Post-test*100).[26] Two-way ANOVA (moments*groups) with repeated measures tests were applied for physical performance, and, when needed, the Bonferroni post hoc test was used. Partial eta squared (η^2□) was calculated from the ANOVA results and interpreted as follows: trivial < 0.01, small 0.01–0.06, medium 0.06–0.14, and large > 0.14. For pairwise comparisons, Cohen's *dz* effect sizes (ES) were utilized and interpreted as trivial (< 0.50), low (0.50–1.25), moderate (1.25–1.90), and high (> 2.0), according to definitions for strength training research with untrained subjects.[27] Nonparametric tests were applied for blood-derived variables presented by the median and interquartile range (IQR). The IQR was calculated by subtraction quartile 1 from quartile 3. Specifically, the Mann-Whitney test was used to test between groups effects. All analyses were performed in SPSS 22.0, and statistical significance was set at $p < 0.05$.

Results

The characteristics and baseline values for the 1RM test of the participants are presented in Table 2. There were no differences between groups at baseline for RT experience, 1RM leg press 45°, 1RM bench press, age, height, weight, and body mass index. The results indicate that the participants were successfully randomized.

Significant group*weeks interaction was found for TTV ($F = 31.02$; η^2□ = 0.52; $p < 0.001$). As expected, G6 presented significantly higher TTV in comparison to the G4 for week 1 ($F = 20.95$; η^2□ = 0.42; $p < 0.001$), week 2 ($F = 25.98$; η^2□ = 0.48; $p < 0.001$), week 3 ($F = 32.46$; η^2□ = 0.53;

$p < 0.001$), and week 4 ($F = 42.10$; $\eta^2 = 0.60$; $p < 0.001$). G6 had a TTV = 74063.0 ± 13263.2 u. a, whereas G4 had a TTV = 44250.0 ± 15827.3 u. a, which confirmed the higher TTV for G6 in comparison to the G4 ($F = 31.26$; $\eta^2 = 0.52$; $p < 0.001$).

Table 2. Participants' characteristics.

	G4 (n = 15)	G6 (n = 15)	p-value
Men/Women	8/7	7/8	
Training experience (months)	13.1 ± 9.7	10.6 ± 7.9	0.23
1-Repetition maximum leg press 45° (kg)	179.3 ± 63.3	193.0 ± 48.8	0.51
1-Repetition maximum bench press (kg)	32.1 ± 18.3	36.5 ± 24.4	0.58
Age (years)	21.5 ± 2.3	21.7 ± 2.5	0.67
Height (cm)	1.65 ± 0.08	1.67 ± 0.07	0.37
Weight (kg)	63.8 ± 7.4	62.4 ± 8.5	0.38
Body mass index (kg/m²)	23.2 ± 2.2	22.4 ± 2.8	0.12

G4 = HIRT with a low volume approach; G6 = HIRT with a high-volume approach.

The percentage change values for muscular performance in response to the G4 and G6 are presented in Figure 2. Significant moments*group interaction was found for the standing long jump ($F = 6.03$; $\eta^2 = 0.17$; $p = 0.02$). However, no differences between groups differences were found for any variable ($p = 0.49$). Regarding between-moments comparisons, main effects suggest significant improvements in 1RM bench press ($F = 51.44$; $\eta^2 = 0.64$; $p < 0.001$), 1RM leg press 45° ($F = 69.87$; $\eta^2 = 0.71$; $p < 0.001$), and drop jump ($F = 10.15$; $\eta^2 = 0.26$; $p = 0.004$). Significant effects were found for the countermovement jump ($F = 4.27$; $\eta^2 = 0.13$; $p = 0.04$), although not confirmed in post hoc analysis ($p = 0.07$). No significant effects were found for medicine ball throw ($F = 3.64$; $\eta^2 = 0.11$; $p = 0.06$), standing long jump ($F = 0.001$; $\eta^2 = 0.001$; $p = 1.00$), and squat jump ($F = 1.68$; $\eta^2 = 0.05$; $p = 0.20$).

Table 3. Blood-derived markers variables analyze for G4 and G6 groups (n = 30).

	G4 (n = 15)		G6 (n = 15)			
	Median	IQR	Median	IQR	Z	p-value
Creatine-kinase (u/L)	−20.96	−90.21	20.12	−38.91	−2.09	0.03
Lactate dehydrogenase (u/L)	−30.22	−27.63	−17.01	−28.68	−2.38	0.01
Creatinine (mg/dL)	7.84	−37.55	17.00	−14.70	−2.59	0.01
Urea (mg/dL)	0.00	−30.42	1.39	−31.43	−0.74	0.45
Aspartate aminotransferase (u/L)	−16.67	−43.63	−5.26	−71.35	−0.33	0.74
Alanine aminotransferase (u/L)	−54.55	−108.33	−64.29	−143.79	−0.33	0.74
Creatine kinase-MB (u/L)	−14.62	−42.70	−10.19	−51.01	−0.51	0.60
White blood cell count (10^9/L)	−27.84	−36.24	−27.45	−26.02	−0.22	0.82
Neutrophil's count (10^9/L)	−10.50	−76.10	−32.35	−43.13	−0.64	0.52
Lymphocyte's count (10^9/L)	−22.68	−47.92	−18.94	−25.46	−1.34	0.17
Monocyte's count (10^9/L)	−24.30	−27.71	−9.30	−37.03	−1.22	0.22
Eosinophil's count (10^9/L)	−45.50	−133.33	0.00	−45.00	−1.78	0.07
Basophil's count (10^9/L)	−50.00	−66.67	−100.00	−150.00	−0.38	0.70

G4 = HIRT with a low volume approach; G6 = HIRT with a high-volume approach; IQR = interquartile range.

The blood-derived markers responses are presented by median and interquartile range in Table 3. The G6 induced higher creatine kinase ($p = 0.03$), lactate dehydrogenase ($p = 0.01$), and creatinine ($p = 0.01$) changes when compared to the G4 group, which may suggest higher muscle damage

responses. Regarding immune markers, however, no differences between-group were found for all the variables analyzed ($p > 0.07$).

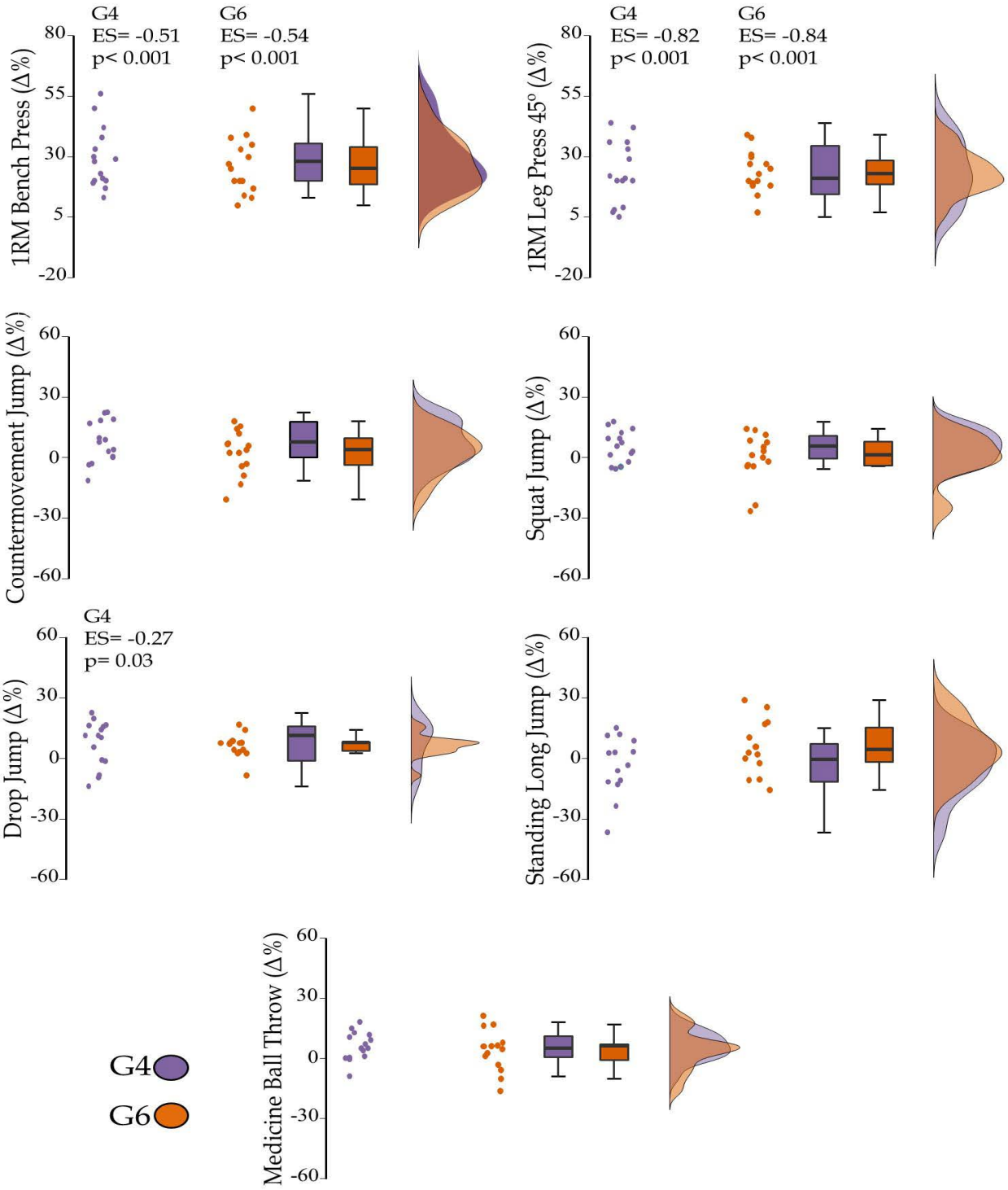

Figure 2. The relative percentage change (Δ%) values for physical performance in response to each group and the magnitude of the effects from pre to post in both groups in 1RM bench press and 1RM leg press 45°. Additionally, it includes drop jump results specifically for G4. G4 = HIRT with a low volume approach; G6 = HIRT with a high-volume approach; ES = magnitude of effect sizes according to Cohen'd_z; RM = repetition maximum.

Discussion

The present study aimed to investigate the effects of HIRT performed with different training volumes on physical performance and blood-derived markers adaptations of recreationally trained subjects. The main finding suggests that a higher HIRT volume did not induce additional benefits on muscle performance, but promoted greater changes in biochemical markers associated with microstructural muscle damage. Thus, the initial hypothesis that four and six-weekly HIRT sets would induce similar physical and physiological adaptations was partially confirmed.

A recent review suggested that increasing training volume would result in greater muscle strength gains in different populations (i.e., men, women, and elderly).[28] However, it seems that performing 2–3 or 4–6 sets per muscle group causes similar effects in the magnitude of strength gains.[29] In general, HIRT seems to cause improvements in muscle strength due to the short recovery intervals and high lifted load that would provide more time under tension and increased volume.[30] However, according to our results, increased HIRT volume does not seem to play an important role in strength/power adaptations. One possible explanation is that muscle strength gains might be primarily mediated by load magnitude and specificity of tasks, which might supersede the effects provided by increased volume and time under tension as previously suggested.[30,31] Moreover, training for volitional fatigue could cause similar effects for strength gains regardless of increased volume and intensity because it would result in a similar activation of motor units and neural adaptations.[32]

There is a spirituous debate regarding the benefits of increasing training volume for RT.[12,33] However, one important aspect that seems to be considered is the interaction between training volume and intensity of effort, since the application of higher efforts might decrease the need for additional volume, and the combination of high effort and high volume might have detrimental effects.[12] This hypothesis could be confirmed by our results since G6 presented greater changes in biomarkers associated with muscle damage. Thus, considering that the lack of time is a relevant barrier to participation in planned exercises,[34] the use of the HIRT technique performed with relatively low training volume might be an interesting strategy for those seeking a time-efficient strategy without compromising the results. Regarding muscle power-related performance, the increases were not expected, since the protocol used in the present study involved repetitions performed at controlled velocity and until MMF, which have been suggested to impair the velocity-related adaptations.[20] However, the low training volume performed by both groups may have reduced the accumulated fatigue effects, and both groups showed increased power-related performance.

The high intensity of effort of RT is related to the increase in blood muscle damage markers.[35] This hypothesis is frequently related to the use of MMF, which would require a longer time for metabolic homeostasis reestablishment and muscle recovery.[14] In this sense, our findings suggested that the increase of muscle damage markers may be more related to higher volume while performing HIRT since higher increases in markers of muscle damage (creatine kinase, lactate dehydrogenase, and creatinine) were found in the G6 group. These results suggest that training volume may have an upper limit and increasing it above an optimal point does not increase the results and induce additional stress. Over the long term, this might be reflected in overtraining and increased risk of injury. Therefore, we recommend the use of the HIRT with low weekly volume, as performed by G4, for bringing relevant improvements while avoiding unnecessary stress. Although the discussion is beyond the scope of the present study, it is important to note that the increases in markers of muscle damage dissociated from increases in

muscle performance reinforces the argument that muscle damage might not be associated with RT adaptations.

The acute effects of the HIRT technique showed that, after 48 hours, the white blood cell count returned to baseline values.[13] Previous studies indicated that blood cell count parameters (neutrophils, monocytes, and lymphocyte count) might be influenced by high-intensity training in the short-term (4 weeks), resulting in reduced blood cell count.[36] Thus, an adequate rest period is suggested to avoid more severe deleterious effects, and despite this phenomenon may not induce immunosuppression, it can be sufficient to result in a raised infection risk.[37] It`s important to highlight that the decrease in the immune response is not necessarily related to impairments in physical performance, which raises the question of whether the relative fall of these variables after a period of HIRT intervention,[13] may induce the "open window" phenomena. Therefore, despite the possible effect of the HIRT on the immune system, it seems not to be sufficient for causing impacts on physical performance. Also, regarding volume prescription models, the minimal-dose approach would cause less pronounced negative effects, since the high volume associated with the high intensity of the HIRT technique would be the main component for immunosuppression.[38]

For a better interpretation of our findings, some limitations should be considered. First, the participants in this study have only recreational experience in RT, hence, applications of our results should not be extrapolated to other populations (i.e., bodybuilders). However, this is probably because most of the population engaged in RT practice. Second, nutritional routines were not controlled and could influence some results. Nevertheless, all participants were continuously oriented to maintain their habitual nutritional habits and prevent the use of substances that potentially could interfere with blood-derived markers (i.e., caffeine and anti-inflammatory drugs). Finally, both approaches proposed here may be considered low-volume protocols when using the traditional RT parameters. Thus, this investigation is not necessarily about low and high training volumes, due to the absence of clear thresholds for advanced RT techniques volumes, and even higher volumes may induce different responses.

Our findings might be important for RT practitioners who seek to improve their neuromuscular performance while saving time and reducing possible overtraining-related adverse issues. The use of these advanced techniques, such as HIRT, can reduce the need for higher training volume. In practice, it seems that four sets per muscle group per week distributed in two training sessions using HIRT can be recommended to increase muscle performance in recreationally trained individuals.

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