

Comparative effects of hypertrophy-, strength-, and power-type resistance exercise on hematological parameters in resistance-trained women

Running title: Hematological impact of resistance exercise types

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Abstract

Introduction and Purpose: The effects of different types of resistance exercise (RE) on hematological markers involved in anemia have remained understudied. Therefore, this study characterized the effects of three types of RE on hematological markers.

Materials and Methods: Ten resistance-trained women (age 26.30 ± 4.95 years, body mass index 22.07 ± 2.02 kg/m²) were recruited and completed hypertrophy (3×10 -12 repetitions with 70% of one repetition maximum [1-RM]), strength (7×3 -5 repetitions with 90 % of 1-RM), and power-type (5×4 repetitions with 40 % of 1-RM) RE at eight stations. Venous blood was sampled before and immediately after each trial. Within-group differences were assessed by dependent t-student and Wilcoxon tests. In addition, between-group differences were examined using an analysis of covariance test.

Results: Power-type RE caused a significant decline in hemoglobin ($P=0.007$), mean corpuscular hemoglobin ($P=0.018$), and mean corpuscular hemoglobin concentration ($P=0.043$). Strength-type RE significantly reduced the mean corpuscular hemoglobin ($P=0.045$). Lymphocyte count was significantly reduced following strength-type ($P=0.045$) and power-type RE ($P=0.004$). However, higher levels of platelet counts ($P=0.014$) and plateletcrit ($P=0.006$) were observed in hypertrophy-type than in power-type RE. The hemoglobin level was significantly lower in power-type RE than in hypertrophy-type RE ($P=0.023$). Moreover, a lower level of mean corpuscular hemoglobin was observed in strength-type relative to hypertrophy-type RE ($P=0.018$).

Conclusion: Hypertrophy-type RE had no adverse effects on hematological parameters. However, hematological markers involved in anemia declined following strength-type and power-type RE. Taken together, coaches should monitor hematological markers in athletes performing high-intensity strength or power training to prevent anemia-related performance decrements.

Keywords: Resistance exercise, Erythrocytes, Leukocytes, Platelets, Women.

Introduction

Anemia is a clinical disorder characterized by a reduced ability of the blood to carry adequate oxygen. As a widely observed phenomenon in athletes, exercise-induced anemia, also known as athlete's anemia, features hemodilution, iron deficiency, gastrointestinal bleeding, and hemolysis resulting from foot-strike and/or the compression of contracting muscles on capillaries (1). Intriguingly, athletes conducting an intensive exercise program are reported to have decreased counts of hemoglobin (Hgb) and hematocrit (Hct) levels (2). Additionally, since the immune system is highly responsive to exercise, periods of intensive exercise can induce a transient immune dysfunction. Importantly, increasing evidence suggests that engaging in heavy acute bouts of intense exercise is associated with an increased likelihood of immune dysfunction, which is inversely related to the health and performance of athletes (3).

As stimulants, stress and exercise cause changes in hematological properties and the immune system. In this regard, it has been demonstrated that acute exercise can modify rheological parameters (4). It has been postulated that acute high-intensity interval training (HIIT) leads to an immediate rise in hematocrit (Hct) and hemoglobin (Hgb) percentage, red blood cell count (RBC), mean cell volume (MCV), platelet count (PLT), total white blood cell (WBC) count, and counts of the white cell subgroups (5). In addition, it has been elucidated that resistance exercise (RE) performed at an intensity corresponding to 70% of one-repetition maximum (1-RM) alters RBC deformability more than training performed at 85% of 1-RM. Reports indicate, moreover, that the Hct, plasma viscosity, and fibrinogen were significantly increased in response to RE, with the changes attributed to RE-induced haemoconcentration (6). Hulmi et al. (7) demonstrated that younger men exhibited a larger immediate RE-induced response in leukocytes and platelets (PLT) compared to older men. Besides, significant increases in PLT count, plateletcrit (PCT), and mean platelet volume (MPV) have been observed after RE; however, this rise was not related to exercise intensity (8). Similarly, Fortunato et al. (9) reported that WBC, lymphocytes (Lym), monocytes (Mon), and neutrophils (Neu) counts increased post-RE in both trained and untrained volunteers. In contrast, significant reductions in hematological and immunological properties were observed following a single bout of intensive judo exercise (10) and completing a 100-km ultramarathon (11).

RE is a well-demonstrated type of exercise that is used by a wide range of individuals who wish to improve health and sports performance (9). Before commencing competitions, athletes enhance their muscle hypertrophy, strength, and power by changing RE intensity, number of repetitions, total work, and rest intervals. Direct mechanical injury caused by repeated muscle contractile activity is proposed as a potential source of exercise-induced hemolysis (11). Despite the importance of selecting an appropriate type of exercise, surprisingly little is known about blood hematological and rheological alterations associated with varying types of RE. Current reports indicate that exercise-induced hematological and immunological changes depend on the duration and intensity of the performed exercise (5). Additionally, sports physicians and coaches are interested in maintaining the health of their athletes during training sessions and competitions. To the best of our knowledge, no recently published study has investigated the effects of different types of RE on hematological parameters. We hypothesize that power-type RE would induce greater hematological disturbances than hypertrophy- or strength-type RE. Hence, the current study compares the effects of hypertrophy-, strength-, and power-type RE on erythrocyte, leukocyte, and platelet levels in resistance-trained women.

Methodology

Ethical considerations. This research was conducted in accordance with the principles of the Helsinki Declaration. All experimental procedures were approved by the ethics committee of the University of Bojnord (IR.UB.REC.1401.006). Initially, all participants were informed of experimental procedures, risks, and benefits involved. They signed informed consent documents that had been approved by the ethics committee. Subjects voluntarily participated in the experimental research. Moreover, volunteers were informed that they were free to leave the intervention at any time.

Subjects. The study's sample size was calculated using G*Power statistical software (version 3.1.5, freeware; G*Power-3.1.5, Heinrich-Heine-University, Germany) using the two-tailed dependent t-test. The parameters used included a significance level (alpha) of 0.05 and a power (1-beta) of 0.8. Ten healthy recreationally resistance-training women from Mashhad (Razavi Khorasan Province, Iran) volunteered to participate in the study. Participants were announced through advertisements placed in bodybuilding gyms as well as information disseminated through social media. The inclusion criteria for this study were: 1) the subjects were young and over 20 years old, 2) participants had been engaged in regular and systematic strength training for at least 1 year prior to the study, and 3) they had regular menstrual periods. Exclusion criteria were as follows: any previous use of medication and nutritional supplements such as anabolic-androgenic steroids, any musculoskeletal disease, and pregnancy. Before data collection, subjects underwent an anthropometric assessment using a body composition analyzer (X-Contact 356 model, Jawon Medical Co., Ltd., South Korea). The subjects' body composition profiles are detailed in Table 1. Furthermore, the schematic timeline for the experimental protocol is illustrated in Figure 1.

Table 1. Subjects' body composition profiles

Body composition	Mean $\pm$ Standard deviation
Age (year)	26.30 $\pm$ 4.95
Weight (kg)	59.51 $\pm$ 7.78
Height (cm)	164 $\pm$ 7.22
Body Mass Index (kg/m ²)	22.07 $\pm$ 2.02
Body Fat Percentage (%)	24.64 $\pm$ 4.98
Lean Body Mass (kg)	44.73 $\pm$ 5.60
Soft Lean Mass (kg)	41.31 $\pm$ 5.21
Mass of Body Fat (kg)	14.78 $\pm$ 3.97
Skeletal Muscle Mass (kg)	26.92 $\pm$ 7.04
Waist-to-Hip Ratio	0.75 $\pm$ 0.05
Abdominal Circumference (cm)	73.26 $\pm$ 4.67
Total Body Water (kg)	32.19 $\pm$ 4.02

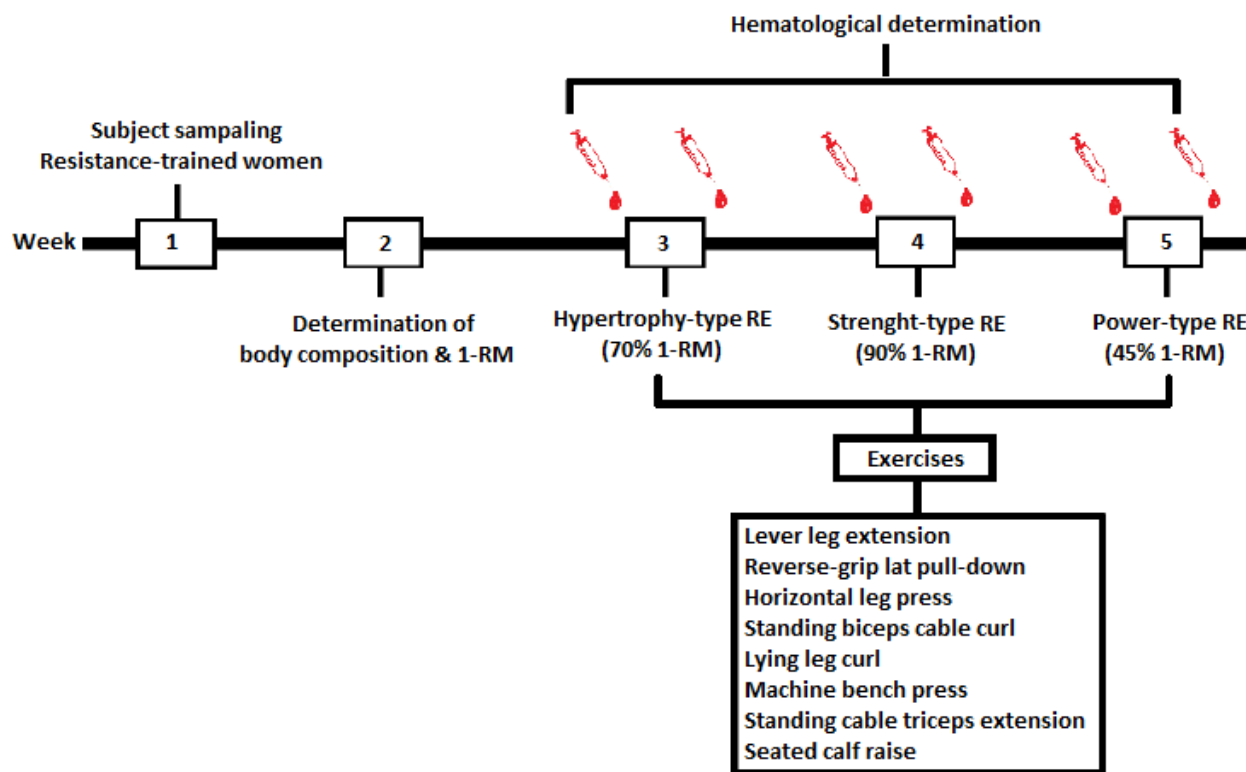


Figure 1. Protocol Timeline

Assessment of 1-RM. 1-RM refers to the maximum amount of weight that can be lifted for one repetition through the full range of motion. One week prior to the start of the intervention, the 1-RM of each exercise was determined by the certified strength and conditioning specialist. The 1-RM of agonist and antagonist muscle groups was established on two separate days. 1-RM tests were always preceded by a general warm-up (5 minutes of cycling on a cycloergometer) and a specific warm-up (lifting light weights using upper- and lower-body muscle groups). Subsequently, based on the participants' estimates, a weight was selected that the subject could lift correctly from a minimum of one time to a maximum of 10 times. By substituting the weight value and the number of repetitions in Epley's 1-RM prediction equation, 1-RM was estimated for each exercise (12).

RE producers. RE protocols were conducted in three separate sessions, each with a one-week interval, under the supervision of a certified strength and conditioning specialist. Initially, participants performed hypertrophy-type RE followed by strength-type RE. Lastly, they performed power-type RE. The upper- and lower-body RE protocol consisted of 8 exercises as follows: lever leg extension, reverse-grip lat pull-down, horizontal leg press, standing biceps cable curl, lying leg curl, machine bench press, standing cable triceps extension, and seated calf raise. Warm-up and cool-down were performed at the beginning and end of each protocol. Subjects were instructed to refrain from any additional exercise during the intervention (12). Each protocol was conducted at the same time of day so as to avoid circadian effects. Participants were asked to have carbohydrate loading for three days prior to 1-RM determination and hypertrophy-, strength-, and power-type RE. Moreover, they were requested not to take nutritional supplementation in the form of carbohydrates, proteins, amino acids, or anabolic steroids during the investigation. The details of the three types of RE are presented in Table 2 (12).

Table 2. Details of hypertrophy-type, strength-type, and power-type RE protocols

Type of resistance exercise	Hypertrophy-type exercise	Strength-type exercise	Power-type exercise
Intensity	70% of 1-RM	90% of 1-RM	40% of 1-RM
Number of sets	3	3	3
Repetitions	10-12	3-5	8-10
Number of exercises	8	8	8
Rest between sets (seconds)	60-90	60-120	60-180
Rest between exercises (seconds)	60-90	60-120	60-180

Hematological determinations. In order to determine hematological levels, a 7 mL blood sample was collected from an antecubital vein by a skilled and qualified technician before and immediately after each intervention. Both blood samples were obtained in a sitting position, as postural changes can influence blood volume and hematocrit concentration. Samples were drawn into tubes containing ethylenediamine tetraacetic acid (EDTA) and analyzed on the same day. Quantitative determinations of hematological parameters were evaluated using a fully automated hematology analyzer (model KX-21 N, Sysmex Corporation, Japan) in Arad Medical Laboratory (Mashhad, Iran). Finally, plasma volume was calculated using the Dill and Costill equation (13).

Statistical Analysis. Data were analyzed using the commercial SPSS software V.16 (IBM Corporation, Chicago, USA) at a significance level of $P < 0.05$. The Shapiro-Wilk test was used to evaluate the normality of data distribution. Within-group differences were assessed by dependent t-student and Wilcoxon tests for parametric and non-parametric data, respectively. Additionally, between-group differences were examined by an analysis of covariance test. Subsequently, the least significant difference post hoc test was used, as confirmed by Levene's test, which demonstrated homogeneity of variances. The results were displayed as mean $\pm$ standard deviation.

Results

The mean and standard deviation values of 1-RM for each exercise were 57.84 ± 12.92 kg for lever leg extension, 39.23 ± 6.61 kg for reverse-grip lat pull-down, 105.09 ± 19.55 kg for horizontal leg press, 27.26 ± 5.82 kg for standing biceps cable curl, 33.91 ± 10.12 kg for lying leg curl, 29.92 ± 7.18 kg for machines bench press, 31.92 ± 6.86 kg for standing cable triceps extension and 17.12 ± 4.83 kg for seated calf raise.

Table 3 details the erythrocyte parameters measured. Our results indicate that only power-type RE resulted in a significant increase in RDW. In contrast, power-type RE caused a significant reduction in Hgb, MCH, and MCHC. Moreover, strength-type RE significantly reduced MCH. Between-group differences showed that the mean Hgb of power-type was significantly lower than hypertrophy-type RE ($P=0.023$). Moreover, a lower level of MCH in strength-type was observed than in hypertrophy-type RE ($P=0.018$). Lastly, no significant time or group effects were observed for RBC and Hct parameters.

Table 3. Effect of RE type on erythrocyte parameters

Erythrocytes	RE type	Pre	Post	Within-group	Between-group
RBC ($10^6/\mu\text{L}$)	Hypertrophy	4.75 ± 0.65	5.00 ± 0.20	$P=0.26$	$P=0.33$
	Strength	4.78 ± 0.18	4.94 ± 0.30	$P=0.43$	
	Power	4.92 ± 0.15	4.85 ± 0.21	$P=0.32$	
Hgb (g/dL)	hypertrophy	13.97 ± 0.48	14.10 ± 0.79	$P=0.49$	$P=0.042$
	Strength	13.29 ± 1.25	13.53 ± 0.94	$P=0.34$	
	Power	14.10 ± 0.62	$13.60 \pm 0.55^{*5}$	$P=0.007$	
Hct (%)	hypertrophy	41.17 ± 1.24	41.57 ± 2.17	$P=0.47$	$P=0.11$

MCV (fL)	Strength	39.45±1.70	40.85±3.35	P=0.056	P=0.97
	Power	40.28±1.95	39.78±1.40	P=0.43	
	hypertrophy	82.94±3.45	83±3.13	P=0.75	
MCH (pg)	Strength	82.56±3.08	82.69±3.49	P=0.51	P=0.04
	Power	81.96±3.46	82.05±3.11	P=0.72	
	hypertrophy	28.05±1.08	28.08±1.23	P=0.82	
MCHC (g/dL)	Strength	28.35±0.96	27.50±1.22* [§]	P=0.045	P=0.12
	Power	28.62±0.94	27.97±1.33*	P=0.018	
	hypertrophy	33.87±0.46	33.88±0.64	P=0.94	
RDW (fL)	Strength	34.12±0.79	33.14±1.38	P=0.39	P=0.60
	Power	34.95±0.73	34.14±0.61*	P=0.043	
	hypertrophy	41.07±3.77	41.85±3.52	P=0.10	
	Strength	42.90±3.64	43.03±3.53	P=0.84	
	Power	40.92±3.56	42.23±2.94*	P=0.007	

Abbreviations: RBC; Red blood cell count, Hgb; Hemoglobin, Hct; Hematocrit, MCV; Mean corpuscular volume, MCH; Mean corpuscular hemoglobin, MCHC; Mean corpuscular hemoglobin concentration, RDW; Red distribution width. * indicates significant differences from Pre. [§] indicates significant differences from strength-type RE. [§] indicates significant differences from hypertrophic-type RE.

Table 4 displays the granulocyte parameters measured. Both strength-type and power-type RE resulted in a significant reduction in lymphocyte count. Additionally, no significant group effect was obtained for WBC, lymphocyte, and granulocyte count.

Table 4. Effect of RE type on leukocytes parameters

Leukocytes	RE type	Pre	Post	Within-group	Between-group
WBC (10 ³ /μl)	Hypertrophy	7.28±1.35	7.38±1.41	P=0.84	P=0.57
	Strength	6.94±1.45	6.91±1.21	P=0.89	
	Power	7.10±1.17	6.78±1.24	P=0.21	
Lymph (10 ³ /μl)	Hypertrophy	2.28±0.65	2.18±0.49	P=0.68	P=0.32
	Strength	2.49±0.52	2.10±0.66	P=0.045*	
	Power	2.40±0.43	1.87±0.44	P=0.004*	
Gran (10 ³ /μl)	Hypertrophy	5.00±1.37	5.36±1.58	P=0.227	P=0.74
	Strength	4.22±1.09	4.51±0.92	P=0.118	
	Power	4.28±0.91	4.50±0.98	P=0.27	

Abbreviations: WBC; White blood cells, Lymph; Lymphocyte, Gran; Granulocyte. * indicates significant differences from Pre.

In the context of platelet measurements, the results indicated that both hypertrophy-type and strength-type RE significantly increased PLT count and PCT. MPV and PDW significantly increased following hypertrophy-type and power-type RE, respectively. Additionally, a significantly higher level of PLT count (P=0.014) and PCT (P=0.006) was observed in hypertrophy-type RE compared to power-type post-exercise. In contrast, no significant group effect was found for MPV and PDW. The changes in platelet measurements are reported in Table 5.

Table 5. Effect of RE type on platelet parameters.

Platelet	RE type	Pre	Post	Within-group	Between-group
PLT (10 ³ /μL)	hypertrophy	260±47.87	290±50.41* [†]	P=0.03	P=0.04
	Strength	249±46.77	265±42.18*	P=0.04	
	Power	246±46.72	242±56.68	P=0.65	
MPV (fL)	hypertrophy	10.36±0.83	10.61±0.90*	P=0.01	P=0.46
	Strength	10.55±0.79	10.65±0.82	P=0.29	
	Power	10.31±0.95	10.40±0.85	P=0.50	

PDW (fL)	hypertrophy	14.64±0.15	14.71±0.27	P=0.30	P=0.76
	Strength	14.65±0.17	14.70±0.24	P=0.43	
	Power	14.60±0.15	14.71±0.22*	P=0.04	
PCT (%)	hypertrophy	0.267±0.03	0.305±0.04*†	P=0.01	P=0.02
	Strength	0.260±0.03	0.279±0.03*	P=0.03	
	Power	0.250±0.03	0.249±0.04	P=0.90	

Abbreviations: PLT; Platelet count, MPV; Mean platelet volume, PDW; Platelet distribution width, PCT; Plateletcrit. * indicate significant differences from Pre. † indicates significant differences from power-type RE.

Discussion

Participation in RE yields health-related benefits and enhances muscular strength, power, endurance, and motor performance in adolescent and adult populations (9). The effects of exercise on blood rheology have been a topic of ongoing interest in sports medicine over the past several decades. In fact, exercise-induced hemolysis can be conventionally considered as destruction and rupture of erythrocytes following physical exercise (11). In this regard, our findings revealed that only hematological parameters of Hgb, MCH, and MCHC decreased significantly after power-type RT. According to previous research, variations in erythrocyte markers are influenced by the intensity of physical activity and the individual's level of preparedness. Notably, high-intensity exercises and combat sports have been associated with a significant decrease in Hgb levels, attributed to increased intravascular hemolysis (10). In reality, declined Hgb following intense exercise can be attributed to intravascular hemolysis induced by mechanical trauma, gastrointestinal bleeding, or oxidative/osmotic damage to RBC (14). Moreover, other researchers have claimed that the hemolysis induced by foot strike results in lower Hgb levels (13). Furthermore, extant reports indicate that the hemolysis of RBCs increases as they pass through capillaries during muscle contraction. Indeed, increased RBC deformity due to muscle contraction causes hemolysis, and subsequently, a decrease in Hgb percentage occurs (15). Work by Cakir-Atabek et al. (15) showed that performing RT at moderate intensity alters RBC deformability more than training performed at submaximal intensity. Furthermore, lactate concentration, blood pressure, and MPV increased after both traditional and circuit RE in healthy males (16). Therefore, direct mechanical injury induced by high speed and repeated muscle contractile activity is a potential source of exercise-induced hemolysis, while other metabolic abnormalities developing during power-type RT (e.g., hypoxia, lactic acidosis, shear stress, oxidative damage, increased concentration of catecholamines) may actively accelerate this phenomenon (11). Power-type RE, which involves explosive movements and rapid changes in force, tends to induce greater shear stress on blood vessels compared to slower, more controlled RE. Shear stress anemia, also known as shear-induced hemolytic anemia, occurs when erythrocytes are damaged or destroyed due to the mechanical forces of flowing blood, particularly in areas of high shear stress (17). Therefore, one of the mechanisms underlying the greater anemia parameters observed after power-type RE than other types may be attributed to higher shear stress.

The immune system protects against injuries and diseases and plays a crucial role in recovery and adaptation after exercise. Intensive exercise results in rapid, transient changes in leukocyte count of the blood (7). Conversely, our finding revealed that lymph counts decreased significantly after strength- and power-type RE, whereas WBC and Gran counts did not change in significantly. The invariability of lymphocyte count indicates that both strength- and power-type RE in the current study can suppress the cellular immune system and intensify the open window phenomenon. However, the hypertrophy-type RE did not contribute to trigger or amplify this phenomenon. Indeed, it appears that the lymphocytopenia commonly occurring after exercise was

more pronounced, suggesting that resistance-trained women may have been more susceptible to pathogens in the systemic circulation.

The findings of the current study are inconsistent with those of Hulmi et al.'s research, which revealed increased lymph and PLT counts in response to one bout of RE (3 and 5 sets of 1-RM squats, 4 and 5 sets of 10-RM leg presses) in young and older adults. In addition, younger men had a larger immediate exercise-induced response in leukocytes and PLT than older men (7). Similarly, Allsopp et al. (18) reported that one bout of the RE protocol (4×10 repetitions of lower and upper body exercises at 70% of 1-RM) under both hypoxic and normoxic conditions results in a dramatic increase in total leukocytes, monocytes, and lymphocyte counts immediately after exercise. However, the hypoxic condition showed a larger lymph response compared to the normoxic condition. Moreover, a significant increase in WBC and lymphocyte count has been revealed in response to one bout of eccentric elbow extension (80% of one maximum repetition, 6 sets, 8-10 replicates/sets), and this elevation continued for up to 24 hours after the eccentric repetition (19). Furthermore, a combined acute bout of endurance and strength exercise induced a substantial increase in neutrophil count, followed by a mixed cell count (including monocytes, eosinophils, and basophils) in the circulation of untrained men (20). The exact mechanism by which lymph responds to RE is unknown. However, there is strong evidence that hormones play a pivotal role in regulating exercise-induced changes in lymphocyte count. It has been clearly demonstrated that growth hormone, noradrenaline, adrenaline, and cortisol play a role in recruiting lymphocytes. In addition, the acute increase in lymph counts following RE is thought to be due to increased sheer stress in the vasculature (18).

Similar to previous reports examining the effect of exercise on platelet-related markers, we observed enhanced PLT and PCT counts as a result of hypertrophy- and strength-type RE. Additionally, higher PLT and PCT levels were observed in hypertrophy-type RE compared to power-type RE. This finding pointed out the transient thrombocytosis and PLT activation induced by RE. Contradictory findings have been reported regarding the effect of RT on platelet count. In this regard, Allsopp et al. (18) showed that acute bouts of upper- and lower-body RE at moderate intensity in older adults did not cause significant changes in PLT count immediately and over 24 hours post-exercise. Our findings are consistent with existing literature indicating acute traditional RE (3 sets of 10 repetitions at 100% of 10-RM for 6 exercises) increases PLT count and activation; likewise, our findings align with research, which indicates that circuit RE (3 sets of 10 repetitions at 100% of 10-RM for 6 exercises) results in higher PLT activation than traditional RE, probably due to exercise-induced increases in shear stress (16). In another study, PLT and PCT increased in response to low-intensity RE with blood flow restriction (20% 1-RM) more than with high-intensity RE (80% 1-RM), although no significant differences in PDW and MPV were observed in female patients with type 2 diabetes (21). Moreover, it has been concluded that one bout of RE (3 sets of 5 to 7 repetitions of 6 exercises at 80% of 1-RM) results in a significant increase in corrected PLT count and corrected PCT in healthy males. These increases were transient and returned to the pre-exercise level by the end of the 30-minute recovery period (6). Research has demonstrated that an increase in epinephrine in response to intensive exercise enhances the release of PLTs from the lungs, liver, and, most importantly, the spleen, as well as the entry of fresh PLTs into circulation (22).

Iron and folic acid are essential for the production of red blood cells and the prevention of anemia. Iron is essential for hemoglobin formation, while folic acid is vital for DNA synthesis and cell division, both of which are necessary for healthy red blood cells (23). One limitation of the current study was the lack of controlled iron and folic acid supplementation prior to the

intervention. In reality, the observed findings might be influenced by the participants' pre-existing iron and folic acid status, rather than solely by the intervention itself. Despite participants having regular menstrual cycles, the specific phase of the menstrual cycle during which data was collected was not standardized (24). Therefore, the history of iron and folic acid supplementation, as well as the menstrual cycle phase, should be considered in future studies.

Conclusion

These findings provide the first direct evidence that hypertrophy-type RE has no adverse effect on hematological parameters. However, some hematological markers involved in anemia decline after strength-type and power-type RE in resistance-trained women. In addition, it is believed that these latter factors can serve as probable indicators of training intensity and can be used as a suitable measure to monitor training load. Taken together, coaches should monitor hematological markers in athletes participating in high-intensity strength or power training to prevent anemia-related performance decrements.

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Authors' Contribution statement

All authors conceived the study, designed it, and coordinated its execution. HT, ER, and SM were involved in data collection, data analysis, and manuscript drafting. Finally, all authors reviewed and approved the final version of the manuscript and concurred with the order of authorship presentation.

Conflict of Interests

There are no conflicts of interest.

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References

1. Chiu YH, Lai JJ, Wang SH, How CK, Li LH, Kao WF, et al. Early changes of the anemia phenomenon in male 100-km ultramarathoners. *Journal of the Chinese Medical Association*. 2015;78(2):108-13. <http://doi: 10.1016/j.jcma.2014.09.004>.
2. Damian MT, Vulturar R, Login CC, Damian L, Chis A, Bojan A. Anemia in sports: a narrative review. *Life*. 2021;11(9):987. <http://doi: 10.3390/life11090987>.
3. Gałazka-Franta A, Jura-Szołtys E, Smółka W, Gawlik R. Upper respiratory tract diseases in athletes in different sports disciplines. *Journal of Human Kinetics*. 2016;53:99-106. <http://doi: 10.1515/hukin-2016-0014>.
4. Ahmadizad S, El-Sayed MS. The acute effects of resistance exercise on the main determinants of blood rheology. *Journal of sports sciences*. 2005;23(3):243-9. <http://doi: 10.1080/02640410410001730151>.
5. Belviranlı M, Okudan N, Kabak B. The effects of acute high-intensity interval training on hematological parameters in sedentary subjects. *Medical Sciences*. 2017;5(3):15. <http://doi: 10.3390/medsci5030015>.
6. Ahmadizad S, El-Sayed MS, MacLaren DP. Responses of platelet activation and function to a single bout of resistance exercise and recovery. *Clinical hemorheology and microcirculation*. 2006;35(1-2):159-68. <https://doi.org/10.3233/CHM-2006-918>.

7. Hulmi JJ, Myllymäki T, Tenhumäki M, Mutanen N, Puurtinen R, Paulsen G, et al. Effects of resistance exercise and protein ingestion on blood leukocytes and platelets in young and older men. *European journal of applied physiology*. 2010;109(2):343-53. <http://doi: 10.1007/s00421-010-1360-7>.
8. Ahmadizad SA, El-Sayed MS. The effects of graded resistance exercise on platelet aggregation and activation. *Medicine and science in sports and exercise*. 2003;35(6):1026-32. <http://doi: 10.1249/01.MSS.0000069406.54766.C6>.
9. Fortunato AK, Pontes WM, De Souza DM, Prazeres JS, Marcucci-Barbosa LS, Santos JM, et al. Strength training session induces important changes on physiological, immunological, and inflammatory biomarkers. *Journal of immunology research*. 2018;2018(1):9675216. <http://doi: 10.1155/2018/9675216>.
10. Hazratian MR, TaheriChadorneshin H, Rashidi A. The effect of one bout of intensive judo exercise on select hematological and immunological parameters in adolescent elite judo athletes. *Asian Journal of Sports Medicine*. 2020;11(2):e101364. <http://doi.org/10.5812/asjsm.101364>.
11. Lippi G, Sanchis-Gomar F. Epidemiological, biological and clinical update on exercise-induced hemolysis. *Annals of Translational Medicine*. 2019;7(12):270. <http://doi: 10.21037/atm.2019.05.41>.
12. Motameni S, TaheriChadorneshin H, Golestani A. Comparing the effects of resistance exercise type on serum levels of oxidative stress and muscle damage markers in resistance-trained women. *Sport Sciences for Health*. 2020;16(3):443-50. <http://doi: 10.1007/s11332-020-00622-w>.
13. TaheriChadorneshin H, Nazari S. The impact of rope jump exercise training on hemolytic anemia parameters in obese adolescent boys. *Zahedan Journal of Research in Medical Sciences*. 2022;24(1):e106947. <http://doi.org/10.5812/zjrms.106947>.
14. Kilic-Toprak E, Ardic F, Erken G, Unver-Kocak F, Kucukatay V, Bor-Kucukatay M. Hemorheological responses to progressive resistance exercise training in healthy young males. *Medical science monitor: international medical journal of experimental and clinical research*. 2012;18(6):CR351–60. <http://doi: 10.12659/msm.882878>.
15. Cakir-Atabek H, Atsak P, Gunduz N, Bor-Kucukatay M. Effects of resistance training intensity on deformability and aggregation of red blood cells. *Clinical hemorheology and microcirculation*. 2009;41(4):251-61. <http://doi: 10.3233/CH-2009-1176>.
16. Ebrahimi Z, Farsinejad A, Mohammadi MH, Ahmadizad S. Comparable effects of circuit and traditional resistance exercise on platelet $\alpha 2b\beta 3$ receptor and platelet activation and function. *Clinical Hemorheology and Microcirculation*. 2023;83(3):293-303. <http://doi: 10.3233/CH-221603>.
17. Horobin JT, Sabapathy S, Simmonds MJ. Repetitive supra-physiological shear stress impairs red blood cell deformability and induces hemolysis. *Artificial organs*. 2017;41(11):1017-25. <http://doi: 10.1111/aor.12890>.
18. Allsopp G, Addinsall A, Stephenson G, Basheer F, Della Gatta P, Hoffmann S, et al. The acute leukocyte and cytokine response of older adults to resistance exercise in normobaric hypoxia. *Biology of Sport*. 2023;40(2):425-38. <http://doi: 10.5114/biolsport.2023.116005>.
19. Ghanbari A, Tayebi SM. The effect of a single session of eccentric resistance exercise on some parameters of white blood cells. *Annals of Applied Sport Science*. 2013;1(4):17-26. <http://aassjournal.com/article-1-48-en.html>
20. Lasmanova J. Acute and chronic effects of combined endurance and strength training on blood leukocytes in untrained healthy men. *Department of Biology of Physical Activity, University of*

Jyväskylä. *Master's Thesis in Exercise Physiology*. 2014;Pp: 71. <http://urn.fi/URN:NBN:fi:jyu-201409042720>.

21. Fini EM, Salimian M, Ahmadizad S. Responses of platelet CD markers and indices to resistance exercise with and without blood flow restriction in patients with type 2 diabetes. *Clinical Hemorheology and Microcirculation*. 2022;80(3):281-9. <http://doi: 10.3233/CH-211229>.

22. Heber S, & Volf I. Effects of physical (in) activity on platelet function. *BioMed research international*. 2015;2015(1):165078. <http://doi: 10.1155/2015/165078>.

23. Manapurath R, Taneja S, Bhandari N, Chowdhury R. Treatment strategies for non-responders to oral iron and folic acid treatment in anemic children: A systematic review. *PLOS Global Public Health*. 2025;5(3):e0003870. <http://doi: 10.1371/journal.pgph.0003870>.

24. Rahman NI, Johan RB, Aspar H, Ernawati E, Ruqaiyah R. Menstrual cycle and length of menstruation in early adolescent girls on the incidence of anemia. *Jurnal Bidan Cerdas*. 2025;7(1):1-7. <http://doi: 10.1186/1824-7288-38-38>.