The effects of exercise training on plasma volume variations: A systematic review

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Abstract

The aim of this systematic review was to summarize the evidence on the acute and long-term effects of exercise training on PV, in both trained and untrained individuals and to examine associations between changes in %PVV and change in physical/physiological performance. Despite the status of participants and the exercise duration or intensity, all the acute studies reported a significant decrease of PV (effect size: $0.85<d<3.45$, very large), and ranged between 7% and 19.9%. In untrained individuals, most of studies reported a significant increase of PV in response to different kind of training including endurance training and high intensity interval training (effect size: $0.19<d<3.52$, small to very large), and ranged from 6.6% to 16%. However, in trained individuals the results are equivocal. We showed that acute exercise appears to induce a significant decrease of PV in both healthy untrained and trained individuals in response to several exercise modalities. Moreover, there is evidence that long-term exercise training induced a significant increase of PV in healthy untrained individuals. However, it seems that there is no consensus concerning the effect of long-term exercise training on PV in trained individuals.

Keywords: Hemoglobin, hematocrit, blood volume, red blood cells.

Introduction

Sports and physical exercise are important elements of lifestyle which are considered beneficial for overall health [1] and there is a large global interest in competitive sports [2]. Improving aerobic performance is key in many sports as well as being importance in overall health [3]. Aerobic performance depends on many different factors related to physiological parameters,

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such as cardiac output (Q) and blood volume (BV) [4]. It is commonly accepted that Q represents a major limiting factor to high-intensity aerobic performance. The aerobic contribution could reach 30 to 45% during an all-out exercise such as 30s-wingate test and represents a greater proportion during repeated sprint exercise [5]. The Q is determined by heart rate, myocardial contractility, and end-diastolic volume, which is influenced by total BV [6-8]. In this context, BV and hemoglobin (Hb) concentration play important roles in oxygen transport and aerobic capacity (*e.g.* maximal oxygen uptake [$\dot{V}O_{2max}$]) [8,9]. As such, the oxygen delivery appears to be the main determining factor of performance during aerobic physical exercise [10]. Alterations in [Hb] and red cell volume are known to be linked to changes in blood volume (BV). Kanstrup et al. [11] demonstrated that an increase in endurance performance and VO_{2max} occurs when hypervolemia is associated with an elevated [Hb], but not with reduced [Hb]. However, other investigations have showed that VO_{2max} can be increased in response to a BV expansion independent of changes in red blood cells (hypervolemic anemia) in untrained individuals [8,12-14].

Moreover, in a critical review, Sawka et al. [15] showed that BV changes occur with human adaptations to physical exercise, environmental stresses, and trauma/illness and as such that erythrocyte volume and plasma volume will change independently of each other and make separate contributions to each adaptation [15]. Warburton et al. [8] also performed a critical review to determine the potential ergogenic properties of volume loading and concluded that volume loading does not result in an improvement in VO_{2max} and/or endurance performance in endurance athletes. That is, volume loading in untrained individuals may improve VO_{2max}, but does not bring these individuals to the aerobic capacity of endurance-trained athletes.

Within the blood components, plasma and haemoglobin/erythrocytes are the key transporters of nutrients and oxygen to active muscles [15,16]; therefore, it is logical that changes in plasma volume (PV) observed after exercise training could affect aerobic performances [8, 15; 17]. Indeed, several studies have demonstrated that induced PV expansion was accompanied by an increase in aerobic exercise performance capacity [17-19]. PV variations (PVV) depends on several intrinsic and individual factors, such as sex [20], age [21], training level [22], acute exercise duration [23], environmental factors [24] and exercise intensity [25] ~~(figure 1)~~. However, hematological and biochemical parameters may vary depending on the type, severity, duration of exercises, and feeding status [26-28]. The Hb and hematocrit (Hct) values of athletes subjected to intensive exercise programs, characteristically, decrease and this status is regarded as sportsman anemia [29].

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Endurance training necessarily leads to adaptations in the cardiovascular system [30]; indeed, many studies have demonstrated that endurance training results in increases in Q, increased vascular conductance, and a greater oxygen extraction, with a consequential increase in aerobic power [31]. The increase in heart rate is responsible for the majority of Q augmentation during exercise; however, maximal heart rate is relatively unaltered with exercise training, with some evidence indicating that heart rate may be reduced during maximal exercise as a chronic training adaptation [32].

Many studies have examined the relationship between PVV, BV variations and performances in response to acute and/or chronic exercise [16, 33, 34]. Previous studies have reported that improved endurance performance was accompanied by increases in PV and decreases in Hct [33]. Since physical exercise and training induces changes in PVV levels, it is important to investigate and understand PVV levels in response to acute and log-term exercise training. Accordingly, we conducted, a systematic review of the effects of acute exercise and long-term exercise training on PVV levels in untrained and trained individuals. Moreover, we examined associations between changes in %PVV and changes in physical/physiological performance.

Methods

This systematic review was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta- Analyses (PRISMA) Statement [35]. The PICOS approach (Population, Intervention, Comparator, Outcomes, Study design) was followed to identify inclusion criteria (Table 1). Only randomized controlled trials and controlled trials that examined the acute and chronic effects of training on plasma volume variations (PVV) in trained and healthy untrained individuals were eligible for inclusion. Studies were included in the current systematic review if they were in accordance with the following criteria: (1) published in peer-reviewed journals; (2) included participants 16 years or older; (3) involved trained and/or untrained individuals; (4) used validated methods of PVV measurements; (5) used exercise testing sessions for cross-sectional studies and, in the case of intervention studies, exercise training programs; and (6) all interventions lasted a minimum of 1 weeks (only for long-term exercise training studies). Studies were excluded if they (1) did not meet the minimum requirements of an experimental study design (e.g. case reports), (2) did not meet the minimum requirements regarding training design (e.g. lack of information on volume, frequency, and/or training methodology), (3) were not written in English, or (4) involved individual with diseases. Moreover, review articles were not included in the current systematic review.

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Insert table 1 here

Literature searches were conducted in four electronic databases, including PubMed, ISI Web of Knowledge, Web of Science, and SPORTDiscus, from database inception until December 2020. The following key terms (and synonyms searched for by the MeSH database) were included and combined using the operators "AND", "OR", and "NOT": ((exercise OR "exercise training*" OR "high-intensity interval training*" OR "high-intensity interval exercise*" OR "high-intensity intermittent training*" OR "high-intensity intermittent exercise*" OR "interval aerobic training*" OR "interval aerobic exercise*" OR "aerobic interval training*" OR "aerobic interval exercise*" OR "intermittent aerobic training*" OR "intermittent aerobic exercise*" OR "high-intensity training*" OR "high-intensity exercise*" OR "sprint interval training*" OR "sprint interval exercise*" OR "strength training*" OR "resistance training*" OR cycling) AND ("physical fitness" OR "physiological adaptation" OR "physiological response" OR "heart rate" OR "oxygen uptake" OR VO2 OR "maximal oxygen uptake*" OR "VO2max" OR "aerobic performance" OR "endurance performance" OR "sprint performance" OR "strength performance" OR "cycling performance") AND (plasma OR "plasma volume" OR "plasma volume variations" OR VVP OR blood OR "blood volume" OR "hematological parameters" OR "hematocrit" OR "Hct" OR "hemoglobin" OR "Hgb" OR "Hb")). In addition, the reference lists and citations (Google Scholar) of the identified studies were explored in order to detect further relevant research papers that may have inadvertently been omitted. Since the scope of this review article is large in terms of outcome measures (e.g. performance, physiological adaptations, health indices), a systematic review, but a meta-analysis was not conducted (i.e., the large number of outcome parameters would have yielded high heterogeneity).

In the current review, only studies using a direct or a valid indirect method to estimate PVV were included. For indirect method, changes in whole blood volume (WBV), red cell volume (RCV) and plasma volume (PV) were calculated from the values obtained for haemoglobin concentration and packed cell volume (PCV) before and after acute exercise or long-term training programs, using the calculations described by Dill and Costill [36]. The equation of Beaumont [37] which has been used to calculate changes in PV on the basis of haematocrit values alone is not applicable as it depends upon a constant red cell volume being maintained [38]. Thus, studies using Beaumont equation only were not included in the present study.

The final screening was performed by two investigators (FR and AJ) based on the relevance

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of the inclusion and exclusion criteria and the identified items for assessing the effects of acute and chronic physical exercise on PVV in trained and healthy untrained individuals using PICOS criteria. If the citation showed any potential relevance, it was screened at the abstract level. When abstracts indicated potential inclusion, full-text articles were reviewed. A third-party consensus meeting was held with a third author (HZ), if the two reviewers were not able to reach agreement on inclusion of an article.

The methodological quality of the included studies was assessed using the Physiotherapy Evidence Database (PEDro) scale (Hcttp://www.pedro.fhs. usyd.edu.au), which has been shown to have good reliability and validity [39]. The PEDro scale has 11 possible points that examine external validity (criterion 1) and internal validity (criteria 2–9) of controlled trials and whether there is sufficient statistical information for interpreting results (criteria 10–11). A cut-off points of 6 on the PEDro scale was used to indicate high-quality studies, as this has been reported to be sufficient to distinguish high quality vs. low quality in previous studies [39]. Two independent researchers (FR and AJ) assessed the quality of the studies, if any ambiguity arose, a third researcher (HZ) was contacted and a unanimous decision was achieved.

To evaluate the magnitude of the effects, percent change (Δ%) was calculated (if not available in the individual studies) for each study using the following equation:

$$\boldsymbol{\Delta\% = (Mpost - Mpre)/Mpre \times 100}$$

Where Mpost represent the mean value after (acute exercise or long-term of training) and Mpre the baseline mean value.

Effect sizes (ES) were computed to present standardized effect of acute and long-term training on the outcome variables (e.g. PVV and physical performances). The different ES were calculated using Cohen's d [40] by dividing the raw ES (difference in means) by the pooled standard deviations:

$$\boldsymbol{ES = (\text{Cohen's d}) = (\text{M1} - \text{M2})/\text{SD pooled}}$$

Values for ES were defined as trivial (<0.2), small (0.2–0.6), moderate (0.6–1.2), large (1.2–2.0), and very large >2.0 [29]. Results for each outcome variable are presented with number of observations (N) of Δ% and ES calculated within the review. All data analysis was processed using Sigma Stat 3.5 software (Systat, Inc, USA). Mean percentages of change at different time points extracted from all studies were presented as mean (Range: minimum and maximum) for all parameters. The ES and Δ% were analyzed in studies where sufficient data was available. A significant difference was indicated when the 95% confidence interval

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(CI) of the ES did not overlap with zero. In addition, the relationships between Δ% of PVV and Δ% of physical/physiological performance were assessed where sufficient data was available using Pearson's product-moment correlation coefficients (r). The magnitude of correlation coefficients were considered as trivial ($r < 0.1$), small ($0.1 < r < 0.3$), moderate ($0.3 < r < 0.5$), large ($0.5 < r < 0.7$), very large ($0.7 < r < 0.9$), nearly perfect ($0.9 < r < 1.0$), and perfect ($r = 1.0$) [40]. Statistical significance for all analyses was set at $p < 0.05$.

Results

Overall, our search identified 3349 records (figure 1). After screening of titles, abstracts and full texts, 30 studies were included in our final analysis. Table 2 illustrates characteristics of the 9 acute and 21 long-term studies. The 15 acute studies [16, 19, 21-22, 33, 41-50] were performed in 6 different countries (France, Japan, Canada, Brazil, United States and United Kingdom) and involved 269 participants. Different kinds of exercise activities (walking, cycling and running) with different durations (30s to >1 h) and intensities (maximal and supramaximal) were used.

Insert table 2 here

The 25 included long-term studies were classified as 'high-quality' studies (mean 6.7 in the PEDro scale score), and only six studies were classified as 'low-quality' study (mean 3.8 in the PEDro scale score) [1,4 8-49, 51, 52, 53] (Table 3). A total of 474 participants underwent exercise-training programs and completed the studies. The 25 long-term studies were carried out in different countries from five continents (Australia, France, Sweden, United Kingdom, Japan, Poland, Qatar, Switzerland, Denmark, Austria, Tunisia, Iran, Germany and USA). Nine studies investigated both male and female subjects, 15 studies investigated male subjects and 1 study involved only women [54]. Fifteen studies investigated healthy trained participants and 10 involved untrained individuals. The training duration was at least 5 to 8 days [53, 55, 56], for several studies it was around between 3 and 8 weeks, for some studies it was around 3 months and for one study the duration was 6 months [57].

Insert table 3 here

Table 4 summarizes the acute effects of exercise on PVV in trained and untrained individuals. Five studies [16, 33, 42, 44-45] were identified that examined the acute effects of exercise on

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PVV in moderately trained subjects. Two studies [19, 22] involved highly trained endurance and sprint athletes. Despite the status of participants and the exercise duration or intensity, all the studies reported significant decrease of PV (effect size: 0.85<d<3.45, very large). The decreases were ranged between 7% [33] and 19.9% [19]. Only one study [41] observed an increase (+7.3%) of PV after 28-mile walk in hill walkers.

Insert table 4 here

Ten studies investigated the effect of long-term training on PVV in healthy untrained men and women (Table 5). Most of studies reported significant increase of PV in response to different kind of training including endurance training and HIIT (effect size: 0.19<d<3.52, small to very large). The increase was ranged from 6.6% [58] to 16% [59]. The study of Mtinangi and Hainsworth [60] investigated the effect of 3 months of a combination of strength and endurance training in both men and women and reported an increase of 230 mL of PV (effect size: 1.58, very large). However, Green et al. [61] reported 10% increase of PV after 8 weeks of cycling at 62% $\dot{V}O_{2max}$ (2 h/d) in men (effect size: 2.71, very large). In untrained individuals, there was no significant correlation between change in %PVV and change in physical/physiological performance.

Insert table 5 here

Table 6 depicted the 15 studies that investigated the effects of long-term exercise training PVV in trained individuals. Seven studies observed a significant increase of PV (4.6% to 10%; effect size: 0.15<d<1.35, small to large) in moderately or highly trained individuals, men and women in response to endurance training [34, 55, 62, 63], HIIT [16, 33] and combined training [43]. Three studies observed no significant changes of PV in response to an interval walking training (5 sets at high intensity (>70% $\dot{V}O_{2peak}$) and slow at 40% $\dot{V}O_{2peak}$) in active men and women [45], or to sprint training in untrained men [57], or to endurance altitude training (21 nights simulated live high at 3000m) in men and women endurance trained athletes [63], or to HIIT at 90–95 % HR_{max} in well-trained sport students [64] (effect size: 0.22<d<2.79, small to large) or to weightlifting in trained men [65] and to altitude training in men and women world class endurance athletes [66]. Two studies reported a significant decrease of PV in response to combined training in track and field 400M athletes [1] and in response to 21 days of endurance altitude training camp in international level road cyclists [10] (effect size: 0.84<d<1.00, large).

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In trained individuals, there was no significant correlation between change in %PVV and change in physical/physiological performance.

Insert table 6 here

Discussion

To the best of our knowledge, the current review is the first systematic review aiming to study the effects of acute exercise and long-term exercise training on plasma volume variations levels in untrained and trained individuals. The results showed that acute exercise appears to induce a significant decrease of PV in both healthy untrained and trained individuals in response to several kind of exercise activities. Moreover, there is evidence that long-term exercise training induces a significant increase of PV in healthy untrained individuals. However, there is no consensus concerning the effect of long-term exercise training on PV in trained individuals.

Recently, only Sawka et al. [15] in their review examined critically the influence of several perturbations (physical exercise, environmental (heat, terrestrial altitude, microgravity, stress, and trauma/sickness) on blood volume. They found that blood volume changes occur with adaptations to physical exercise, environmental stresses, and trauma/illness [15]. More specifically, these authors showed that blood volume increases over time with exercise training and that PV expansion can occur within 24 h and during the first 2 weeks of exposure accounts for nearly all of the blood volume expansion response [15]. However, Sawka et al. [15], the authors did not take into account neither the individual status (trained vs. untrained) nor the duration of exercise (acute exercise vs. long-term exercise training).

Consistent reports on the effect of acute exercise on PVV have been shown, where, despite the status of participants and the exercise duration or intensity, significant decreases of PV are demonstrated [16, 19, 21, 22, 33, 43, 44, 50]. In adult male subjects, Berthoin et al. [21, 50] and Zouhal et al. [19] reported a significant reduction in PV from baseline after very strenuous exercise. Several factors such as gender [20], age [21] and the level of training of subjects [22] influence the amplitude of the PVV. For all these factors, it seems that the intensity of exercise plays a major role in this decrease. For example, Berthoin et al. [49] reported in adult men a maximum fall of 17.2±3.5% following a supramaximal exercise at 120% of maximal aerobic speed (e.g., velocity eliciting maximal oxygen uptake). These values are slightly higher than those observed in other studies such as that of Hebestreit et al. [50] who found in male physical

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education and sports students, three minutes after a 30-second Wingate exercise, a 16% drop in PV. However, Zouhal et al. [19] indicated that the level of training also affects the magnitude of the PVV. These last authors measured a maximum fall of -19.97±3.05% in athletes specialized in sprinting, -9.45±3.05% in endurance athletes and -9.05±3.31% in sedentary subjects after a 30 second Wingate. Moreover, Derbré et al. [57] measured a maximum fall of -9% in adolescents after a 6-second sprint test carried out on an ergometric bicycle. Accordingly, the values of PVV did not differ before and after training, and even after detraining.

The aging process impairs balance of fluids and electrolytes [67, 68], leading to reduced PV among elderly individuals [69]. Intensity dependent PV losses have been reported in response to exercise lasting 6 min [70] and 20 min [71] and changes of similar magnitude have been previously reported following sprinting [67, 72-75]. Moreover, changes (12.5%) in PV post-warmup were followed by a further 5.5% PV reduction immediately post-sprint, reinforcing the potential influence of intensity of exercise on PV change. Although the literature is sparse with respect to the effect of duration of maximal-intensity exercise on PV change, Stokes et al. [76] reported larger decreases in PV 5 min after a 30-s sprint (14.8%) when compared with a 6-s sprint (5.1%). Finally, 20 min after this exercise (sprinting), PV losses were still evident. The persistence of reductions in PV during recovery from sprinting is probably related to water movements into previously exercised muscles [77] probably due to sustain vasodilation [78-80] and is consistent with other studies adopting similar exercise protocols [72, 76].

According to the majority of reports, the hemoconcentration observed after acute exercise is influenced by several factors: 1.) Sweating induced fluid loss, which plays an essential role in moderate-long duration endurance exercise [81-82], however, it is likely not implicated in sprinting exercise; 2.) The increase in hydrostatic pressure, secondary to the rise in blood pressure which promotes extravasation of water out of the capillaries [83-84]; 3.) An increase in osmotic pressure, secondary to the accumulation of metabolic by-products (H^+ ions, lactate, ammonium, K +, etc.) especially following sprint exercise [85]; and, 4.) The response of the hormones that control the electrolyte balance including aldosterone (ALD), antidiuretic hormone (ADH) and atrial natriuretic factor (ANF) [85].

Jabbour et al. [86] showed that after HIIT, the acute PVV decreased were attenuated compared to those observed before HIIT program. Mtinangi and Hainsworth [60] showed that PVV increased after 2–3 months of exercise training using the 5BX/XBX Royal Canadian Air Force program. In this context, Jabbour et al. [86] showed less change in PV in response to a warm-

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up after HIIT. Similar results have been reported in response to long-term or relatively short-term continuous exercise training [53, 62, 87, 88]. Convertino et al. [53] showed that PVV increase by +12% after 8 days of graded training on ergometer cycle at 65% $\dot{V}O_{2max}$. Similarly, Carrol et al. [87] showed that PVV increases by +11% after endurance training for 26 weeks at 40-80% HR_{max}. Recent studies have shown also significant increase in PVV by 8% after HIIT cycling at 40-50% HR [77], by+16% after endurance training at 50-70% of maximal aerobic velocity (MAV) [59] and by +6% after cycling exercise training at 60-75% $\dot{V}O_{2peak}$ [58].
Most studies showing PV increases have been conducted in physically fit populations (i.e., athletes, active subjects) and they have evaluated the training effects on PV variations reported a significant increase in PV in response to exercise [77]. According to Mtinangi and Hainsworth [60], subjects that had higher initial plasma and blood volumes and (i.e., if the peak recorded oxygen uptake is regarded as a measure of fitness), would also the fittest subjects before starting to train. However, the increase in PV has been proposed as a risk factor that could worsen the symptoms of hypertension by increasing the mean circulatory filling pressure due to decreased total vascular compliance, and increasing venous rerun to the heart/cardiac output, resulting in the renal adaptation and an upward shift of the set point of arterial pressure [60].

Silva et al. [89] showed that PV decreased by 11.2% after 12 weeks of specific soccer training and was significantly correlated to the alteration percentage of Hb and Hct changes. In contrast, Heisterberg et al. [90] recorded no significant changes in Hb and Hct levels over a 6-months period in which the training and match load varied considerably. Indeed, PV measured after a 6-week period of match congestion was significantly higher (+ 6.1%).
Gibala et al. [91] showed that a short-training period involving high intensity intermittent exercises may result in significant variations of PV. Green et al. [92] showed that PV increased by 11.6% in response to three consecutive days of intermittent supramaximal interval cycling exercise in moderately trained subjects. According to data provided by Mtinangi and Hainsworth [60], significant increases in PV were reported after 2–3 months of exercise training using the 5BX/XBX Royal Canadian Air Force program. Furthermore, Alis et al. [93] reported higher PV loss in response to high intensity training protocol for 10 healthy men compared to aerobic running exercise. It has been shown that high intensity training results in a sufficient decrease in PV to increase plasma constituent concentrations [86]. Two main mechanisms may explain the increase in PV with training. The first, of two phases, occur with plasma proteins increases, especially albumin [94]. In fact, when plasma protein concentration increases, the oncotic pressure increases, and fluid is reabsorbed from the interstitial fluid into the blood

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vessels [53, 85, 94]. Thus, the increase of plasma albumin is responsible of the first phase of rapid PV increase, which occurs after the first hour of recovery from an exercise training session [89]. During the second phase, protein synthesis is upregulated by repeated exercise exposure, and new plasma proteins are formed. The second mechanism is the secretion of hormones that cause reabsorption of water and sodium in the kidneys, which increases blood plasma, namely antidiuretic hormone and aldosterone [53, 85, 94]. The oncotic pressure exerted by the proteins keep this increased fluid in the vascular space. Nearly all of the increase in blood volume during the first 2 weeks of training can be explained by this increase in plasma volume [53, 85, 94].
It has been demonstrated that the enhancement of aerobic exercise performance is associated with an increase in BV, which consists in a PV increase [8, 15, 53, 95-98]. Carroll et al. [87] showed a significant increase of PVV accompanied by an increase of $\dot{V}O_{2max}$ (+11.2%) after 26 weeks of endurance training program. Gibala et al. [96] showed that 3 to 6 of HIIT sessions for 2 weeks could significantly increase endurance performances.

More recently, Ben Abderrahaman et al. [33] showed a significant increase of $\dot{V}O_{2max}$ and MAV and a significant correlation after HIIT between PVV and (i) $\dot{V}O_{2max}$ ($r = 0.76$) and (ii) MAV ($r = 0.60$). Kataoka et al. [58] showed that PVV increased by +6% after cycling exercise training at 60-75% $\dot{V}O_{2peak}$ accompanied by +13% of improvement in $\dot{V}O_{2peak}$ performances. In addition, Jabbour et al. [78] showed that PVV increased by +8% after HIIT cycling at 40-50% HR. Montero et al. [59] showed that PVV increased by +16% after endurance training at 50-70% MAV accompanied by +11% of MAV performances improvement. Similarly, Rhibi et al. [16] showed a significant correlation after HIIT between PVV and TTE. In contrast, several studies conducted with endurance athletes and soccer players showed significant negative correlations between Hct and measures of physical fitness, suggesting increased performance with a decreasing Hct value [98-99]. In fact, changes in PV independent of Hb have more complicated effect on both $\dot{V}O_{2max}$ and endurance performance due to the concomitant hemodilution effect [16, 90].

Limitations

The limitation of the current review is that several studies dealing with the effect of a long-term exercise training on PVV used the indirect method (e.g., Dill and Costill method [36]). The indirect methods available have clear disadvantages when judging PV change because RCV and the number of erythrocytes cannot assumed to be constant. The method described by Dill and Costill can be accurate for acute exercise responses but not for a long-term exercise training effects. In fact, Dill and Costill's description of the RCV-space assumes an unaltered number

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of erythrocytes in the circulation which can hardly be expected in the long-term exercise training. Thus, this is a clear limitation of the Dill and Costill method. Most certainly more studies using more accurate and precise methods to describe PVV after long-term exercise training are needed.

Conclusion

This systematic literature review demonstrates that acute exercise appears to induce a significant decrease of PV in both healthy untrained and trained individuals in response to several kinds of exercises. Furthermore, there is evidence to suggest that long-term exercise training can also induce a significant increase of PV in healthy untrained individuals. However, there is currently no consensus concerning the effect of long-term exercise training on PV in trained individuals. Therefore, further studies are needed to investigate the effects of long-term exercise training on PV in highly trained athletes, especially those associated with high intensity endurance training, sprint training, strength training.

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Table legends:

Table 1: Inclusion criteria according to the PICOS approach.

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Table 2. Characteristics of the studies that examined the acute and long-term effects of exercise training on plasma volume in healthy untrained and trained individuals.

MAV: velocity; s: maximal aerobic second; MAP: maximal aerobic power; HR: hear rate.

Table 3: Physiotherapy evidence database (PEDro) score of the included acute and long-term studies.

Table 4: Effect of acute exercise on plasma volume variation in trained and untrained individuals.

Hb: *Hemoglobin****; HIIT****: High intensity interval training;* ***Ht****: Hematocrit;* ***HR_{max}:*** *heart rate max;* ***MAV****: maximal aerobic velocity;* ***PV:*** *plasma volume;* ***PVV****: plasma volume variation;* ***Ht1****: resting value;* ***Ht_x*** *: value at the time of exercise;* ***d****: day;* ***$\dot{V}O_{2max}$****: maximal aerobic consumption;* ***$\dot{V}O_{2peak}$****: maximal oxygen uptake;* ***W:*** *week****.***

Table 5: Effect of long-term exercise training on plasma volume variation in healthy untrained individuals.

Hb: Hemoglobin; HIIT: High intensity interval training; Ht: Hematocrit; HR_{max}: heart rate max; MAV: maximal aerobic velocity; PV: plasma volume; PVV: plasma volume

variation; Ht1: resting value; Ht_x : value at the time of exercise; d: day; $\dot{V}O_{2max}$: maximal aerobic consumption; $\dot{V}O_{2peak}$: maximal oxygen uptake; W: week.

Table 6: Effect of long-term exercise training on plasma volume variation in trained individuals.

Hb: Hemoglobin; HIIT: High intensity interval training; HIIR: high-intensity interval running; Ht: Hematocrit; MAV: maximal aerobic velocity; BV: blood volume; $\dot{V}O_{2peak}$: maximal oxygen uptake; PVV: plasma volume variation; h: hour; d: day; W: week; PV: plasma volume; HR_{max}: heart rate max; Ht1 = resting Ht (original% Ht); Ht2 = Ht exercise (% final Ht); tHb: Total hemoglobin mass; $\dot{V}O_{2max}$: maximal aerobic consumption; TTE: time to exhaustion during intermittent exercise; P_{peak}: power peak; NC: no change; SJ: squat jump.

Figure legends:

~~**Figure 1:** Different factors affecting the plasma volume variations.~~

Figure 1: Selection process for research articles (n = 21) included in this systematic review. Adapted version of the recommendations in the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) statement [35].

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Table 1: Inclusion criteria according to the PICOS approach.

PICOS components	**Details**
Population	Trained and healthy untrained humans
Intervention	Acute and long-term exercise training
Comparator	Active and passive controls
Outcomes	Measures of plasma volume variations (VVP), physical fitness (e.g. aerobic performance [VO_{2max}], anaerobic performance), physiological responses (e.g., maximal oxygen uptake [VO_{2max}]), and hematological parameters (hematocrit, hemoglobin, blood volume)
Study Design	Randomized controlled trials and controlled trials

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Table 2. Characteristics of the studies that examined the acute and long-term effects of exercise training on plasma volume in healthy untrained and trained individuals.

Study	PEDro scale	Year	Country	Gender / Status	Sample size	Age, years (mean ± SD or range)	Exercise & Training characteristics	Duration
Acute studies								
Sellami et al. [43]		2019	France	Men, women / Moderately trained	36	20.8 ± 0.2	Running-based anaerobic running test	
Sellami et al. [44]		2021	France	Men / Moderately trained	28	40.9±2.1	Wingate test, 30s	
Rhibi et al. [16]		2019	France	Men / Moderately trained	39	21.9±1.3	Intermittent exercise	
Uchida et al. [45]		2018	Japan	Men and women /active subjects	27	68.2 ± 1.0	Graded cycling test	
Pereira et al. [46]		2017	Brazil	Men / runners	14	29±4	21.1 km road race	
Tsampoukos et al. [47]		2014	United Kingdom	Women / University sport players	8	23.6 ± 1.8	Maximal 30s sprint	
Ben Abderrahman et al. [33]		2013	France	Men / Moderately trained	15	21.1 ± 1.1	Maximal graded test	
Zouhal et al. [19]		2007	France	Men / Endurance and sprinters highly trained	18	21.2 ± 0.7	Wingate test, 30s	
Moussa et al. [22]		2003	France	Men / Sprinters Endurance highly trained	21	21.1 ± 0.6	Wingate test, 30s	
Berthoin et al. [48]		2000	France	Male	8	Unable to access	maximal exercise and Supra maximal Exercise	
Berthoin et al. [49]		2002	France	Male	16	Unable to access	Incremental and maximal exercise	
Berthoin et al. [21]		2003	France	Male Adult, Children	17	Adult 21.9±1.9 Children 11.3±1.1	maximal exercise and Supra maximal Exercise	
Hebestreit et al. [50]		1996	Canada	Active Boys and adult	10	Adult 24.9±4.9 Children 9.6±0.9	High Intensity Exercise	
Pugh [41]		1996	United Kingdom	hill walkers	6	NM	28-mile walk	
Gillen [42]		1985	USA	Active subjects	6	17-23	Eight 4-min bouts of exercise at 85% maximal O2 uptake with 5-min recovery periods between bouts.	
Long-term studies								
Skalenius et al. [1]	4	2019	Sweden	Men / 400 m athletes	23	20.9±2.3	Training camp (Aerobic exercises, sprint, jumping, strength and agility)	3 weeks

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Sitkowski et al. [10]	6	2018	Poland	Men, women / International road cyclists	32	20.3±2.6	Endurance altitude training (training camp)	21 days
Rhibi et al. [16]	7	2019	France	Men / moderately trained	39	21.9±1.3	HIIT (100%-110% MAV)	8 weeks
Ben Abderrahman et al. [33]	7	2013	Tunisia	Men / Moderately trained	15	21.1±1.1	HIIT (100-110% MAV)	7 weeks
Saidi et al. [34]	7	2019	France	Men / Soccer players	18	20.1 ± 0.4	Continuous running, HIIR and specific soccer training	6 weeks
Sellami et al. [44]	7	2020	France	Men / Moderately trained	28	40.8 ± 1.9	Combined sprint and resistance training	13 weeks
Uchida et al. [45]	7	2108	Japan	Men and women / Active	27	68.2± 1.0	Interval walking training	5 weeks
Stephenson [55]	6	2019	United Kingdom	Men and Women / para-triathletes and triathletes	29	28.0 ± 8.0	Endurance training	8 days
Derbré et al. [57]	7	2009	France	Men / without sprint training experience	12	14.8 ±0.3	Sprint training program	6 months
Kataoka et al. [58]	7	2016	Japan	Men, women /untrained	21	69.0±1.0	Cycling exercise training	8 weeks
Montero et al. [59]	5	2017	Switzerland	Men, women /untrained	9	27.0±4.0	Endurance training (50-70% MAP)	8 weeks
Mtinangi and Hainsworth [60]	5	1999	United Kingdom	Men, women / untrained	11	40.0 ± 0.1	Strength and endurance training	3 months
Green et al. [61]	4	1991	USA	Men / untrained	8	21.3±1.4	Cycling (62% MAV)	8 weeks
Branch et al. [54]		. 1988	USA	Women/ Untrained	26	32±5	Treadmill training or cycle training 3-5 times / week at 80% VO2max	12 weeks
Bejder et al. [62]	5	2017	Denmark	Men / well trained cyclists	11	23.0±5.0	Endurance training	3 weeks
Lobigs et al. [63]	3	2018	Australia	Men and women / Trained endurance athletes	34	29.0 ± 7.7	Endurance altitude training	21 days
Menz et al. [64]	7	2015	Austria	Men, women / Well trained sport students	35	25.5±2.5	HIIT (90–95% HR_{max})	3 weeks
Jabbour et al. [86]	5	2017	Qatar	Men, women /untrained	30	38.0 ± 3.0	HIIT	6 weeks
Tayebi et al. [65]	7	2010	Iran	Men / Trained weight-lifters	40	Data unavailable	Weightlifting	1 month
Heinicke et al. [66]	5	2005	Germany	Men, women / endurance athletes	10	26.0 ±3.5	Altitude training at 2050 m	3 weeks
Carroll et al. [87]	7	1995	USA	Men, women / untrained	38	67.5±5.2	Endurance training	26 weeks
Convertino et al. [53]	4	1983	USA	Men / untrained	4	22.0 ±2.0	Graduate training on ergometer cycle (65% MAV)	8 days
Bonne et al. [100]		2014	Sweden	Men / untrained	9	27 ± 3	60 min; 4 times weekly at 65% $\dot{V}_{O2max}$ for 6 wk	6 weeks
Schmidt et al. [101]		1988	Germany	Men/ untrained	6	23.6±2.3	Ergometer training 5 times a week for 45 min	3 weeks

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Scumacher et al. [102]		2008	Germany	Men/ Elite cyclist	7	20.6±1.05	Endurance training, stage races	Five-day professional cycling stage race

Abbreviations:

HR: hear rate; **MAV**: maximal aerobic velocity; **MAP**: maximal aerobic power; **s**: second; **NM:** not measured.

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Table 3: Physiotherapy evidence database (PEDro) score of the included acute and long-term studies.

Study	Yea	Eligibility criteria	Randomized allocation	Blinded allocation	Group Homogeneity	Blinded subjects	Blinded therapists	Blinded assessor	Drop out \15 %	Intention To treat analysis	Between-group Comparison	Point estimates and variability	PEDro Score
Long-term Studies													
Skalenius et al. [1]	2019	●	○	○	○	○	○	●	●	○	○	●	4
Sitkowski et al. [10]	2018	●	○	○	●	○	○	●	●	○	●	●	6
Rhibi et al. [16]	2019	●	●	○	●	○	○	●	●	○	●	●	7
Berthoin et al. [21]	2003	●	○	○	●	○	○	●	●	○	○	●	5
Ben Abderrahman et al. [33]	2013	●	●	○	●	○	○	●	●	○	●	●	7
Saidi et al. [34]	2019	●	●	○	●	○	○	●	●	●	○	●	7
Sellami et al. [43]	2020	●	●	○	●	○	○	●	●	○	●	●	7
Uchida et al. [45]	2108	●	●	○	●	○	○	●	●	○	●	●	7
Berthoin et al. [48]	2000	●	○	○	○	○	○	●	●	○	○	●	4
Berthoin et al. [49]	2002	●	○	○	○	○	○	●	●	○	○	●	4
Hebestreit et al. [50]	1996	●	○	○	●	○	○	●	●	○	○	●	5
Stephenson [56]	2019	●	○	○	●	○	○	●	●	○	●	●	6
Derbré et al. [57]	2009	●	●	○	●	○	○	●	●	○	●	●	7
Kataoka et al. [58]	2016	●	●	○	●	○	○	●	●	○	●	●	7
Montero et al. [59]	2017	●	○	○	●	○	○	●	●	○	○	●	5
Mtinangiand Hainsworth [60]	1999	●	○	○	●	○	○	●	●	○	○	●	5
Green et al. [62]	1991	●	○	○	○	○	○	●	●	○	○	●	4
Branch et al. [54]	1999	●	●	○	●	○	○	●	●	○	●	●	7
Bejder et al. [62]	2017	●	○	○	●	○	○	●	●	○	○	●	5
Lobigs et al. [63]	2018	●	○	○	●	○	○	○	○	○	○	●	3
Menz et al. [64]	2015	●	●	○	●	○	○	●	●	○	●	●	7
Jabbour et al. [86]	2017	●	○	○	●	○	○	●	●	○	○	●	5
Tayebi et al. [65]	2010	●	●	○	●	○	○	●	●	○	●	●	7
Heinicke et al. [66]	2005	●	○	○	●	○	○	●	●	○	○	●	5
Carroll et al. [87]	1995	●	●	○	●	○	○	●	●	○	●	●	7
Convertino et al. [53]	1983	●	○	○	○	○	○	●	●	○	○	●	4
Bonne et al. [100]	1996	●	●	○	●	○	○	●	●	○	●	●	6
Schmidt et al. [101]	1988	●	○	○	●	○	○	●	●	○	●	●	6

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Scumacher et al. [102]	2008	●	●	○	●	○	○	●	●	●	○	●	7

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Table 4: Effect of acute exercise on plasma volume variation in trained and untrained individuals.

Study	Population (N/ sex /age)	Status	Acute exercise intervention	Methods of PV measure	Outcomes (% of change)	Effect size (d-Cohen)
Rhibi et al. [16]	39 /men / 21.9±1.3	Moderately trained	IE at 100% MAV IE at 110% MAV	PVV (%) = 100× (Hb1/Hb2) × ((1-Ht2×10⁻²)/(1-Ht1×10⁻²))-100	↓ (11.6%)	0.7
Zouhal et al. [19]	18/men/21.2 ± 0.7	Endurance and sprinters highly trained	Wingate test	PVV (%) = 100× (Hb1/Hb2) × ((1-Ht2×10⁻²)/(1-Ht1×10⁻²))-100	↓ (19.9%)	3.5
Berthoin et al. [21]	8 male and 9 prepubertal children	Physical education students and prepubertal children	maximal aerobic power and supramaximal exercise	PVV (%) = 100× (Hb1/Hb2) × ((1-Ht2×10⁻²)/(1-Ht1×10⁻²))-100	↓ (16.9)	1.5
Moussa et al. [22]	21/ men / 21.1 ± 0.6	Sprinters Endurance highly trained	Wingate test	PVV (%) = 100× (Hb1/Hb2) × ((1-Ht2×10⁻²)/(1-Ht1×10⁻²))-100	↓ (18.3%)	2.4
Ben Abderrahman et al. [33]	15/men / 21.1 ± 1.1	Moderately trained	Maximal graded test	PVV (%) = 100× (Hb1/Hb2) × ((1-Ht2×10⁻²)/(1-Ht1×10⁻²))-100	↓ (7.0%)	0.3
Pugh [41]	6 subjects	Hill walkers	28-mile walk	Determined from blood volume and Ht	↑ (7.3%)	NA
Gillen [42]	6 men (17-23)	Active subjects	Eight 4-min bouts of exercise at 85% maximal oxygen uptake with 5-min recovery periods between bouts.	PV was determined using the Evans blue dye dilution	↓ (15.0%)	NA
Sellami et al. [43]	28 / men / 21.2±1.2 / 40.9±2.1	Moderately trained	Wingate test	PVV (%) = 100× (Hb1/Hb2) × ((1-Ht2×10⁻²)/(1-Ht1×10⁻²))-100	↓ (12.7%)	0.8
Sellami et al. [44]	36 / men, women / 20.8±0.2	Moderately trained	Running-based anaerobic running test; six 35-m sprints with 10 s of recovery in-between.	PVV (%) = 100× (Hb1/Hb2) × ((1-Ht2×10⁻²)/(1-Ht1×10⁻²))-100	↓ (12.6%)	1.3

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Uchida et al. [45]	27/ men, women/ 68.2±1.0	Active subjects	Graded cycling test	The PV was determined using the Evans blue dye dilution method	↓ (12.5%)	2.8
Pereira et al. [46]	14 / men /29.0 ±4.0	Runners	21.1 km road race	Not mentioned	↓ (9.8%)	1.4
Tsampoukos et al. [47]	8 /women/23.6 ± 1.8	University sport players	Maximal 30 s sprint	PVV (%) = 100× (Hb1/Hb2) × ((1-Ht2×10 $^{-2}$)/(1-Ht1×10^{-2}))-100	↓ (17.4%)	2.2
Berthoin et al. [48]	8 male adults	Active subjects	Maximal and supra maximal exercise	PVV (%) = 100× (Hb1/Hb2) × ((1-Ht2×10 $^{-2}$)/(1-Ht1×10^{-2}))-100	↓ (17.4%)	2.8
Berthoin et al. [49]	16 male adults	Active Subjects	Incremental and maximal exercise	PVV (%) = 100× (Hb1/Hb2) × ((1-Ht2×10 $^{-2}$)/(1-Ht1×10^{-2}))-100	↓ (3.8%)	0.5
Hebesrteit et al. [50]	5 boys and 5 male adults	Moderate to highly active	Wingate test	PVV (%) = 100× (Hb1/Hb2) × ((1-Ht2×10 $^{-2}$)/(1-Ht1×10^{-2}))-100	↓ (15.0%)	1.4

Abbreviations:

MAV: maximal aerobic velocity; **PVV**: plasma volume variation; **Ht1**: resting value; **Ht_x**: value at the time of exercise; **W:** week, ↓: decrease.; ↑: increase; **NA:** not available.

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Table 5: Effect of long-term exercise training on plasma volume variation in healthy untrained individuals.

Study	Population (N/ sex /age)	Training intervention	Methods of PV measure	PVV (% of changes; d-Cohen)	Physical performances and physiological outcomes (%changes; d-Cohen)
Kataoka et al. [58]	21 / men, women /69.0±1.0	Cycling exercise training: 3 sessions per week. Session of 60 min at 60 – 75% of VO_{2peak}	PV was determined using the Evans blue dye dilution method	↑ (6.6 %; 0.9)	+12.8% (2.2) $\dot{V}O_{2peak}$
Montero et al. [59]	9 / men, women / 27.0±4.0	Endurance training at 50 to 70 % MAV	PVV (%) = 100 × [(Hb1/Hbx) × (100 − Htx)/(100 −Ht1)] − 1.	↑ (16%; 0.3)	+11.4 % (0.4) $\dot{V}O_{2max}$
Mtinangi and Hainsworth [60]	11 / men, women / 40.0 ±0.1	Strength and endurance training	PV was determined using the Evans blue dye dilution	↑ (230 ml; 1.6)	Data unavailable
Green et al. [61]	8 / men / 21.3 ± 1.4	Cycling 62% VO_{2max} (2 h/d)	Red cell mass measured by Cr-labeled RBC and PV by 1-labeled human serum albumin	↑ (10%; 2.7)	+17.2% (1.9) $\dot{V}O_{2max}$
Branch et al. [54]	26 / women / 32 ± 5	Treadmill training or cycle training 3-5 times / W at 80% VO2max during 12 W	PV was determined using the Evans blue dye dilution	↑ (6 %) cycle training ↓ (5 %) treadmill training	NM
Jabbour et al. [86]	30 / men, women /38.0 ±3.0	HIIT cycling at 40-50% HR_{max}	PVV (%) = 100× (Hb1/Hb2) × ((1-Ht2×10 $^{-2}$)/(1-Ht1×10^{-2}))-100	↑ (8.4%; 0.2)	NM
Carroll et al. [87]	38 / men, women/ 67.5±5.2	Endurance training (uphill treadmill walking) for 26 weeks: 1W-4W: 40-50% HR_{max} 5W-W14: 60-70% HR_{max} >15W: 75-80% HR_{max}	PV was determined using the Evans blue dye dilution	↑ (+11.2%; 3.5)	+11.2% (0.5) $\dot{V}O_{2max}$
Convertino et al. [53]	4 / men / 22.0 ± 2.0	Graduate training on ergometer cycle at 65% VO_{2max} (2h/d)	PVV (%) = 100× (Hb1/Hb2) × ((1-Ht2×10 $^{-2}$)/(1-Ht1×10^{-2}))-100	↑ (12.3%; 0.3)	+11.2% (1.9) $\dot{V}O_{2max}$
Bonne et al. [100]	9 / men / 27 ± 3	60 min; 4 times weekly at 65% VO_{2max} for 6 W	PVV (%) = 100× (Hb1/Hb2) × ((1-Ht2×10 $^{-2}$)/(1-Ht1×10^{-2}))-100	↑147 ± 168 ml (5 ± 5%)	+10 ± 7% $\dot{V}O_{2max}$
Schmidt et al. [101]	6 / men / 23.6 ± 2.3	Three weeks ergometer training 5 times a week for 45 min	PV was determined using the Evans blue dye dilution	↑ (13%; 0.9)	+10% (1.1) $\dot{V}O_{2max}$

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Abbreviations:

Hb: Hemoglobin**; HIIT**: High intensity interval training; **Ht**: Hematocrit; **HR_{max}:** heart rate max; **MAV**: maximal aerobic velocity; **NM:** not measured; **NC:** no change; **PV:** plasma volume; **PVV**: plasma volume variation; **Ht1**: resting value; **Ht_x**: value at the time of exercise; **d**: day; **$\dot{V}O_{2max}$**: maximal aerobic consumption; **$\dot{V}O_{2peak}$**: maximal oxygen uptake; **W:** week**.**

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Table 6: Effect of long-term exercise training on plasma volume variation in trained individuals.

Study	Population (N/ sex /age)	Status	Training intervention	Methods of PV measure	PVV (% of changes; d-Cohen)	Physical performances and physiological outcomes (%changes; d-Cohen)
Skalenius et al. [1]	23/men/20.9±2.3	400 m athletes	Aerobic exercises, speed endurance, short sprint, jumping, strength, core and agility exercises	PVV (%) = 100× (Hb1/Hb2) × ((1-Ht2×10⁻²)/(1-Ht1×10⁻²))-100	↓ (4.5 %; 1.0)	-2.0% (0.6) 300m sprint test
Sitkowski et al. [10]	32 / men, women / 20.3±2.6	International level road cyclists	21 days of endurance altitude training camp	PV were determined by optimized carbon monoxide (CO) re-breathing method	↓ (0.3 L; 0.8)	NM
Rhibi et al. [16]	39 / men / 21.9±1.3	Moderately trained	HIIT at 100% MAV and 110% MAV)	PVV (%) = 100× (Hb1/Hb2) × ((1-Ht2×10⁻²)/(1-Ht1×10⁻²))-100	↑ (8.0%; 0.7)	+32.5% (2.0) TTE
Ben Abderrahman et al. [33]	15 / men / 21.1±1.1	Moderately trained	HIIT at 100% -110% MAV	PVV (%) = 100× (Hb1/Hb2) × ((1-Ht2×10⁻²)/(1-Ht1×10⁻²))-100	↑ (5%; 0.3)	+6.8% (0.4) $\dot{V}O_{2max}$
Saidi et al. [34]	18 / men /20.1 ± 0.4	Soccer players	Low/moderate intensity continuous running at 50–70% HR_{max} HIIR at 90–100% HR_{max})	PVV (%) = 100× (Hb1/Hb2) × ((1-Ht2×10⁻²)/(1-Ht1×10⁻²))-100	↑ (6.1%; 0.6)	+2.5% (0.5) SJ
Sellami et al. [43]	28/ men/ 21.2±1.2 / 40.9±2.1	Moderately trained	Combined sprint and resistance training (sprint cycling at 100% PMA, sprint running at 50%VMA and resistance exercise at 40-65% 1-RM)	PVV (%) = 100× (Hb1/Hb2) × ((1-Ht2×10⁻²)/(1-Ht1×10⁻²))-100	↑ (4.6%; 0.7)	+10.9% (1.1) $\dot{V}O_{2max}$
Uchida et al. [45]	27 / men, women / 68.2±1.0	Moderately trained	Interval walking training (5 sets at high intensity (>70% $V\dot{O}_{2peak}$) and slow at 40% $V\dot{O}_{2peak}$)	PV was determined using the Evans blue dye dilution method	NC	+1.9% (0.5) $\dot{V}O_{2peak}$
Stephenson [55]	29/ men, women / 28.0 ± 8.0	Para-triathletes and triathletes	Endurance training: 5 Heart rate-controlled sessions and 3 passive heat exposures	PVV (%) = 100× (Hb1/Hb2) × ((1-Ht2×10⁻²)/(1-Ht1×10⁻²))-100	↑ (12.7%; 1.5)	+4.5% (0.6) peak power output
Derbré et al. [57]	12 / men / 14.8 ±0.3	Without specific sprint training experience	Sprint training program	PVV (%) = 100× (Hb1/Hb2) × ((1-Ht2×10⁻²)/(1-Ht1×10⁻²))-100	NC	+10.69% (1.60) Peak power output
Bejder et al. [62]	11 / men / 23±5	Well trained cyclists	Endurance training [W1: 310 km (TRT11 h) + W2: ↑ 250% training volume +W3: 240 km (TRT8 h)]	Plasma volume (mL) = BV (mL) − Red cell volume (mL)	↑ (10%; 0.2)	NM
Lobigs et al. [63]	34 / men, women / 29.0 ± 7.7	Trained endurance athletes	Endurance altitude training (21 nights simulated live high at 3000m)	PVV (%) = 100× (Hb1/Hb2) × ((1-Ht2×10⁻²)/(1-Ht1×10⁻²))-100	NC	NM
Menz et al. [64]	35 / men, women / 25.5±2.5	Well-trained sport students	HIIT at 90–95 % HR_{max}	PVV (%) = 100× (Hb1/Hb2) × ((1-Ht2×10⁻²)/(1-Ht1×10⁻²))-100	NC	+3.5% (0.3) $\dot{V}O_{2max}$
Tayebi et al. [65]	40/ men / NM	Trained weight-lifters	Weightlifting (1 month with 3 sessions at 90 min per week)	PVV (%) = 100× (Hb1/Hb2) × ((1-Ht2×10⁻²)/(1-Ht1×10⁻²))-100	NC	NM

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Heinicke et al. [66]	10/ men, women / 26±3.5	World class endurance athletes	Altitude training at 2050 m: 4-6h per day for 6 days per week	PV= BV – Red cell volume • Red cell volume = tHb/Mean [Hb] ×100 • BV= Red cell volume×100/Ht	NC	NM
Scumacher et al. [102]	7/men 20.6±1.05	Elite cyclists	Stage races	Plasma volume (mL) = BV (mL) − Red cell volume (mL)	↑ 9.5%; 1.2)	NM

Abbreviations:

Hb: Hemoglobin**; HIIT**: High intensity interval training; **HIIR**: high-intensity interval running; **Ht**: Hematocrit; **MAV**: maximal aerobic velocity; **BV**: blood volume**;** $\dot{V}O_{2peak}$: maximal oxygen uptake; **PVV**: plasma volume variation; **h**: hour; **d**: day; **W**: week; **PV**: plasma volume; HR_{max}**:** heart rate max; **Ht1** = resting Ht (original% Ht); **Ht2** = Ht exercise (% final Ht); **tHb**: Total hemoglobin mass**;** $\dot{V}O_{2max}$: maximal aerobic consumption; **TTE**: time to exhaustion during intermittent exercise; **NM:** not measured; **NC**: no change; P_{peak}: power peak; **SJ**: squat jump.

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