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Hematological Changes in Response to a Drastic Increase in Training Volume in Recreational Cyclists

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HEMATOLOGICAL CHANGES IN RESPONSE TO A DRASTIC INCREASE IN TRAINING VOLUME IN RECREATIONAL CYCLISTS

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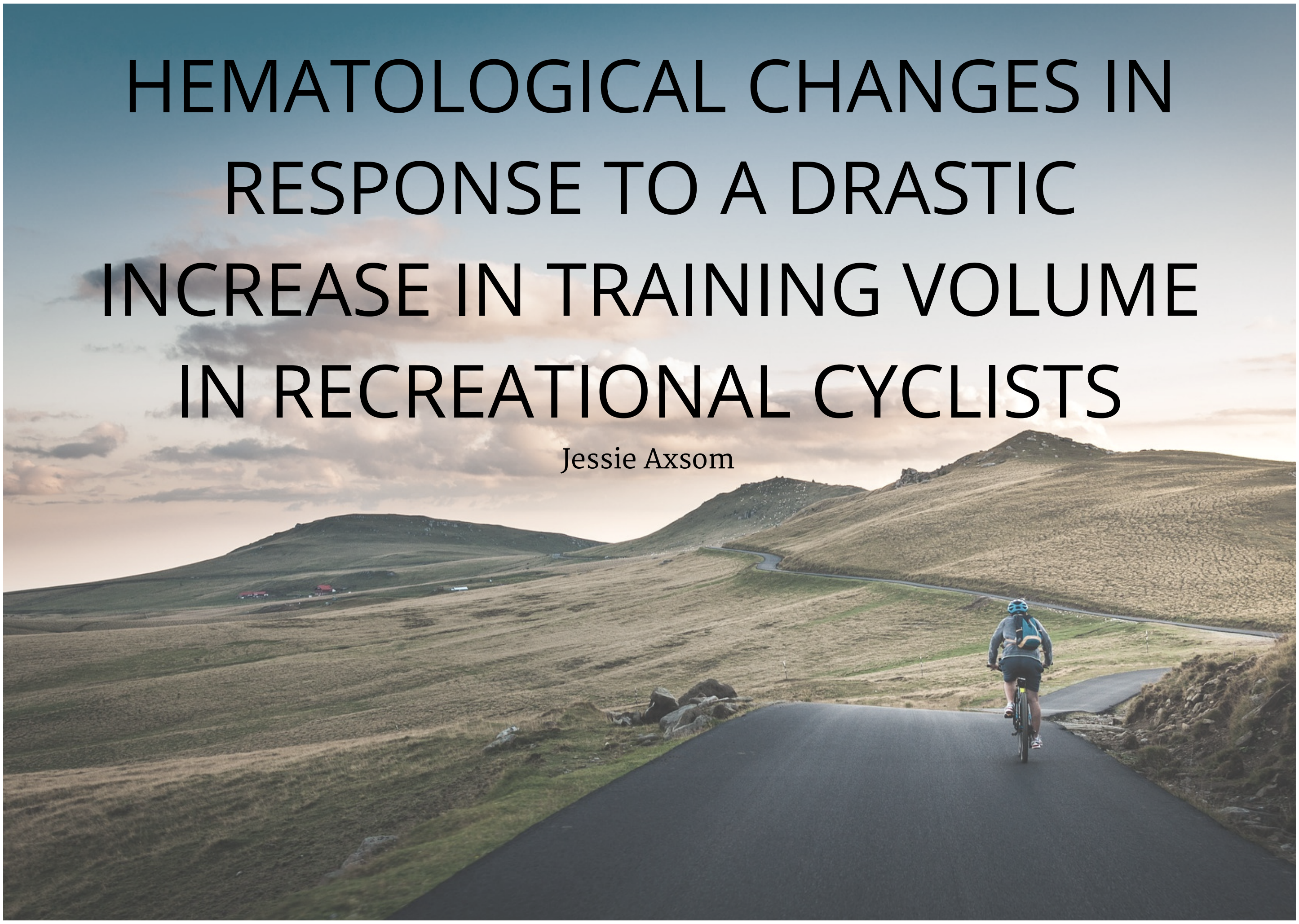

ABSTRACT

Changes in blood volume contribute to improvement in oxygen utilization (VO_2max) with chronic endurance exercise training. Although hematological changes resulting from long-term endurance training have been well documented, it has not been well established whether an increased volume of endurance training preferentially affects plasma volume or red blood cell volume. To answer this question, I studied seven female and four male recreational cyclists before and after exposure to drastic increases (632%) in training volume. Following the 10-week training period, the mean hematocrit (Hct) of the 11 subjects who completed the study significantly ($p<0.05$) increased from 42.9% to 48.45%. Mean hemoglobin (Hb) also increased significantly ($p<0.05$) from 14.6g/dL to 16.4 g/dL. The changes in Hct and Hb were not significantly ($p>0.05$) correlated with the change in self-reported weekly mileage (R = 0.13 and 0.16, respectively). Based on these findings, it appears that red blood cell volume expansion is a more significant contributor to improvement in VO_2max.

Endurance exercise training has been shown to have many physiological effects on the human body. When an individual completes a large volume of aerobic exercise, changes could include metabolic, endocrine, cardiovascular, neurological, and hematological adaptations. These adaptations are important to study as they have many implications for an individual's health span, or the amount of one's life spent in good health and at full function. Endurance exercise can help prevent diseases such as type 2 diabetes or cardiovascular disease, thus improving an individual's health span.

One of the best ways to measure if individuals have made improvements in their aerobic fitness after completing endurance exercise training is to measure the maximum volume of oxygen they can use. This measure, "VO_2max," is measured in milliliters per kilogram of body weight per minute. VO_2max helps show the ability of an individual to transport oxygen to working muscles during exercise. One factor that contributes to VO_2max is the volume of blood that helps deliver oxygen to these muscles. Blood can be divided into two general components: plasma and hematocrit (Hct). Plasma is mostly water-based liquid that blood cells and proteins are suspended in, and hematocrit is the ratio of erythrocytes (red blood cells) in relation to total blood volume. Hemoglobin (Hb) is the count of red blood cells in a given volume of blood.

Several previous studies have shown changes in blood volume contribute to improvements in VO_2max with extended endurance exercise training. This has been illustrated by the fact that endurance-trained athletes have higher blood volumes and VO_2max values than sedentary controls. Krip, Gledhill, Jamnik, and Warburton (1997) found that when comparing six trained male cyclists to six untrained males of similar age, the trained males had, on average, 16% greater total blood volume and a 54.4% higher VO_2max. When these untrained subjects were given a 500mL blood volume expansion using 6% Dextran 70 (Marcodex), VO_2max increased by 12.7% (Krip et al., 1997). Additionally, when the trained subjects underwent a 500mL reduction in blood volume, there was a significant decrease in VO_2max (7%) (Krip et al., 1997).

Similar results were found in several other studies; these studies all found that induced hypovolemic anemia (a reduction in blood volume and red blood cell count) by blood withdrawal decreased VO_2max (Buick, Gledhill, Froese, Spriet, & Meyers, 1980; Kanstrup & Ekblom, 1984). Furthermore, reinfusion of red blood cells following normocythemia (the return to normal red blood cell levels) results in a subsequent increase in VO_2max greater than pre-hypovolemia. (Buick et al., 1980; Kanstrup & Ekblom, 1984). These findings indicate a strong link between VO_2max and increases in blood volume and suggests oxygen transport mechanisms could contribute to limitations in maximal aerobic capacity. Overall, cross-sectional data has found endurance athletes possess 20–25% higher blood volumes than untrained subjects, regardless of age or gender (Convertino, 1991).

Research shows that shorter endurance training durations (roughly four weeks) yield blood volume increases that are attributed entirely to plasma volume expansion (Fortney & Senay, 1979). However, longer training durations (roughly eight weeks or more) show blood volume increases attributed to both plasma volume expansion and red blood cell expansion (Ray, Cureton, & Ouzts, 1990). Further evidence for these findings comes from two longitudinal studies. The first found that nine sedentary untrained females exposed to four weeks of stationary cycle exercise exhibited a 9% blood volume expansion, a 9.7% plasma volume expansion, and a 7% red cell volume expansion (Fortney & Senay, 1979).

The second found that when 16 sedentary men completed cycling training four d/wk, 40 min/d for eight weeks they showed a 8% blood volume expansion, 6% plasma volume expansion, and 11% red cell volume expansion (Ray et al., 1990). A literature review by Convertino (1991) observed that most expansions in blood volume plateaued after one week of training and almost all of the blood volume expansion at 10 days of training was attributed to increases in plasma volume. The average increase in blood volume in the longitudinal studies reviewed by Convertino was 7%.

Although hematological changes resulting from long term endurance training have been well documented, it has not been well established whether an increased volume of endurance training preferentially affects plasma volume or red blood cell volume. Additional research on the subject can have implications for understanding physiological changes occurring in athletes adapting to more rigorous training programs or moving from the recreational to elite level.

This study measures changes in the Hct and Hb of recreational cyclists as they undergo intense endurance training over the course of approximately 10 weeks. Because Hct is the ratio of red blood cells in relation to total blood volume, and Hb is the count of red blood cells in a given volume of blood, these measurements demonstrate if red blood cell volume expansion and plasma volume expansion have occurred. An increase in Hct suggests that red blood cell volume increased either exclusive of plasma volume or to a greater extent than plasma volume. A decrease in Hct suggests the converse. The purpose of this study was to determine if long-term endurance training has a greater effect on red blood cell volume or plasma volume. I hypothesized that subjects would exhibit a preferential increase in red blood cell volume.

METHODS

Potential participants in the study were identified by their involvement with the program "4k for Cancer." Individuals enrolled in this program undertook a 4,000 mile bicycle ride across the United States from June 1, 2015, to August 8, 2015 (approximately 70 days total). Twelve subjects volunteered for this study (eight females and four males).

One female subject had to be excluded from the study because she failed to submit information regarding her pre-study training levels. The subjects averaged (mean ± SD) 22.4 ± 1.4 years of age, 175.5 ± 11.6 cm in height, 75.3 ± 26.1 kg pre-weight, and 76.5 ± 34.8 weekly self-reported miles pre-study (see Table 1). All of the subjects averaged 560 miles/wk over the course of the program. This was an average increase in training volume of 632.0%.

Subjects had a small amount of blood (5-10 mL) drawn from an antecubital vein on two separate occasions; one draw was immediately pre-trip and the other on day 55 of the trip.

Both blood draws were completed in the morning, prior to consumption of food or fluids. Blood was collected into EDTA tubes and a small portion (less than 100 ul) of whole blood (blood containing all of its components) was immediately analyzed for Hct and Hb using a HemoCue automated analyzer. Samples were analyzed in duplicate, and if there was a greater than 5% difference between the two samples, analysis was repeated a third time.

Subjects also had their age, gender, height, and weight recorded (see Table 2). Changes in Hct and Hb were analyzed using paired t-tests. Subjects self-reported their cycling mileage one month prior to and during the "4k for Cancer" trip. Pearson correlation coefficients were used to determine the association between the change in weekly mileage (recorded pre-trip to post-trip) to the change in both Hb and Hct. Statistical significance was set *a priori* at $P < 0.05$.

TABLE 1. PRE-TRAINING DESCRIPTIVE STATISTICS OF SUBJECTS, INCLUDING AGE, HEIGHT, GENDER, WEIGHT, AND SELF-REPORTED WEEKLY MILEAGE.

Subject Number	Gender	Age (years)	Height (cm)	Weight (kg)	Average Self-Reported Weekly Mileage (miles)
1	F	22	175.3	68.5	95
2	F	20	160.0	62.6	90
3	M	22	175.3	70.5	17
4	F	22	165.1	61.7	50
5	F	24	177.8	64.4	150
6	M	22	190.5	83.0	80
7	M	25	198.1	148.8	25
8	F	23	177.8	74.4	85
9	M	23	177.8	78.9	90
10	F	21	172.7	66.2	50
11	F	22	160.0	48.9	50
Average		22.4 ± 1.4	175.5 ± 11.6	75.3 ± 26.1	76.5 ± 34.8

TABLE 2. POST-TRAINING DESCRIPTIVE STATISTICS OF SUBJECTS, INCLUDING AGE, HEIGHT, GENDER, WEIGHT, AND SELF-REPORTED WEEKLY MILEAGE.

Subject Number	Gender	Age (years)	Height (cm)	Weight (kg)	Average Self-Reported Weekly Mileage (miles)
1	F	23	175.3	68.9	560
2	F	21	160.0	63.3	560
3	M	22	175.3	68.5	560
4	F	22	165.1	60.8	560
5	F	24	177.8	62.4	560
6	M	22	190.5	81.2	560
7	M	25	198.1	140.6	560
8	F	23	177.8	75.3	560
9	M	24	177.8	73.0	560
10	F	21	172.7	68.3	560
11	F	22	160.0	51.7	560
Average		22.6 ± 1.3	175.5 ± 11.6	74.0 ± 23.45	560 ± 0

RESULTS

The mean Hct of the 10 subjects who completed the study significantly ($p<0.05$) increased from 42.9% to 48.45% (see Figure 1). The mean Hb also increased significantly ($p<0.05$) from 14.6g/dL to 16.4 g/dL (See Figure 2). Subjects exhibited a small non-significant ($p>0.05$) mean weight change from 75.74 kg pre-weight to 74.55 kg post-weight. The changes in Hct and Hb were not significantly ($p>0.05$) correlated with the change in weekly mileage ($R=0.13$ and 0.16 respectively).

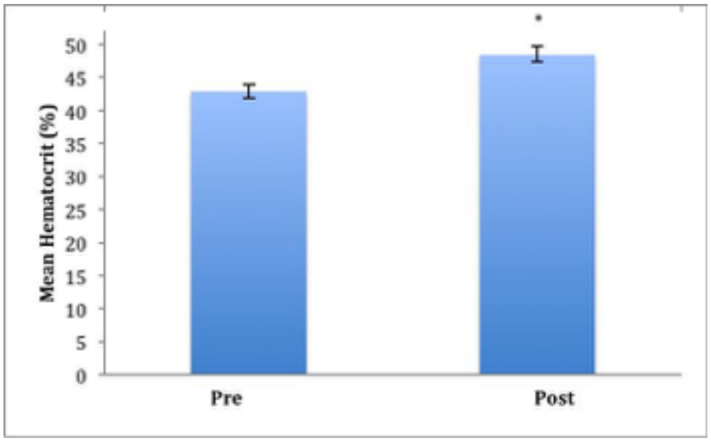

FIGURE 1. Pre and post-training mean hematocrit (%) values of 11 recreational cyclists following a dramatic increase in training volume over a 10-week period.

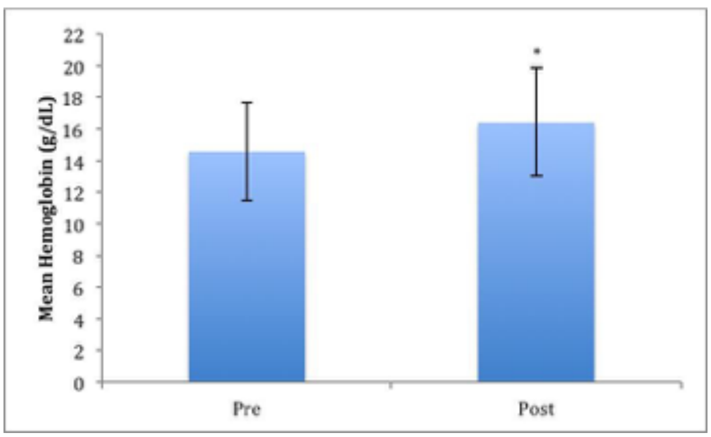

FIGURE 2. Pre and post-training mean hemoglobin (g/dL) values of 11 recreational cyclists following a dramatic increase in training volume over a 10-week period.

DISCUSSION

Previous studies have determined increases in blood volume during the initial two to four weeks of training can be attributed almost entirely to a plasma volume expansion (Convertino, 1991). When the duration of training increases, however, increases in blood volume become equally distributed between red blood cell mass and plasma volume. (Akgün, Tartaroglu, Durusoy, & Kocatürk, 1974; Convertino, 1993; Convertino, Mack, & Nadel, 1991; Oscai, Williams, & Hertig, 1968; Ray et al., 1990).

This discrepancy seems to indicate that hemostatic adaptations continue when individuals are exposed to long-term endurance training regimens. The major finding of this study is that the cyclists' Hct and Hb increased substantially following a large increase in training volume over a long duration. Furthermore, the substantial increase in hematocrit suggests that red blood cells increased either exclusive of plasma volume or to a greater extent than plasma volume. This finding indicates that increases in red blood cell volume may be a more important factor in hemostatic changes in trained individuals than previously thought.

It is important to note an explanation for this data. Past findings have indicated overtraining may be associated with increased Hct values (Aïssa Benhaddad et al., 1999). Therefore, increasing the volume of training over a longer period in already-trained endurance athletes could preferentially affect red blood cells over plasma. The average weekly mileage of our subjects was increased sevenfold, so it is possible overtraining was a factor in Hct increases.

There were several limitations in this study worth exploring in future research. Total blood volume was not calculated; previous studies suggest that an increase in blood volume would almost certainly occur (Convertino, 1991; Kanstrup & Ekblom, 1984; Krip et al., 1997). Because total blood volume was not calculated, changes in plasma volume could not be calculated. However, due to the increases in Hct, it can be inferred that plasma volume did not increase as much as red blood cell volume. The effects of altitude-induced increases in Hct during the ride were also not examined. Past studies have identified altitude as having effects on hematological adaptations at altitudes above 2,000m (Convertino, 1993; Sawka, Hubbard, Francesconi, & Horstman, 1983; Schmidt et al., 2002). Subjects in this study were only exposed to altitudes above the 2,000m threshold for two consecutive days, which research suggests is not enough exposure to affect blood volume adaptations (Zubieta-Calleja, Paulev, Zubieta-Calleja, & Zubieta-Castillo, 2007). Also, male and female data were combined, and menstrual cycles could have influenced variables. However, there was in increase of Hb and Hct in every subject, which suggests gender differences did not influence the results.

The study did not observe a correlation between the changes in weekly mileage and Hct and Hb. One explanation could be there is a mileage or mileage increase above which Hct and Hb do not increase further. Another explanation could be the homogenous pre-study weekly training mileage of the subject group. This homogeneity caused the increases in training mileage to be reasonably uniform across subjects. Finally, there could be a relationship between increased mileage and changes in Hct and Hb, but the study did not have enough statistical power to detect it because of the low subject number.

The results of this study are important because research has shown that endurance exercise training has implications in general health and the development of chronic diseases. Previous studies have explored the various effects of endurance exercise on human physiology, and it has become evident that the volume and mode of training have important impacts on observed effects. Little research exists that examines the transition from recreational athlete status to elite athlete status. Future research should examine this transition to enable a better understanding of how changes in volume of endurance exercise influence physiological effects.

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