

**Higher Calf Venous Compliance in Male Runners than Swimmers**Juliane P. Wallace<sup>1</sup>, Philip M. Anton<sup>1</sup>, Jeff A. Goelz<sup>2</sup>, Alexander T. Sougiannis<sup>1</sup><sup>1</sup>Department of Kinesiology, <sup>2</sup>Recreational Sports and Services Southern Illinois University, Carbondale, Illinois**ABSTRACT**

**Wallace, JP, Anton, PM, Goelz JA, Sougiannis, AT.** Higher Calf Venous Compliance in Male Runners than Swimmers. **JEPonline** 2012;15(6):49-59. Previous research suggests that cardiovascular, blood volume, and sympathoadrenal response differences exist when swimming and upright endurance exercise training are compared. Although calf venous compliance has been shown to increase with endurance exercise training, it remains unknown whether the mode of endurance training affects these training adaptations. The purpose of this study was to determine calf and forearm venous compliance differences between highly trained male runners and swimmers. Ten healthy endurance trained collegiate track and cross country athletes ( $20.7 \pm 1.8$  yrs,  $69.6 \pm 6.2$  mL·kg<sup>-1</sup>·min<sup>-1</sup>), 10 healthy endurance trained collegiate swimmers ( $21.1 \pm 1.6$  yrs,  $59.1 \pm 9.9$  mL·kg<sup>-1</sup>·min<sup>-1</sup>), and 10 healthy college age normally active males ( $21.3 \pm 2.3$  yrs,  $41.6 \pm 8.1$  mL·kg<sup>-1</sup>·min<sup>-1</sup>) underwent maximal graded exercise testing and assessment of calf and forearm venous compliance. Using venous occlusion plethysmography, limb venous compliance was determined as the first derivative of the pressure-volume relationship during cuff pressure reduction. Venous compliance of the calf was greater in the runners than the swimmers and controls ( $P < 0.05$ ), while there was no difference in venous compliance of the forearms ( $P < 0.05$ ) between groups. Capacitance of the calf was greater in the runners than the swimmers and controls ( $P < 0.05$ ) with no difference in capillary filtration volumes in either the calf or forearm measurements. The gravity dependent training mode of running enhances calf venous compliance to a greater degree than swimming.

**Key Words:** Vascular Function, Endurance Training, Exercise Mode

## INTRODUCTION

There is evidence indicating that orthostatic tolerance is reduced in highly trained athletes (11,17,20), which may be linked to training-induced modifications in venous compliance. While endurance training increases calf venous compliance in runners (7,14), the occurrence of this adaptation (or changes in arm venous compliance) via other exercise modes is not as clear. Specificity of training posture has been linked to other cardiovascular response differences (10,18). As an example, hypervolemia is not as pronounced in supine cycling (18) or swimming (15) compared with upright exercise and training mode-specific differences also exist between runners and swimmers in regard to alterations in cardiac dimension (19).

Differences in body position and training environment during exercise may play a role in the alterations just mentioned and may also influence venous compliance adaptation in both the calf and forearm of runners and swimmers. Bleeker et al. (2) suggested that gravity is a major factor in cardiovascular adaptations to horizontal posture (2). They found that an 18 day bed rest regimen triggered reductions in leg venous compliance with increases in leg venous outflow resistance. While it remains unknown whether this decline in calf venous compliance was due primarily to extreme deconditioning or prolonged exposure to horizontal posture, gravity was likely a contributing factor.

Running uses the lower body primarily in a gravity-dependent environment while swimming uses the upper and lower body in an environment much less influenced by gravity. These postural and gravitational training differences warrant evaluation of possible disparity in training-related arm and leg venous compliance adaptation. Assessing these possible variations would provide mechanistic insight into whether an increase in venous compliance with endurance training is either a response to central cardiovascular training effects, a specific response to hypervolemia in muscle groups utilized during exercise training, or is a result of the effects of gravity.

Possible training mode-specific modulation of leg venous compliance may also have important implications for arterial blood pressure regulation during and after exercise as well as during orthostatic stress. Therefore, the purpose of this study was to determine differences in limb venous compliance in male Division I endurance trained swimmers and runners, as well as normally active controls. We hypothesized that runners would have greater calf venous compliance than swimmers and that swimmers would have greater forearm venous compliance, due to the different training environments and the increased reliance on upper body musculature during swimming. Further, we hypothesized that both runners and swimmers would have greater arm and leg venous compliance than sedentary controls.

## METHODS

### Subjects

Twenty apparently healthy NCAA Division I male endurance swimmers and track and cross-country runners (10 swimmers and 10 runners), along with 10 healthy normally active age-matched male controls were recruited for participation in this study. The swimmers were tested toward the end of their season and, at the time of testing, were typically swimming 6 d·wk<sup>-1</sup>, 33,000-39,000 m·wk<sup>-1</sup>. The runners were tested in the middle of their training season and were running 6 d·wk<sup>-1</sup>, 65-80 km·wk<sup>-1</sup>. Swimmers and runners were considered endurance-trained with the primary difference in training being exercise modality. Swimmers and runners reported limited resistance training as the only exercise method used for cross-training purposes (swimmers did not report running and runners did not report swimming). The control group reported no regular exercise, which was defined as 20-45 min of moderate intensity exercise at least 3 or more days each week). All subjects were deemed

apparently healthy based on their medical history (no cardiovascular disease or venous insufficiency), resting blood pressure <130/90 mmHg, body fat percentage <30%, and no reported tobacco use. This project was approved by the institutional review board of Southern Illinois University and written informed consent was obtained according to practices established by the Southern Illinois University Carbondale Human Subjects Committee.

### Experimental Protocol

The subjects reported to the laboratory in the morning prior to any exercise. They had not consumed either caffeine for at least 12 hrs or food for at least 3 hrs. Data collection was performed at a stable room temperature of 23°C. The methods employed for this study were similar to those used previously in this lab (7-9), a slightly modified version of the protocol validated by Halliwill, Minson, and Joyner (6). Body composition was assessed using Lange Skinfold calipers, utilizing a 3-site protocol. A balance scale and stadiometer were used to assess height (cm) and body mass (kg). Resting blood pressure was assessed using a non-invasive blood pressure monitor (Dinamap 9300, Critikon, Tampa, FL).

Following assessment of anthropometric status and resting blood pressure, venous compliance was evaluated in both the dominant calf and forearm. Changes in calf and forearm volume were determined using strain gauge plethysmography (ECR5 Hokanson, Bellevue, WA) with pressure controlled using a venous collecting cuff (AG101 Hokanson, Bellvue, WA). To determine venous compliance, subjects were placed in a supine position with the dominant limb elevated above the level of the heart and supported at the level of the thigh and ankle or brachium and wrist to promote venous drainage. A mercury-in-silastic strain gauge was then applied around the maximal circumference of the segment tested to detect changes in limb volume relative to baseline measurements. A venous-collecting cuff was then placed ~5 cm proximal to the knee on the dominant leg, and the elbow on the dominant arm. Following instrumentation and 15 min of rest, venous collecting cuff pressure was applied at 60 mmHg for 8 min and, then, subsequently reduced by 5 mmHg /5s to 10 mmHg. At the onset of cuff pressure, an initial rapid increase of limb volume occurred (capacitance response) followed by a slower, but continuous rise in volume caused by net transcapillary fluid filtration from blood to tissue. Calf volume measurements were conducted first, followed by forearm volume measurements.

Each subject underwent an incremental treadmill test to determine maximum oxygen consumption ( $\text{VO}_2\text{ max}$ ) via open circuit spirometry (TrueMax 2400 ParvoMedics). This modality was chosen since it was similar to the training modality of the endurance-trained runners and was the preferred mode for the swimmers (over combined upper and lower body ergometry). All subjects met the standard criteria for achievement of  $\text{VO}_2\text{ max}$  (1).

### Analysis

Venous compliance was calculated using pressure-volume curves resulting from a decrease in pressure. The curves were compared using the quadratic regression model [ $\Delta$  limb volume =  $\beta_0 + \beta_1 \cdot$  (cuff pressure) +  $\beta_2 \cdot$  (cuff pressure)<sup>2</sup>]. The group-average regression parameters  $\beta_1$  and  $\beta_2$  were used together as an estimate of compliance [i.e., compliance =  $\beta_1 + 2 \cdot \beta_2 \cdot$  (cuff pressure)]. The derivative of the pressure-volume curve was used to determine the group-related differences in venous compliance.

The capacitance response was calculated from the volume increase at the onset of cuff pressure to the line defined from the filtration slope between 3 and 8 min of cuff pressure application. Total capillary filtration during cuff pressure was calculated from the rate of filtration ( $\text{mL} \cdot \text{min}^{-1}$ ) multiplied by the time of the cuff pressure application (8 min). Total calf volume increase was equal to the sum of

the capacitance and net capillary filtration volumes. Differences in participant characteristics were determined using an ANOVA on exercise training mode. Statistical significance was set at  $P < 0.05$ .

## RESULTS

### Subject Characteristics

Physical characteristics are summarized in Table 1. Body mass was higher in swimmers and controls compared with runners ( $P < 0.05$ ) and height and calf volume also tended to be higher in swimmers compared with runners ( $P = 0.089$  and  $P = 0.058$  respectively). Swimmers had greater forearm volume than the runners ( $P < 0.05$ ), but the control group forearm volume was not different from either of the trained groups. The groups did not differ significantly in age, systolic blood pressure, or diastolic blood pressure. The runners had a significantly higher  $\text{VO}_2$  max value than the swimmers and controls ( $P < 0.05$ ) and the swimmers had significantly higher  $\text{VO}_2$  max than the controls ( $P < 0.05$ ).

**Table 1. Selected Participant Characteristics.**

Variable	Controls	Runners	Swimmers
Age (yrs)	21 $\pm$ 2	21 $\pm$ 1	21 $\pm$ 1
Height (cm)	181.64 $\pm$ 3.7	180.73 $\pm$ 4.3	184.44 $\pm$ 4.3
Body Mass (kg)	86.4 $\pm$ 12.1*	70.8 $\pm$ 5.7	85.3 $\pm$ 10.9 *
Body Fat %	14 $\pm$ 6*	9 $\pm$ 2	12 $\pm$ 5
Systolic Blood Pressure (mmHg)	124 $\pm$ 7	120 $\pm$ 8	128 $\pm$ 8
Diastolic Blood Pressure (mmHg)	72 $\pm$ 8	70 $\pm$ 9	76 $\pm$ 10
$\text{VO}_2$ max ( $\text{mL} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ )	41.6 $\pm$ 8.1*¥	69.6 $\pm$ 6.2	59.1 $\pm$ 9.9*
Calf Volume (mL)	3929 $\pm$ 401	3744 $\pm$ 300	4049 $\pm$ 303
Forearm Volume (mL)	1956 $\pm$ 209	1772 $\pm$ 207	2096 $\pm$ 146 *

Values are means  $\pm$  SD; n = 10 controls; n = 10 runners; n = 10 swimmers;  $\text{VO}_2$  max = maximal oxygen consumption; BP = blood pressure. \*  $P < 0.05$  vs. runners, ¥  $P < 0.05$  vs. swimmers.

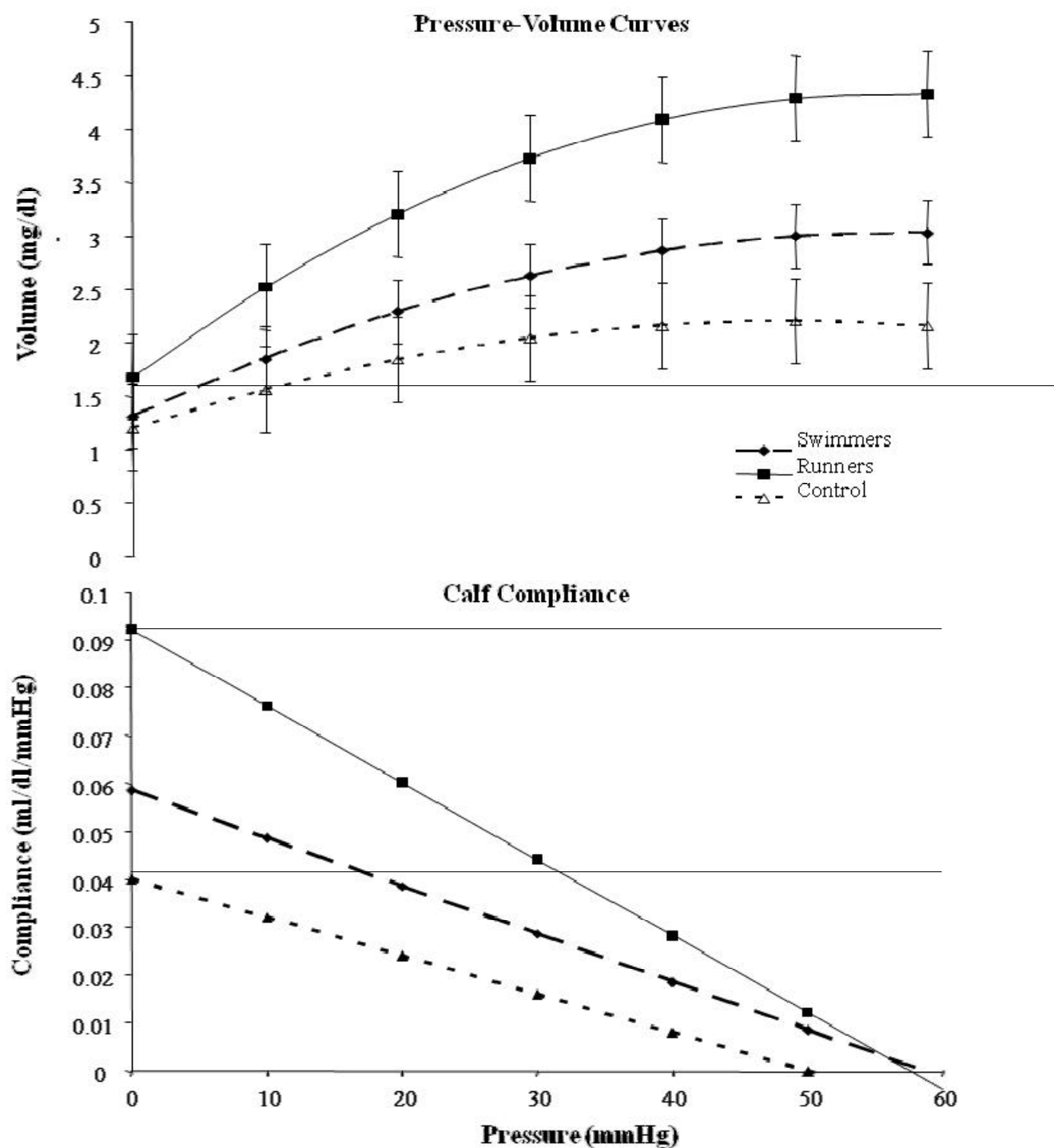
### Venous Compliance

The runners had a greater calf venous compliance than the swimmers and controls ( $P < 0.05$ ; Table 2, Figure 1). However, there were no significant differences in forearm venous compliance between the three groups (Table 2; Figure 2). The volume increase associated with the capacitance response in the calf was larger in the runners than the swimmers and controls ( $P < 0.05$ ; Figure 3). There were no differences in forearm capacitance or capillary filtration volumes between the three groups (Figure 4).

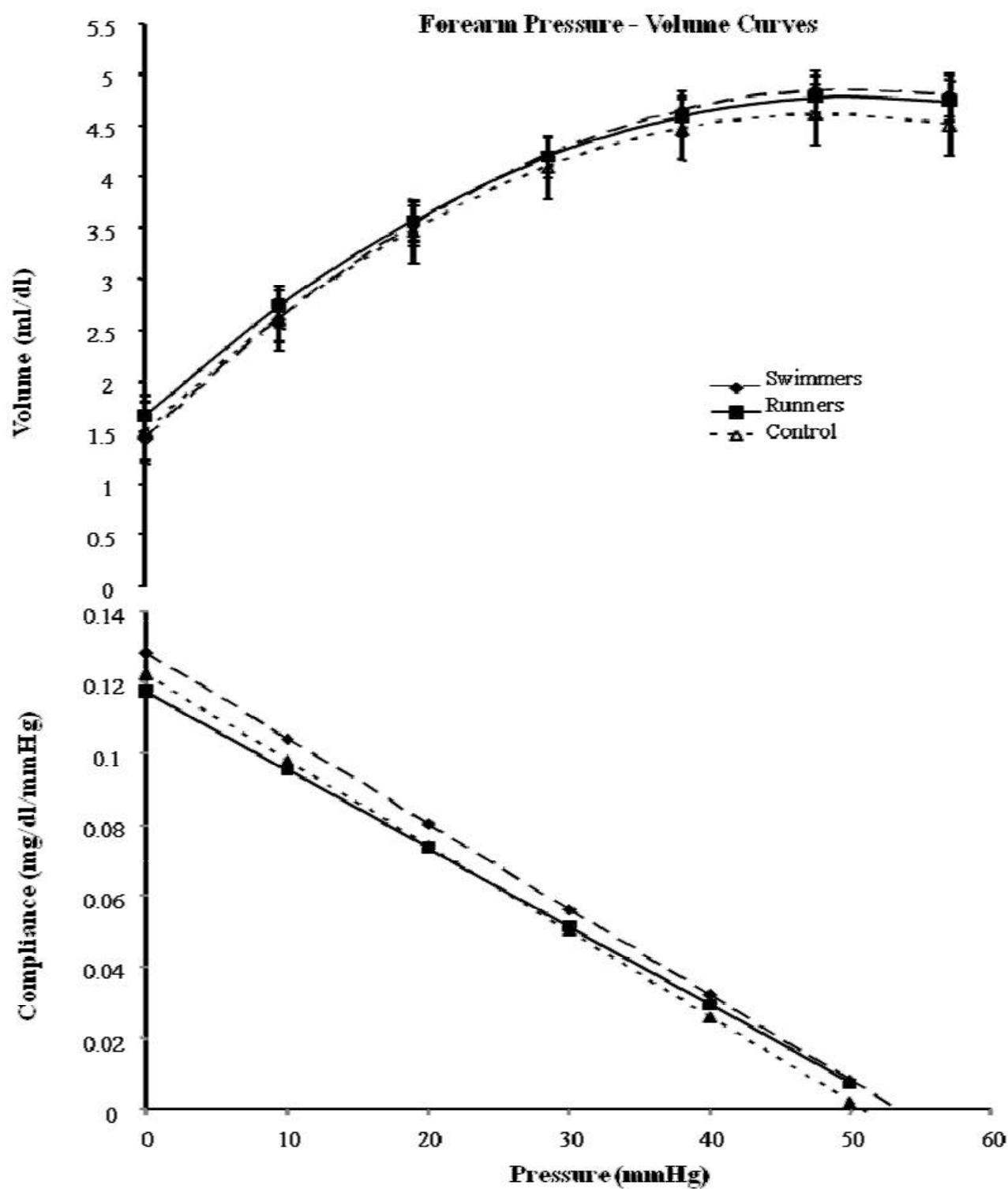
**Table 2. Pressure-Volume Regression Parameters.**

	$\beta_0$	$\beta_1$	$\beta_2$
Male Swimmers <i>D Calf volume</i>	1.3148 $\pm$ .5049	.0586 $\pm$ .0288*	-.0005 $\pm$ .0001*
Male Runners <i>D Calf volume</i>	1.6791 $\pm$ .4197	.0922 $\pm$ .0586	-.0008 $\pm$ .0005
Male Controls <i>D Calf volume</i>	1.2567 $\pm$ .3456	.0465 $\pm$ .0664*	-.0004 $\pm$ .0006*
Male Swimmers <i>D Forearm volume</i>	1.315 $\pm$ .7802	.1281 $\pm$ .0253	-.0012 $\pm$ .0001
Male Runners <i>D Forearm volume</i>	1.6602 $\pm$ .8402	.1174 $\pm$ .0041	-.0011 $\pm$ .0006
Male Controls <i>D Forearm volume</i>	1.5 $\pm$ .6458	122 $\pm$ .0136	-.0012 $\pm$ .0012

Values are means  $\pm$  SD. ? Limb Volume =  $\beta_0 + \beta_1 \times (\text{Cuff Pressure}) + \beta_2 \times (\text{Cuff Pressure})^2$  \*  $P < 0.05$  vs. runners calf.



**Figure 1. Pressure-Volume Curves (top) and Pressure-Compliance Slopes (bottom) of the Calf for Runners (solid line), Swimmers (dashed line), and Normally Active (dotted line) Males**



**Figure 2. Pressure-Volume Curves (top) and Pressure-Compliance Slopes (bottom) of the Forearm for Runners (solid line), Swimmers (dashed line), and Normally Active (dotted line) Males.**

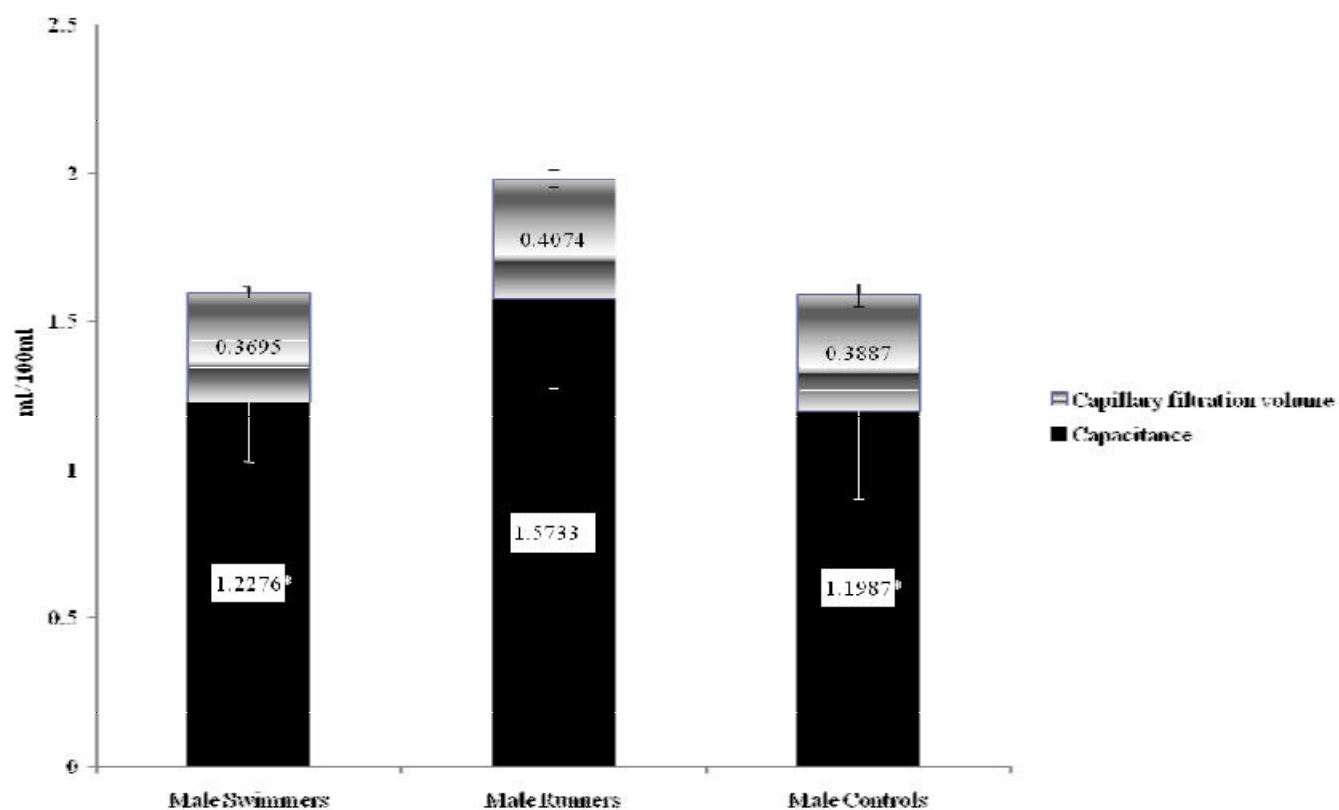


Figure 3. Capacitance and Capillary Filtration Volumes in the Calf of Runners, Swimmers, and Normally Active Males. \* $P < 0.05$  vs. runners.

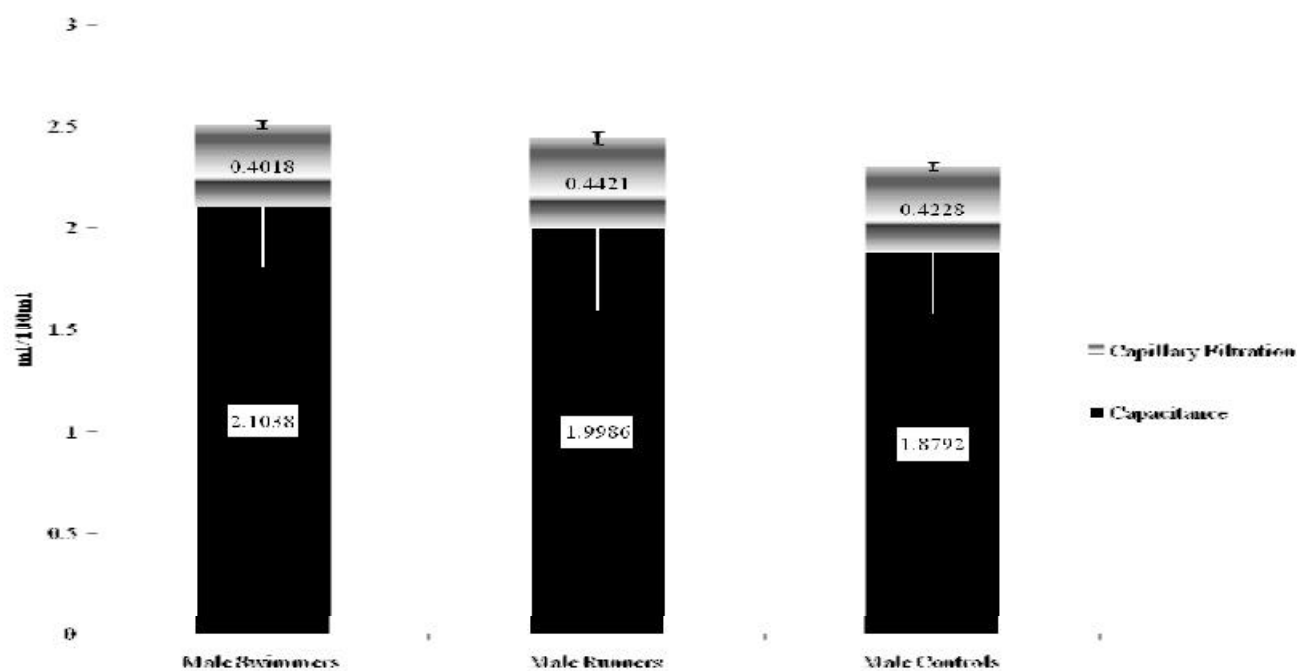


Figure 4. Capacitance and Capillary Filtration Volumes in the Forearm of Runners, Swimmers, and Normally Active Males.

## DISCUSSION

To the best of our knowledge, this is the first study to evaluate the effects of exercise training mode (gravity dependent vs. gravity independent) on upper and lower limb venous compliance. Due to the low gravity nature of swimming and previous research examining the relationship between gravity and venous compliance, we hypothesized a lower venous compliance in the legs of the swim-trained subjects compared to runners. In addition, we expected that the increased use of the upper body during swim training would increase forearm venous compliance in this population. The primary findings of the present study support the first hypothesis but not the second.

### Calf Venous Compliance

Previous research has shown that endurance trained individuals have greater calf venous compliance compared with sedentary individuals (7,14). However, these studies evaluated endurance trained runners alone. Monahan and colleagues (14) found that chronic endurance training was associated with higher calf venous compliance in both older and younger males when compared to sedentary peers. Hernandez and Franke (7) assessed calf venous compliance in young and older normally active and endurance trained groups and found that calf venous compliance was greater in both endurance trained groups compared to their normally active peers. In addition, they found that the older individuals had lower calf venous compliance than their younger counterparts. But, the endurance trained older individuals had very similar calf venous compliance as the normally active younger people, indicating that sedentary lifestyle may actually be a greater influence on calf venous compliance than age (7,14).

In an attempt to determine the role of muscle mass on calf venous compliance, Monahan and colleagues (14) ran a regression analysis on calf volume and calf venous compliance in their pooled group of young and older sedentary and endurance-trained subjects. They found no significant relationship between calf volume and compliance ( $r = -0.45$ ), which led the investigators to suggest that changes in limb venous compliance are due primarily to changes within the walls of the veins as opposed to changes in muscle mass with endurance training (14). Bleeker and colleagues (2) evaluated the effects of 18-days of bed rest, an extreme model of physical inactivity, on leg and arm venous properties. They found that while calf venous compliance was decreased following bed rest, arm venous compliance was unchanged. Since there was no change in limb volume over the 18 days of bed rest, it was suggested that the change in calf venous compliance was most likely due to structural changes in the vessel wall (2).

The results of the present study show greater calf venous compliance in the runners compared to the swimmers. This finding, along with the bed rest study mentioned previously (2), support the idea that gravity has a profound effect on lower limb venous compliance. This effect is most likely accomplished through adaptations in the vessel wall, and that it is secondary to increased hydrostatic forces associated with upright posture in a gravitational environment (2,5,13).

### Forearm Venous Compliance

Bed rest studies (2,3,21) have consistently indicated no change in forearm venous compliance despite diminished venous compliance in the calf. It is generally thought that this is due to the fact that in an upright posture, hydrostatic forces exerted on leg veins are higher than the forces affecting arm veins. In the present study, there was no difference in forearm venous compliance between highly trained runners and swimmers, or normally active males, despite the fact that the arms are used heavily during swim training and the forearm volume of the swimmers was larger than that of the runners. Based on the findings of bed rest studies (2,3,21), this lack of difference in forearm venous



compliance between swimming and running is likely due to lower hydrostatic forces experienced in the non-gravitational environment in which the swimmers train, as well as the horizontal training position. In other words, the findings of this investigation suggest that the training environment (gravity vs. microgravity) plays a greater role in venous compliance adaptation to training than does the muscle mass utilized.

Previous research suggested that running may elicit greater hypervolemia than swim training (15,18). While we are unaware of any studies comparing blood volume in chronically exercising swimmers and runners of the age and training level of those in the present investigation, it is possible that the runners in the present study have a higher blood volume, which is supported by the significantly higher  $\text{VO}_2$  max of the runners. If the runners have a greater blood volume than the swimmers, this might contribute to their higher capacitance volume and calf venous compliance. However, if this central adaptation were primarily responsible for the increased calf venous compliance in the runners, then we would expect that the forearm venous compliance would be greater in the runners as well.

Several limitations should be considered when evaluating the results of the present study. First, when using venous occlusion plethysmography to assess venous compliance it is assumed that venous pressure is equal to venous collecting cuff pressure. We feel that the use of 8 min of cuff pressure inflation allowed us to meet the assumption that collecting cuff pressure is equal to venous pressure. However, this point was obviously not assessed directly. Second, since our study evaluated only young healthy male athletes, our results cannot be generalized to all populations. It is possible that female or older swimmer and runner populations may respond differently.

## CONCLUSIONS

To the best of our knowledge these data are the first to provide evidence that endurance-trained runners have higher calf venous compliance than swimmers without any differences in forearm venous compliance. The gravity dependent training mode of running enhances calf venous compliance to a greater degree than swimming. These findings related to training mode modulation of leg venous compliance may have important implications for arterial blood pressure regulation during orthostatic stress, as well as during and after exercise in young athletes. In addition, they provide further evidence that an alteration in the vessel wall is the mechanism behind changes in venous compliance.

---

**Address for correspondence:** Wallace JP, Ph.D. Department of Kinesiology, Southern Illinois University, Carbondale, IL USA 62901-4310. Phone (618) 453-3124; FAX: (618) 453-3329; Email. [juliane@siu.edu](mailto:juliane@siu.edu)

---

## REFERENCES

1. American College of Sports Medicine. **ACSM's Guidelines for Exercise Testing and Prescription**. Philadelphia, PA: Lippincott, Williams, & Wilkins; 2010. p. 82.
2. Bleeker MW, De Groot PC, Pawelczyk JA, Hopman MT, Levine BD. Effects of 18 days of bed rest on leg and arm venous properties. **J Appl Physiol**. 2004;96(3):840-847.

3. Bonde-Petersen F, Suzuki Y, Kawakubo K, Gunji A. Effect of 20 days bed rest upon peripheral capillary filtration rate, venous compliance and blood flow in arms and legs. **Acta Physiol Scand Supp.** 1994;616:65-69.
4. Convertino VA. Endurance exercise training: conditions of enhanced hemodynamic responses and tolerance to LBNP. **Med Sci Sports Exerc.** 1993;25(6):705-712.
5. Convertino VA, Doerr DF, & Stein SL. Changes in size and compliance of the calf after 30 days of simulated microgravity. **J Appl Physiol.** 1989;66(3):1509-1512.
6. Halliwill JR, Minson CT, Joyner MJ. Measurement of limb venous compliance in humans: technical considerations and physiological findings. **J Appl Physiol.** 1999;87(4):1555-1563.
7. Hernandez JP, Franke WD. Age- and fitness-related differences in limb venous compliance do not affect tolerance to maximal lower body negative pressure in men and women. **J Appl Physiol.** 2004;97(3):925-929.
8. Hernandez JP, Franke WD. Effects of a 6-month endurance-training program on venous compliance and maximal lower body negative pressure on older men and women. **J Appl Physiol.** 2005;99:1070-1077.
9. Hernandez JP, Godar BE. Calf venous compliance in endurance trained females. **JEPonline.** 2009;12:39-49.
10. Holmer I, Stein E, Saltin B, Ekblom B, Astrand, P-O. Hemodynamic and respiratory responses compared in swimming and running. **J Appl Physiol.** 1974;37:49-54.
11. Levine B. Regulation of central blood volume and cardiac filling in endurance athletes: The Frank-Starling mechanism as a determinant of orthostatic tolerance. **Med Sci Sports Exerc.** 1993;25:727-732.
12. Levine B, Lane L, Buckey J, Friedman D, Blomqvist C. Left ventricular pressure-volume and Frank-Starling relations in endurance athletes. Implications for orthostatic tolerance and exercise performance. **Circulation**, 1991;84:1016-1023.
13. Louisy F, Schroiff P, Gruell A. Changes in leg vein filling and emptying characteristics of lower limb volumes during long-term head down bed rest. **J Appl Physiol.** 1997;82:1726-1733.
14. Monahan KD, Dinunno FA, Seals DR, Halliwill JR. Smaller age associated reductions in leg venous compliance in endurance exercise-trained men. **Am J of Physiol Heart Circ Physiol.** 2001;281:H1267-H1273.
15. Parker-Jones P, Davy K, DeSouza C, Tanaka H. Total blood volume in endurance-trained postmenopausal females: Relation to exercise mode and maximal aerobic capacity. **Acta Physiol Scand.** 1999;166:327-333.
16. Raven PB, Pawelczyk JA. Chronic endurance exercise training: a condition of inadequate blood pressure regulation and reduced tolerance to LBNP. **Med Sci Sports Exerc.** 1988;25:713-721.

17. Raven P, Rohm-Young D. Physical fitness and cardiovascular response to lower body negative pressure. **J Appl Physiol.** 1984;56:138-144.
18. Ray CA, Cureton KJ, Outzts HG. Postural specificity of cardiovascular adaptations to exercise training. **J Appl Physiol.** 1990;69(6):2202-2208.
19. Spirito P, Pelliccia A, Proschan M, Granata M, Spataro A, Bellone P, et al. Morphology of the "athlete's heart" assessed by echocardiography in 947 elite athletes representing 27 sports. **Am J Cardiol.** 1994;74:802-806.
20. Stevens G, Foresman B, Shi X, Stern S, Raven P. Reduction in LBNP tolerance following prlonged endurance exercise training. **Med Sci Sports Exerc.** 1992;24:1235-1244.
21. Wilson TE, Shibasaki M, Cui J, Levine BD, Crandall CG. Effects of 14 days of head-down bed rest on cutaneous vasoconstrictor responses in humans. **J Appl Physiol.** 2003;94:2113-2118.

### Disclaimer

The opinions expressed in **JEPonline** are those of the authors and are not attributable to **JEPonline**, the editorial staff or the ASEP organization.