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The Effects of an Acute High NaCl Diet on the Measurement of Limb Venous Compliance

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THE EFFECTS OF AN ACUTE HIGH NaCl DIET ON THE MEASUREMENT OF
LIMB VENOUS COMPLIANCE

by
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B.S., Athletic Training, University of Nebraska-Lincoln 2009

A Research Paper
Submitted in Partial Fulfillment of the Requirements for the
Master of Science in Education degree

Department of Kinesiology
In the Graduate School
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RESEARCH PAPER APPROVAL

THE EFFECTS OF AN ACUTE HIGH NaCl DIET ON THE MEASUREMENT OF
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for the Degree of
Master of Science in Education

Approved by:

Dr. Juliane Wallace, Chair

Graduate School
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April 13, 2011

AN ABSTRACT OF THE RESEARCH PAPER OF

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presented on April 13, 2011, at Southern Illinois University Carbondale.

TITLE: THE EFFECTS OF AN ACUTE HIGH NaCl DIET ON THE MEASUREMENT
OF LIMB VENOUS COMPLIANCE

MAJOR PROFESSOR: Dr. Juliane Wallace

Calf venous compliance improves with aerobic training and declines with age. Individuals with hypertension often have decreased arterial and venous compliance. Acute high consumption of NaCl may increase net transcapillary fluid filtration in the limbs, but it is unknown if this acutely high NaCl intake will alter non-invasive assessment of calf venous compliance. In humans, assessment of limb venous compliance is generally performed using venous occlusion plethysmography; however, there is no standard recommendation for pre-assessment food consumption and it remains unknown if acute high NaCl intake will affect limb venous compliance measures in humans. **PURPOSE:** To determine if acute high NaCl consumption will alter measures of calf venous compliance using venous occlusion plethysmography. **METHODS:** Ten healthy college aged males ($22.5 \pm .99163$ yrs, 33.66 ± 3.07386 ml*kg⁻¹*min⁻¹) participated in this study, and underwent assessment of calf venous compliance following random assignment of either 12 hours of fasting or consumption of 3055 ± 68.77 mg of

NaCl in the 12 hours prior to testing. Utilizing venous occlusion plethysmography, limb venous compliance was determined in both trials using the first derivative of the pressure-volume relationship during cuff pressure reduction. Compliance was compared as the slope of the compliance-pressure relationship. Data were analyzed using a paired sample t-test. **RESULTS:** There were no significant differences in calf venous compliance ($\beta_0 = .5741 \pm .21760$ $\beta_1 = .0781 \pm .01165$ $\beta_2 = -.0005 \pm .00011$ vs. $\beta_0 = .5674 \pm .40101$ $\beta_1 = .0830 \pm .01209$ $\beta_2 = -.0006 \pm .00012$), capacitance ($1.7844 \pm .12761$ vs. $1.864 \pm .13723$ ml) or capillary filtration ($0.7346 \pm .09415$ vs. $0.7028 \pm .07804$ ml) volumes between the fasted and acute NaCl intake conditions. **CONCLUSION:** These data suggest that calf venous compliance assessment using venous occlusion plethysmography is not affected by acute high NaCl consumption.

TABLE OF CONTENTS

<u>CHAPTER</u>	<u>PAGE</u>
ABSTRACT.....	i
LIST OF TABLES.....	iv
LIST OF FIGURES.....	v
CHAPTERS	
CHAPTER 1 – Introduction.....	1
CHAPTER 2 – Methods.....	4
CHAPTER 3 – Results.....	7
CHAPTER 4 – Discussion.....	12
REFERENCES.....	15
VITA.....	20

LIST OF TABLES

<u>TABLE</u>	<u>PAGE</u>
Table 1	8
Table 2	9

LIST OF FIGURES

<u>FIGURE</u>	<u>PAGE</u>
Figure 1	10
Figure 2	10
Figure 3	11

CHAPTER ONE

INTRODUCTION

Upright posture causes a translocation of blood towards the lower limbs due to the effects of gravity, thus resulting in a great challenge to the human circulatory system (Blomqvist, & Stone, 1983; Rowell, 1993). This translocation decreases the venous return of blood to the heart and results in low cardiac output which, subsequently, leads to a decrease in arterial blood pressure (Borst, Wieling, Van Brederode, Hond, de Rijk, & Dunning, 1982). This phenomenon is called orthostatic intolerance. The compliance of the veins in the legs is a factor which can contribute to orthostatic intolerance. Increases in venous compliance elevate the venous capacitance, reducing venous return and stroke volume. Decreasing venous compliance increases baroreceptor activity causing vasoconstriction, which subsequently decreases venous capacitance and increases venous return and stroke volume. Lower venous compliance can decrease the chances of orthostatic hypotension by increasing central venous pressure. The compliance of the veins in the legs is thought to be one of the mechanisms that impact the hemodynamic stress associated with change in posture.

There are many studies that have looked at different variables and their effect on limb venous compliance. The effects of exercise and endurance training on venous compliance have been studied in different age groups (Hernandez, & Franke, 2005; Monahan, Dinunno, & Halliwill, 2001; Hernandez, & Franke, 2004; Raven, & Pawelczyk, 1993). Age itself is also a variable of venous compliance that has been studied using strain gauge plethysmography (Hernandez, & Franke, 2004; Lanne, &

Olsen, 1997; Monahan, Dinunno, Seals, Halliwill, 2001). Venous compliance mechanisms have been addressed using bedrest to determine how the hydrostatic pressure gradients that act along the blood vessels in erect posture effect compliance (Eiken, Kolegard, & Mekjavic, 2008; Louisy, Schroiff, & Guell, 1997; Kolegard, Mekjavic, & Eiken, 2009). There have also been multiple studies that look at gender differences in venous compliance; however, gender is not a factor in the current study and will not be discussed here.

All of these studies have used different methods to assess venous compliance that have been modified over time (Buckey, Lane, Plath, Gaffney, Baisch, & Blomqvist, 1992; Melchoir, & Fortney, 1993; Robinson, & Wilson, 1968). In 1999, Halliwell, Minson, & Joyner used strain gauge plethysmography and a venous collecting cuff to determine venous compliance. They performed assessments using previously accepted methodologies and compared the findings to a newly modified method. This noninvasive method of testing was shown to be a valid, quick, and easy method to assess whole limb compliance. This method of assessment does have limitations that are discussed by most researchers when using strain gauge plethysmography. Because the collecting cuff is measuring whole limb volume, capillary filtration has been posed as a possible limitation. Studies have been done on capillary filtration to investigate if this is really a limitation to whole limb volume assessment (Buckey, Peshock, & Blomqvist, 1988; Rowell, 1986). A limitation not discussed is the possible need to control diet, specifically NaCl intake, prior to assessment.

We know that chronically high NaCl diets can lead to hypertension and other cardiovascular issues (Rich, McCullough, Olmedo, Malarick, & Moore, 1991). The

vascular effects of NaCl intake have been studied in hypertensive and borderline hypertensive patients and found that a high salt intake decreased the compliance of salt sensitive hypertensives; however, studies cannot determine if the results were caused by structural changes in the veins due to the chronic salt loading (Takeshita, Ashihara, Yamamoto, Imaizumi, Hoka, Ito, et. al., 1984; Draaijer, Kool, Van Bortel, Nieman, De Leeuw, Van Hooff, et. al., 1995). A high dietary salt intake has also been shown to increase arterial constriction and decrease vascular compliance (Sanders, 2009). The effects of sodium on baroreceptor reflex in arteries have been studied, but found no correlation to venous compliance (Creager, Roddy, Holland, Hirsch, & Dzau, 1991).

The Halliwell et. al. (1999) method of strain gauge plethysmography does not look at, or control for, acute NaCl intake prior to testing. We have yet to determine if an acute high NaCl intake will affect the assessment of limb venous compliance using venous occlusion plethysmography. This is important in determining whether or not diet should be controlled prior to assessment of limb venous compliance using strain gauge plethysmography. Therefore, the purpose of this study was to determine the effects of an acute high NaCl diet on limb venous compliance assessment using venous occlusion plethysmography. A high salt intake has been shown to decrease vascular compliance in some populations (Sanders, 2009; Takeshita, et. al., 1984; Draaijer, et. al., 1995); therefore, we hypothesized that venous compliance would be decreased following an acute NaCl diet in males.

CHAPTER TWO

METHODS

Participants

Ten men from the Southern Illinois University-Carbondale campus were studied. All participants were healthy based on medical history, resting arterial blood pressure below 140/90 mmHg, nonsmoking, body mass index below 27kg/m^2 , not currently taking medications with known cardiovascular or autonomic nervous system actions, and no history or symptoms of venous insufficiency. We obtained written informed consent from all participants on a Southern Illinois University Institutional Review Board approved form.

Instruments

Changes in calf volume were measured noninvasively using strain gauge plethysmography (ECR5 Hokanson, Bellevue, WA) at the maximal calf circumference. We placed a venous collecting cuff around the thigh and connected it to an external air source that allowed pressure to be precisely and rapidly modulated within the cuff (AG101 Hokanson, Bellevue, WA).

Maximal oxygen consumption was measured using a graded treadmill exercise test to exhaustion using open circuit spirometry.

Procedures

This experiment was a within participant design with two conditions. One condition was a fasting condition, which required the participants to fast for 12 hours prior to the venous compliance test. The second condition involved consuming an acute high NaCl diet, which included a high sodium meal around 8pm the evening before testing and again at 7am the morning of testing. Participants reported to the laboratory on three separate occasions. In the first visit, we obtained anthropometric data, performed a VO₂max test in order to determine fitness level, and randomly determined the order of treatment (acute high sodium diet vs. fasting). In the second and third visits, we conducted the venous compliance measurements in either the fasted state or following the acute high sodium diet. All participants will refrain from caffeine ingestion and exercise for 12 hours prior to testing. Participants were placed in the supine position and instrumented for measurement of calf volume (strain gauge plethysmography) and venous collecting cuff pressure. We positioned the right leg above the level of the heart to promote venous drainage and determine venous compliance. Calf venous compliance was determined using a slightly modified version of Halliwell et al. (1999) that has been utilized previously (Hernandez & Franke, 2004). Following instrumentation and a 20 minute period of rest venous collecting cuff pressure was applied at 60mmHg for 8 minutes. After this 8 minute period, we reduced collecting cuff pressure at a rate of 5mmHg/5s to 0mmHg, followed by a one minute rest period at 0mmHg to ensure data collection.

Data Analysis

All data was recorded on a Dell PC (Biopac data acquisition software) for later analyses with SPSS. Within participant differences between treatments were assessed using a paired t-test (SPSS version 17).

During assessment of calf venous compliance, the resulting pressure-volume curves during the step down in pressure are nonlinear and well described by the quadratic regression equation, $[(\Delta\text{limb volume}) = \beta_0 + \beta_1 * (\text{cuff pressure}) + \beta_2 * (\text{cuff pressure})^2]$. Due to the derived nonlinear pressure-volume curves, a single number is inadequate to characterize the slope of this relation because compliance becomes a function of a specific pressure (i.e. Compliance is distinctly different at each pressure level). Accordingly, to simplify data presentation, the first derivative of the pressure-volume curve $[\text{compliance} = \beta_1 + 2 * \beta_2 * (\text{cuff pressure})]$ will be calculated using the regression parameters β_1 and β_2 (slope components) from the quadratic regression equation. The first derivative yields a linear pressure-compliance relation that can be evaluated graphically (Halliwell, Minson, & Joyner, 1999).

Calf pressure capacitance was estimated during each trial by visually identifying the point at which the pressure-volume relation appeared to shift from a rapid filling response (capacitance response) to a slower, less pronounced, increase in volume after application of venous collecting cuff pressure indicative of calf vein creep or transcapillary filtration (Lanne, & Olsen, 1997). These measures were made by the same investigator and were reported as the percent change in calf volume from the point before collecting cuff pressure application.

CHAPTER THREE

RESULTS

Table 1 summarizes the anthropometric characteristics and cardiovascular variables of all participants in the study. Age and maximal oxygen consumption were only measured during the first visit and not during the testing conditions. There were no changes in height or weight between the two testing visits for all participants. There were no significant differences between systolic blood pressure, diastolic blood pressure, resting heart rate, or calf volume between the fasted condition and the acute NaCl diet condition ($p < .05$).

There were no significant differences ($p < .05$) in calf volume between testing conditions (Table 1). There were also no significant differences in either the slope of the pressure-volume relationship or the compliance between testing conditions ($p < .05$, Fig. 1 & Fig. 2).

Table 2 shows the beta values used in determining the pressure-volume parameters. There were no significant differences between the fasted and acute high NaCl diet conditions ($p < .05$).

There were no significant differences found in the venous capacitance or capillary filtration between the fasted and acute sodium intake conditions ($p < .05$, Fig. 3).

Table 1. *Participant characteristics*

Variable	Fasted	NaCl
N	10	10
Age, yr	22.5 ± .99163	
VO₂ max ml/kg/min.	33.66 ± 3.07386	
Height, cm	181.8110 ± 2.04458	181.8110 ± 2.04458
Body mass, kg	89.87 ± 3.526	89.87 ± 3.526
Body fat, %	21.3342 ± 2.697	21.3342 ± 2.697
Body mass index, kg/m²	27.0457 ± .65984	27.0457 ± .65984
Systolic BP, mmHg	123.3 ± 1.36667	124.0 ± 1.22927
Diastolic BP, mmHg	76.7 ± 1.82605	74.1 ± 2.36854
Heart rate, beats/min.	66.0 ± 3.18329	67.8 ± 3.24482
Calf Volume, ml	2656.4533 ± 162.92170	2656.3503 ± 164.39184

Values are means ± SE. N = number of subjects; VO₂ max = maximal oxygen uptake; BP = blood pressure.

Table 2. *Pressure-Volume regression beta values*

	β_0	β_1	β_2
Fasted Condition	.5741 ± .21760	.0781 ± .01165	-.0005 ± .00011
NaCl Condition	.5674 ± .40101	.0830 ± .01209	-.0006 ± .00012

Values are means ± SE. Δ Limb volume = $\beta_0 + \beta_1 \times (\text{cuff pressure}) + \beta_2 \times (\text{cuff pressure})^2$

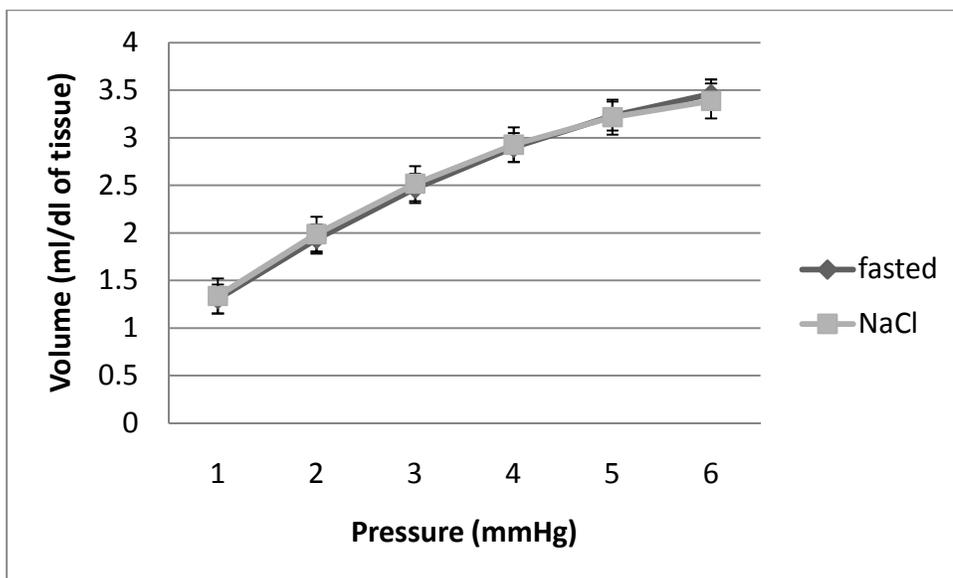


Figure 1. Pressure-volume curves. All values are means \pm SE.

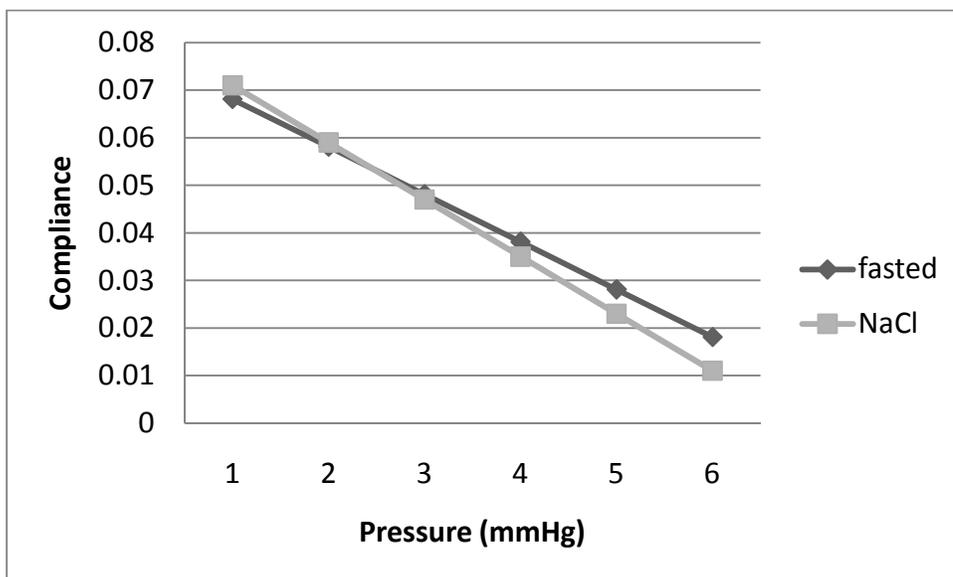


Figure 2. Pressure-compliance slopes. All values are means \pm SE.

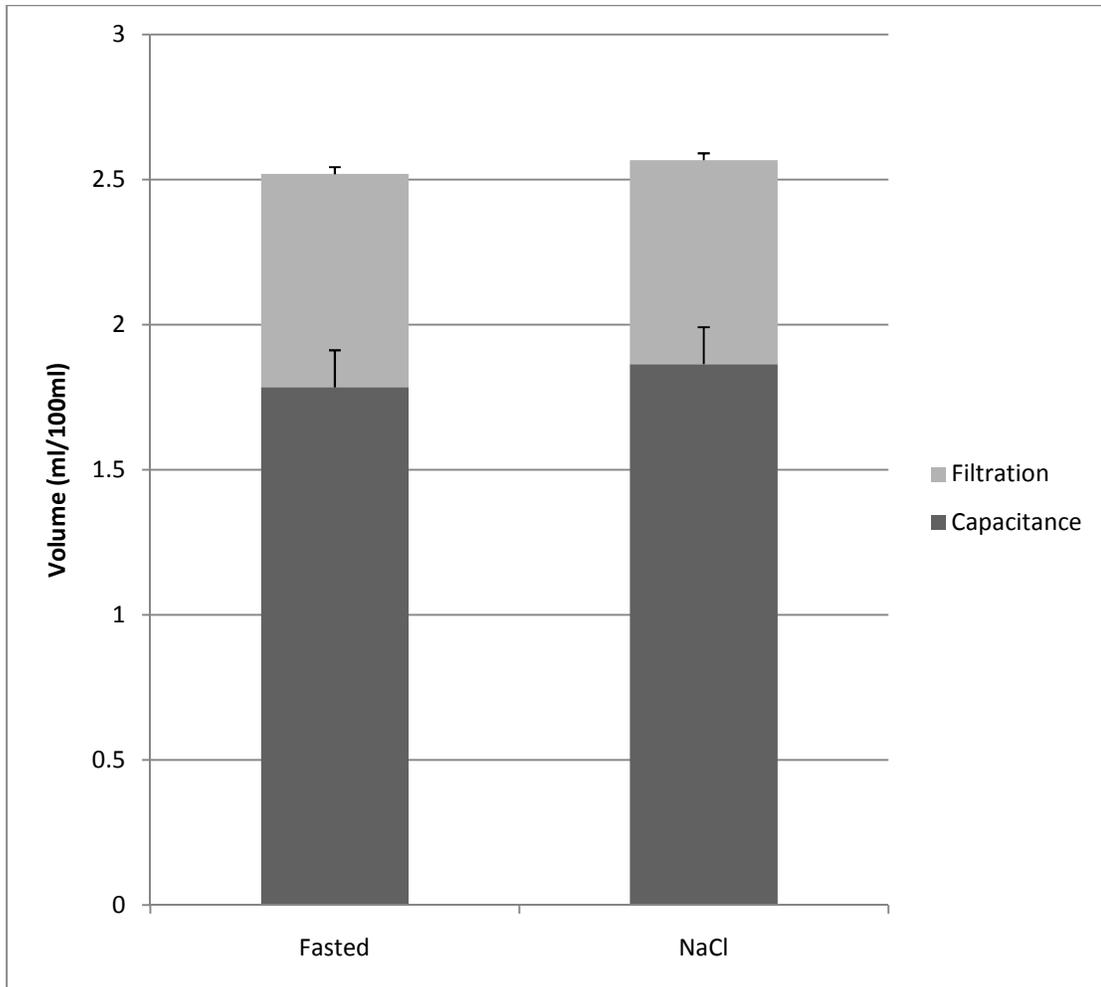


Figure 3. The contribution of venous capacitance and capillary filtration. Values are means \pm SE.

CHAPTER FOUR

DISCUSSION

The Halliwell et. al. (1999) method of measuring limb venous compliance using strain gauge plethysmography is noninvasive, quick, reliable, and valid (Halliwell et. al., 1999). This methodology has been used in multiple studies to assess venous compliance (Hernandez, & Franke, 2004; Hernandez, Franke, 2005). The purpose of this study was to determine if an acute high intake of NaCl would affect the assessment of limb venous compliance using this methodology.

We hypothesized that an acute intake of NaCl in the participants' diets would show a decrease in compliance in the NaCl condition versus the fasted condition after reviewing previous research that supports a decrease in vascular compliance with a high salt intake in some populations (Sanders, 2009; Takeshita, et. al., 1984; Draaijer, et. al., 1995). The results of the study did not support our hypothesis and actually found no significant differences in compliance measurements between a fasted condition and acute NaCl intake condition (Fig. 2). Furthermore, there were no significant differences in any cardiovascular variables, capacitance, capillary filtration, regression beta values or pressure-volume curves (Fig. 1, Fig. 3, Table 1, Table 2).

There have been different mechanisms previously studied that have effects on venous compliance. Orthostatic stress and baroreceptor reflexes have been studied with lower body negative pressure and their effects on venous compliance (Monahan, & Ray, 2004; Lindenberger, & Lanne, 2006). These studies support a reduction in calf venous compliance during sympathoexcitation due to lower body negative pressure stress that appear to be specific to baroreceptor unloading and not muscle reflex engagement or cold

stress. One focus investigated with salt diets are the possible effects on the vessel walls during a high salt diet (Takeshita, et. al., 1984; Draaijer, et. al., 1995; Creager, et. al., 1991). These studies support the hypothesis that a chronic high salt diet will decrease venous compliance. We can only speculate the mechanism for no change in compliance between the two conditions in this study. The most likely explanation is that an acute intake of NaCl does not alter the venous walls that can attribute to a change in compliance in the same way that a chronic high salt intake does (Takeshita et.al.,1984).

The recommended daily value of sodium intake in the United States is less than 2400 mg per day. Previous research using a high salt diet has used different intakes to induce the high salt concentration in their participants. These studies were not looking at acute intake, however, so the intakes were extended over time from 5-7 days. The intake of sodium per day ranged from 4598 mg/day up to 7931 mg/day (Takeshita, et. al., 1984; Draaijer, et. al., 1995; Creager, et. al., 1991). In our study we had the participants intake an average of 3055 mg of sodium in the 12 hours previous to testing. This is slightly more than 125% of the recommended daily value. However, the recommended daily value and the average daily value of a college aged male may not be the same. The NaCl intake that we had our participants ingest may not be exaggerated enough from their average daily intake of NaCl to elicit a change in compliance.

Going forward from this research, we need to continue to question the methodology of current paradigms in order to evolve with available knowledge and technology. This study may also serve as pilot work for future studies investigating the influence of other diets on venous compliance. More research needs to be done to further investigate the effects of NaCl on venous compliance in normotensive participants and

the effects of acute NaCl loading of the assessment of venous compliance. More in depth research should also be done to determine the factors that lead to the results found in this study. However, these results support the use of this methodology without extensive dietary control prior to assessment.

There are several limitations associated with the current study. First, the results of this study cannot be generalized to other genders or age groups because of the specificity of the participants. It has been shown that there are differences in venous compliance between genders and age (Hernandez, & Franke, 2004; Hernandez, & Franke 2005). Second, the two conditions were assigned to the participants; however, adherences to the instructions were self-reported and there is no way to show conclusively that they adhered to our instructions. Finally, the acute NaCl diet may not have been high enough to elicit any vascular changes in our participants. The diet was over 125% that of the daily recommended daily value, but the average NaCl intake of our participants were not determined. Determining the participants' average NaCl intake would help increase the amount of NaCl needed to produce an acute effect.

In conclusion, to the best of our knowledge, this is the first research assessing the effects of an acute NaCl diet on limb venous compliance assessment. We hypothesized that an acute intake of NaCl in the participants' diets would show a decrease in compliance in the NaCl condition versus the fasted condition. The data from the current study suggest that calf venous compliance assessment using venous occlusion plethysmography is not affected by acute high NaCl consumption.

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