



HAL
open science

Leg crossing with muscle tensing, a physical counter-manoevre to prevent syncope, enhances leg blood flow

Jan T Groothuis, Nynke van Dijk, Walter ter Woerds, Wouter Wieling, Maria Te Hopman

► To cite this version:

Jan T Groothuis, Nynke van Dijk, Walter ter Woerds, Wouter Wieling, Maria Te Hopman. Leg crossing with muscle tensing, a physical counter-manoevre to prevent syncope, enhances leg blood flow. *Clinical Science*, 2006, 112 (3), pp.193-201. 10.1042/CS20060241 . hal-00479344

HAL Id: hal-00479344

<https://hal.science/hal-00479344>

Submitted on 30 Apr 2010

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Leg crossing with muscle tensing, a physical counter-manoeuvre to prevent syncope, enhances leg blood flow

Jan T Groothuis*, Nynke van Dijk†, Walter ter Woerds*, Wouter Wieling† and
Maria TE Hopman*

*Department of Physiology, Radboud University Nijmegen Medical Centre, PO Box 9101, 6500 HB
Nijmegen, The Netherlands and †Department of Internal Medicine, Academic Medical Centre, PO
Box 22660, 1100 DD Amsterdam, The Netherlands

Short title: Leg crossing with muscle tensing enhances blood flow

Address for correspondence:

Maria TE Hopman, MD, PhD

Department of Physiology (143)

Radboud University Nijmegen Medical Centre

Geert Grooteplein Noord 21

PO Box 9101

6500 HB Nijmegen

The Netherlands

Tel: +31243613650

Fax: +31243540535

E-mail: M.Hopman@fysiol.umcn.nl

Abstract

In patients with orthostatic intolerance the mechanisms to maintain blood pressure fail. A physical counter-manoeuve to postpone or even prevent orthostatic intolerance in these patients is leg crossing combined with muscle tensing. Although the central haemodynamic effects of physical counter-manoevres are well documented, not much is known about the peripheral haemodynamic events. Therefore, the purpose of the present study was to examine the peripheral haemodynamic effects of leg crossing combined with muscle tensing during 70° head-up tilt (HUT). Thirteen healthy subjects were monitored for 10 minutes in the supine position followed by 10 minutes in 70° HUT and, finally, 2 minutes of leg crossing with muscle tensing in 70° HUT. Mean arterial blood pressure (MAP), heart rate, stroke volume, cardiac output and total peripheral resistance were measured continuously by Portapres. Leg blood flow was measured using Doppler ultrasound. Leg vascular conductance was calculated as leg blood flow divided by MAP. Results show a significant increase in MAP (13 mmHg), stroke volume (27%) and cardiac output (18%), a significant decrease in heart rate (-5 bpm) and no change in total peripheral resistance during the physical counter-manoeuve when compared to baseline 70° HUT. A significant increase in leg blood flow (325 ml/min) and leg vascular conductance (2.9 AU) were seen during the physical counter-manoeuve when compared to baseline 70° HUT. The present study indicates that the physical counter-manoeuve of leg crossing combined with muscle tensing clearly enhances leg blood flow and at the same time elevates mean arterial blood pressure.

Key words: orthostatic intolerance; physical counter-manoevres; leg blood flow; leg vascular conductance; head-up tilt

Introduction

Orthostatic stresses are common daily events in humans. In the upright position a gravitational displacement of blood from the thorax to the venous vascular beds of the legs, buttock and abdomen occurs. During orthostasis approximately 600 – 700 ml of blood is transferred to the regions below the diaphragm [1, 2], which is known as ‘venous pooling’. This results in a reduced venous return to the heart and a fall in central venous pressure with a consequent decrease in cardiac filling, stroke volume and cardiac output [3]. The cardiovascular system in healthy humans is exquisitely adapted to maintain sufficient cardiac output in the upright posture. Neural pathways of the autonomic nervous system mediate rapid short-term adjustments to orthostatic stress, by increasing total peripheral resistance and heart rate. Concurrently, an increase in muscle tone in the legs prevents excessive pooling and promotes the venous return when upright [3]. In patients with orthostatic intolerance these regulatory mechanisms fail to maintain blood pressure in the upright posture [1, 4-6]. Patients with autonomic failure, who suffer from severe orthostatic hypotension due to failure of sympathetic neural vasomotor control [3], can promote venous return and raise cardiac output by applying physical counter-manoevres that raise muscle skeletal tone, e.g. leg crossing and muscle tensing [3, 7-10]. Also patients with vasovagal syncope have successfully used these physical counter-manoevres to counteract their orthostatic intolerance [5, 6, 11]. Leg crossing and muscle tensing, lead to an increase in mean arterial blood pressure and postpone or even prevent syncope [5, 8, 11-13].

It has recently been shown that the blood pressure raising effect of physical counter-manoevres in patients with orthostatic intolerance is solely due to an increase in cardiac output [12, 13]. However, leg vascular resistance itself could be affected in several ways during performance of the physical counter-manoevre. On the one hand, it has been suggested that leg vascular resistance would increase as a consequence of compression of the large arteries in the legs by the squeezing manoeuvre [6, 11, 14]. Some questions may be raised by this latter suggestion since a very high pressure is needed to compress the large arteries and compression will only occur at the sight of squeezing, i.e. a small part of the thigh and not the entire leg. On the other hand vasodilatation is known to occur during muscle tensing [15-17] and could occur during performance of the physical counter-manoevre.

The purpose of the present study, therefore, is to examine the peripheral haemodynamic effects of leg crossing combined with muscle tensing during 70° head-up tilt. We tested the hypothesis that leg blood flow would increase during the physical counter-manoeuvre in the head-up tilt position.

Methods

Subjects

Seventeen healthy, normotensive subjects, nine males and eight females, volunteered to participate in this study. The subjects' medical history did not reveal any episodes of vasovagal syncope, cardiovascular diseases or any other morbidity. None of the subjects used any medication and all subjects were non-smokers. All subjects gave written informed consent. The study has been carried out in accordance with the Declaration of Helsinki (2000) and was approved by the medical ethical committee of our institution.

Experimental procedures and protocol

Subjects refrained from caffeine, alcohol and nicotine for at least 12 hours and did not eat for 2 hours prior to testing. The experiment took place in the morning, in a quiet, temperature-controlled room (between 22°C and 24°C). Before the experiment the subjects received instructions on how to perform the physical counter-manoevre. They practised leg crossing combined with muscle tensing standing on the tilt table. This physical counter-manoevre consisted of crossing the right leg in front of the left leg at thigh level and pressing the legs firmly against each other. Simultaneously, the subjects were asked to tense the muscles of the legs and buttocks to their best ability, and to maintain this tension during the measurement. The physical counter-manoevre was performed while standing on both legs, distributing the body weight equally on both legs. Subjects were instructed to avoid straining during the physical counter-manoevre. [5, 13]

Subjects were then placed in the supine position on a manually controlled tilt table with footboard in such manner that they could stand on the footboard in the head-up tilt position. The subjects were supported with a chest belt to prevent them from falling down during the experiment in case of vasovagal syncope. When presyncopal symptoms occurred the experiment was aborted and the subject was immediately tilted back to the supine position.

During a acclimatization period of minimal twenty minutes in the supine position the measurement apparatus was connected, where after the experimental protocol started with ten minutes in the supine

position in order to establish steady state values. Subjects were subsequently tilted manually within five seconds to 70° head-up tilt. In this position subjects were instructed to relax, standing with the weight of the body equally distributed on both legs. After ten minutes in the head-up tilt position the subjects were asked to perform the physical counter-manoeuve. The physical counter-manoeuve was executed within two seconds. The physical counter-manoeuve was continued for two minutes. Then the subjects were tilted back to the supine position and the experiment was ended.

Measurements

Arterial blood pressure and heart rate were continuously and non-invasively measured using Portapres (TNO, Amsterdam, the Netherlands), a portable blood pressure device. A finger cuff was attached to the middle phalanx of the third finger of the right hand in order to measure the finger arterial blood pressure and heart rate. Finger arterial blood pressure measurements accurately reflect intra-arterial blood pressure changes during orthostatic stress [18]. Data were collected during the experiment at a rate of 200 Hz. A built-in expert system, physiocal, was in operation during the entire experiment to establish and adjust the proper volume clamp set point. Mean arterial blood pressure (MAP) values were derived beat to beat. Heart rate was the inverse of the interbeat interval. Stroke volume (SV) was determined by a three-element model of arterial input impedance, using the Modelflow program, that provides accurate estimates of changes in SV during orthostatic stress [19]. Cardiac output (CO) was calculated as SV times heart rate, and total peripheral resistance was calculated as MAP divided by CO. Monitoring of CO needs calibration against a gold standard if accurate absolute values are required [6, 12]. Because the Modelflow measure was not calibrated in the present study, SV, CO and total peripheral resistance were expressed as relative change from steady state values in the head-up tilt position [12, 20]. Changes in SV, CO and total peripheral resistance were calculated only in the head-up tilt position because there is some debate on using Modelflow with change of posture [21]. Changes in Modelflow CO during leg crossing with muscle tensing are in excellent agreement with CO changes measured by inert gas breathing [12].

Mean red blood cell velocity (V_{mean}) and systolic and diastolic vessel diameter of the right common femoral artery were measured with a Doppler ultrasound device (Megas, ESAOTE, Firenze, Italy)

with a 5-7.5 MHz broadband linear array transducer. Doppler ultrasound measurements were performed on the right leg, which is the actively crossed leg. The sample volume was placed in the middle of the vessel, ~ 2 cm proximal of the bifurcation of the common femoral artery into the deep and superficial femoral artery. The angle of inclination for the red blood cell velocity measurements was consistently below 60°, which is online visible on the screen, and the vessel area was adjusted parallel to the transducer. A single analyst manually traced the Doppler waveforms thereafter. V_{mean} was calculated as the average of 10 Doppler waveforms every 15 seconds in supine and HUT position. At the start of the physical counter-manoevre (Time = 0 in figures 2 and 4) V_{mean} was calculated every 5 seconds for a 20-second period and thereafter every 2 seconds. For diameter measurements at five minutes in supine and head-up tilt position, two consecutive longitudinal vessel images were analyzed at the peak-systolic and end-diastolic phase. The diameter of the common femoral artery was calculated as $1/3 \cdot \text{systolic} + 2/3 \cdot \text{diastolic diameter}$ [22]. Leg blood flow was calculated with the following formula: $(\pi \cdot r^2 \cdot V_{\text{mean}}) \cdot 60$ ($r = 1/2 \cdot \text{diameter of the common femoral artery}$). Leg blood flow was calculated in the supine position using the supine diameter, and in the upright position using the upright diameter. For the calculations the assumption that the femoral artery diameter did not change is crucial. This assumption was confirmed by a pilot study performed in our laboratory in five healthy young men (22-28 years). Right common femoral artery diameter (in cm) in supine: 9.6 ± 0.6 , HUT: 9.8 ± 0.8 and physical counter-manoevre: 10.1 ± 0.7 (non-significant differences within the error margin of the ultrasound device ($CV = 1.5\%$ [22])).

Leg vascular conductance was calculated as leg blood flow divided by MAP. We choose to use leg vascular conductance as it is the most appropriate parameter to quantify the functional importance of local responses in the regulation of blood pressure, when large changes in blood flow are present [23]. For these calculations, we assumed that central venous pressure was near zero in the supine position and that hydrostatic pressure made an identical contribution to leg venous pressure as to leg arterial pressure.

Data analysis

Steady state values of MAP, heart rate, SV, CO, total peripheral resistance, V_{mean}, leg blood flow and leg vascular conductance were averaged over the intervals 7 to 9.5 min in supine and head-up tilt position and 1.5 to 2 min in head-up tilt position combined with the physical counter-manoeuve. SV, CO and total peripheral resistance in the head-up tilt position combined with the physical counter-manoeuve (interval 1,5 to 2 min) were also expressed as percentage change from steady state values in the head-up tilt position.

Statistical analyses

Results are expressed as mean \pm SEM or as mean (95%CI). Differences in steady state values of MAP, heart rate, V_{mean}, leg blood flow and leg vascular conductance between the supine and head-up tilt position and differences in MAP, heart rate, SV, CO, total peripheral resistance, V_{mean}, leg blood flow and leg vascular conductance between the head-up tilt position and head-up tilt position combined with the physical counter-manoeuve were tested with a two-tailed paired Student's t-test. Differences in diameter of the common femoral artery between supine and the head-up tilt position were tested with a two-tailed paired Students t-test. Gender differences in leg blood flow and leg vascular conductance between the head-up tilt position and head-up tilt position combined with the physical counter-manoeuve were tested with a two-tailed unpaired Student's t-test. A 2-sided probability value of < 0.05 was considered to be statistically significant.

Results

Four subjects, one male and three females, could not complete the protocol, due to presyncopal symptoms, and had to be returned to the supine position before the physical counter-manoevre could be performed. This left thirteen subjects for analysis, eight males and five females. General characteristics of the thirteen subjects are shown in table 1.

Central parameters

A significant increase in heart rate (24 bpm (20 to 29)) (mean (95%CI)) was seen between the supine and head-up tilt position with no change in MAP (1 mmHg (-2 to 4)). (Table 2, Figure 1). An immediate rise in MAP, SV and CO and a decline in total peripheral resistance were seen at the start of the physical counter-manoevre (Figure 1). After the rapid initial changes significant increases in steady state values were seen in MAP (13 mmHg (8 to 18)), SV (28 % (17 to 39)) and CO (21 % (10 to 31)), a significant decrease in heart rate (-5 bpm (-10 to -1)), but no change in total peripheral resistance (-3 % (-12 to 6)) (Table 2, Figure 1).

Peripheral parameters

A significant increase in diameter of the right common femoral artery (0.03 cm (0.00 to 0.07)) was seen between the supine and head-up tilt position, while significant decreases were seen in V_{mean} (-4.4 cm/s (-9.3 to -1.6)), leg blood flow (-165 ml/min (-291 to -30)) and leg vascular conductance (-1.8 (-3.7 to -0.2)) (Table 2, Figure 2 and 3). An immediate rise in leg blood flow and leg vascular conductance in the right, actively crossed, leg was seen at the start of the physical counter-manoevre (Figure 2). The physical counter-manoevre in the head-up tilt position resulted in significant increases in steady state values of V_{mean} (7.4 cm/s (1.8 to 15.5)), leg blood flow (325 ml/min (82 to 691)) and leg vascular conductance (2.9 AU (0.8 to 6.1)) in the right common femoral artery (Table 2, Figure 2 and 3).

No gender differences were detected in leg blood flow and leg vascular conductance steady state values nor in changes in leg blood flow and leg vascular conductance between the head-up tilt position

and head-up tilt position combined with the physical counter-manoevre (Figure 4).

Discussion

The major findings of this study are that the physical counter-manoevre, leg crossing combined with muscle tensing, enhances leg blood flow and leg vascular conductance. Concurrently, the physical counter-manoevre increases mean arterial blood pressure and cardiac output with an unchanged total peripheral resistance. Thus the hypothesis that leg blood flow would increase during the physical counter-manoevre could be confirmed, however the increase in leg vascular conductance was not hypothesised.

Haemodynamic effects

The head-up tilt position causes a gravitational displacement of blood from the thorax to the venous vascular beds of the legs, buttock and abdomen, known as 'venous pooling'. SV decreases resulting in a decrease in CO and MAP [1, 6, 8, 24, 25]. In order to maintain sufficient CO, sympathetic activation results in an increase in peripheral vasoconstriction and heart rate [1, 6, 8, 24-27]. In the present study, no change in MAP with an increase in heart rate was seen between supine and the head-up tilt position (Table 2, Figure 1) and leg blood flow and leg vascular conductance decreased (Table 2, Figure 2-3). Supine and head-up tilt leg blood flow values found in this study are in agreement with previous studies [1, 24, 26-28].

In parallel with previous studies [6, 8] we documented that leg crossing with muscle tensing during head-up tilt enhanced SV as well as CO and MAP, while heart rate decreased (Table 2, Figure 1). We attribute the increase in CO to the fact that leg crossing with muscle tensing raises intramuscular pressure of the skeletal muscles in the legs, which causes mechanical compression of the venous vascular beds. This will counteract the 'venous pooling' and translocate venous blood back to the thorax, resulting in an increase in cardiac filling, SV and CO [5-9, 12, 13]. This translocation of venous blood occurs in the first 30 seconds after the onset of the physical counter-manoevre [20].

This study is the first to report that, leg crossing with muscle tensing during head-up tilt increases leg blood flow (Table 2, Figure 2 and 3). Several factors could be involved. First, blood flow increases instantly at the onset of dynamic exercise [29] and peaks within thirty seconds [20, 30-32] (Figure 2). However, in the present study the subjects did not perform sustained dynamic exercise but maintained isometric muscle tensing after the dynamic initial bout. Isometric exercise also increases blood flow by dilatation of the vasculature, but the dilatation is less pronounced compared to dynamic exercise. ~~in~~ Femoral artery blood flow increases slightly during isometric contractions of the quadriceps muscle at 5 to 50 percent of maximal voluntary contraction (MVC) [15-17]. Sjogaard et al, reported that the increase in blood flow fell with increasing MVC, due to the increase in intramuscular pressure [16]. MVC was not measured in the present study, but young healthy individuals can persist 25 to 50 percent of MVC during a two-minute period before fatigue occurs. Femoral artery blood flow increases during this period by about 40 % [15-17]. Hence, only a minor part of the increase in leg blood flow in the present study (> 200% increase) could be explained by maintained muscle tensing. A second explanation may be that leg blood flow increases as a result of an increase in the arterio-venous pressure gradient ($P_{\text{arterial}} - P_{\text{venous}}$) due to venous emptying and increase in MAP. Hydrostatic pressure, caused by the upright position, ~~is~~ can be assumed to be equal on the venous and arterial side of the leg circulation. Therefore, leg blood flow (pressure difference divided by resistance) will increase due to an increase in MAP and a decrease in venous pressure [8, 29, 31]. Thirdly, as a result of the instant venous emptying induced by leg crossing with muscle tensing, withdrawal of the veno-arteriolar axon 'reflex' could occur. If so, the consequent increase in leg vascular conductance [28, 33, 34] will contribute to the increase in leg blood flow. A fourth possible explanation is related to baroreflex activity. In response to a rise in MAP upon leg crossing with muscle tensing arterial baroreceptor activity increases, resulting in a decrease in heart rate, CO and total peripheral resistance [35]. In the present study, the physical counter-manoeuvre caused an increase in MAP with a slight decrease in heart rate. Total peripheral resistance, however, did not change (table 2, figure 1). If baroreceptor activity explains the increase in leg blood flow during leg crossing with muscle tensing, by causing a reflex increase in leg vascular conductance, then this should have been reflected in a decrease in total peripheral resistance.

Finally, central command, present at the start and during exercise, could have contributed to a vasodilation during the physical counter-manoeuve.

Leg vascular conductance increases about 2.5 fold, when the steady state values of head-up tilt with and without the physical counter manoeuvre are compared, however, the decrease in peripheral resistance is not reflected in the total peripheral resistance change between head-up tilt and head-up tilt with the physical counter-manoeuve (Table 2). Total peripheral resistance is a computed central cardiovascular parameter (MAP divided by CO). It expresses total body peripheral resistance, which is the sum of vasodilatation in the active muscles of the legs and apparently vasoconstriction in other areas of the body, such as the nonworking muscles, kidneys and splanchnic vascular bed.

Gender differences

In accordance with the study of van Dijk et al. [12], who reported no gender differences in *central* haemodynamic effects, except for a larger increase in systolic blood pressure and pulse pressure in male individuals, when a physical counter-manoeuve was applied in the head-up tilt position in patients with vasovagal syncope, we found no gender differences in *peripheral* haemodynamic effects, such as leg blood flow and leg vascular conductance changes induced by the physical counter-manoeuve (Figure 4). However, we must take the small sample size (male n = 8, female n = 5) into account.

Limitations

Doppler ultrasound measurements were performed on the right common femoral artery, the leg that was actively crossed over the left leg. One may argue that the results obtained in this study do not represent left leg peripheral haemodynamics directly. The physical counter-manoeuve encompassed crossing the right leg in front of the left leg at thigh level and pressing them firmly against each other. Simultaneously, the muscles of both legs and buttocks were tensed. The pressure applied is assumed to be similar in both legs resulting in partial compression of the thigh vascular bed. Although the anatomical site of pressure is different between both legs, i.e. right leg: medial-dorsal and left leg:

medial-ventral, the results obtained for the right common femoral artery likely apply for the left common femoral artery as well.

For calculation of the leg blood flow during the physical counter-manoevre we used the diameter of the common femoral artery in the head-up tilt position. We assumed that the diameter would not change during the entire experiment [24]. Although we found a significant difference in diameter of the common femoral artery between supine and head-up tilt, this difference is within the error margin of the ultrasound method used ($CV = 1.5\%$ [22]). It is not likely that the physical counter-manoevre did affect the diameter of the common femoral artery, because 1) the crossing of the legs occurred on thigh level and the ultrasound measurements were performed well above this level in the inguinal area and 2) to affect the diameter of a large conduit artery you will need a very high pressure and still it is probably more a deforming of than an actual change in diameter.

We studied healthy, normotensive subjects. However, physical counter-manoevres are usually advised to patients with orthostatic intolerance [9-13]. Patients with orthostatic intolerance show similar initial central and peripheral haemodynamic effects from supine to the upright posture, compared with healthy subjects [5, 8, 12, 13, 25, 36-38]. These patients show a drop in CO before the onset of syncope, starting at the onset of the prodromal symptoms. If a physical counter-manoevre is applied at the moment that prodromal symptoms occur, as is advised, the central haemodynamic effects are similar to healthy subjects [8, 13]. We therefore believe that the changes in peripheral parameters in the present study would also apply for patients with orthostatic intolerance.

Conclusion

The present study demonstrates that the physical counter-manoevre of leg crossing combined with muscle tensing clearly enhances leg blood flow and at the same time elevates mean arterial blood pressure. The largest and immediate effect seems to be achieved by the compression of the venous vascular bed at the onset of the physical counter-manoevre, translocating blood back to the thorax, simultaneously with this effect an enhanced arterio-venous pressure gradient and possibly withdrawal of the veno-arterial reflex may occur, explaining the observed increase in leg blood flow.

Acknowledgements

We would like to acknowledge the participation of all subjects in this study. In addition, we would like to thank Bregina Kersten and Jos Evers for assistance during the experiments.

References

- 1 Rowell, L.B. (1993) Reflex control during orthostasis. In Human cardiovascular control (Rowell, L.B., eds), pp. 37-80, Oxford University Press, New York
- 2 Smith, J.J. and Ebert, T.J. (1990) General responses to orthostatic stress. In Circulatory responses to the upright posture (Smith, J.J., eds), pp. 1-46, CRC Press, Boca Raton, FL
- 3 Smit, A.A.J., Halliwill, J.R., Low, P.A. and Wieling, W. (1999) Pathophysiological basis of orthostatic hypotension in autonomic failure. *J Physiol* **519**, 1-10
- 4 Jardine, D.L., Ikram, H., Frampton, C.M., Frethey, R., Bennett, S.I. and Crozier, I.G. (1998) Autonomic control of vasovagal syncope. *Am J Physiol Heart Circ Physiol* **274**, H2110-2115
- 5 Krediet, C.T.P., van Dijk, N., Linzer, M., van Lieshout, J.J. and Wieling, W. (2002) Management of Vasovagal Syncope: Controlling or Aborting Faints by Leg Crossing and Muscle Tensing. *Circulation* **106**, 1684-1689
- 6 van Lieshout, J.J., Pott, F., Madsen, P.L., van Goudoever, J. and Secher, N.H. (2001) Muscle Tensing During Standing : Effects on Cerebral Tissue Oxygenation and Cerebral Artery Blood Velocity. *Stroke* **32**, 1546-1551
- 7 Bouvette, C.M., McPhee, B.R., Opfer-Gehrking, T.L. and Low, P.A. (1996) Role of physical countermeasures in the management of orthostatic hypotension: efficacy and biofeedback augmentation. *Mayo Clin Proc* **71**, 847-853
- 8 ten Harkel, A.D.J., van Lieshout, J.J. and Wieling, W. (1994) Effects of leg muscle pumping and tensing on orthostatic arterial pressure: a study in normal subjects and patients with autonomic failure. *Clin Sci* **87**, 553-558
- 9 van Lieshout, J.J., ten Harkel, A.D.J. and Wieling, W. (1992) Physical manoeuvres for combating orthostatic dizziness in autonomic failure. *Lancet* **339**, 897-898
- 10 Van Lieshout, J.J., Wieling, W., Karemaker, J.M. and Secher, N.H. (2003) Syncope, cerebral perfusion, and oxygenation. *J Appl Physiol* **94**, 833-848
- 11 Wieling, W., Colman, N., Krediet, C.T.P. and Freeman, R. (2004) Nonpharmacological treatment of reflex syncope. *Clin Auton Res* **14**, i62-i70

- 12 van Dijk, N., de Bruin, I.G.J.M., Gisolf, J., et al. (2005) Hemodynamic effects of leg crossing and skeletal muscle tensing during free standing in patients with vasovagal syncope. *J Appl Physiol* **98**, 584-590
- 13 Krediet, C.T.P., de Bruin, I.G.J.M., Ganzeboom, K.S., Linzer, M., van Lieshout, J.J. and Wieling, W. (2005) Leg crossing, muscle tensing, squatting, and the crash position are effective against vasovagal reactions solely through increases in cardiac output. *J Appl Physiol* **99**, 1697-1703
- 14 Brignole, M., Croci, F., Menozzi, C., et al. (2002) Isometric arm counter-pressure maneuvers to abort impending vasovagal syncope. *J Am Coll Cardiol* **40**, 2053-2059
- 15 Wesche, J. (1986) The time course and magnitude of blood flow changes in the human quadriceps muscles following isometric contraction. *J Physiol* **377**, 445-462
- 16 Sjogaard, G., Savard, G. and Juel, C. (1988) Muscle blood flow during isometric activity and its relation to muscle fatigue. *Eur J Appl Physiol* **57**, 327-335
- 17 Gaffney, F.A., Sjogaard, G. and Saltin, B. (1990) Cardiovascular and metabolic responses to static contraction in man. *Acta Physiol Scand* **138**, 249-258
- 18 Imholz, B.P.M., Wieling, W., van Montfrans, G.A. and Wesseling, K.H. (1998) Fifteen years experience with finger arterial pressure monitoring:: assessment of the technology. *Cardiovasc Res* **38**, 605-616
- 19 Harms, M.P., Wesseling, K.H., Pott, F., Jenstrup, M., van Goudoever, J. and Secher, N.H. (1999) Continuous stroke volume monitoring by modelling flow from non-invasive measurement of arterial pressure in humans under orthostatic stress. *Clin Sci* **97**, 291-301
- 20 Wieling, W., Harms, M.P., ten Harkel, A.D.J., van Lieshout, J.J. and Sprangers, R.L.H. (1996) Circulatory response evoked by a 3 s bout of dynamic leg exercise in humans. *J Physiol* **494**, 601-611
- 21 Bogert, L.W.J. and van Lieshout, J.J. (2005) Non-invasive pulsatile arterial pressure and stroke volume changes from the human finger. *Exp Physiol* **90**, 437-446
- 22 de Groot, P.C.E., Poelkens, F., Kooijman, M. and Hopman, M.T.E. (2004) Preserved flow-mediated dilation in the inactive legs of spinal cord-injured individuals. *Am J Physiol Heart Circ Physiol* **287**, H374-380

- 23 O'Leary, D.S. (1991) Regional vascular resistance vs. conductance: which index for baroreflex responses? *Am J Physiol Heart Circ Physiol* **260**, H632-637
- 24 Arbeille, P. and Herault, S. (1998) Cardiovascular echographic and Doppler parameters for the assessment of orthostatic intolerance. *Eur J Ultrasound* **7**, 53-71
- 25 Jardine, D.L., Melton, I.C., Crozier, I.G., et al. (2002) Decrease in cardiac output and muscle sympathetic activity during vasovagal syncope. *Am J Physiol Heart Circ Physiol* **282**, H1804-1809
- 26 Imadojemu, V.A., Lott, M.E.J., Gleeson, K., Hogeman, C.S., Ray, C.A. and Sinoway, L.I. (2001) Contribution of perfusion pressure to vascular resistance response during head-up tilt. *Am J Physiol Heart Circ Physiol* **281**, H371-375
- 27 Groothuis, J.T., Boot, C.R.L., Houtman, S., van Langen, H. and Hopman, M.T.E. (2005) Leg vascular resistance increases during head-up tilt in paraplegics. *Eur J Appl Physiol* **94**, 408-414
- 28 Leyk, D., Hoffmann, U., Baum, K., Wackerhage, H. and Essfeld, D. (1998) Leg blood flow during slow head-down tilt with and without leg venous congestion. *Eur J Appl Physiol* **78**, 538-543
- 29 Tschakovsky, M.E. and Sheriff, D.D. (2004) Immediate exercise hyperemia: contributions of the muscle pump vs. rapid vasodilation. *J Appl Physiol* **97**, 739-747
- 30 Sheriff, D.D. (2003) Muscle pump function during locomotion: mechanical coupling of stride frequency and muscle blood flow. *Am J Physiol Heart Circ Physiol* **284**, H2185-2191
- 31 Laughlin, M.H. (1987) Skeletal muscle blood flow capacity: role of muscle pump in exercise hyperemia. *Am J Physiol Heart Circ Physiol* **253**, H993-1004
- 32 Delp, M.D. (1999) Control of skeletal muscle perfusion at the onset of dynamic exercise. *Med Sci Sports Exerc* **31**, 1011-1018
- 33 Leyk, D., Essfeld, D., Baum, K. and Stegemann, J. (1994) Early leg blood flow adjustment during dynamic foot plantarflexions in upright and supine body position. *Int J Sports Med* **15**, 447-452
- 34 Tschakovsky, M.E. and Hughson, R.L. (2000) Venous emptying mediates a transient vasodilation in the human forearm. *Am J Physiol Heart Circ Physiol* **279**, H1007-1014
- 35 Lanfranchi, P.A. and Somers, V.K. (2002) Arterial baroreflex function and cardiovascular variability: interactions and implications. *Am J Physiol Regul Integr Comp Physiol* **283**, R815-826

- 36 Brown, C.M., Stemper, B., Welsch, G., Brys, M., Axelrod, F.B. and Hilz, M.J. (2003) Orthostatic challenge reveals impaired vascular resistance control, but normal venous pooling and capillary filtration in familial dysautonomia. *Clin Sci* **104**, 163-169
- 37 Wieling, W., van Lieshout, J.J. and ten Harkel, A.D.J. (1998) Dynamics of circulatory adjustments to head-up tilt and tilt-back in healthy and sympathetically denervated subjects. *Clin Sci* **94**, 347-352
- 38 Chandler, M.P. and Mathias, C.J. (2002) Haemodynamic responses during head-up tilt and tilt reversal in two groups with chronic autonomic failure: pure autonomic failure and multiple system atrophy. *J Neurology* **249**, 542-548

Table Legends

Table 1. General characteristics of the subjects. Values represent mean \pm SEM. MAP, mean arterial blood pressure. *, significantly different from male subjects.

Table 2. Steady state values of central and peripheral haemodynamic parameters during supine, head-up tilt and head-up tilt with physical counter-manoevre. n = 13. Values represent mean \pm SEM.

Stroke volume, cardiac output and total peripheral resistance are presented as absolute values. MAP, mean arterial blood pressure. AU, arbitrary units. V_{mean}, mean red blood cell velocity. *, significantly different from supine. †, significantly different from head-up tilt.

Figure Legends

Figure 1. Central haemodynamic effects of leg crossing combined with muscle tensing in the head-up tilt position. Graphs represent mean \pm SEM. $n = 13$. Mean arterial blood pressure (MAP), heart rate (HR), stroke volume (SV), cardiac output (CO) and total peripheral resistance (TPR) are shown. SV, CO and TPR are presented as percentage from steady state head-up tilt values (%bl). The black vertical lines indicate the different stages of the experiment. The dotted vertical lines distinguish the immediate effects from the steady state effects in head-up tilt position with physical counter-manoevre. Time = 0 indicates the start of the physical counter-manoevre. Note the time scale is not continuous.

Figure 2. Peripheral haemodynamic effects of leg crossing combined with muscle tensing in the head-up tilt position. Values represent mean \pm SEM. $n = 13$. Leg blood flow (upper graph), and leg vascular conductance (lower graph) are shown. The black vertical lines indicate the different stages of the experiment. The dotted vertical lines distinguish the immediate effects from the steady state effects in head-up tilt position with physical counter-manoevre. AU, arbitrary units. Time = 0 indicates the start of the physical counter-manoevre. Note the time scale is not continuous.

Figure 3. Steady state values of leg blood flow (upper plot) and leg vascular conductance (lower plot) in the supine, head-up tilt and head-up tilt position with the physical counter-manoevre (leg crossing combined with muscle tensing). $n = 13$. Values represent mean \pm SEM. AU, arbitrary units. *, significantly different from supine. †, significantly different from head-up tilt.

Figure 4. Leg vascular conductance effect of leg crossing combined with muscle tensing in the head-up tilt position for male (\blacktriangle , $n = 8$) and female (\circ , $n = 5$) subjects. Values represent mean \pm SEM. The black vertical lines indicate the different stages of the experiment. The dotted vertical line distinguishes the immediate effects from the steady state effects in head-up tilt position with physical

counter-manoevre. AU, arbitrary units. Time = 0 indicates the start of the physical counter-manoevre. Note the time scale is not continuous.

Table 1.

	All subjects	Male subjects	Female subjects
	(n = 13)	(n = 8)	(n = 5)
Age, yr	23.6 ± 1.0	22.4 ± 0.7	25.2 ± 2.3
Height, cm	184.3 ± 3.1	191.5 ± 2.6	173.0 ± 2.0 *
Body mass, kg	75.4 ± 3.3	82.3 ± 3.0	64.4 ± 3.5 *
Body mass index, kg/m ²	22.0 ± 0.5	22.3 ± 0.4	21.5 ± 1.2
Diastolic blood pressure, mmHg	70.9 ± 1.3	71.0 ± 1.7	70.8 ± 2.1
Systolic blood pressure, mmHg	120.1 ± 2.0	120.3 ± 3.0	120.0 ± 3.0
MAP, mmHg	87.3 ± 1.0	87.4 ± 1.8	87.2 ± 1.2

Table 2.

	Supine	Head-up tilt	Leg crossing
<i>Central parameters</i>			
MAP, mmHg	90.4 ± 3.2	89.3 ± 2.5	102.5 ± 3.4†
Heart rate, bpm	67.3 ± 2.3	91.8 ± 3.2*	86.4 ± 3.3†
Stroke volume, ml	92.4 ± 6.6	65.3 ± 5.1	82.6 ± 5.6
Cardiac output, l/min	6.12 ± 0.47	5.93 ± 0.52	7.02 ± 0.50
Total peripheral resistance, AU	0.960 ± 0.089	0.991 ± 0.089	0.941 ± 0.081
<i>Peripheral parameters</i>			
Diameter femoral artery, cm	0.95 ± 0.04	0.98 ± 0.04*	
V _{mean} , cm/s	7.9 ± 0.8	3.5 ± 0.3*	10.8 ± 1.2†
Leg blood flow, ml/min	318.5 ± 25.2	153.7 ± 12.8*	478.7 ± 57.4†
Leg vascular conductance, AU	3.58 ± 0.32	1.75 ± 0.16*	4.60 ± 0.48†

Figure 1

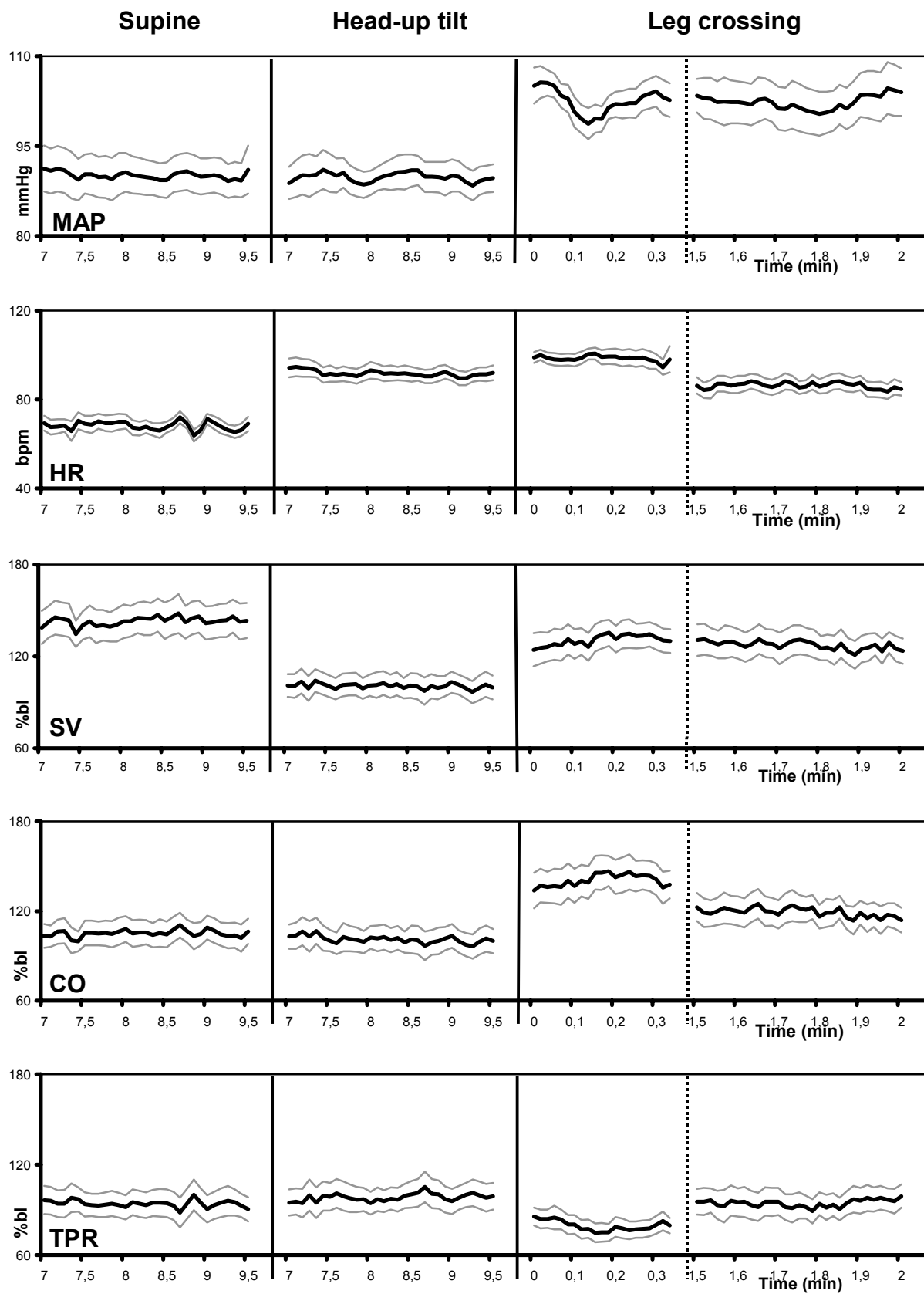


Figure 2

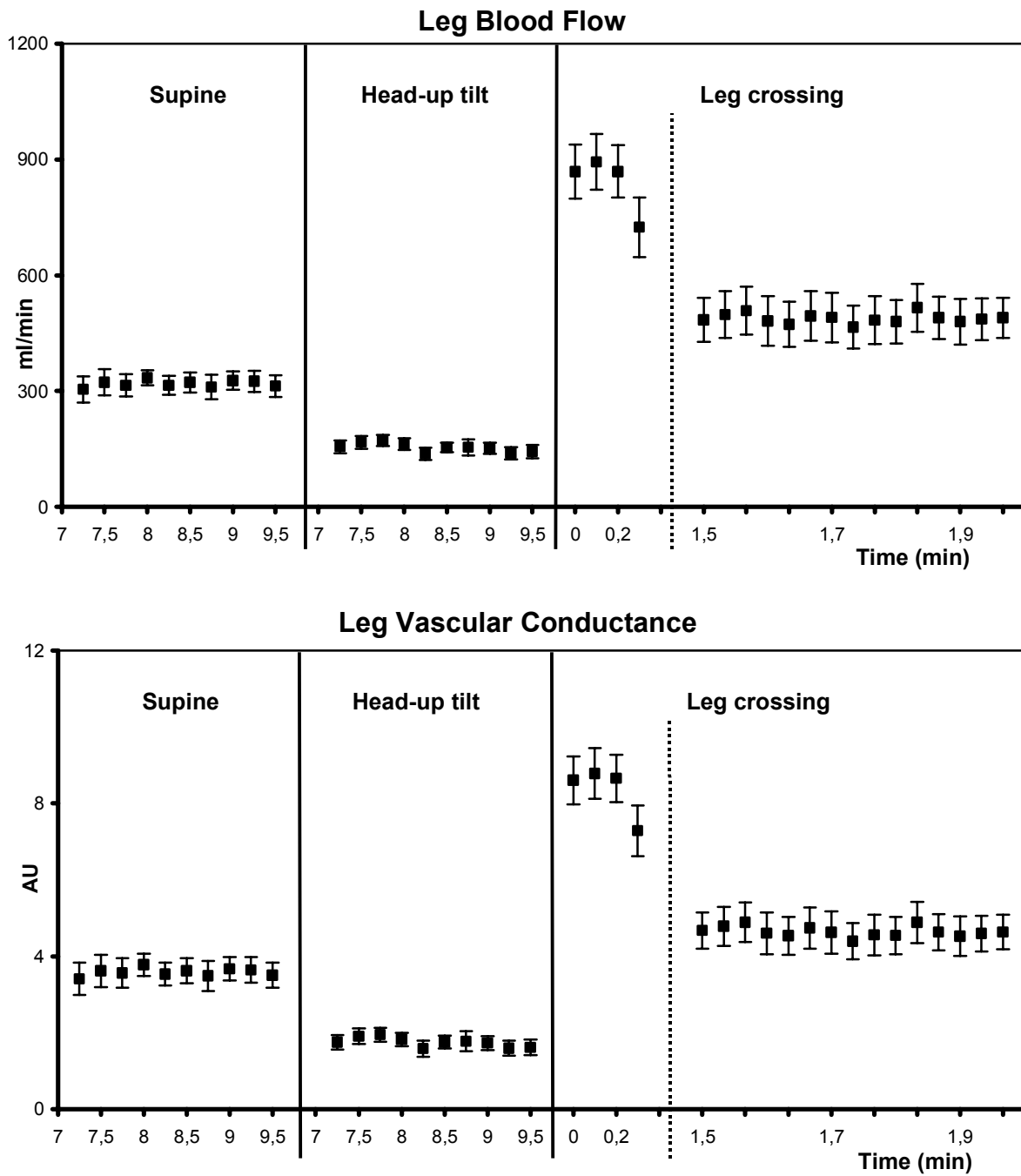


Figure 3

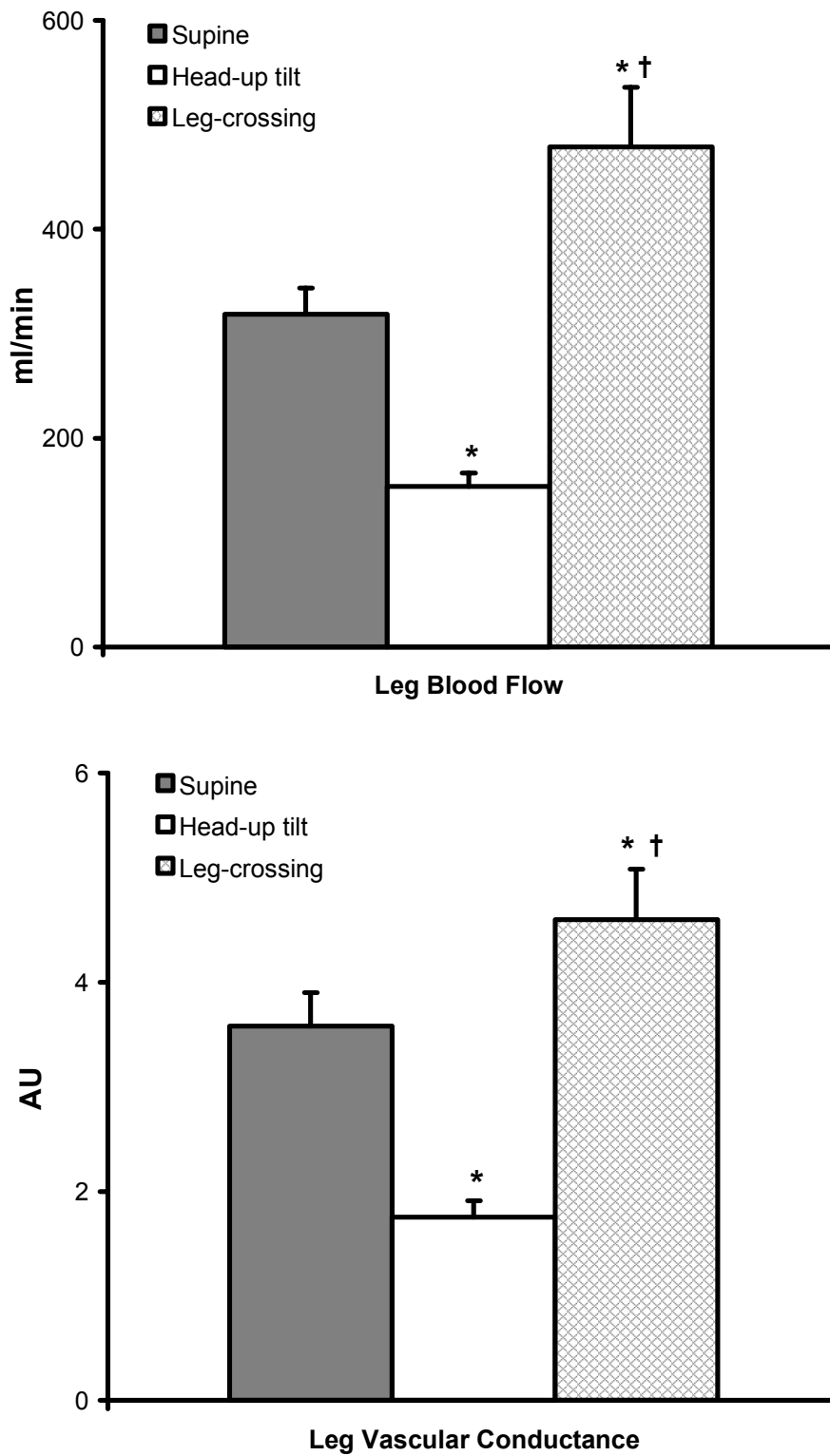


Figure 4

