Influence of compression hosiery on physiological responses to standing fatigue in women

WILLIAM J. KRAEMER, JEFF S. VOLEK, JILL A. BUSH, LINCOLN A. GOTSHALK, PAUL R. WAGNER, ANA L. GÓMEZ, VLADIMIR M. ZATSIORSKY, MARCOS DUZRTE, NICHOLAS A. RATAMESS, SCOTT A. MAZZETTI, and BEVERLY J. SELLE

The Human Performance Laboratory, Ball State University, Muncie, IN 47306; Laboratory for Sports Medicine and the Biomechanics Laboratory, Department of Kinesiology, The Pennsylvania State University, University Park, PA 16802; Diagnostic Medical Sonography, South Hills School of Business and Technology, State College, PA 16801; and E. I. du Pont de Nemours and Company, Inc., Wilmington, DE, 19880

ABSTRACT

KRAEMER, W. J., J. S. VOLEK, J. A. BUSH, L. A. GOTSHALK, P. R. WAGNER, A. L. GÓMEZ, V. M. ZATSIORSKY, M. DUZRTE, N. A. RATAMESS, S. A. MAZZETTI, and B. J. SELLE. Influence of compression hosiery on physiological responses to standing fatigue in women. *Med. Sci. Sports Exerc.*, Vol. 32, No. 11, pp. 1849–1858, 2000. **Purpose:** The purpose of this investigation was to examine the influence of various designs of commercial hosiery, which use graduated compression, on the physiological and performance responses to standing fatigue. **Methods:** Twelve healthy women (age = 23.0 ± 2.1 yr, height = 165.7 ± 5.0 cm, percent body fat = 22.6 ± 4.2%, body mass = 60.0 ± 8.9 kg) volunteered to participate in this investigation. All subjects completed four identical standing fatigue protocols with different garment conditions each separated by 7 d. The standing fatigue protocol involved a total of 8 h of standing on hard floors during which subjects participated in various tasks and experimental testing procedures. In addition, all activity and dietary profiles of the subjects were carefully controlled 48 h before each experimental session. Before the standing fatigue protocol, subjects completed a battery of tests to establish morning baseline values. Experimental tests included determination of lower leg venous cross-sectional area, blood pressure, heart rate, perceived discomfort ratings, circumferences measurements, total body water, variation in center of pressure during "quiet" standing, vertical jump performance, and specific regional patterns of foot pressures. **Results:** This investigation demonstrated that commercial hosiery with various forms of graduated compression and construction were effective in mediating a reduction in edema in the ankles and legs while reducing the amount of venous pooling and discomfort in the lower body. Different constructions of garments may mediate these overall effects via different physiological mechanisms related to fluid shifts and muscle tissue damage. **Conclusion:** Wearing various types of graduated compression hose during the day as it relates to women in standing professions may minimize edema and muscle tissue disruption, thereby increasing comfort in the legs. **Key Words:** WORK CAPACITY, WOMEN′S HEALTH, FORCE PRODUCTION, OCCUPATIONAL STRESS

A variety of occupations require employees to spend a majority of their working day in a standing position. Many of these employees are young women in the military, food service, banking, airline, hair care, and health care industries who may stand as much as 70–90% of their working hours (6). Long periods of standing have been typically associated with significant amounts of fatigue and body discomfort at the end of the workday (6,7,11,18,23). The impact of such fatigue remains speculative but may express itself in compromised productivity and happiness on the job (10,19,25). It has been hypothesized that both physiological and psychological stresses are associated with standing fatigue (18,25).

The pain and discomfort in the body, especially in the feet and legs, associated with standing fatigue may be hypothesized to be physiologically mediated via cardiovascular (e.g., hydrostatic pressure, venous pooling of blood, venous valve incompetence, edema) and muscle tissue mechanisms (e.g., muscle fatigue and tissue injury) (11,13,15,18,19,23). Standing for long periods of time may result in disruption of certain muscle fiber membranes due to static and dynamic loading, especially in the lower body musculature (6,18). The tissue damage in turn contributes to increased edema due to the inflammatory response to cell damage (6). With standing fatigue the loading of the hydrostatic column pressures contribute to the classic edema observed in the feet and legs. Hard surfaces have been shown to further promote these symptoms (2,11,18). In addition, with static loading of the musculature in the standing position, fluid (i.e., edema

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and pooled blood) movements out of the various tissue bio-compartments (e.g., muscle) may be compromised due to circulatory limitations and reduced effectiveness of the venous-muscle pump mechanisms (9).

Clothing is one intervention that may be able to help alleviate such physiological and psychological stresses. To obviate circulatory limitations (e.g., blood clots) due to circulatory insufficiency, surgical support garments (e.g., clinical hosiery) with high levels of compression ranging from 18.4 to greater than 59 mm Hg (12) have been used to attenuate such symptoms in clinical populations (8,15,21). Different from clinical hosiery, less compressive commercial hosiery (e.g., graduated compression) is worn by many women in the workplace for fashion, function, appearance, and comfort. However, no direct evidence exists as to the actual ergonomic effects of such hosiery in younger women. In addition, no data exist as to possible mechanisms that may mediate any protective effects against the stress of standing fatigue. Therefore, the primary purpose of this investigation was to examine the influence of various designs of commercial hosiery that use light to moderate graduated compression on the physiological and performance responses to standing fatigue. Such data will provide important new insights into possible roles played by hosiery for young women's leg health in occupations where standing fatigue is a significant occupational stressor. It was our hypothesis that the graduated compression hosiery would enhance the venous-muscle pump, thereby reducing the magnitude of edema, muscle tissue disruption, and discomfort associated with standing fatigue.

METHODS

Subjects. Twelve healthy women (mean age of 23.0 ± 2.1 yr, height of 165.7 ± 5.0 cm, percent body fat of 22.6 ± 4.2%, and body mass of 60.0 ± 8.9 kg) volunteered to participate in this investigation designed to examine the influence of wearing various hosiery on the physiological and performance responses to prolonged standing. All subjects were informed of the possible risks of the investigation before signing an informed consent document approved by the university's Institutional Review Board for use of human subjects in research. All subjects were completely familiarized with all of the testing protocols to be used in the study in preliminary laboratory sessions.

Experimental approach. All subjects completed four identical standing fatigue protocols each separated by seven days. The use of a within subject design allowed each subject to perform each of the experimental treatments and act as her own control. Subjects wore their normal undergarments for the experimental "control condition." The control undergarments did not have any compression associated with them and did not cover the legs. Using a balanced design for the set of treatments, subjects were then randomly assigned to a four-treatment profile. A double-blinded protocol was used in this investigation (i.e., investigators and technicians did not know what type of garments were being worn). The treatments consisted of a control condition, and hose A, B, and C. Hosiery compression values were determined on medium size pantyhose via HARTA Hose Pressure tester mk 2A (Segar Design, Nottingham, United Kingdom) as described in BS 7563 (British Standard Specification for Nonprescriptive Graduated Support Hosiery). The hosiery compression profile is reported as a function of pressure (mm Hg) and distance from the heel of the adjustable former. The mean hosiery pressure (mm Hg) values at 10 (e.g., ankle), 31 (e.g., calf), and 60 (e.g., thigh) cm distance from the heel were: hosiery A, ankle: 7.7, calf, 7.6 thigh 9.0; hosiery B, ankle: 7.6; calf, 6.8 thigh, 5.2; hosiery C, ankle: 15.4, calf, 8.4, thigh, 8.6.

TABLE 1. Experimental test protocols and timeline for the standing fatigue protocol.

Time	Test
7:30	Ultrasound
8:15–8:35	BP/HR/Blood/Discomfort Scales/Circumferences/BIA
8:35–8:45	Plantar Pressure
8:45	**Onset of Standing Protocol**
8:45–8:55	Force Plate (quiet standing)
	Force Plate (natural standing)
	Force Plate (maximal jumps)
9:00–10:00	Task 1 (Cards) and Carrying Task (15 min)
10:00–10:10	Snack
10:10–11:00	Task 2 (reading, computer)
11:00–11:10	Discomfort Scales/Circumferences/BP/HR/BIA
11:10–12:30	Task 3 (board games) and Carrying Task (15 min)
12:30–12:40	Discomfort Scales/Circumferences/BP/HR/BIA
12:40–12:50	Plantar Pressure
12:50–1:00	Force Plate (quiet standing)
	Force Plate (natural standing)
	Force Plate (maximal jumps)
1:00–1:30	Lunch Break (seated)
1:30–1:40	Discomfort Scales/Circumferences/BP/HR/BIA
1:40–4:05	Task 4 (video, TV) and Carrying Task (15 min)
4:05–4:25	Snack
	BP/HR/Blood Draw/Discomfort Scales/Circumferences/BIA
4:25–4:35	Plantar Pressure
4:35–4:45	Force Plate (quiet standing)
	Force Plate (natural standing)
	Force Plate (maximal jumps)
5:00–5:15	Ultrasound

BP, blood pressure; HR, heart rate; BIA, bio-electrical impedance, TV, television,

Experimental standing fatigue protocol. A standing fatigue protocol was designed to produce an orthostatic stress that would result in measurable psychological and physiological changes over the day in order to test the impact of an intervention. Pilot testing showed this protocol to be effective (see Table 1). The standing fatigue protocol involved a total of 8 h of standing on hard floors at a constant room temperature (22°C) during which subjects participated in various tasks and experimental testing procedures as specifically outlined in Table 1. The protocol was performed on the same hard floor to limit changes in calf temperature due to the standing surface (2,18). In addition, all activity and dietary profiles of the subjects were carefully controlled 48 h before each experimental session. Before the standing fatigue protocol, subjects completed a battery of tests to establish morning baseline values. Experimental tests included determination of lower leg venous cross-sectional area, blood pressure, heart rate, resting blood sampling, perceived discomfort ratings, circumference measurements, total body water, variation in center of pressure during "quiet" standing, vertical jump performance, and specific regional patterns of foot pressures. As shown in Table 1, several of the experimental tests were performed periodically throughout the day (e.g., mid-day) to assess the pattern of change in these selected variables. All subjects wore the identical style of shoe (i.e., 1.5-inch heel, standard women's pump) for all testing to standardize the effects of footwear in the study. Subjects were allowed a 30-min seated lunch break in the middle of the day. All subjects met with a registered dietician in planning their diets over the experimental period. Food and beverage consumption were carefully standardized for each subject during the four experimental sessions to control for the potential influence of hydration status and dietary nutrients on the physiological responses to prolonged standing. In addition, subjects were required to complete three 15-min periods of walking with a 10-pound plate held overhead in order to simulate a common loading task stress experienced by workers who carry light loads while standing for prolonged periods (e.g., servers, flight attendants, etc.). All baseline tests were again administered at the end of the 8-h day. Room temperature was kept constant (22°C) to eliminate possible environmental influences on leg volume (22). All laboratory tests were piloted in preliminary studies and demonstrated a test-retest reliability with intraclass correlations of $R \geq 0.95$.

Circumference measurements. Circumferences of the ankle, calf, and thigh were obtained on the right side of the body over the 8-h period. Initial markings were made on the leg with a permanent marker during the first experimental session to ensure that circumference measurements were obtained from exactly the same anatomical location. Marks were examined by the investigator and re-marked when needed over the experimental period. A Gulick II measuring tape (Country Technology, Gays Mills, WI) was used to measure the circumferences in exactly the same location. The same investigator performed all circumference measurements for a subject to eliminate intertester variability. All measurements were obtained without hose. Measurements were obtained from two trials, and if they differed by more than 2 mm, subsequent measures were obtained.

Body mass and total body water. Body mass was determined on a modified electronic scale platform consisting of a load cell and total body water was estimated via bioelectrical impedance analysis (TBF-105 Body Fat Analyzer/Scale, Tanita Corporation of America, Inc., Skokie, IL). Pressure contact electrodes on the scale platform allowed determination of impedance and estimation of total body water.

Ultrasound techniques. To develop an ultrasound technique for measurement of venous diameter that was both accurate and repeatable, the following approach for measurement was used. The same investigator evaluated all images. The veins were traced using the integrated trackball system on the Hewlett-Packard Image Point ultrasound instrument (Hewlett-Packard Corp., Andover, MA). The circumference was traced on the inside border of the venous wall. During each scan, the examiner was able to compare the tracing with an original baseline tracing done at the beginning, to assure the exact same path and contour of the trace each time. The actual numerical measurement was removed from the printed image so the examiner did not have access to the previous measurement data while the subsequent scan was performed. All of the venous wall boundaries were clearly delineated for accurate tracing of the venous walls.

To address the problem of obtaining identical cross-sectional views for each measurement, it was first determined that, because of the extreme variability in venous anatomy from subject to subject, it would be impossible to use the same anatomical location in all subjects. For example, several of the subjects had bifid (double) popliteal veins and multiple (=3) posterior tibial veins. It was also determined that utilizing the same anatomical location in all the subjects was not important to the study as all subjects participated in all treatment conditions, so long as the identical location could be repeatedly obtained on each individual subject the approach was valid. Baseline images for the posterior tibial and popliteal veins were obtained for each subject. The scans were performed with all subjects standing upright. All images were obtained from the right leg of each subject. Example image scans can be seen in Figures 1 and 2.

The posterior tibial vein images were obtained with the subject's feet spread evenly apart and equal weight bearing on both legs. The popliteal images were obtained with the subject's feet spread evenly apart and with the right knee slightly flexed. It was determined that this slight flexion was necessary to facilitate adequate probe contact in the popliteal area. The probe location used in obtaining the baseline scans was marked with permanent marker on the skin. The baseline images were also used by the examiner to create an identical sectional image by comparing the internal muscular, bony, and vascular anatomy with that of the baseline image. The internal anatomy proved to be much more useful than the external landmarks, due to the variability of the vascular anatomy with even a very slight movement of the probe. An additional potential source of error in obtaining repeatable images was the possibility of compressing the vein with the external pressure of the probe. We found that this potential pitfall was greatly minimized by scanning the veins with the subject in the standing position. In this position, the hydrostatic pressure within the vein created sufficient pressure to resist inadvertent compression by the probe unless substantial pressure was deliberately applied to the vein. The specific measurement point chosen on each subject was based solely on the ability to obtain clear and reproducible images of the same anatomy on consecutive scans. Thus, the most anterior located branch of the posterior tibial veins was selected in some subjects, whereas the posterior branch was chosen in others. The same vessel was then chosen on subsequent scans.

In the popliteal location, a measurement point above the lesser saphenous vein confluence was chosen in some cases, in others a point below the lesser saphenous. In subjects with bifid popliteal veins, an attempt was made to choose a point above the bifurcation of the vein. Where this was not practical, one of the two veins was selected, with the primary determining factor again being repeatability of

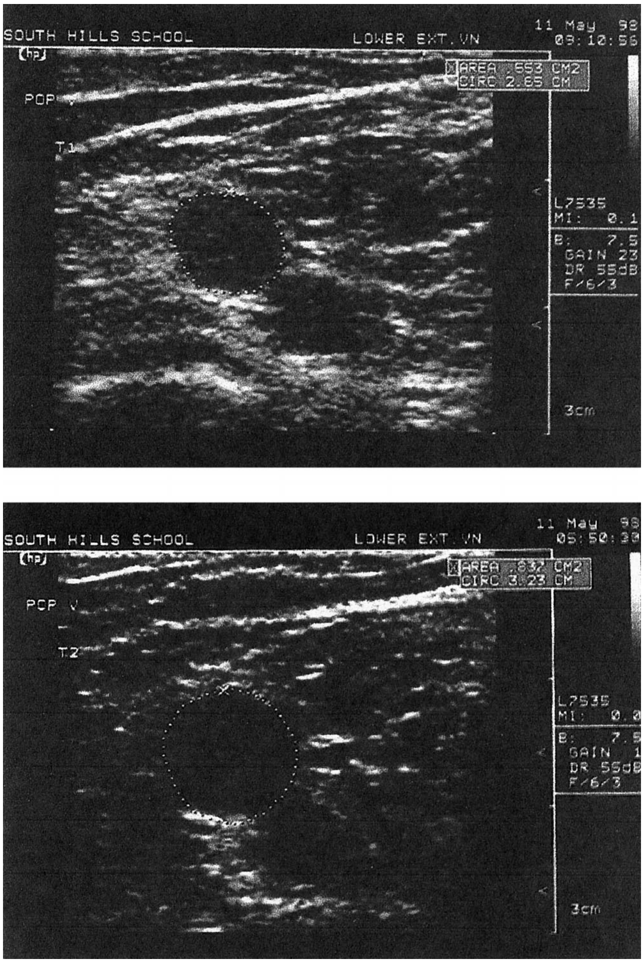

Figure 1—Upper panel, example sonographic exploratory cross-sectional view of the posterolateral ankle, locating the bifid (split) posterior tibial vein (PTV). The left bifurcation was selected for this subject and traced, producing an area calculation for trial 1 pre-8 h of standing. Lower panel, the identical view of the left bifurcation of the PTV was traced for trial 2 at the end of the day after standing for 8 h with the area calculation produced.

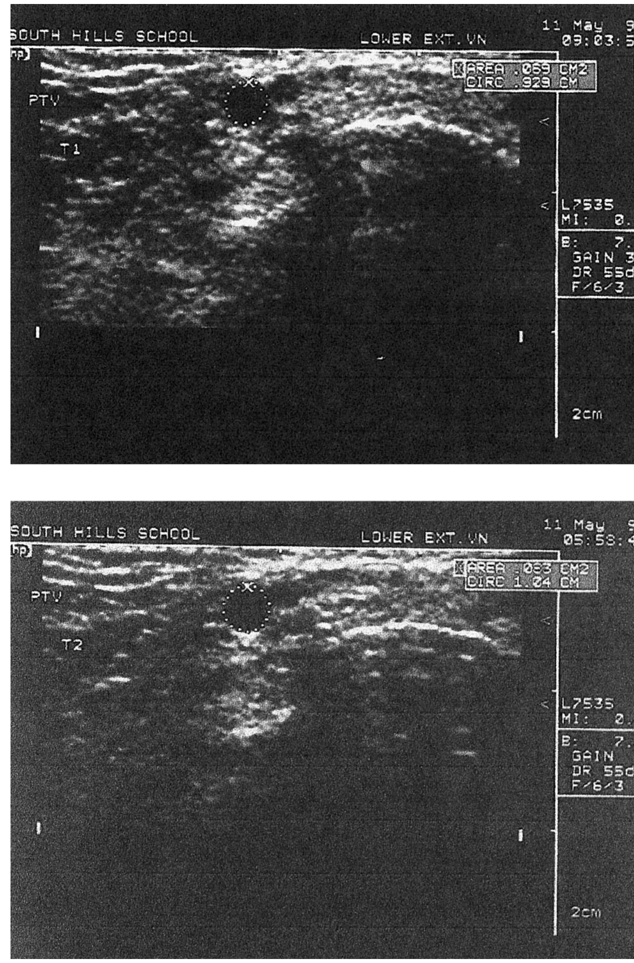

Figure 2—Upper panel, example sonographic view of the posterior knee, locating the popliteal vein (POP). This subject's vein (traced) is located superficial to the artery (right and inferior). The tracing of the vein produces the area calculation for trial 1 pre-8 h of standing. Lower panel, the identical view of the left bifurcation of the PTV was traced for trial 2 at the end of the day after standing for 8 h with the area calculation produced.

obtaining the same plane on subsequent scans. The reproducibility of the measurement technique was verified by high test-retest reliability statistic which yielded an intraclass correlation coefficient in blinded trials of $R = 0.98$.

Concern for venous valve incompetence and vascular insufficiency has been a problem in some subjects in prior work (15). Because our pilot studies showed a significant increase in the diameter of both the popliteal and the posterior tibial veins after 8 h of standing activity, we wanted to determine whether any venous valvular incompetence developed during the course of the day in these healthy young women. We did not expect any in this population. Venous valvular incompetence has been well documented in patients with chronic varicose veins and can lead to venous stasis disease with accompanying venous stasis ulcers, thrombophlebitis, debilitation, and severe leg pain (15). Venous blood flow in the popliteal vein was recorded utilizing standard Doppler technique. Again, the Hewlett-Packard Image Point system was utilized, which was shown to be quite sensitive in both the color and pulsed-wave Doppler modes. The subject was placed in the recumbent, right anterior oblique position with the left leg in front of the right leg. The right popliteal vein was examined with the leg slightly flexed at the knee. Utilizing color and duplex Doppler, the sample volume was placed within the lumen of the popliteal vein, and a spectral waveform was recorded with the patient in normal, shallow respiration. Spontaneity and phasicity of the flow was documented on the spectral tracing. Proximal and distal limb compressions were then performed while the Doppler was being recorded from the popliteal vein. In the normal vein with competent valves, the distal limb compression should cause an augmentation of flow in the monitored area as a bolus of blood is forced out of the calf and up the leg into the popliteal vein. Upon release of the calf, no retrograde flow should be observed within the vein. The proximal compression should create a brief period of retrograde flow as the venous valve leaflets close, and then no retrograde flow beyond that. All 12 young women were shown to have normal valvular function, which further characterized this population as being healthy.

Maximal vertical jump height. Maximal vertical jump height was measured using 40×90 cm force platform (model 4060S Bertec Inc., Worthington, OH). Subjects were instructed to stand with their feet about shoulder width apart with their hands held on their waist and to jump as high as possible using a counter movement action to initiate the jump. Subjects were allowed three jumps at each testing session with the highest jump used for analysis. Signals of the three force components and three moment components from the force plate were acquired at a sampling frequency of 200 Hz and recorded via a personal computer (model P5–100, Gateway 2000, Inc., N. Sioux City, SD) for processing. The maximum jump height achieved was calculated from the vertical impulse generated from the force plate.

Blood pressure and heart rate. Heart rate was determined via palpation on the carotid artery in the neck and blood pressure was obtained using a stethoscope and sphygmomanometer while the subject was in a standing position. The same investigator made all measurements on a subject.

Blood chemistry, sampling, and analyses. On experimental days, subjects reported to the laboratory in the morning and remained quiet for 15 min to equilibrate the hydrostatic position. A standard fluid intake was also used each day before the protocol to standardize hydration status. Blood samples (about 5 mL for each sample) were obtained from an antecubital forearm vein using a needle, syringe, and Vacutainer set-up in the morning and after the fatigue protocol on each experimental day. The blood was processed and centrifuged (1500 $\times$ *g*) and the resultant serum stored at -84°C until analyzed. Serum creatine kinase activity was determined in duplicate via spectrophotometry (Novaspec II, Pharmacia LKB Biochrom Limited, Cambridge, United Kingdom) and commercial assay kits (Sigma Diagnostics, St. Louis, MO). Hemoglobin was analyzed in triplicate using the cyanmethemoglobin method (Sigma Diagnostics, St. Louis, MO) and hematocrit was analyzed in triplicate from whole blood via microcentrifugation and microcapillary technique. Percent changes in plasma volume were calculated using hemoglobin and hematocrit values (5). Intra- and inter-assay variances for all assays were less than 5%.

Quiet standing protocol. This test measured the patterns of the center of pressure migration during 40 s of unperturbed upright standing in a bipedal posture on a 40 $\times$ 90 cm force platform (Model 4060S Bertec Inc.). Subjects were instructed to stand with their feet about shoulder width apart with their arms at their sides and to remain quiet for 40 s on the hard force plate surface. Data acquisition was performed using a personal computer (model P5–100, Gateway 2000, Inc.) with a 12 bit A/D board (model AT-MIO-64E-3, National Instruments Corporation, Dallas, TX) controlled by a special code written using LabView software (LabView 4.1, National Instruments Corporation Dallas, TX). The signals of the three force plate components and three moment components from the force plate were acquired with a sampling frequency of 20 Hz, and the data were recorded for future processing. These data were analyzed with the previously developed code in the Metlab software. The analysis was performed on data for a-p direction (COPa-p) and m-1 direction (COPm-1).

Perceived discomfort ratings. Over the course of the standing protocol, subjects completed 120-point Likert scales designed to quantify perceived discomfort in 30 body segments (15 upper body and 15 lower body). The degree of discomfort was rated from 0 (none) to 120 (very noticeable). Additionally, subjects recorded their perceived discomfort the evening after each standing protocol (i.e., at 7:00 p.m. and 10:00 p.m.) and the morning after the standing protocol (i.e., 7:00 a.m. and 12:00 p.m.). A composite score was then calculated for the upper and lower body for analysis of the large data base.

Plantar foot pressures during locomotion. Specific alterations in patterns of plantar foot pressure were determined via the EMED-SF2 system (Novel Inc., Minneapolis, MN) at a sampling rate of 71 Hz. The system consists of a computer linked pressure platform matrix of 2016 sensors, with two sensors per cm^2. The 225 $\times$ 445 mm platform was built into a short runway so that the surface of the platform was contiguous with that of the runway. At a preliminary visit by the subject, the application of a forensic ink was applied to the plantar surface of the foot, and the normal standing foot pressure image was determined for each foot on a specially treated paper. The footprints were traced and data scanned into the EMED computer program. The EMED test consisted of 10 barefoot walking trials across the EMED pressure platform, with the subjects coached to walk slowly and normally. Five trials for each foot were collected and composited by the program. It was matched to the subject's preliminary footprint in the program which allows the pressure means of 10 areas of the foot to be calculated (e.g., area 1 being the medial half of the heel, area 2 the lateral half of the heel, up to area 8 the large toe, area 9 the second and the third toes, and area 10 being the fourth and fifth toes).

Statistical analyses. The statistical evaluation of the data was accomplished with a multivariate analysis of variance with repeated measures. When appropriate, Tukey's *post hoc* tests were used for pairwise comparisons. Test-retest reliability for the various dependent variables demonstrated intraclass correlation coefficients of $R \geq 0.95$. By using the nQuery Advisor® software (Statistical Solutions, Saugus, MA), the statistical power for the *N* size used ranged from 0.80 to 0.91. Statistical significance was chosen as $P \leq 0.05$.

RESULTS

Figure 3 presents the changes in circumferences of the various limb segments, ankle (Fig. 3A), calf (Fig. 3B), and thigh (Fig. 3C). Significant reductions in the size of the ankle and calf were observed with the use of the hosiery treatments. No significant changes were observed in the thigh circumferences.

Table 2 presents the changes in body mass and total body water over the 8-h workday. Significant increases were observed in all groups as to body mass with the progression of the day due to the intake of food and fluids. Increases in body water over the day were observed in each treatment

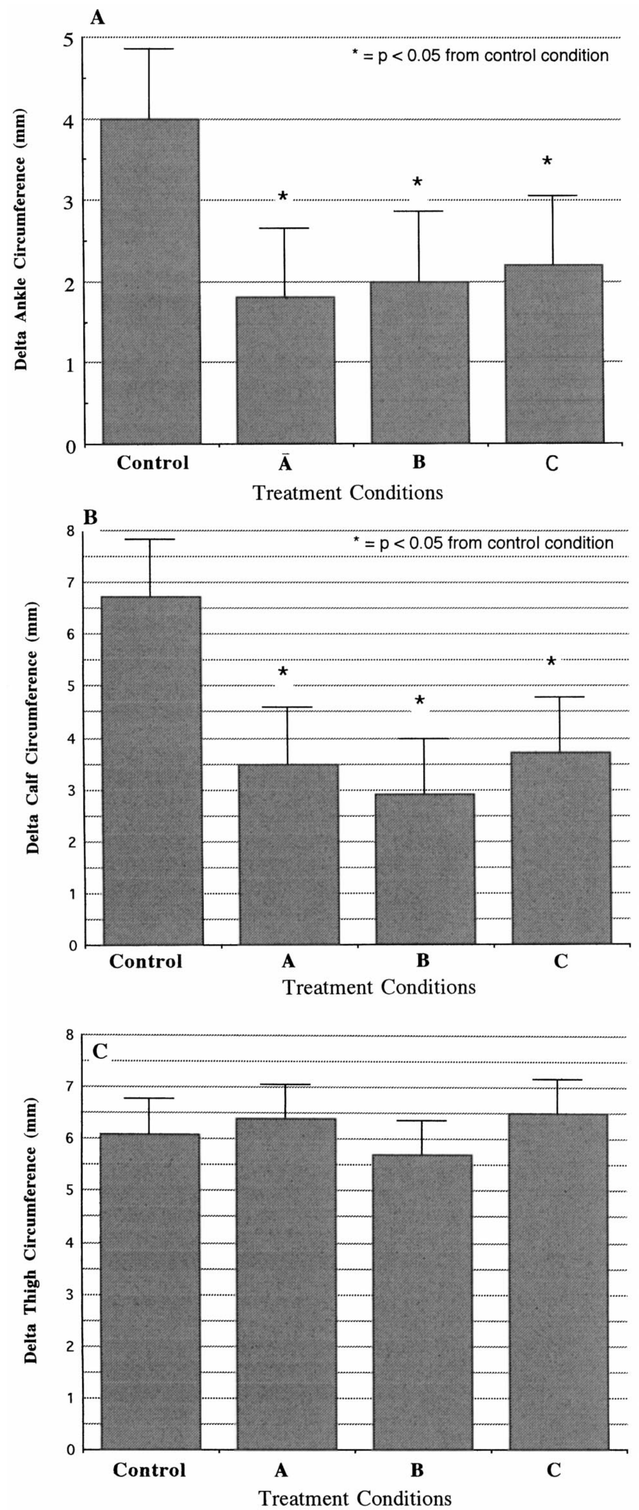

Figure 3—Delta changes in the circumferences of the ankle (A), calf (B), and thigh (C) over the 8-h standing fatigue protocol.

condition. Subtle differences were observed between treatment conditions with total body water lower in two of the hosiery conditions, most likely reflecting the lower retention of fluid volume.

Figure 4 shows the responses of the delta changes in the venous vessel cross-sectional area changes over time. Significant reductions in the size of the vessels were observed for all of the hosiery conditions for both the popliteal vein (Fig. 4A) and the posterior tibial vein (Fig. 4B). Such data demonstrate a reduction in venous pooling of blood with the use of various graduated compression hosiery styles.

Blood pressure and heart rates are shown in Table 3. In general, few significant differences in heart rates over the day were observed, and only two early measures in the B garment were lower than the control condition. The use of the hose resulted in a general increase in systolic blood pressure with diastolic pressures higher than control conditions by the end of the day. Such changes appear to offset the classical delayed orthostatic hypotension observed with standing greater than 30 min.

Changes in maximal vertical jump height and power are presented in Table 4. No significant changes in maximal vertical jump height were observed over the 8-h day. However, all of the hosiery conditions did have a positive change potentially reflective of greater lower body force and power capabilities. Garment C did demonstrate a trend ($P = 0.082$) for an increase in vertical jump power and height over the 8-h workday.

Figure 5 depicts the responses of plasma volume changes over the 8-h test day (panel A) and the changes in serum creatine kinase concentrations (panel B). Significant increases in plasma volume movement into the circulation were observed with the hosiery treatments when compared with control conditions. In addition, garment A had significantly higher increases than garment C for fluid movement into the circulation. An increase was observed in the creatine kinase values in the control condition and was used as an indirect marker of muscle tissue damage. All of the hosiery treatments observed a reduction of creatine kinase values, indicating a reduction in muscle tissue disruption over the day. Garment C was significantly greater than all of the garments in reducing the amount of tissue disruption over the standing test day.

The standard deviation in the center of mass during quiet standing for the control condition was −1.2, whereas the standard deviations for garments A, B, and C were −0.8, 0.5, and −0.3, respectively. Thus, all of the hosiery conditions produced significantly less movement around the center of mass in this experimental test. The change in the composite of the discomfort ratings over the 8-h day is shown in Figure 6. In all of the hosiery conditions in the lower body, there was a smaller increase in discomfort over the day. Conversely, in the upper body, only the A and B garments displayed a significantly lower increase in discomfort over the workday.

Only few changes were observed in plantar pressures during simple walking. The only significant difference occurred at the area surrounding the cuboid bone for garment C, which was significantly less than control (right foot = 342 ± 60 vs 375 ± 105, respectively; left foot = 374 ± 76 vs 432 ± 93, respectively).

TABLE 2. Body mass and total body water (TBW) responses.

	Control	A	B	C
Body mass (kg)				
1	59.9 ± 5.3	59.7 ± 5.7	59.9 ± 6.1	59.7 ± 5.8
2	60.1 ± 5.7	59.9 ± 5.7	59.9 ± 6.1	59.9 ± 5.9*
3	59.9 ± 5.7	59.6 ± 5.6	59.8 ± 6.0	59.8 ± 5.8
4	60.5 ± 5.8*	60.0 ± 5.6	60.1 ± 5.8*	60.4 ± 5.8*
5	60.6 ± 5.9*	59.8 ± 5.6#	60.1 ± 6.0*	60.3 ± 5.9*‡
TBW (L)				
1	74.6 ± 4.6	74.5 ± 4.9	74.7 ± 5.0	74.7 ± 4.8
2	75.8 ± 5.6*	74.8 ± 4.5	75.0 ± 5.1	75.5 ± 5.4*
3	76.2 ± 5.4*	75.4 ± 4.7*	75.2 ± 4.9	76.2 ± 5.5*
4	76.5 ± 5.5*	75.3 ± 4.4*	75.4 ± 4.8*	76.4 ± 5.3*
5	78.1 ± 5.7*	75.9 ± 4.3*#	76.5 ± 4.7*#	77.2 ± 4.2*‡

* $P \leq 0.05$ from corresponding value at timepoint 1.
# $P \leq 0.05$ from corresponding value during the Control condition.
‡ $P \leq 0.05$ from corresponding value during the A condition.

DISCUSSION

The unique finding of this investigation was that commercial hose with various graduated compression profiles and different constructions were all effective in attenuating the swelling and venous pooling of blood in the ankles and legs of healthy young women. In addition, a reduction in lower leg discomfort was observed. The physiological mechanisms by which these garments achieve the desired positive effects appear different and may reflect the inherent differences in garment construction. Nevertheless, such fashion hosiery appear to be effective in mediating positive benefits in both psychological and physiological mechanisms related to women's leg health.

The reduction of swelling in the ankles and legs appears to be due to the use of graduated compression in the various garments. The impact of the garments were not observed at the anatomical level of the thigh, possibly indicating that the compression levels used in this study are far below what might be needed to affect the larger muscle mass limbs. Furthermore, normal long-term standing activity in healthy young individuals is not typically associated with edema in this body segment. The changes in the estimation of total body water demonstrate that changes in edema are likely local in nature as increases in total body water were observed in all of the treatment conditions. Such data lend support to the hypothesis that the graduated compression garments contributed to an enhanced local environment in the bio-compartments of the lower limbs despite the overall retention of fluid volume in the body. Part of this increase in total body water is also most likely due to nutritional intakes over the day. The impact of compression garments on local measures of edema has been repeatedly observed in various clinical populations (3,16,17,21). For example, Krijnen et al. (16), showed that, in men with chronic venous insufficiency, high compression socks were the most effective intervention to reduce swelling and complaints of pain and discomfort with standing. The effectiveness of the garments used in this study, despite the use of lower compression levels than are seen in medical hose, demonstrated actual benefits of compression. It appears that the needed compressive forces to reduce swelling normally associated with standing fatigue in healthy young women are significantly less than for those with specific clinical complications (e.g., vascular insufficiency populations) (3,16,17,21), thus indicating the benefit from use of compression hose to offset standing job stress.

The swelling in the ankles and legs was associated with a significant increase in the activity of creatine kinase found in the blood after the 8-h standing fatigue protocol in the control condition. Creatine kinase has been used as an indirect marker for muscle tissue disruption (4). It was observed that the activity of creatine kinase in the blood for the hosiery treatment conditions did not increase with the standing fatigue protocol indicating less muscle tissue damage and cellular disruption. Furthermore, garment C was associated with the highest reduction in apparent muscle cell trauma as a 50% reduction in the concentration of creatine kinase was observed over the workday. This response appears to be related to the garment construction and higher compression levels used in this hosiery. The stress of the standing fatigue protocol has been attributed to the increasing static strain in muscle fiber which can cause disruption of the muscle fiber membranes resulting in increased muscle tissue edema (25). It has been theorized by Edwards (6) that such muscle tissue damage may be secondary to the unconscious central motor control mechanisms that may mediate the feelings of discomfort and pain associated with this type of occupational environment. It has been observed that the primary focus of pain and discomfort is related to the lower body muscles supporting the upper body and head (6,18). In our study, we observed a significant reduction in ratings of muscle discomfort in the lower body with limited effects for upper body musculature from the control treatment. These data support the concept that the focus of pain and discomfort with standing is related to the local demands on the neuromuscular system and any reduction of psychological symptoms may require interventions which impact these local mechanisms (e.g., edema, local muscle fatigue).

Venous insufficiency has been shown to be a problem in many workers in standing professions (15). Limited data are available on healthy young women who also make up a significant number of workers in standing professions. Our data demonstrate a remarkable reduction in the amount of venous pooling in the veins of the legs at two anatomical levels. Whether this effect is evident at higher anatomical levels in the vessel remains unknown. This pooling of blood

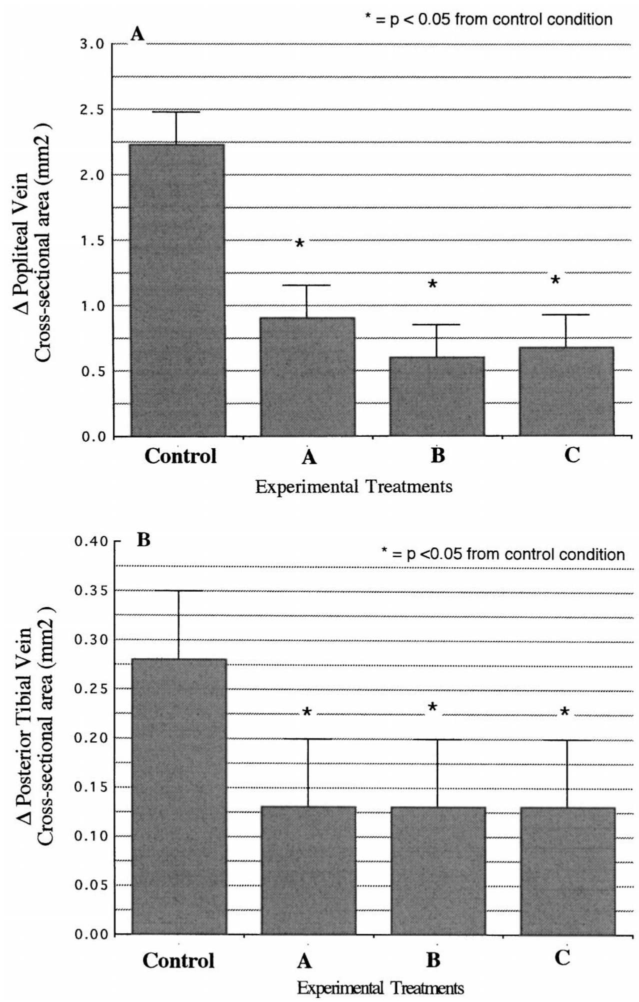

Figure 4—Delta changes in the cross-sectional areas of the popliteal vein (A) and the posterior tibial vein (B) over the 8-h standing fatigue protocol using ultrasound technology.

occurred in the venous system despite the use of healthy young women. However, all subjects in this investigation were shown to have normal valvular function with no venous valvular incompetence developed during the course of the day for any of the treatments. Thus, the cardiovascular adjustments to standing fatigue with light loading are associated only with small reductions in the ability of the body to return blood to the heart. It appears that the primary mechanism for this may be related to a compromised "muscle pump," which appears to be aided by the use of the various graduated compression hose. It has long been known that clinical use of higher compressive stockings has helped various vascular patient populations enhance circulation and avoid clinical complications (13,15,18,19,23).

Both swelling and venous pooling in the ankles and legs were attenuated by each of the hose used in this study. The exact mechanism(s) that mediate the removal of water from the damaged tissues or interstitial spaces in the lower limb bio-compartments (e.g., musculature) remain speculative. The data from this investigation provide possible insight into the role of the hosiery to differentially mediate a reduction in local retention of fluids. The C garment reduced the apparent damage to tissue to the highest degree and appeared to limit the amount of edema related to inflammatory mechanisms in the local areas of the ankles and calf. The A garment was observed to have the highest plasma volume shift of water into the circulatory system which could indicate a higher rate of fluid removal from the tissues (9). The B garment appears to mediate the reduction in swelling with a combination of the two different mechanisms to achieve a similar overall effect. Thus, the construction of hose may differentially affect the physiological mechanisms, which become operational to achieve a similar specific outcome. The interaction of a reduction in muscle damage and changes in the flux of water from the tissues to the circulatory compartment at the local anatomical level of the garments may all be enhanced with the use of various graduated compressive hose. The reduction in swelling with the use of various hose appears to be accomplished via different physiological mechanisms related to the compression ergonomics of the garment.

Prior work by Streeten and Anderson (24) has shown that standing can cause lightheadedness and fatigue including a reduction in blood pressure, which can result in syncope or presyncopal symptoms after 13–30 min. The delayed orthostatic hypotension was corrected by an inflation of a cuff around the limbs to only 45 mm Hg. Such data indicated that orthostatic hypotension associated with more than 10 min of standing could be potentially debilitating but was a correctable condition. In the current study, due to the movement, we observed no hypotension development, despite a mean trend of lower systolic pressures in the control condition. It appears that all of the hosiery treatment conditions increased

TABLE 3. Heart rate and blood pressure (BP) responses.

	Control	A	B	C
Heart rate (bpm)				
1	73 ± 13	72 ± 11	75 ± 13	73 ± 13
2	75 ± 8	72 ± 11	68 ± 9*	69 ± 8
3	75 ± 11	72 ± 11	69 ± 11*	69 ± 7
4	73 ± 10	74 ± 12	72 ± 13	72 ± 10
5	74 ± 10	72 ± 10	73 ± 13	70 ± 7
Systolic BP (mm Hg)				
1	96 ± 6	100 ± 8	95 ± 12	96 ± 9
2	94 ± 10	101 ± 7	103 ± 6*	102 ± 8*
3	93 ± 10	103 ± 4*#	105 ± 6*#	101 ± 8*#
4	99 ± 8	109 ± 8*#	108 ± 10*#	108 ± 6*#
5	90 ± 6*	107 ± 6*#	110 ± 7*#	107 ± 9*#
Diastolic BP (mm Hg)				
1	59 ± 10	61 ± 7	59 ± 10	59 ± 6
2	56 ± 13	61 ± 11	65 ± 5	63 ± 8
3	56 ± 11	64 ± 8	64 ± 9	63 ± 7
4	51 ± 8*	61 ± 10#	63 ± 4#	63 ± 8#
5	51 ± 9*	64 ± 9#	66 ± 9#	67 ± 8#

* $P \leq 0.05$ from corresponding value at timepoint 1.
\# $P \leq 0.05$ from corresponding value during the control condition.

TABLE 4. Changes in maximal vertical jump height and power before and after the standing fatigue protocol.

	Control	A	B	C
Vertical jump (cm)				
Pre	23.7 ± 4.1	23.0 ± 4.2	23.7 ± 3.9	22.8 ± 4.0
Post	23.2 ± 4.0	23.7 ± 3.6	23.8 ± 4.0	24.2 ± 3.8
Power (W)				
Pre	1248.8 ± 298.9	1162.5 ± 312.7	1227.6 ± 337.9	1186.6 ± 350.0
Post	1205.8 ± 362.5	1216.8 ± 311.6	1255.7 ± 364.0	1281.3 ± 341.7

the systolic blood pressure, but this may have provided a series of beneficial effects as a higher pressure gradient for venous blood flow return and may be a contributing factor in the reduction in venous pooling and the elimination of any type of orthostatic hypotension (24).

To date, no data have been collected on the influence of commercial hose on a "quiet standing" task during an 8-h test day. Adlerton and Moritz (1) reported that body sway and movement in quiet standing were maintained by compensatory mechanisms activated during muscle fatigue. In our study, we observed a general trend for less movement in the quiet standing task for each of the hosiery treatment conditions by the end of the test day when compared with control conditions. Reductions in movement of the center of mass may result from decreasing lower body discomfort as well as from a reduction in the swelling and venous pooling in the limbs. The lack of an effect for the B garment is unclear. Furthermore, high compression in the C garment may have allowed for more effective proprioception mechanisms to become operational (14). Madeleine et al. (18) found that greater pain alters the motor system and postural activity, which may in part help to explain greater movement in the control condition. Hägg (10) reported that a decreased activity level during standing increases the amount of edema. In addition, it has been shown that exercise reduces the amount of negative side effects from standing during a workday (11,20,25). Thus, the amount of inherent activity performed during a day may impact the severity of the symptoms observed. With the use of light activity in our standing fatigue protocol, we mimicked many industry and service workers who do not have the opportunity for high levels of movement in their job.

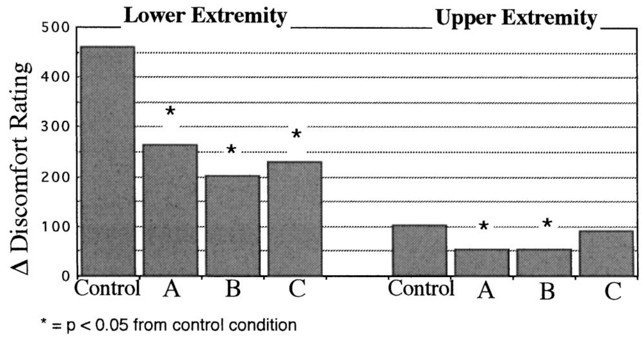

Figure 6—Changes in the composite discomfort ratings for lower and upper body areas. An increase in the discomfort indicates a greater overall composite, whereas lower increases mean lower ratings of pain and discomfort.

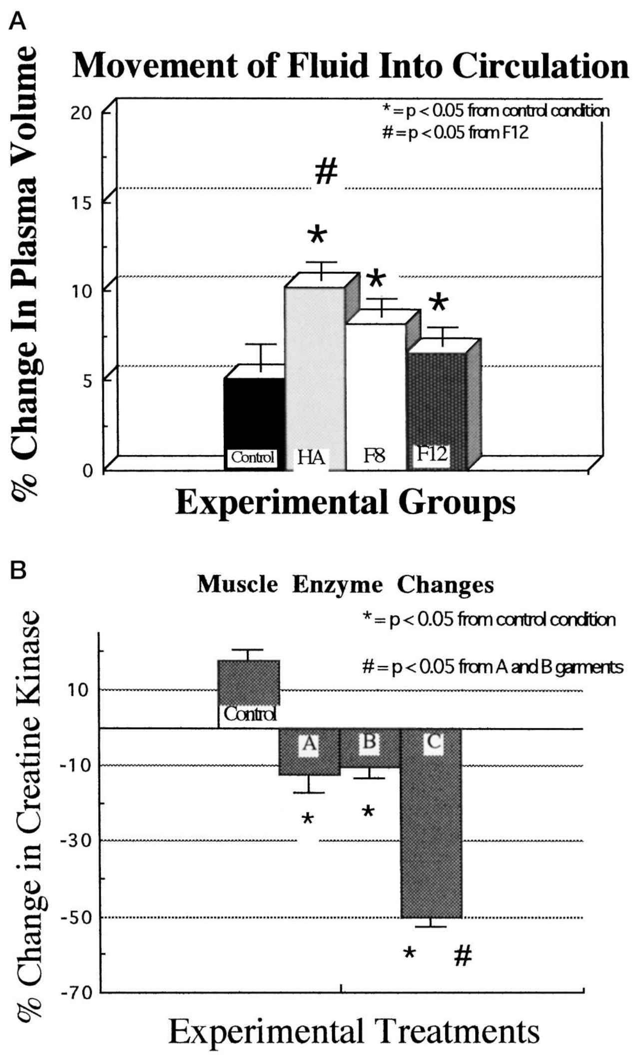

Figure 5—Delta changes in the plasma volume shifts (A) and creatine kinase concentrations (B) over the 8-h standing fatigue protocol.

The changes in the plantar pressures on the foot were hypothesized to be due to the expected swelling of the leg and ankle. With dynamic locomotion only a limited amount of alterations in plantar foot pressure were observed. The lack of changes in the pressures on the foot demonstrates that despite swelling and discomfort in the legs, pressure distributions were not affected. This again may be due to the relative fitness and leanness of the young women used in this investigation and is worthy of further evaluation in other individuals with different body composition profiles.

The impact of the standing fatigue on maximal power capabilities of the lower body was assessed via the use of a maximal counter-movement vertical jump on a force plate (14). The lack of any significant changes in this measure in the control conditions demonstrated that with standing fatigue the primary motor unit pools affected appear to be the ones with predominately slow-twitch muscle fibers typically used for postural control and standing. It might be hypothesized that the majority of symptoms and muscle damage arises from these muscle fibers. The negative impacts of standing fatigue do not appear to be related to muscle fibers recruited for maximal force and power production. Ultimately, these data indicate that there is little interaction with the fatigue process related to standing with higher threshold motor units. Fatigue of high threshold motor units may be more important when standing is connected with lifting tasks of higher percentages of maximal strength (13,25). Interestingly, all of the hosiery garments did elicit a positive impact on the measure with a trend ($P = 0.082$) for an actual improvement observed in the higher compression garment C. It has been shown that higher compression shorts improve repetitive jump power by enhancing proprioceptive mechanisms related to jumping skills (14). How much of that mechanism is operational with lower compression levels remains speculative at this time.

In summary, this study was undertaken to identify whether the pain and discomfort associated with standing fatigue could be attenuated by using hosiery with much lower compression levels than those found in medical compression garments used to obviate circulatory limitations. A variety of testing protocols was used to identify those physiological responses that could be associated with the pain and discomfort of standing fatigue. Commercially available sheer compression hosiery were used in this investigation, which demonstrated that hosiery with various forms of graduated compression and construction were effective in mediating a reduction in swelling (edema) in the ankles and legs while reducing the amount of venous pooling and discomfort in the lower body. Different garment compression gradients and levels may mediate these overall effects via different physiological mechanisms related to fluid shifts and muscle tissue damage. Wearing various types of graduated compression hose during the day as it relates to women in standing occupations may contribute to optimal leg health.

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Address for correspondence: William J. Kraemer, Ph.D., Professor/Director, The Human Performance Laboratory, Ball State University, Muncie, IN 47306; E-mail: wkraemer@bsu.edu.

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