Effects of Standing and Light-Intensity Activity on Ambulatory Blood Pressure

ZACHARY S. ZEIGLER, SARAH L. MULLANE, NOE C. CRESPO, MATTHEW P. BUMAN, and GLENN A. GAESSER

School of Nutrition and Health Promotion, Healthy Lifestyles Research Center, Arizona State University, Phoenix, AZ

ABSTRACT

ZEIGLER, Z. S., S. L. MULLANE, N. C. CRESPO, M. P. BUMAN, and G. A. GAESSER. Effects of Standing and Light-Intensity Activity on Ambulatory Blood Pressure. *Med. Sci. Sports Exerc.*, Vol. 48, No. 2, pp. 175–181, 2016. **Purpose**: This study aimed to compare ambulatory blood pressure (ABP) response to accumulated standing (STAND), cycling (CYCLE), and walking (WALK) to a sitting-only (SIT) day in adults. **Methods**: Nine overweight or obese (body mass index, 28.7 ± 2.7 $kg \cdot m^{-2}$) adults (30 ± 15 yr) participated in this randomized crossover full-factorial study. Four conditions (WALK, STAND, CYCLE, and SIT) were randomly performed 1 wk apart. WALK, STAND, and CYCLE conditions consisted of progressively increasing activity time to accumulate 2.5 h during an 8-h simulated workday. WALK (1.0 mph) and STAND (0.0 mph) were completed on a treadmill placed underneath a standing-height desk. During CYCLE, participants pedaled on a Monark cycle ergometer at a cadence and energy expenditure equivalent to WALK. Participants remained seated during the SIT condition. Participants wore an ABP cuff from 0800 h until 2200 h on all conditions. Linear mixed models were used to test condition differences in systolic (SBP) and diastolic (DBP) blood pressure. Chi-square was used to detect frequency difference of BP load. **Results**: There was a whole-day (during and after work hours) SBP and DBP treatment effect ($P < 0.01$). Systolic blood pressure during STAND (132 ± 17 mm Hg), WALK (133 ± 17 mm Hg), and CYCLE (130 ± 16 mm Hg) were lower compared with that during SIT (137 ± 17 mm Hg) (all $P < 0.01$). CYCLE was lower than STAND ($P = 0.04$) and WALK ($P < 0.01$). For DBP, only CYCLE (69 ± 12 mm Hg) was lower than SIT (71 ± 13 mm Hg; $P < 0.01$). Compared with SIT, WALK, STAND, and CYCLE reduced SBP load by 4%, 4%, and 13%, respectively (all $P < 0.01$). **Conclusions**: Compared with sitting, accumulating 2.5 h of light-intensity physical activity or standing during an 8-h workday may reduce ABP during and after work hours. **Key Words:** POSTEXERCISE HYPOTENSION, FRACTIONIZED EXERCISE, LIGHT INTENSITY, BLOOD PRESSURE LOAD

Sedentary behavior, such as prolonged sitting with energy expenditure <1.5 METs, is associated with increased risk of chronic disease independent of overall physical activity (PA) (14,23). As a result, leading health agencies in Canada (4), Australia (2), and the United Kingdom (34) have provided recommendations to reduce sedentary behavior in addition to increasing PA. The workplace has been identified as an opportune setting for health promotion (37), and desk-bound employees are considered a key target group for sitting reduction strategies (30). Recent evidence shows that active workstations, such as desks that allow for standing, walking, or cycling, are not only feasible (6,18,32,33) but may help reduce fatigue and musculoskeletal discomfort (31). However, the potential health benefits of reducing sitting time are not well understood.

Hypertension is a major independent risk factor for cardiovascular disease, and even those with prehypertension are at increased risk for cardiovascular morbidity and mortality (16). Currently, the only recommended treatment for prehypertension is to modify lifestyle, typically in the form of a PA intervention (35). It is well documented that an acute exercise bout of moderate-to-vigorous intensity can result in postexercise hypotension (PEH) (1,3,26), with multiple bouts leading to chronic favorable adaptations in those with elevated blood pressure (BP) (27). Accumulation of PA throughout the day has also been shown to reduce ambulatory BP (ABP) in individuals with hypertension and prehypertension (25,26). Recently, we demonstrated that the accumulation of very low-intensity walking (1.0 mph; approximately 2 METs) decreased ABP and BP load that persisted 6 h after the last walking bout (39). However, it was not clear

Address for correspondence: Glenn Gaesser, Ph.D., School of Nutrition and Health Promotion, Arizona State University, 550 N 3rd Street, Phoenix, AZ 85004, MC 3020; E-mail: glenn.gaesser@asu.edu.
Submitted for publication May 2015.
Accepted for publication August 2015.

0195-9131/16/4802-0175/0
MEDICINE & SCIENCE IN SPORTS & EXERCISE®

DOI: 10.1249/MSS.0000000000000754

whether the BP-lowering effect of low-intensity walking was due to walking *per se* or due to changing posture.

The purpose of this study was to compare ABP responses to a single-day protocol of interrupting sitting behavior via walking (WALK), standing (STAND), and slow cycling (CYCLE) to a sitting-only (SIT) condition in overweight or obese, sedentary adults. This factorial design allowed for assessing the independent and interactive effects of increasing energy expenditure and/or changing posture on BP. We hypothesized that WALK, CYCLE, and STAND conditions would result in lower BP response compared with the SIT condition.

METHODS

Participants. Overweight (body mass index (BMI), $\geq$25 kg·m^{-2}) or class I obese (BMI, 30 to <35 kg·m^{-2}) men and women between the ages of 18 and 55 yr were recruited via e-mail list serves and flyers posted throughout the university community. Because this study examined both BP and blood glucose responses during the four different conditions, participants had to meet either prehypertension or impaired fasting glucose criterion. In this report, we present only the BP data. Prehypertension was defined as mean systolic BP (SBP) of 120–139 mm Hg or mean diastolic BP (DBP) of 80–89 mm Hg (7). Seven participants met the prehypertension criterion. In addition, to be included in the study, participants had to be considered insufficiently physically active (<150 min·wk^{-1} of moderate-intensity PA). PA level was assessed by the International PA Questionnaire (28). Exclusion criteria included 1) known CAD, 2) orthopedic limitations for performing PA, and 3) obesity to the extent that the ambulatory monitor could not fit the participant properly. All procedures were approved by the Arizona State University institutional review board, and a written informed consent was obtained from participants before participation.

Blood pressure screening. Three BP measurements were taken on two separate occasions 3 d apart with an automated Oscar 2 ABP System (SunTech Medical, Morrisville, NC) according to the protocol described by the World Health Organization (36). On the first day, BP was taken in both arms. The arm with the highest BP was used for screening on the second day. Six total measurements were averaged together and used to determine whether participants met prehypertensive BP criteria. If participants met the prehypertensive BP criteria or the fasting blood glucose criteria (100–125 mg·dL^{-1}), height and weight were measured.

Experimental design. Each participant completed a seated workday (SIT), standing workday (STAND), cycling workday (CYCLE), and walking workday (WALK) in a random order, with each condition 7 d apart. Participants were asked to refrain from exercise for 24 h before each condition, and all conditions were performed in the same simulated office environment in our research laboratory. Participants were given a standardized meal for dinner the night before coming to the laboratory for each condition and were also given a standardized breakfast, lunch, two snacks, and dinner on the day of each condition. Foods included a selection of microwaveable meals with a choice of snacks (cookies, yogurt, chips, and fruit). Snack and meal selections were variable between participants but constant within participants for all conditions and were recorded and repeated each week in order to maintain consistency for each participant across study conditions. Energy contents of the meals were approximately 400 ± 80 kcal for breakfast, 590 ± 25 kcal for lunch, and 780 ± 23 kcal for dinner. Lunch was delivered to the simulated office to minimize outside activity by participants. For each condition, participants were asked to stay in the simulated office from 0800 h to 1600 h and were asked to refrain from any structured exercise for the rest of the day. Participants reported to the laboratory the following morning to return their ABP monitor.

The structure of the four treatment days and total time spent in activity on treatment days were similar. The Zephyr BioHarness^{TM} (Annapolis, MD) was worn directly on the skin over each participant's sternum while participants were at the laboratory and was used to measure HR during all conditions (20). The Zephyr provides real-time HR monitoring, which allowed the matching of HR between WALK and CYCLE days via Bluetooth. The activPal^{TM} (12) triaxial PA monitor (PAL Technologies Ltd, Glasgow, Scotland) was worn on the right thigh during each condition from 0800 to 2200 h to record time spent sitting, standing, and walking both while in the laboratory and outside the laboratory. The activPAL^{TM} is a uniaxial accelerometer that produces a signal related to thigh inclination. Posture is inferred from the position of the thigh and is classified as sitting/lying, standing, or walking using proprietary software. The activPAL^{TM} interfaces with a Windows-compatible PC, and the software package (activPAL^{TM} Professional Research Edition) analyzes the activity record using proprietary algorithms.

To control for spontaneous changes in PA between conditions, participants wore the GENEActiv (GA) (Kimbolton, United Kingdom) accelerometer continuously throughout the study period, including all visits. Each participant wore the GA triaxial accelerometer on his/her nondominant wrist for 5 wk. Activity counts were accumulated over 60-s epochs during the measurement period. Data were collected in units of acceleration. Only data with at least 600 min·d^{-1} of wear time were included in analyses. Nonwear time was 60 min or more in which the device did not pick up any activity. Time spent in sedentary, light-, and moderate-to-vigorous PA was then calculated from published cut points (9).

During the SIT day, participants were asked to remain seated at a desk for the whole day. Participants were free to use the restroom when needed, but no other PA was permitted. During the STAND day, participants were asked to stand for a predetermined time each hour. Participants switched between sitting and standing on a treadmill that was placed underneath the TrekDesk Treadmill Desk (trekdesk.com). To be able to compare the results with those from our previous work (39)

and others (31), participants were asked to stand at progressively longer intervals throughout the day, as follows: 10 min at 0850 and 0950 h, 15 min at 1045 and 1145 h, 20 min at 1240 and 1320 h, and 30 min at 1400 and 1530 h, for a total of 2.5 h of standing over the 8-h day. During the WALK day, participants walked at 1.0 mph, 0% grade, on a commercially available treadmill (Weslo Cadence G 5.9, Logan UT) that was placed under the TrekDesk. Time spent walking was matched to standing time on the STAND day. During the CYCLE day, participants were asked to cycle on a Monark ergometer (894e) placed under the TrekDesk at similar time intervals and at a work rate (approximately 20 W) and cadence that matched the intensity and step rate of the WALK day. Time and intensity of activity were verified by one of the investigators via direct observation through a one-way mirror located in an adjacent office and by the PA monitors. The standing height workstation was placed adjacent to a sitting desk workstation, allowing participants to easily move between the two. Participants were asked to perform their normal daily computer-based work activities either while standing, walking, cycling or being seated at the specified times.

ABP monitoring. The Oscar 2 ABP System has been validated in accordance to the standards of the British Hypertension Society (11). The intraclass correlation coefficient for 24-h ABP monitoring is estimated at 0.95 for SBP and 0.90 for DBP (21). The nondominant arm was used for ABP monitoring in all participants. The Oscar 2 was programmed to take measurements every 15 min throughout the day (0900–2200 h). Participants were free to remove the ABP monitor at 2200 h. One repeat measurement was taken if the first measurement was unsuccessful. During each trial, participants were instructed to abstain from exercise (outside of what was prescribed), not shower while wearing the monitor, and stop moving and straighten out their arm with the BP cuff during the measurement.

Statistical analysis. All statistical analyses were performed using SPSS software version 21 (SPSS 21.0; IBM Corporation, Armonk, NY). Sample size calculations to achieve statistical power were based on data from previous research published on PA and 24-h ABP reduction (3). The estimated sample size was 10 participants in order to detect a difference of 4 mm Hg in SBP over 24 h between SIT and the other groups ($\alpha = 0.05$, $\beta = 0.80$). Data were expressed as means ± SD unless otherwise specified. Data were analyzed for normality, and values with skewed or kurtotic distributions were transformed to achieve normality. Descriptive statistics were used for the demographics of the participants. All P values were calculated assuming two-tailed hypothesis, and $P < 0.05$ was considered statistically significant. Statistical analysis included ABP data collected from 0800–1900 h of the same day. The hours from 1900–2200 h were not analyzed because there were too many missing readings for all participants and trials due to varying bedtimes among participants. Periods of work hours (0800–1600 h) and postwork hours (1600–1900 h) were analyzed separately. Linear mixed models were used to detect differences in SBP and DBP by treatment condition over the entire measurement period (with the SIT condition treated as the control condition). The analysis was conducted in a hierarchical fashion using the restricted maximum likelihood model and "autoregressive heterogeneous 1" covariance error structure. Treatment condition, baseline BP, time, age, gender, and BMI were used as fixed effects, and time was also used as a random effect to account for both interindividual and diurnal variations in ABP. One-way ANOVA was used to test for baseline BP differences. We also used ABP measurements for calculation of BP load (percentage of BP readings, ≥140/90 mm Hg while awake), which was analyzed with dependent-samples chi-square tests. Pairwise comparisons in frequency differences were made using the z-test, and least significant difference correction was applied in the statistical software to appropriately adjust for the P value. Linear mixed models were also used to compare HR differences over the course of the workday between conditions. Free-living comparisons were made for postural allocation (i.e., activPAL^{TM}) and PA (i.e., GENEActiv) to test for condition differences in spontaneous behavioral changes outside of the laboratory sessions. Postural behavior (activPAL^{TM}) during work hours and after work hours was analyzed with ANOVA and compared minutes spent sitting, standing, and walking. ANOVA was also used to assess mean activity counts using the GA between conditions.

RESULTS

Ten participants were enrolled in the study. One participant did not complete the study because of unrelated health concerns. Consequently, nine participants (two men and seven women) were used in the analysis, with mean ± SD age of 30 ± 15 yr (range, 18–55 yr), BMI of 28.7 ± 2.7 kg·m^{-2} (range, 25–33 kg·m^{-2}), SBP of 129 ± 16 mm Hg

TABLE 1. HR (bpm) measured continuously with the Bioharness and at the time of BP measurement with the Oscar 2 during SIT, STAND, WALK, and CYCLE for the periods of work hours (0800–1600 h), postwork hours (1600–1900 h), and all day (0800–1900 h).

	SIT	STAND	WALK	CYCLE	*P* Value
Work hours (0800–1600 h)					
Bioharness (bpm)	74 ± 6	74 ± 6	80 ± 6*	83 ± 6*	<0.001**
Oscar 2 (bpm)	71 ± 12	72 ± 12	77 ± 13*	78 ± 14*	<0.001**
Postwork hours (1600–2000 h)					
Oscar 2 (bpm)	75 ± 10	77 ± 12	78 ± 12	77 ± 11	0.168
All day (0800–2000 h)					
Oscar 2 (bpm)	72 ± 11	74 ± 12	78 ± 12*	78 ± 13*	<0.001**

*Differs from SIT and STAND only, $P < 0.05$.
**$P < 0.05$, linear mixed models.

TABLE 2. Mean and median time in minutes (min) spent seated, standing, or walking derived from the activPAL™ for SIT, STAND, WALK, and CYCLE days during work hours (0800–1600 h), postwork hours (1600–2200 h), and all day (0800–2000 h).

	SIT	STAND	WALK	CYCLE	*P* Value
Work hours					
Seated (mean ± SD)	420 ± 54*	252 ± 99	269 ± 27	342 ± 77	0.001**
Median (range)	415 (337–490)	283 (230–346)	271 (215–301)	318 (274–487)	
Standing (mean ± SD)	33 ± 27	174 ± 36***	26 ± 11	40 ± 47	<0.001**
Median (range)	18 (11–73)	162 (128–235)	23 (14–42)	23 (13–155)	
Walking (mean ± SD)	10 ± 5	11 ± 5	146 ± 18***	68 ± 55	<0.001**
Median (range)	9 (5–19)	9 (3–19)	153 (107–163)	59 (16–139)	
Postwork hours					
Seated (mean ± SD)	220 ± 86	243 ± 65	226 ± 41	224 ± 67	0.928
Median (range)	174 (159–366)	227 (193–382)	218 (175–291)	242 (100–302)	
Standing (mean ± SD)	66 ± 21	55 ± 22	71 ± 39	43 ± 17	0.232
Median (range)	63 (39–94)	46 (35–100)	63 (25–140)	43 (23–66)	
Walking (mean ± SD)	29 ± 15	32 ± 23	53 ± 27	37 ± 21	0.275
Median (range)	22 (17–51)	23 (11–73)	54 (15–95)	42 (6–63)	
All day					
Seated (mean ± SD)	666 ± 74*	522 ± 50	492 ± 56	560 ± 117	0.011**
Median (range)	650 (576–765)	513 (474–612)	488 (422–592)	546 (375–729)	
Standing (mean ± SD)	94 ± 39	227 ± 38***	96 ± 44	70 ± 22	<0.001**
Median (range)	85 (50–155)	208 (197–288)	92 (39–162)	69 (46–106)	
Walking (mean ± SD)	41 ± 16	46 ± 26	196 ± 19****	144 ± 59****	<0.001**
Median (range)	36 (27–63)	37 (23–92)	198 (170–226)	164 (31–195)	

*Differs from STAND and WALK only, $P < 0.005$.
**$P < 0.05$, ANOVA.
***Different from all other conditions, $P < 0.05$.
****Differs from SIT and STAND only, $P < 0.005$.

(range, 115–138 mm Hg), and DBP of 75 ± 12 mm Hg (range, 52–90 mm Hg). Seven of the nine subjects met the prehypertension criterion.

PA. Table 1 illustrates that there were no significant differences for HR between WALK and CYCLE conditions. HR was examined both continuously using the Bioharness and at the point of BP assessment with the Oscar 2. As expected, HR during WALK and CYCLE conditions was higher than that during SIT and STAND ($P < 0.01$).

Table 2 illustrates a significant difference in the time spent sitting, standing, and walking between conditions during work hours and across the full day, thus validating the experimental design. During the work hours, participants spent significantly higher amounts of time sitting during SIT (420 ± 54 min; range, 337–490 min) and CYCLE (342 ± 77 min; range 274–487 min) compared with during STAND (252 ± 99 min; range, 230–346 min) and WALK (269 ± 27 min; range, 215–301 min) ($P < 0.05$). As expected, significantly higher amounts of walking were detected during the WALK condition (146 ± 18 min; range, 107–163; $P < 0.01$), and significantly higher amounts of standing were detected during the STAND condition (174 ± 36 min; range, 128–235; $P < 0.01$). Our results also indicated that the number of minutes spent seated, standing, or walking after work hours was not significantly different between conditions ($P > 0.05$).

Assessment of PA behavior between conditions was made via the GA across the 5-wk period (including baseline). There was no difference between conditions on time spent in sedentary behavior ($P = 0.65$), light-intensity PA ($P = 0.15$), moderate-intensity PA ($P = 0.75$), moderate- to vigorous-intensity PA ($P = 0.85$), or vigorous PA ($P = 0.60$) throughout the study.

ABP. There were no significant differences in baseline SBP ($P = 0.16$) or DBP ($P = 0.06$) between the four conditions. SBP was significantly lower during the STAND, WALK, and CYCLE days compared with that during SIT over the entire ABP observation period (0800–1900 h) and during the work hours (0800–1600 h) (Table 2). Only STAND and

TABLE 3. Mean ± SD SBP and DBP for SIT, STAND, WALK, and CYCLE days at baseline (first BP reading of the day), all day (0800–1900 h), during work hours (0800–1600 h), and postwork hours (1600–1900 h).

	SIT	STAND	WALK	CYCLE	*P* Value
SBP (mm Hg)					
Baseline	124 ± 15	133 ± 14	129 ± 12	125 ± 17	0.160
All day, 0800–1900 h	137 ± 17	132 ± 17*	133 ± 17*	130 ± 16**	<0.001***
Work hours, 0800–1600 h	134 ± 17	131 ± 16*	131 ± 16*	129 ± 16**	<0.001***
Postwork hours, 1600–1900 h	140 ± 18	134 ± 20****	135 ± 17	127 ± 15**	<0.001***
DBP (mm Hg)					
Baseline	70 ± 10	74 ± 10	69 ± 9	68 ± 10	0.061
All day, 0800–1900 h	71 ± 13	72 ± 12	71 ± 13	69 ± 12**	<0.001***
Work hours, 0800–1600 h	72 ± 12	74 ± 11*	73 ± 11	71 ± 11****	<0.001***
Postwork hours, 1600–1900 h	72 ± 15	68 ± 16*	69 ± 68	65 ± 14*	0.009***

*Differs from SIT only, $P < 0.05$.
**Different from all other conditions, $P < 0.05$.
***$P < 0.05$, linear mixed models.
****Differs from STAND only, $P < 0.05$.

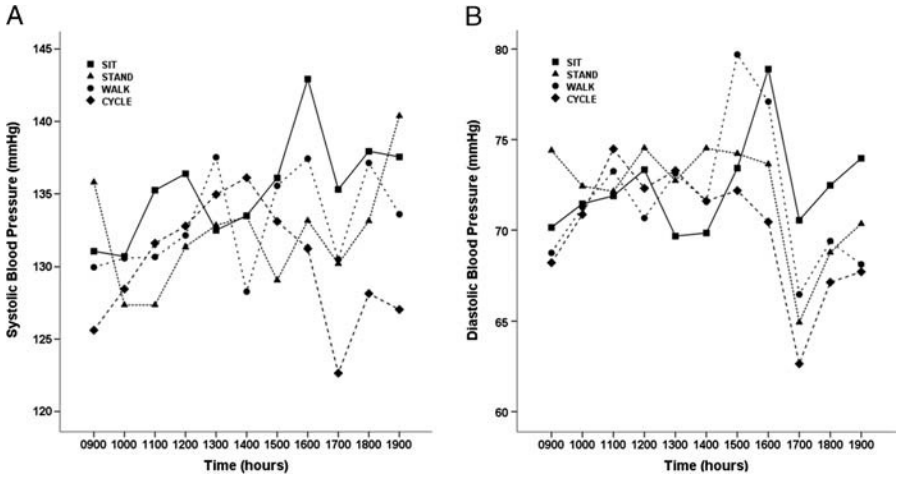

FIGURE 1—A. Mean SBP over time between four conditions (SIT, STAND, WALK, and CYCLE) ($P < 0.05$; linear mixed models). B. Mean DBP over time between four conditions (SIT, STAND, WALK, and CYCLE) ($P < 0.05$; linear mixed models).

CYCLE showed mean SBP and DBP reductions after work hours (1600–1900 h). No condition provoked decreases in DBP during work hours (0800–1600 h). During the CYCLE condition, both SBP and DBP were lower than during all other conditions (Table 3; Fig. 1A and B).

SBP load (percentage of readings, ≥140 mm Hg) was statistically different between conditions, with 40% of SIT, 36% of STAND and WALK, and 27% of CYCLE readings over 140 mm Hg ($P = 0.01$). CYCLE was statistically lower than all other conditions ($P < 0.01$) (Fig. 2). There was no difference on DBP load ($P = 0.09$).

DISCUSSION

The main finding of this study is that, among overweight or obese men and women, most of whom had prehypertension, 2.5 h of accumulated standing, walking at 1.0 mph, or cycling at the same intensity as walking over the course of an 8-h workday significantly decreased ambulatory SBP when compared with a day spent primarily sitting. This BP-lowering effect was observed during work hours and for at least 3 h after participants left the simulated office in our laboratory, which suggests a residual effect through the day. We recently demonstrated that the accumulation of walking at 1 mph significantly reduced ABP (39). The present results extend these findings by showing that not only does very low-intensity walking lower mean ABP, but changing posture alone (i.e., standing) and increasing energy expenditure alone (i.e., cycling) elicit similar results.

Interestingly, our results also indicate that when matched for exercise HR (and similar energy expenditure estimated from walking speed and cycling work rate), cycling was superior to walking for lowering ABP. To our knowledge, this is the first study to show these results and is contrary to our original hypothesis. The reasoning behind this is not immediately apparent. Postexercise BP reduction is primarily mediated by decreases in systemic vascular resistance (13). Resistance vessels in the exercised skeletal musculature remain dilated long after maximal exercise (17), but the extent to which this pertains to accumulated light-intensity PA in the current study is unknown. In addition, total muscle mass activation is different in cycling and walking (8), but the mass of the working muscle has been reported to not influence the magnitude of PEH (22). Further research is necessary to examine the mechanisms responsible for these findings.

Fractionized exercise of moderate-to-vigorous intensity has been shown to reduce BP for several hours after exercise, and this effect has been reported to be greater than a single bout of continuous exercise of equal intensity and total duration (1,3). Our previous work (39) with walking at 1.0 mph (approximately 2 METs) demonstrated that the intensity threshold includes the light-intensity domain. The current study moves beyond accumulating PA to decreasing sedentary time (i.e., accumulated periods of standing) as a means of BP control. Participants were asked to walk, stand, or cycle every hour throughout their workday, completing eight periods of no

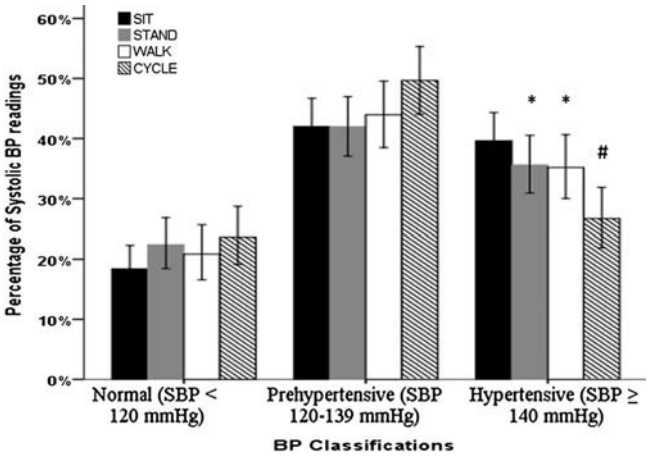

FIGURE 2—Number of SBP readings within BP classification. *Error bars* represent 95% confidence interval. *Different from SIT. #Different from all other conditions ($P < 0.01$; chi-square, McNemar).

sitting for between 10 and 30 min. The accumulation of 150 min of light-intensity PA or standing was sufficient to lower systolic and diastolic ABP for at least 3 h after the last session. In addition to reducing average ambulatory SBP, all three conditions reduced SBP load when compared with the SIT day. This may have clinical relevance, as BP load may be a better predictor of cardiovascular abnormalities than mean ABP (38).

A novel and unexpected finding was that the accumulation of standing time reduced mean systolic ABP by as much as light-intensity walking both during and for at least 3 h after the workday. The mechanisms behind these findings are challenging to describe, as we did not measure other indices besides HR and BP. It is known that postural changes affect BP regulation. Indeed, orthostatic changes typically produce an immediate significant drop in BP with values returning near to baseline within approximately 40 s (29). Individual heterogeneity of the hemodynamic response to postural changes is evident (24). These immediate changes to the cardiovascular system are unlikely to explain the sustained BP reduction witnessed in our study.

Reproducibility of ABP monitoring may be affected by several factors such as posture (5) and PA (19). We found no postural or PA differences after the workday between conditions, suggesting that the BP changes we observed were due to our intervention as opposed to outside factors. Our participants wore the GA for 5 wk to ensure no changes in PA behavior over the course of the study. Results indicate that activity outside of what we prescribed did not change over the study duration. Thus, the observed ABP outcomes were not likely influenced by PA behaviors outside the laboratory.

Our study has several strengths. First, the crossover design limited between-participant errors in interpreting the ABP responses. Second, because of the great inter- and intraparticipant variation in BP throughout the day, measuring average ABP is considered the strongest method of describing daily BP changes. In addition, using accelerometers allowed for objective estimates of PA and postural behavior instead of relying on self-report. The fact that ABP remained lower during the 3 h of monitoring after the workday ended, during which time the accelerometers indicated similar postures, total activity counts, and time spent in PA categories for the four conditions, suggests that PA did not confound our observed BP-lowering effects of the conditions. Third, food intake was controlled for, negating possible dietary effects on BP. Fourth, all four conditions were performed in a simulated office in our laboratory, controlling for possible effects of location on BP (10). Lastly, all interventions were monitored via direct observation by one of the researchers and verified by accelerometers.

Our study also has limitations. As this was an acute study, we can only speculate as to the possible chronic effects of this type of intervention. If a BP reduction of this magnitude were to be realized at the population level, this could potentially result in significant reductions of BP-related illnesses. For example, BP reductions of 3–4 mm Hg (compared with control) could contribute to reductions in mortality from stroke, cardiovascular disease, and all causes by 4%–8% (35). In addition, mean 24-h ABP may be superior to BP taken in a physician's office when predicting cardiovascular morbidity and mortality (15). However, it remains to be established if this type of intervention could lead to sustained reductions in BP. In addition, our sample size was relatively small, and therefore, larger studies and clinical trials should be conducted to further explore the magnitude, dose–response, and long-term significance of these findings. Our specific design of accumulating 2.5 h of nonsitting time, with progressively greater durations throughout the workday, may prove to be more than necessary to reduce ABP. We selected this design on the basis of our recent work (39). But because PEH has been demonstrated after exercise bouts as short as 10 min (3), the longer-duration walking and cycling periods in the afternoon may not be necessary to reduce ABP during and after the workday.

In conclusion, accumulation of 2.5 h of standing or performing light-intensity (approximately 2 METs) walking or cycling over the course of an 8-h workday significantly reduced systolic ABP and BP load compared with a control day spent primarily sitting. Our findings may have use in worksite settings where equipping all offices with treadmills is not feasible. In addition, the incorporation of light-intensity cycling could be more appealing than moderate-to-vigorous exercise. Reducing sitting time, even if replaced by only standing or light-intensity PA, may improve BP and reduce CHD risk especially among sedentary desk-bound office workers.

We thank the School of Nutrition and Health Promotion at Arizona State University for their support of this study.

The authors have no conflict of interest to declare.

The results of this study do not constitute endorsement by the American College of Sports Medicine.

REFERENCES

1. Angadi SS, Weltman A, Watson-Winfield D, et al. Effect of fractionized vs continuous, single-session exercise on blood pressure in adults. *J Hum Hypertens*. 2010;24(4):300–2.
2. Australian Government Department of Health. Australia's physical activity and sedentary behaviour guidelines for adults. 2014 [Internet] [cited 2011 Nov 12]. Available from: http://www.health.gov.au/internet/main/publishing.nsf/content/health-pubhlth-strateg-phys-act-guidelines.
3. Bhammar DM, Angadi SS, Gaesser GA. Effects of fractionized and continuous exercise on 24-h ambulatory blood pressure. *Med Sci Sports Exerc*. 2012;44(12):2270–6.
4. Canadian Physical Activity Guidelines and Canadian Sedentary Behavior Guidelines [Internet]. Canada: Candaian Society for Exercise Physiology [cited 2015 May 5]. Available from: http://www.csep.ca/english/view.asp?x=949.

5. Cavelaars M, Tulen JH, van Bemmel JH, Mulder PG, van den Meiracker AH. Haemodynamic responses to physical activity and body posture during everyday life. *J Hypertens*. 2004; 22(1):89–96.
6. Chau JY, Daley M, Srinivasan A, Dunn S, Bauman AE, van der Ploeg HP. Desk-based workers' perspectives on using sit-stand workstations: a qualitative analysis of the Stand@Work study. *BMC Public Health*. 2014;14:752.
7. Chobanian AV, Bakris GL, Black HR, et al. Seventh report of the Joint National Committee on Prevention, Detection, Evaluation, and Treatment of High Blood Pressure. *Hypertension*. 2003;42(6): 1206–52.
8. Ericson M. On the biomechanics of cycling. A study of joint and muscle load during exercise on the bicycle ergometer. *Scand J Rehabil Med Suppl*. 1986;16:1–43.
9. Esliger DW, Rowlands AV, Hurst TL, Catt M, Murray P, Eston RG. Validation of the GENEA accelerometer. *Med Sci Sports Exerc*. 2011;43(6):1085–93.
10. Gellman M, Spitzer S, Ironson G, et al. Posture, place, and mood effects on ambulatory blood pressure. *Psychophysiology*. 1990; 27(5):544–51.
11. Goodwin J, Bilous M, Winship S, Finn P, Jones SC. Validation of the Oscar 2 oscillometric 24-h ambulatory blood pressure monitor according to the British Hypertension Society protocol. *Blood Press Monit*. 2007;12(2):113–7.
12. Grant PM, Ryan CG, Tigbe WW, Granat MH. The validation of a novel activity monitor in the measurement of posture and motion during everyday activities. *Br J Sports Med*. 2006;40(12):992–7.
13. Halliwill JR, Buck TM, Lacewell AN, Romero SA. Postexercise hypotension and sustained postexercise vasodilatation: what happens after we exercise? *Exp Physiol*. 2013;98(1):7–18.
14. Hamilton MT, Hamilton DG, Zderic TW. Role of low energy expenditure and sitting in obesity, metabolic syndrome, type 2 diabetes, and cardiovascular disease. *Diabetes*. 2007;56(11):2655–67.
15. Hansen TW, Kikuya M, Thijs L, et al. Prognostic superiority of daytime ambulatory over conventional blood pressure in four populations: a meta-analysis of 7,030 individuals. *J Hypertens*. 2007; 25(8):1554–64.
16. Huang Y, Su L, Cai X, et al. Association of all-cause and cardiovascular mortality with prehypertension: a meta-analysis. *Am Heart J*. 2014;167(2):160–8.
17. Isea JE, Piepoli M, Adamopoulos S, Pannarale G, Sleight P, Coats AJ. Time course of haemodynamic changes after maximal exercise. *Eur J Clin Invest*. 1994;24(12):824–9.
18. Karakolis T, Callaghan JP. The impact of sit–stand office workstations on worker discomfort and productivity: a review. *Appl Ergon*. 2014;45(3):799–806.
19. Kario K, Schwartz JE, Pickering TG. Ambulatory physical activity as a determinant of diurnal blood pressure variation. *Hypertension*. 1999;34(4 Pt 1):685–91.
20. Kokonozi A, Astaras A, Semertzidis P, et al. Development and clinical evaluation of a physiological data acquisition device for monitoring and exercise guidance of heart failure and chronic heart disease patients. In: *Computing in Cardiology*. Piscataway, NJ: IEEE; 2010:1099–102. Available from: http://ieeexplore.ieee.org/xpl/login.jsp?tp=&arnumber=5738169&url=http%3A%2F%2Fieeexplore.ieee.org%2Fxpls%2Fabs_all.jsp%3Farnumber%3D5738169.
21. Lehmkuhl LA, Park S, Zakutansky D, Jastremski CA, Wallace JP. Reproducibility of postexercise ambulatory blood pressure in stage I hypertension. *J Hum Hypertens*. 2005;19(8):589–95.
22. MacDonald JR, MacDougall JD, Hogben CD. The effects of exercising muscle mass on post exercise hypotension. *J Hum Hypertens*. 2000;14(5):317–20.
23. Marshall SJ, Ramirez E. Reducing sedentary behavior: a new paradigm in physical activity promotion. *Am J Lifestyle Med*. 2011; 5(6):518–30.
24. Nardo CJ, Chambless LE, Light KC, et al. Descriptive epidemiology of blood pressure response to change in body position. *ARIC Study Hypertens*. 1999;33(5):1123–9.
25. Padilla J, Wallace JP, Park S. Accumulation of physical activity reduces blood pressure in pre- and hypertension. *Med Sci Sports Exerc*. 2005;37(8):1264–75.
26. Park S, Rink LD, Wallace JP. Accumulation of physical activity leads to a greater blood pressure reduction than a single continuous session, in prehypertension. *J Hypertens*. 2006;24(9):1761–70.
27. Pescatello LS, Franklin BA, Fagard R, et al. American College of Sports Medicine position stand. Exercise and hypertension. *Med Sci Sports Exerc*. 2004;36(3):533–53.
28. Rosenberg DE, Bull FC, Marshall AL, Sallis JF, Bauman AE. Assessment of sedentary behavior with the International Physical Activity Questionnaire. *J Phys Act Health*. 2008;5(1 Suppl): S30–44.
29. Tanaka H, Sjöberg BJ, Thulesius O. Cardiac output and blood pressure during active and passive standing. *Clin Physiol*. 1996; 16(2):157–70.
30. Thorp AA, Healy GN, Winkler E, et al. Prolonged sedentary time and physical activity in workplace and non-work contexts: a cross-sectional study of office, customer service and call centre employees. *Int J Behav Nutr Phys Act*. 2012;9:128.
31. Thorp AA, Kingwell BA, Owen N, Dunstan DW. Breaking up workplace sitting time with intermittent standing bouts improves fatigue and musculoskeletal discomfort in overweight/obese office workers. *Occup Environ Med*. 2014;71(11):765–71.
32. Torbeyns T, Bailey S, Bos I, Meeusen R. Active workstations to fight sedentary behaviour. *Sports Med*. 2014;44(9):1261–73.
33. Tudor-Locke C, Schuna JM Jr, Frensham LJ, Proenca M. Changing the way we work: elevating energy expenditure with workstation alternatives. *Int J Obes (Lond)*. 2014;38(6):755–65.
34. United Kingdom Government Department of Health. UK physical activity guidelines: adults (19–64 years). In: *Guidance from the Chief Medical Office (CMO)*. London, United Kingdom: United Kingdom Government Department of Health. 2011. Available from: https://www.gov.uk/government/publications/uk-physical-activity-guidelines.
35. Whelton PK, He J, Appel LJ, et al. Primary prevention of hypertension: clinical and public health advisory from The National High Blood Pressure Education Program. *JAMA*. 2002;288(15):1882–8.
36. Whitworth JA; World Health Organization, International Society of Hypertension Writing Group. 2003 World Health Organization (WHO)/International Society of Hypertension (ISH) statement on management of hypertension. *J Hypertens*. 2003; 21(11):1983–92.
37. World Health Organization. Preventing noncommunicable diseases in the workplace through diet and physical activity: WHO/World Economic Forum report of a joint event. 2008. Available form: http://www.who.int/dietphysicalactivity/workplace/en/.
38. Zachariah PK, Sumner WE 3rd. The clinical utility of blood pressure load in hypertension. *Am J Hypertens*. 1993;6(6 Pt 2):194S–7.
39. Zeigler ZS, Swan PD, Bhammar DM, Gaesser GA. Walking workstation use reduces ambulatory blood pressure in adults with prehypertension. *J Phys Act Health*. 2015;12(6 Suppl):S119–27.