

Effects of Daily Activities on Ambulatory Blood Pressure During Menstrual Cycle in Normotensive Women

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The purpose of this study was to determine whether (1) there is a menstrual phase effect on blood pressure (BP) and heart rate (HR), and (2) the effects of physical effort, posture, or moods on BP and HR is mediated by the menstrual phase. Twelve normotensive women, aged between 28 and 50, with normal menstrual cycles were studied. BP was measured at 30- to 60-min intervals during a 24-hr period using an ambulatory BP monitor on Days 1, 8, 15, and 22 of the menstrual cycle. Participants were asked to report their posture, physical effort, and mood ("annoyed," "tense," and "happy") on 5-point Likert-type scales each time the ambulatory BP monitor took measurements. Systolic BP (SBP) was lower on Day 8 of the cycle. Diastolic BP (DBP) and HR were lower on Days 1 and 8. Daytime SBP was affected by the time of the day and posture, but not by moods, whereas daytime DBP was affected by posture and levels of tenseness. The level of physical effort only affected HR, not BP. The average daytime physical and emotional variables had little influence over the average daytime BP. In 12 normotensive women with a normal menstrual cycle, SBP was lower during the follicular phase and DBP and HR were lower during the follicular phase and menstruation even after controlling the effects of other factors. Physical activity or moods had only momentary effects on BP or HR. A cross-validation statistical method used is suggested to study how individuals are affected by various factors. With the use of this method, the inclusion of menstrual phase in the model improved the prediction of SBP for 5 out of the 12 women studied.

KEY WORDS: blood pressure; menstrual cycle; moods; posture; physical activity; cross-validation method.

INTRODUCTION

Cardiovascular diseases are among the leading causes of death in women (Murphy, 2000). High blood pressure (BP) is a major risk factor for cardiovascular diseases. Previous studies have suggested that female sex hormones and their withdrawal play a role in the pathogenesis of hypertension (Rosenthal & Oparil, 2000). A normal menstrual cycle

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begins with the follicular phase, which is the period between menstruation and ovulation. The second phase of the cycle is the luteal phase, which is preceded by ovulation and followed by menstruation. There is a cyclical change in sex hormones during the course of the menstrual cycle. For example, progesterone and estradiol (estrogen) levels are lower during the follicular phase and higher during the luteal phase (Carr & Blackwell, 1993). Therefore, investigating the fluctuations of BP during the course of the menstrual cycle in premenopausal women may help understand the effects of hormonal factors on BP regulation.

A small number of ambulatory BP (ABP) studies have examined the question of whether there is a monthly pattern of BP oscillations corresponding to hormone levels in premenopausal women (Goldstein, Shapiro, Chicz-DeMet, & Guthrie, 1999; Heintz et al., 1996; Karpanou, Vyssoilis, Gerogoudi, Toutouza, & Toutouza, 1993; Litschauer, Zauchner, Huemer, & Kafka-Lutzow, 1998; Manhem, Jern, Pilhall, Hansson, & Jern, 1992; Manhem, Jern, Pilhall, Shanks, & Jern, 1991; Williamson, Buddle, Brown, & Whitworth, 1999). In most of these studies, participants were studied only during the luteal and follicular phases of the menstrual cycle. Some studies observed a significantly higher systolic BP (SBP; Manhem et al., 1991, 1992) and heart rate (HR) (Goldstein et al., 1999) during the luteal phase compared with the follicular phase, whereas others demonstrated no differences (Heintz et al., 1996; Litschauer et al., 1998; Williamson et al., 1999). Consequently, results from these studies regarding the effect of the menstrual cycle phase on BP remain inconclusive. In the present study, we extended the measurements of ABP over 4 days—at the commencement of menstruation, the follicular phase, ovulation, and the luteal phase.

The BP fluctuations occurring in daily life may be associated, in part, with differences in the levels of physical activity and emotions that occur throughout an individual's day. The interaction effects of the menstrual phase and physical as well as emotional factors on BP have been noted in the literature in studies comparing work to nonwork days (Goldstein et al., 1999) and in studies examining the cardiovascular responses to laboratory stress throughout the menstrual cycle (Manhem et al., 1991, 1992). Goldstein et al. demonstrated that SBP and DBP were higher during work days than off work days. Daytime epinephrine was higher during work than off work days. HR was higher during the luteal than the follicular phase. No phase and day (work vs. off work days) interactions were found, suggesting that the difference in activity level did not explain the phase effect on HR. In addition, activity (determined by an actigraph) and posture (determined from participants' self reports) did not influence cardiovascular or neuroendocrine findings. The increase in HR during the luteal phase was associated with higher daytime and nighttime norepinephrine, suggesting a predominance of sympathetic activity during this phase. In addition to higher levels of SBP and HR observed during the luteal phase, HR reactivity to stress was higher in the luteal phase compared with the follicular phase in 11 normotensive women in the study by Manhem et al. (1991). Yet, the same group of researchers found no difference in HR reactivity between the two phases in hypertensives (Manhem et al., 1992).

The purpose of this study was to determine whether (1) there is a menstrual phase effect on BP and HR, and (2) the menstrual phase mediates the effects of physical effort, posture, or moods on BP or HR. To accurately determine the effects of physical effort, posture, and moods on ABP, it is important to obtain an adequate number of observations throughout the day and throughout the month in a natural setting. To that end, we included the participants' self-report of the physical effort, posture, and moods they were experiencing concurrently

with each ABP measurement in our analysis. We hypothesized that the phase of menstrual cycle is an important determinant of ABP and HR even after controlling for the effects of physical activity, posture, and moods.

METHODS

Participants

This study was approved by the Institutional Review Board for the Protection of Human Subjects. All participants signed a written informed consent and were paid \$100 for completion of the study. Twelve normotensive women with normal menstrual cycles were recruited for study via flyers and word of mouth. We determined the normal menstrual cycle status from self-reports of a predictable cycle ranging from 28 to 31 days. Participants were excluded if they were on birth control pills, other hormones, or vasoactive medications.

Procedures

Each participant underwent a battery of anthropometric measurements, collection of demographic data, and office BP measurements 1–7 days before the first scheduled study day. In cooperation with the subject, the days of data collection were scheduled so that all measurements occurred during workdays or school days. BP and HR were recorded by an ABP monitor during a 24-hr period on Days 1, 8, 15, and 22 of the menstrual cycle, approximately representing the commencement of menstruation, follicular, ovulation, and luteal phase, respectively. To eliminate the possible effects of habituation and sequence of testing on BP, data collection was randomly started on different days of the cycle. The normal cycle was confirmed by verifying with each subject that Day 22 was followed by menstruation within 6–9 days.

Ambulatory BP Monitoring

Each subject was fitted with the appropriately sized BP cuff connected to an ABP monitor (SpaceLabs ambulatory BP monitor [Model 90207, SpaceLabs Medical, Inc., Redmond, WA]), and a calibration procedure was performed. This procedure consisted of three readings in the seated position, each taken with the ABP monitor and a mercury column simultaneously by means of a “T” connector between the two instruments. Readings for both SBP and DBP (diastolic BP) agreed within 5 mmHg on all three attempts.

The ABP monitor was programmed to measure SBP, DBP, and HR at 30-min intervals from 0600 to 2200 and at 60-min intervals from 2200 to 0600. Participants were instructed to carry on with their ordinary daily activities and to avoid strenuous exercise during the four study days. They were given a diary and were asked to identify their posture (whether they were sitting, standing, or lying) and to rate both their physical effort and experience of three moods (annoyed, tense, and happy) on 5-point Likert scales each time the ABP monitor took measurements while they were awake. The physical effort and mood scales were based on work by Krantz and colleagues (Gabbay et al., 1996; Hedges, Krantz, Contrada, & Rozanski, 1990; Krantz et al., 1994). Previous studies have validated diaries of this type

with spouse observers' ratings and comparisons of home and work ratings (Hedges et al., 1990; Krantz et al., 1994).

Artifactual ABP readings were eliminated using the modified Casadei procedure, a standard editing criterion (Winnicki, Canali, Mormino, & Palatini, 1997). As with other editing criteria, the modified Casadei procedure eliminates measurements that fall outside the range of 70–240 mm Hg for SBP, 40–140 mm Hg for DBP, 40–125 beats per minute for HR, and 20–100 mm Hg pulse pressure (PP).

Measurements

ABP profiles included averages and standard deviations of 24-hr, daytime, and night-time BP and HR measures. PP was calculated as SBP – DBP. Mean arterial pressure (MAP) was calculated as two-thirds DBP plus one-third SBP.

Statistical Analyses

ABP and diary data were analyzed using SAS (SAS Institute Inc., Cary, NC). Statistical analyses were performed at two levels. At the population level, we wished to identify physical effort, posture, and moods that affected one or more cardiovascular parameters. At this level, participants were considered as a random sample from the population and the cardiovascular parameters were considered as repeated measures with the participants' age, body mass index (BMI), and waist–hip ratio (WHR) as covariates at the participant level and physical conditions (posture and effort) and moods as covariates at the time level. The menstrual phase and the time of the day were treated as fixed effects. The time of the day is adjusted by waking time. We considered the time of the day as continuous with both linear and quadratic terms (see Table I). Because of the possible dependence in time points, heterogeneity in variances, participant interaction in covariate relations, and missing observations, a mixed model was the most appropriate analysis for this type of data (Littell, Milliken, Stroup, & Wolfinger, 1996). We used SAS PROC MIXED for data analysis. Since we were simultaneously testing a few hypotheses, only *p* values less than .01 were considered to be significant. After the significant factors were identified, these factors were used to build a model in equational form so that we could identify the magnitude of the effect.

Any dependent variables that can predict the response are useful in controlling the response. However, which dependent variable is good for prediction usually varies at the individual level. For example, posture may affect one individual's SBP, but not the other's. To make our findings more pertinent to clinical practice, we extended our investigation to the individual level in order to detect what proportion of the population might benefit from our findings. At this level, we used the previously determined statistically significant variables to build a model for each person. We judged the usefulness of the posture, activity, and mood measures for each individual by their improvement in predicting cardiovascular parameters. We chose to use cross-validation methodology for model selection (Chatterjee & Hadi, 1988; Linhart & Zucchini, 1986). The basic idea of this technique is to use the first part of the data for model building. The second part of the data is used for testing whether the model so built is good in prediction. This procedure was accomplished by Prediction Sum of Squares (PRESS) in SAS procedure PROC GLM.

The variables of physical effort, annoyed, tense, and happy were rated on 5-level ordinal scales from 0 to 4. Each of these variables can be considered as a discrete or a continuous variable. Both of the options were explored. The results differed very little because most participants concentrated their ratings on two or three levels instead of being evenly distributed over the five levels. We report only the continuous option. Posture (sitting, standing, and lying) was considered as a cardinal variable.

RESULTS

Demographics

Participants ranged in age from 28 to 50 years with a mean of 39.7 and a standard deviation of 7.7. Based on two measurements per participant, mean office SBP was 118.3 mm Hg with a range of 104.5–134.5 and mean office DBP was 71.7 mm Hg with a range of 58.0–84.5. Body height ranged from 1.57 to 1.73 m with a mean of 1.64, and weight ranged from 47.3 to 121.7 kg with a mean of 77.26. BMI ranged from 18.74 to 48.14 with a mean of 28.75. WHR ranged from 0.71 to 0.94 with a mean of 0.79. All participants were nonsmokers.

Effects at the Population Level

In our first analysis, we put all factors (the menstrual cycle phase, time of the day, and the posture, activity, and mood measures) into the mixed model. Only daytime data were used because daily diary measures were recorded only during the day. The significance of a factor was chosen only when it affected the response after the influence of other factors was considered (i.e., the partial correlation or Type III test in SAS was statistically significant). This was a conservative way to claim the significance of a factor when many factors were present simultaneously. However, daily diary measures were interrelated, thus increasing the possibility that the effects of each factor on cardiovascular parameters would be obscured. For example, ratings of happiness were negatively correlated with ratings of annoyance ($r = -.31$), and ratings of tenseness were positively correlated with physical effort ($r = .40$) and annoyance ($r = .42$).

Table I presents the output for the Type III tests of the fixed effects using the SAS PROC MIXED procedure. The menstrual cycle phase was a strong determinant of daytime SBP, DBP, and HR. Posture also significantly affected SBP, DBP, and HR. The time of the day affected SBP and PP. Physical effort affected HR but not BP. A summary of mean BP at different stages of the menstrual cycle is shown in Table II. The standard deviations of the estimates were very similar because they were estimated together by the same likelihood equation in the mixed model.

When a factor was judged as statistically significant, multiple comparisons for categorical variables were performed using the LSMEANS option and the slopes of regression lines for continuous variables were calculated using the SOLUTION option from the SAS PROC MIXED. Table III summarizes the significant population and participant effects. SBP was lower on Day 8 than on other Days, DBP was lower on Days 1 and 8 than on Day 22, and HR was lower on Days 1 and 8 than on Days 15 and 22. BMI was positively

Table I. *F* Statistics and *p* Levels for Type III Test of Fixed Effects

	Numerator <i>df</i> ^a	<i>F</i>			
		SBP	DBP	PP	HR
Age	1	0.05	0.13	0.00	2.47
BMI	1	6.20*	1.34	2.12	1.83
WHR	1	0.80	0.76	0.05	1.44
Phase	3	7.42**	4.22*	2.33	20.62**
Time	1	6.10*	3.24	9.27*	4.96
Time*Time	1	13.29**	0.06	9.32*	5.23
Posture	2	4.94*	23.37**	1.58	73.27**
Physical effort	1	4.73	0.35	0.73	6.96*
Annoyance	1	0.20	2.55	0.48	7.67*
Tenseness	1	0.20	7.22*	15.65 ^{b*}	2.26
Happiness	1	0.15	0.36	0.02	5.09

Note. SBP = systolic blood pressure; DBP = diastolic blood pressure; PP = pulse pressure; HR = heart rate; BMI = body mass index; WHR = waist-hip ratio; Time = time of the day adjusted by waking time; Time*Time = quadratic component of the time effect.

^aDenominator *df* = 1234.

^{b*}interaction with phase significant at *p* level of .01.

p* < .01. *p* < .001.

related to SBP (*p* = .014). However, even after consideration of the BMI effect on SBP, the effect of phase on SBP remained significant. Although the time of the day was related to SBP and PP, there were no time and phase interactions.

In terms of the effects of physical and emotional variables on cardiovascular parameters, posture was an important determinant. Daytime SBP was strongly affected by posture, but not by physical effort or moods. Posture also affected DBP and HR. Tenseness was the only mood that correlated with daytime DBP. For each unit increase in tenseness, DBP increased by 0.903 mmHg. Menstrual phase, posture, physical effort, and annoyance significantly affected daytime HR. For each unit increase in physical effort, HR increased by 1.44 beats per minute. In contrast, for each unit increase in level of annoyance, HR decreased 1.58 beats per minute. There was an interaction between menstrual phase and level of tenseness that affected pulse pressure.

The average daytime physical and emotional variables had little influence over the average daytime BP, nor did they have any significant effect on nighttime levels (data not shown). When we examined the drop of BP from day to night (defined as daytime average – nighttime average), we found that only the nocturnal drop of SBP was affected by the menstrual cycle phase at the .05 significance level (Table IV).

Table II. Mean Daytime BP at Different Stages of the Menstrual Cycle

Stage of cycle	Blood pressure (mm Hg)	
	Systolic	Diastolic
Menstruation (Day 1)	119.97 ± 2.05	73.98 ± 2.01
Follicular (Day 8)	116.82 ± 2.05	73.88 ± 2.01
Ovulation (Day 15)	118.78 ± 2.05	75.22 ± 2.01
Luteal (Day 22)	119.26 ± 2.05	75.54 ± 2.00

Note. The values following the ± symbol are the estimation standard errors.

Table III. Statistically Significant Population Factors and Participant Effects

Variables	Gain level	
	Population	Participant
SBP (mm Hg)		
Phase	D1 (119.9) > D8 (116.8), D15 (118.8) > D8 (116.8), D22 (119.3) > D8 (116.8)	5/12
Time	Sitting (119.7) > Lying (116.8)	7/12
Posture	Standing (120.5) > Lying (116.8)	5/12
DBP (mm Hg)		
Phase	D22 (75.5) > D8 (73.9), D22 (75.5) > D1 (73.9)	6/12
Posture	Standing (77.8) > Sitting (75.5) > Lying (71.4)	5/12
Tenseness	Slope = 0.903	4/12
PP (mm Hg)		
Time		4/12
Tenseness by phase interaction	Slope = -3.80 (D1), 1.14 (D8), -0.53 (D15), -1.87 (D22)	4/12
HR (beats/min)		
Phase	D15 (81.6) > D1 (77.5), D22 (83.3) > D1 (77.5), D15 (81.6) > D8 (78.7), D22 (83.3) > D8 (78.7)	8/12
Posture	Standing (88.1) > Sitting (80.2) > Lying (72.6)	11/12
Physical effort	Slope = 1.44	4/12
Annoyance	Slope = -1.58	2/12

Note. SBP = systolic blood pressure; DBP = diastolic blood pressure; PP = pulse pressure; HR = heart rate; D1 = Day 1 of the cycle; D8 = Day 8 of the cycle; D15 = Day 15 of the cycle; D22 = Day 22 of the cycle. The first column lists the cardiovascular parameters and the daily activity measures that can affect it. The second column gives the magnitude of the effect at the population level, where slope is defined as the change in the parameter when the independent variable changes 1 unit. The third column displays the number of beneficiaries out of 12 participants each time a new significant factor was added. The variables were added into the prediction equation sequentially according to the order of the first column.

Finally, we examined whether the daily variability of BP was affected by the menstrual phase. Only the variability of nighttime SBP changed with the menstrual phase ($p = .06$); Day 1 variability ($SD = 5.55$) was smaller than that of the other days ($SD = 7.56$).

Effects at the Individual Level

At this level, we focused attention on the number of individuals for whom the new variable would improve the prediction in cardiovascular parameter changes. The results are presented in the third column of Table III. For example, the prediction of HR was improved

Table IV. Nocturnal Drop in BP Over the Menstrual Cycle Phases

	SBP (mm Hg)	DBP (mm Hg)
Day 1	13.35 ± 1.42	13.19 ± 1.16
Day 8	9.59 ± 1.38	10.80 ± 1.09
Day 15	11.48 ± 1.38	12.06 ± 1.06
Day 22	12.70 ± 1.41	12.82 ± 1.06
<i>p</i> value	.055	.156

Note. The values are mean ± standard error of the mean, and the *p* value represents that for claiming the differences in four menstrual cycle days.

Table V. Participant-Level Reduction of Prediction Error in SBP When New Variables are Added Into the Model

Participant	No model	Phase	Phase + time	Phase + time + posture
1	1.0	0.930	0.916	0.917
2	1.0	1.018	1.011	1.001
3	1.0	1.051	0.936	0.896
4	1.0	0.917	0.872	0.793
5	1.0	1.053	0.959	0.972
6	1.0	0.976	0.910	0.978
7	1.0	1.025	0.966	0.921
8	1.0	0.601	0.605	0.568
9	1.0	1.033	1.049	0.988
10	1.0	0.949	0.905	0.793
11	1.0	1.039	1.020	1.087
12	1.0	1.006	1.044	1.068

Note. The prediction errors are measured by PRESS with “no model” as the reference point. For example, for participant 1, the model with phase has the prediction error 0.930 relative to the 1.0 from no model.

by phase in 8 participants and the prediction was again improved for 11 participants when posture information was added.

To further illustrate the cross-validation building method, we used SBP as an example. The order of model building is no model (without using any independent variable), model with the menstrual phase, and model with the menstrual phase, time, and then posture. PRESS values are given in the table for each individual. As Table V shows, the phase model was better than “no model” (i.e., reduced the prediction error) in participants 1, 4, 6, 8, and 10 (5 out of 12). Similarly, the phase + time model is better than both no model and the phase model in participants 1, 3, 4, 5, 6, 7, 10 (7 out of 12).

DISCUSSION

The basic question we posed was whether the menstrual cycle phase is an important determinant of ABP. The salient finding from this study was that the menstrual phase remained a strong determinant of ambulatory SBP, DBP, and HR even after controlling for the effects of posture, physical effort, and moods. It should be addressed, however, that the differences in BP and HR among the menstrual phases were very small. Therefore, the clinical significance of the cyclical change in sex hormones during a normal menstrual cycle in the regulation of BP remains to be determined.

In this study, the mean level of SBP during the follicular phase was significantly lower than the mean for all other phases. The mean level of DBP was higher during the luteal phase than during the follicular phase or menstruation. The mean level of HR during menstruation and the follicular phase was also significantly lower than the mean for other phases. Our findings concur with previous reports of a significantly higher SBP (Manhem et al., 1991, 1992) and HR (Goldstein et al., 1999) during the luteal phase. Although the underlying cause of the menstrual phases' effect on BP and HR was not specifically evaluated in this study, others have suggested that there is a hypertensive effect or enhanced reaction to stress during the luteal phase when plasma progesterone concentration is high (Greenberg, Imeson, Thompson, & Meade, 1985). A predominance of sympathetic activity during the

luteal phase has been suggested (Sato, Miyake, Akatsu, & Kumashiro, 1995) and attributed to the difference in HR reactivity between the luteal and the follicular phase (Goldstein et al., 1999). A higher plasma concentration of fluid-regulation hormones (i.e., aldosterone, renin) during the midluteal phase than in the follicular phase has been noted (Stephenson Kolka, 1985; Stephenson, Kolka, Francesconi, & Gonzalez, 1989). The findings from these previous studies suggest that there is a distinct difference in stress reaction, sympathetic activity, and/or fluid-regulation between the luteal and the follicular phase due to the difference in the level of sex hormones (i.e., progesterone and estrogen) between these two phases. Yet, there is a subtle difference between our and previous findings on the effect of menstrual phase on BP and HR. We demonstrated a significantly lower SBP during the follicular phase and equivalent SBP levels during menstruation, ovulation, and the luteal phase. DBP was lower during the follicular phase and menstruation than during the luteal phase. We also found higher levels of HR during ovulation and the luteal phase than during menstruation and the follicular phase. Therefore, the difference in progesterone, autonomic activities, and fluid-regulation hormones between the luteal and the follicular phase cannot completely explain the phase effect on BP and HR.

Karpanou et al. (1993) demonstrated that premenopausal hypertensive women have increased testosterone during ovulation and increased testosterone and plasma renin activity during the luteal phase. When compared to normotensive women, hypertensive women had higher testosterone during the ovulatory and the luteal phase. It has also been demonstrated that serum testosterone level predicts BP elevation independent of age and ovulatory status (Ayala et al., 1999). Our data support the notion that testosterone exerts a hypertensive effect and contributes to the observed higher level of SBP and HR during ovulation and the luteal phase. However, testosterone levels were not assessed in this study.

In the study by Karpanou et al., hypertensive women with low plasma renin activity (<2 ng/mg/h) had a significantly higher BP during ovulation whereas hypertensives with relatively high plasma renin activity exhibited no change in BP during the cycle. Although further discussion in this regard is beyond the scope of this paper, these findings raise an interesting question as to whether sex hormones play an active role in BP regulation only when fluid-regulation hormones and the autonomic nervous system are less active.

The small number of participants studied limits the generalizability of the findings reported in this study. Previous researchers only studied participants during 2 or 3 days of their menstrual cycle. In the current study, each participant was studied over 4 days, and each day had 40 data collection points, providing 1920 BP measurements.

It is evident that psychological and environmental factors encountered daily strongly influence BP (Carels, Sherwood, & Blumenthal, 1998). Negative moods affected SBP, DBP, and HR (Carels, Blumenthal, & Sherwood, 2000). Consistent with previous findings, our data indicate that tenseness affects DBP and annoyance affects HR. DBP increases as the level of tenseness increases, whereas HR decreases as the level of annoyance increases. Clearly, increased tenseness may evoke sympathetic activation and vasoconstriction, and consequently an increase in DBP. With regard to the effect of annoyance on HR, it is likely that negative mood associated with disgusting stimuli may evoke trophotropic changes, thus activating the parasympathetic branch of the autonomic nervous system and decreasing HR. It must be acknowledged, however, that the effects of some factors on cardiovascular variables might have been obscured because of the strong colinearity among factors.

Physical activity and mood ratings were obtained using self-report. As such, the Likert scales were not standardized among participants and there was undoubtedly some variability in how the participants rated their moods and physical effort. In addition, it should be mentioned that other self-reported moods, such as subjective experience of sadness, fear, anxiousness, nervousness, and anger, were not investigated in this study. Ratings of physical effort may have been improved had we used an ambulatory activity recorder. Because the Spacelabs ABP monitor is unable to accurately measure BP during arm movement, participants may have limited their physical activity on the days they were studied. Indeed, Costa and colleagues have reported that ABP monitoring and diary completion is associated with reduced activity (Costa, Copley, Griffith, & Steptoe, 1999).

In addition, we should be careful when using emotional variables to predict BP because the direction of causation is not clear. Thus, whether decreasing tenseness can reduce DBP needs to be studied in more systematic manipulations of tenseness.

In this study, the effects of daily activity measures (i.e., physical effort, posture, and moods) on BP and HR appear to have only a short duration of influence. The average daytime activity measures did not influence the average daytime BP or HR, nor did they have any carryover effect to the night. Our findings confirm the results of previous investigators (Goldstein et al., 1999) that activity (as measured by an actigraph) and posture during ABP monitoring had a limited influence on BP and HR.

In addition to the new findings in this report, the two-stage statistical analysis we used may be useful in future studies of cardiovascular parameters, which have large variability within and between participants even under normal condition. Since many environmental effects (including physical and emotional factors) are small compared to these normal variations, they are difficult to detect or confirm. The elevation of BP and HR during the luteal phase is a typical example. Some observations by others supported this assertion whereas others did not. These conflicts make it difficult to apply these findings in the clinical setting. Even when an environmental effect appears statistically significant in a number of studies, it would be idealistic to expect that the effect will be equally applicable to everyone in those studies. The participant sensitivity should be considered. In order to better determine clinical applicability, we recommend that future studies use the prediction error method to estimate the proportion of participants that can benefit from information about an environmental effect.

In summary, the mean level of SBP during the follicular phase was significantly lower than the mean for all other phases. The mean levels of DPB during menstruation and the follicular phase were lower than the mean for the luteal phase. The mean level of HR during menstruation and the follicular phase was also significantly lower than the mean for other phases. The menstrual phase remained a strong determinant of ambulatory SBP, DBP, and HR even after controlling for the effects of physical activity and moods. Using a cross-validation statistical method, the prediction of SBP, DBP, and HR was improved by including the menstrual phase in 5 out of the 12, 6 out of 12, and 8 out of the 12 women studied, respectively.

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REFERENCES

- Ayala, C., Steinberger, E., Sweeney, A., Mueller, W. H., Waller, D. K., Hardy, R., et al. (1999). The relationship of serum androgens and ovulatory status to blood pressure in reproductive-age women. *American Journal of Hypertension*, 12, 772–777.
- Carels, R. A., Blumenthal, J. A., & Sherwood, A. (2000). Emotional responsivity during daily life: Relationship to psychosocial functioning and ambulatory blood pressure. *International Journal of Psychophysiology*, 36, 25–33.
- Carels, R. A., Sherwood, A., & Blumenthal, J. A. (1998). Psychosocial influences on blood pressure during daily life. *International Journal of Psychophysiology*, 28, 117–129.
- Carr, B. R., & Blackwell, R. E. (1993). The normal menstrual cycle: The coordinated events of the hypothalamic-pituitary-ovarian axis and the female reproductive tract. In B. R. Carr & R. E. Blackwell (Eds.), *Textbook of reproductive medicine* (pp. 209–219). East Norwalk, CT: Appleton & Lange.
- Chatterjee, S., & Hadi, A. S. (1988). *Sensitivity analysis in linear regression*. New York: Wiley.
- Costa, M., Cropley, M., Griffith, J., & Steptoe, A. (1999). Ambulatory blood pressure monitoring is associated with reduced physical activity during everyday life. *Psychosomatic Medicine*, 61, 806–811.
- Gabbay, F. H., Krantz, D. S., Kop, W. J., Hedges, S. M., Klein, J., Gottdiener, J. S., et al. (1996). Triggers of myocardial ischemia during daily life in patients with coronary artery disease: Physical and mental activities, anger and smoking. *Journal of American College of Cardiology*, 27, 585–592.
- Goldstein, I. B., Shapiro, D., Chicic-DeMet, A., & Guthrie, D. (1999). Ambulatory blood pressure, heart rate, and neuroendocrine responses in women nurses during work and off work days. *Psychosomatic Medicine*, 61, 387–396.
- Greenberg, G., Imeson, J. D., Thompson, S. G., & Meade, T. W. (1985). Blood pressure and the menstrual cycle. *British Journal of Obstetric Gynaecology*, 92, 1010–1014.
- Hedges, S. M., Krantz, D. S., Contrada, R. J., & Rozanski, A. (1990). Development of a diary for use with ambulatory monitoring of mood, activity, and physiological function. *Journal of Psychopathology and Behavior Assessment*, 12, 203–217.
- Heintz, B., Schmauder, C., Witte, K., Breuer, I., Baltzer, A., Sieberth, H. G., et al. (1996). Blood pressure rhythm and endocrine functions in normotensive women on oral contraceptives. *Journal of Hypertension*, 14, 333–339.
- Karpanou, E. A., Vyssoilis, G. P., Gerogoudi, D. G., Toutouza, M. G., & Toutouzas, P. K. (1993). Ambulatory blood pressure changes in the menstrual cycle of hypertensive women. Significance of plasma renin activity values. *American Journal of Hypertension*, 6, 654–659.
- Krantz, D. S., Hedges, S. M., Gabbay, F. H., Klein, J., Falconer, J. J., Merz, C. N., et al. (1994). Triggers of angina and ST-segment depression in ambulatory patients with coronary artery disease: Evidence for an uncoupling of angina and ischemia. *American Heart Journal*, 128, 703–712.
- Linhart, H., & Zucchini, W. (1986). *Model selection*. New York: Wiley.
- Litschauer, B., Zauchner, S., Huemer, K. H., & Kafka-Lutzow, A. (1998). Cardiovascular, endocrine, and receptor measures as related to sex and the menstrual cycle phase. *Psychosomatic Medicine*, 60, 219–226.
- Littell, R. C., Milliken, G. A., Stroup, W. W., & Wolfinger, R. D. (1996). *SAS system for mixed models*. Cary, NC: SAS Institute.
- Manhem, K., Jern, C., Pilhall, M., Hansson, L., & Jern, S. (1992). Cardiovascular responses to stress in young hypertensive women. *Journal of Hypertension*, 8, 861–867.
- Manhem, K., Jern, C., Pilhall, M., Shanks, G., & Jern, S. (1991). Haemodynamic responses to psychosocial stress during the menstrual cycle. *Clinical Science*, 81, 17–22.
- Murphy, S. L. (2000). *Deaths: Final data for 1998* (National Vital Statistics Report, Vol. 48, No. 11). Hyattsville, MD: National Center for Health Statistics.
- Rosenthal, T., & Oparil, S. (2000). Hypertension in women. *Journal of Human Hypertension*, 14, 691–704.
- Sato, N., Miyake, S., Akatsu, J., & Kumashiro, M. (1995). Power spectral analysis of heart rate variability in healthy young women during the normal menstrual cycle. *Psychosomatic Medicine*, 57, 331–335.
- Stephenson, L. A., & Kolka, M. A. (1985). Menstrual cycle phase and time of day after reference signal controlling arm blood flow and sewing. *American Journal of Physiology: Regulatory Integrative Comparative Physiology*, 249, R186–R191.

- Stephenson, L. A., Kolka, M. A., Francesconi, R., & Gonzalez, R. R. (1989). Circadian variations in plasma renin activity, catecholamines and aldosterone during exercise in women. *European Journal of Applied Physiology and Occupational Physiology*, 58, 756–764.
- Williamson, P. M., Buddle, M. L., Brown, M. A., & Whitworth, J. A. (1999). Ambulatory blood pressure monitoring (ABPM) in the normal menstrual cycle and in women using oral contraceptives. Comparison with conventional blood pressure measurement. *American Journal of Hypertension*, 9, 953–958.
- Winnicki, M., Canali, C., Mormino, P., & Palatini, P. (1997). Ambulatory blood pressure monitoring editing criteria: Is standardization needed? Hypertension and Ambulatory Recording Venetia Study (HARVEST) Group, Italy. *American Journal of Hypertension*, 10, 419–427.