Ambulatory Blood Pressure Monitoring Is Associated With Reduced Physical Activity During Everyday Life

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Objective: The objective of this study was to assess the impact on noninvasive ambulatory blood pressure monitoring on physical activity measured objectively by use of triaxial accelerometers. **Methods:** Twenty-four working men and women performed ambulatory blood pressure plus activity monitoring for 1 working day and evening and activity monitoring alone for a separate day and evening. Blood pressure measures were taken at 20-minute intervals during the day and 30-minute intervals in the evening and were accompanied by diary assessments of mood, location, and posture. Comparisons were made of energy expenditure on the 2 days and of activity levels during the minutes surrounding each blood pressure reading and diary completion. **Results:** Energy expenditure assessed in terms of activity calories per hour was significantly lower during blood pressure plus activity monitoring compared with activity monitoring alone (mean 37.3, SD = 16.3 vs. mean = 43.0, SD = 18.7 kcal, respectively: $p = .02$). Energy expenditure was lower during the 4 minutes surrounding each blood pressure reading than in the intervals between blood pressure readings. However, energy expenditure was also lower in the intervals between blood pressure readings than during comparable times on the activity only monitoring day. Blood pressure, heart rate, and physical activity were moderately correlated within individuals. **Conclusions:** Ambulatory blood pressure recording using automated sphygmomanometers is associated with reduced physical activity during the monitoring day. This is due partly to regular periods of immobility during cuff inflation and deflation and diary completion and partly to more general self-imposed restrictions on activity. This pattern has implications for the representativeness of ambulatory blood pressure monitoring, and the construction of ambulatory monitoring diaries. **Key words:** Ambulatory monitoring, physical activity, blood pressure.

BP = blood pressure.

INTRODUCTION

The ambulatory monitoring of BP and heart rate using automated noninvasive instruments has become an important technique in psychosomatic and behavioral medicine during recent years (1). It has been used to investigate the influence of such factors as work stress (2), mood (3), social interaction (4), and individual difference variables (5, 6) on cardiovascular function. Ambulatory monitoring is seen as complementary, or by some investigators as superior, to laboratory mental stress testing for evaluating behavioral influences on cardiovascular activity (7, 8). It has the advantage of assessing behavioral factors under naturalistic conditions that are more representative of everyday life than are laboratory settings.

However, the representativeness of cardiovascular data collected during ambulatory BP monitoring depends on whether participants behave as usual. When interviewed after ambulatory monitoring, some individuals report being embarrassed by cuff inflation, particularly when other people are present (9). They may consequently reduce levels of social involvement and activity. Subjects may be instructed to be immobile during cuff inflation and deflation to ensure reliable readings, but this interrupts ongoing activity. White (10) has noted that because activity is reduced during the BP measurement process, values may be 5 to 6 mm Hg lower than those recorded immediately before cuff inflation. Ambulatory BP monitoring in behavioral medicine is generally accompanied by paper or electronic diary assessments of activity, posture, mood, and location, which are expected to be completed immediately after each BP registration (11, 12). The completion of diaries may take several minutes on each occasion, leading to periods of relative inactivity accumulating over the day. Because physical activity has pronounced effects on BP (13–15), the result may be that ambulatory monitoring periods are not typical of everyday life.

The influence of ambulatory BP monitoring on daily activity was investigated by Blanchard et al. (16), who analyzed diary recordings from a sample of hypertensive patients during 24-hour monitoring, comparing these recordings with those from a similar period in which patients were prompted by a wrist watch alarm to complete the diary every 30 minutes without wearing the BP monitor. Patients tended to limit their activities to home and work on the BP monitoring day rather than going to other places. They were more likely to be supine and less likely to be standing on the BP monitoring day and were less likely to engage in

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physical activity than when wearing the alarm watch alone.

This study suggests that daily routines are changed during ambulatory BP monitoring. However, Blanchard et al. did not include objective measures of physical activity, so results were based on differences in self-reports. In addition, the completion of an activity diary every 30 minutes during the alarm-only day may also have disrupted routines. We therefore decided to investigate the influence of ambulatory BP monitoring on everyday activities using triaxial accelerometers for the assessment of energy expenditure. We compared a working day and evening of BP plus activity monitoring with a comparable day and evening of activity monitoring alone in a group of working men and women. We predicted that energy expenditure would be lower on the BP plus activity monitoring day than on the activity-only monitoring day.

If physical activity is reduced during prolonged ambulatory BP monitoring, this might be because participants are immobile during the BP readings themselves and subsequent diary completion. This possibility was investigated by comparing energy expenditure during the period immediately surrounding BP readings with the interval between readings and with comparable time periods during the activity-only monitoring day.

METHODS

Participants

These data were collected as part of a larger study of cardiovascular risk and job stress conducted in a sample of junior high and high school teachers (17). Twenty-four school teachers (15 men and 9 women) participated in the current study. Their average age was 40.8 years (SD = 8.0 years), and average body mass index was 25.4 (SD = 2.9). Three participants were cigarette smokers. Twelve participants were classroom teachers, and 12 had more senior administrative posts as well as class work.

Measures

Ambulatory BP and heart rate monitoring were performed using the Spacelabs 90217, a lightweight version of the 90207 noninvasive monitor (18, 19). BP monitoring was accompanied by completion of a diary developed during previous work in this laboratory (20). Participants recorded their location, posture, and activity together with ratings of subjective pressure and control immediately after every BP registration.

Activity was recorded in 1-minute epochs using a TriTrac-R3D research ergometer (Reining International, Madison, WI) worn on a waist band. This solid-state monitor contains accelerometers that assess movement in three planes: mediolateral, anteroposterior, and vertical. The monitor uses the integrated vector magnitude movement count together with information concerning sex, age, weight, and height to calculate estimated energy expenditure in kilocalories. Validation of the TriTrac and related triaxial accelerometers indicates that the instruments provide reliable and acceptable assessments of energy expenditure in different postures (21–23). For example, Bouten et al. (21) reported a correlation of 0.98 between integrated triaxial accelerometer values and energy expenditure assessed by oxygen consumption during rest and standardized activities.

Procedure

Measurements were performed as part of a 12-month follow-up assessment, so participants were already familiar with ambulatory BP monitoring from the previous year. All participants had a BP plus activity monitoring day and an activity-only monitoring day. The BP plus activity monitoring day came first for 20 subjects, whereas the activity-only monitoring day was first for the remaining four participants. The 2 days were consecutive, and the first day was randomly chosen between Monday and Thursday. On both days, subjects were instructed to carry on as normal but to keep their arms still during cuff inflation and deflation.

Monitors were fitted between 8 AM and 9 AM on a working day at the work site, and BP readings were taken at 20-minute intervals until 6 PM and at 30-minute intervals between 6 PM and 10:30 PM. BP was recorded at fixed intervals, and there was no warning signal before cuff inflation. On the activity-only day, the TriTrac accelerometers were worn on the waist for a comparable time period. Participants did not complete the diary on the activity-only monitoring day.

Data Analysis

Activity calories for each minute of both days were computed. To compare energy expenditure on the BP plus activity monitoring and activity only days, average activity calories per hour were calculated for 12 consecutive hours beginning at 8 AM and ending at 8 PM. Data collected after 8 PM were excluded from this analysis, because some individuals removed the instruments before they were scheduled to do so. These data were analyzed by repeated-measures analysis of variance with day (BP plus activity vs. activity only) and hour as within-subject factors. Post hoc analyses were performed using Tukey's honestly significant difference test. Reported F ratios and significance values are based on degrees of freedom, which were determined by applying the Huynh-Feldt correction procedure for controlling for Type 1 errors in repeated-measures designs.

The difference between activity during BP readings and activity during the intervals between readings was analyzed by averaging activity calories for the minute in which cuff inflation was initiated, the preceding minute, and the 2 subsequent minutes. These four minutes (BP recording activity) were compared with 14 of the remaining minutes of the 20-minute interval preceding that BP recording (between-recording intervals), leaving 2 minutes in every 20 unanalyzed to ensure clear separation of the two periods. Analysis was restricted to the first 28 valid BP registrations for each individual, because this was the minimum number of valid data points common to all participants, and the interval between readings was 30 as opposed to 20 minutes in the evening. The difference between activity calories in these two periods was analyzed by using repeated-measures analysis of variance with period (BP recording vs. between-recording intervals) and BP reading number (1–28) as within-subject factors. The BP recording and between-recording intervals were then compared across BP plus activity and activity-only monitoring days using repeated-measures analysis of variance.

Associations between energy expenditure and cardiovascular activity were analyzed by linear regression. BP and heart rate readings were screened, and outliers were excluded according to the methods described by Berardi et al. (24). Separate regressions were computed for systolic, mean, and diastolic BP and heart rate. All valid BP and heart rate readings were included as dependent variables, with activity calories for the 4 minutes surrounding each reading as the independent variables.

RESULTS

The mean values of BP, heart rate, and activity recorded during the BP plus activity monitoring day are summarized in Table 1. Participants were normotensive and showed the expected decrease in BP and heart rate during the evening hours. The difference between daytime and evening systolic, mean, and diastolic BPs were significant (t = 3.31, 3.40, and 3.50, $p < .005$), whereas the difference in heart rate was of borderline significance ($t = 2.00$, $p = .057$). Energy expenditure was also reduced in the evening compared with the working day ($t = 3.08$, $p < .01$). Six participants rated the ambulatory BP monitoring day as more stressful than usual, 11 rated it as normal, and 5 rated it as less stressful than usual.

Energy Expenditure During BP Plus Activity vs. Activity-Only Monitoring Alone

The analysis of activity calories per hour showed a main effect of day ($F(1,23) = 5.78$, $p < .02$). Activity calories per hour during the BP plus activity monitoring day averaged 37.3 kcal (SD = 16.32 kcal), compared with 43.0 kcal (SD = 18.65 kcal) during activity-only monitoring. The average values per hour in the two groups are shown in Figure 1. The main effect for hour was significant ($F(4,105) = 2.60$, $P < .04$, $\varepsilon = 0.42$), but there was no interaction between day and hour. This indicates that the difference in activity was similar across the 12 hours analyzed. Separate comparisons using Tukey's honestly significant difference indicate significant differences between the 2 days for all hours except 11 AM to 1 PM and 6 PM to 8 PM ($p < .05$). There were no differences related to the order in which the two experimental conditions were performed ($F(1,22) = 0.11$).

TABLE 1. BP, Heart Rate, and Energy Expenditure During Ambulatory Monitoring[a]

	Daytime (8:00 AM–5:40 PM)	Evening (6:00 PM–10:30 PM)
Systolic BP (mm Hg)	127.5 (11.0)	122.3 (10.8)
Mean BP (mm Hg)	96.9 (10.5)	92.7 (9.8)
Diastolic BP (mm Hg)	82.5 (7.3)	77.8 (6.6)
Heart rate (beats/min)	77.2 (9.8)	74.1 (8.9)
Energy expenditure (kcal)	38.7 (16.1)	24.7 (15.4)

[a] Values are mean (SD).

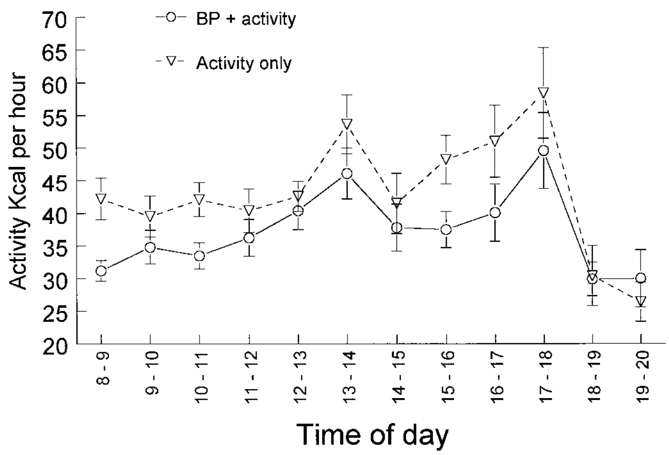

Fig. 1. Mean activity calories per hour between 8:00 AM and 8:00 PM recorded on the BP plus activity monitoring day and activity-only monitoring day. Error bars indicate SEM.

Activity During BP Readings

Mean activity calories per minute during the BP recording period averaged 0.496 kcal (SD = 0.28 kcal), compared with 0.601 kcal (SD = 0.30 kcal) during the between-recording intervals. The difference was significant ($F(1,23) = 12.2$, $p < .002$), indicating that energy expenditure was reduced during the period immediately surrounding each BP reading compared with other times during the BP monitoring day. There was no significant interaction between the two periods and the BP reading sequence.

Activity During Between-Recording Intervals

The between-recording intervals on the BP plus activity monitoring day were compared with comparable intervals recorded during the activity-only monitoring day. The results are depicted in Figure 2. There was a main effect of day ($F(1,23) = 11.7$, $p < .002$), because activity levels were higher on the activity-only monitoring day compared with the BP plus activity monitoring day. This effect did not interact with time of day. Thus, the difference in energy expenditure between the days was not due solely to the relative immobility of participants during the period immediately surrounding BP readings.

A similar comparison was performed of activity calories measured during the 4-minute BP recording periods and the comparable 4-minute periods during the activity-only monitoring day. These data are shown in Figure 2 and indicate, as expected, that energy expenditure was reduced on the BP monitoring day ($F(1,23) = 17.5$, $p < .001$). Interactions with time of day were not significant.

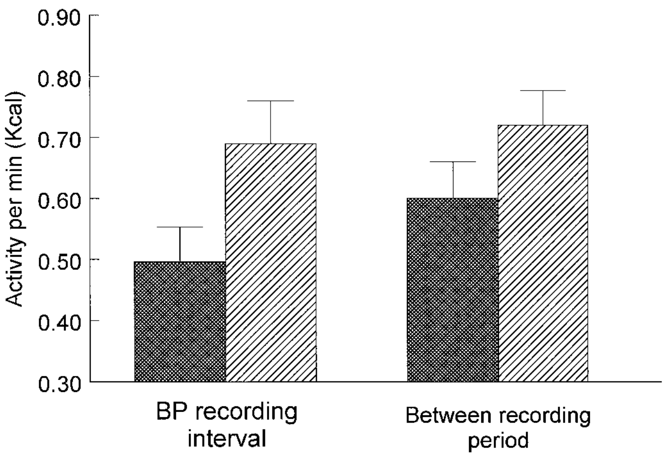

Fig. 2. Mean activity calories per minute during the 4 minutes surrounding each BP reading (BP recording interval) and the period between recordings on the BP plus activity monitoring day (▩) and the activity-only monitoring day (▨). Error bars indicate SEM.

Physical Activity, BP, and Heart Rate

The regression analyses of activity on BP and heart rate are summarized in Table 2. Positive associations between cardiovascular activity and energy expenditure were observed for all variables. The association was strongest for heart rate and systolic BP, intermediate for mean BP, and of marginal significance for diastolic BP.

DISCUSSION

Ambulatory BP monitoring using automated sphygmomanometers has been of immense value in the investigation of psychosocial influences of cardiovascular function. However, the technique is not without methodological costs, and the notion that the ambulatory BPs are representative of everyday life must be qualified.

This study replicates and extends the observation of Blanchard et al. (16) that people tend to limit their activities during ambulatory BP monitoring. Blanchard et al. used an earlier Spacelabs monitor that was somewhat heavier than the one used in this study. Significantly lower energy expenditure, as estimated objectively by accelerometers, was recorded on a

TABLE 2. Regression of Physical Activity on Cardiovascular Measures

	β	95% CI	t	p
Systolic BP	3.77	2.38–5.15	5.35	.0001
Mean BP	2.21	1.16–3.26	4.13	.0001
Diastolic BP	0.93	−0.03–1.89	1.91	.056
Heart rate	4.82	3.42–6.22	6.76	.0001

working day and evening of ambulatory BP monitoring as compared with activity-only monitoring. Because cardiovascular activity is strongly influenced by physical activity level, our findings suggest (but do not prove) that BP and heart rate recorded during ambulatory monitoring may be lower than that on a typical day and evening. Proof of such an effect is problematic; several studies involving continuous intraarterial and intermittent noninvasive ambulatory recording have been performed (25), but the differences between the measures typically lie within the margin of error for these techniques.

The lower energy expenditure during ambulatory BP monitoring is partly a result of the requirement for immobility during the recording procedure itself (Figure 2). This means that the effect will be larger when recordings are made more frequently, because participants will be inactive for a greater proportion of the time. The effect may also be amplified if the period of immobility is extended by the use of elaborate BP diaries. Researchers in this field must consider the tradeoff between detailed information and frequent recordings on one hand and the repeated disruption and reduction in normal activity on the other. More data collection may lead to the disappearance of the phenomenon under investigation.

Periodic immobility is not, of course, required for other types of ambulatory monitoring, such as Holter electrocardiography or ambulatory assessment of cardiac impedance (26). Nonetheless, our data suggest that the reduced physical activity during the monitoring day was not due only to the need for participants to keep their arms still during cuff inflation and deflation. Energy expenditure was lower in the intervals between recordings as well in comparison with the activity-only monitoring day. This may be due to a reluctance to perform normal duties while wearing the BP monitor, concern about sudden violent movements disturbing the apparatus, or perhaps a desire that readings should seem as "normal" as possible. Participants in ambulatory monitoring studies may have beliefs about the relationship between BP, mood, and emotion (27) and so may avoid situations in which they believe that BP might be elevated.

The associations between BP, heart rate, and energy expenditure were lower than those described by some investigators (13, 14). This may be a result of not including recordings during the night, because the range of cardiovascular and physical activity is greatly extended by including daytime and nighttime values. We decided not to continue recording through the night because Blanchard et al. (16) found no differences in sleep patterns between BP monitoring and diary recording days, and BP recorded during the night with automated sphygmomanometers are satisfactory in comparison with intraarterial values (28). Our results are similar to those of Shapiro and Goldstein (29), who reported modest within-subject correlations between wrist actigraph measures and systolic BP and heart rate.

Our study involved a working population of school teachers, and participants were involved in a variety of activities over the day, including teaching classes, administrative work, and talking to students and colleagues. The results therefore may not be generalized to other populations in which activities are more limited. The impact of ambulatory BP monitoring on activity may be reduced in populations who have more limited options concerning activities and timing of duties during the working day. Findings may also depend on the type of BP monitor used. We studied an instrument that measured BP at fixed intervals, and a variable interval protocol may not have the same effects on physical activity. Nonetheless, the results suggest that inferences concerning the representativeness of ambulatory monitoring periods should be tempered by consideration of the impact of the measurement procedure.

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