Ambulatory heart rate is underestimated when measured by an ambulatory blood pressure device

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Objective To test the validity of ambulatory heart rate (HR) assessment with a cuff ambulatory blood pressure (ABP) monitor.

Design Cross-instrument comparison of HR measured intermittently by a cuff ABP monitor (SpaceLabs, Redmond, Washington, USA), with HR derived from continuous electrocardiogram (ECG) recordings (1) in a controlled laboratory experiment and (2) during long-term recording in a true naturalistic setting.

Participants Six normotensive subjects participated in the laboratory study. A total of 109 male white-collar workers underwent ambulatory monitoring, of which 30 were mildly hypertensive.

Methods Four different laboratory conditions (postures: lying, sitting, standing, walking), repeated twice, were used to assess the short-term effects of cuff inflation on the HR. To test the actual ambulatory validity, participants simultaneously wore a continuous HR recorder and the ABP monitor from early morning to late evening on 2 workdays and one non-workday. Diary and vertical accelerometery information was used to obtain periods of fixed posture and (physical) activity across which HR from both devices was compared.

Results. Laboratory results showed that the ABP device reliably detected HR during blood pressure measurement, but that this HR was systematically lower than the HR directly before and after the blood pressure measurement. The ambulatory study confirmed this systematic underestimation of the ongoing HR, but additionally showed that its amount increased when subjects went from sitting to standing to light physical activity (2.9; 4.3 and 9.1 bpm (beats/min), respectively). In spite of this activity-dependent underestimation of HR, the correlation of continuous ECG and intermittent ABP-derived HR was high (median $r = 0.81$). Also, underestimation was not different for normotensives and mild hypertensives.

Conclusions A direct effect of cuff inflation leads to the underestimation of ongoing HR during cuff-based ABP measurement. Additional underestimation of HR occurs during periods with physical activity, probably due to behavioural freezing during blood pressure measurements. HR underestimation was not affected by hypertensive state. When its limitations are taken into account, ABP-derived ambulatory HR can be considered a reliable and valid measure. *J Hypertens* 19:1301–1307 © 2001 Lippincott Williams & Wilkins.

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Keywords: ambulatory blood pressure monitoring, heart rate, electrocardiogram, ecological validity, mild hypertension

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Introduction

Ambulatory monitors for blood pressure (BP) and heart rate (HR) are in widespread use in the clinical assessment of hypertension, antihypertensive drug effects, and the study of risk factors in cardiovascular disease [1–3]. Ambulatory monitoring is also increasingly used in psychophysiological studies, on the effects of psychosocial factors on the level of BP and HR in everyday settings, for example, the effects of job strain on work and leisure time BP and HR values [4,5]. There is convincing evidence that the predictive value of ambulatory BP is better compared to clinical BP [6,7]. Recent studies brought to attention that HR, an independent predictor of hypertension [8] and cardiovascular disease [9,10], should also be preferably assessed in an ambulatory setting [11]. Day–night differences in HR, for instance, may predict cardiovascular disease risk more reliably than resting HR [12]. Since most ambulatory cuff blood pressure devices yield HR data at the time of the BP measurement, an increasing number of studies in the field of hypertension report on the ambulatory HR profile [13,14].

Before routine use of ambulatory HR data from ambulatory blood pressure (ABP) monitoring becomes practical, the validity of ambulatory HR recording by such

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devices needs to be assessed in more detail. A number of factors may compromise this validity. During ambulatory studies, subjects are routinely instructed to keep their cuff-arm quiet during measurements for an optimal yield of the ambulatory BP (ABP) recording. This is necessary because it is known that the accuracy of the BP readings decreases during motion [15,16]. This means that subjects may (or rather must) change their ongoing behaviour and posture when the cuff starts to inflate. Although short-term changes in body movement during a BP measurement may have only a minor effect on the BP [17], effects on the rapidly responding heart rate may be severe. Moreover, the effects of cuff inflation on BP are countered by baroreflex action that will largely be effected through changes in the HR. It is uncertain how both of these affect the ecological validity of ambulatory HR recording.

This article reports two studies that examine the validity of HR assessed by a cuff ABP monitor (SpaceLabs 90207). Short term effects of cuff inflation *per se* were examined in a laboratory study that measured the continuous electrocardiogram (ECG) before, during and after arm cuff inflation in four different postures. This allowed examination of the possible physiological effects of an arm cuff-based BP measurement on the HR, as well as possible systematic errors between the two devices due to different HR detection methods. The ecological validity of the intermittent HR from the ABP recordings was further examined in an ambulatory experiment. During three different days, 109 male white-collar workers wore the ABP monitor, together with a device that continuously records HR from the ECG [18,19]. Continuous ECG-derived HR (ECG-HR) was averaged over periods of time with fixed posture and physical activity. HR derived intermittently from the ABP monitor (ABP-HR) was then averaged over all measurements that fell within these periods. It was tested whether ABP-HR was equal to the target ECG-HR during all postures and types of activity. To test whether these differences are influenced by hypertensive status, a comparison between normotensives and mild hypertensives was made.

Study 1: laboratory experiment

Materials and methods

To explore the short-term effects of a cuff-based BP measurement on the HR, a laboratory experiment was conducted in six healthy volunteers (three males; three females), 27–40 years of age. HR was measured by the Vrije Universiteit Ambulatory Monitoring System (VU-AMS) continuously from the time series of R wave to R wave intervals derived by a three-lead ECG. Reliability and validity of the VU-AMS have been described previously [18,19]. Continuous HR was recorded during a session with four different conditions, always applied in fixed order: lying, sitting, standing and walking. After 20 min, each condition was repeated in a second session but in reverse order. The duration of the conditions was 5 min and, after 3 min into each condition, one ABP measurement was, made by a Spacelabs 90207 device (Spacelabs) in the non-dominant arm with an arm-cuff appropriate for the arm diameter. Each condition was split into three periods: before, during and after the BP measurement. In the period during BP measurements, three events were marked in the continuous HR signal by an event marker: start of cuff inflation, start of slow cuff deflation (after inflation above systolic pressure) and start of rapid cuff deflation (after diastolic detection). Since the ABP monitor extracts HR from the pressure oscillations in the period between slow cuff deflation and rapid cuff deflation, only continuous HR from this period was used to calculate the target ECG-HR during BP measurement.

Repeated measures of analysis of variance (ANOVA) with the SPSS General Linear Models procedure (GLM version 8.0 for windows; SPSS, Chicago, Illinois, USA) was used to test the effects of session (first, second), postures (lying, sitting, standing, walking) and periods (before, during, after BP measurement) on the ECG-HR. To compare the mean HR of the two devices (ABP-HR versus ECG-HR) this analysis was repeated using the HR data during the blood pressure measurement period only.

Results

In all subjects, it was impossible to obtain a valid registration during the walking condition as the ABP device produced error codes due to movements. Even 'freezing' the cuff-arm during walking did not result in a valid registration. Therefore, the walking condition was removed for further analyses.

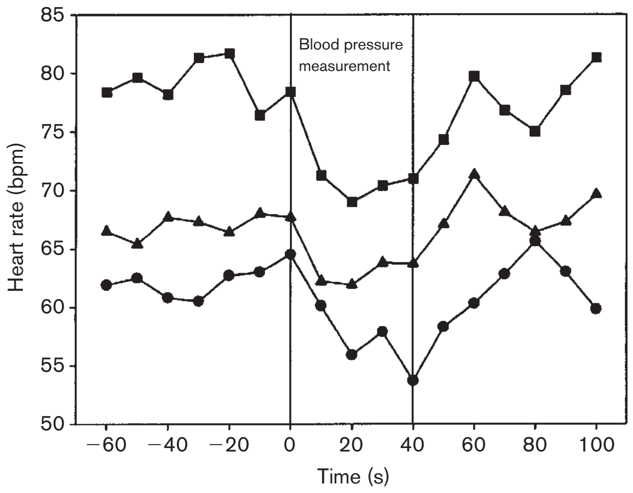
Table 1 shows the mean HR values before, during and after the ABP measurement, during lying, sitting and standing. The expected posture effects on HR were found ($F = 10.45$; $P = 0.026$), with supine HR lower than sitting HR, and sitting HR lower than standing HR. More importantly, all subjects showed a significant decrease in HR during the ABP measurement ($F = 40.11$; $P = 0.002$). The pattern was virtually the same in the six subjects and as an illustration, the HR of one subject is plotted in Figure 1. The Spacelabs device gives only one HR value, which is the mean HR during its measurement interval between slow and rapid cuff deflation. Comparison of this value with the mean ECG-HR obtained in this identical interval yielded no device differences ($F = 0.08$; $P = 0.79$), nor was there evidence for a posture by condition interaction. In summary, HR significantly decreased during the cuff blood pressure measurement and the ABP monitor reliably detected this lower HR.

Table 1 **Mean and SD of 12 observations of heart rate before, during and after a cuff blood pressure registration measured continuously by electrocardiogram (ECG) and by an ambulatory blood pressure (ABP) device as a function of posture**

		HR-ECG (bpm)		HR-ABP (bpm)	
Posture	*n*	before ABP	during ABP	after ABP	during ABP
Lying	12	66.2 ± 6.8	61.6 ± 6.3	65.9 ± 5.8	61.4 ± 5.8
Sitting	12	69.6 ± 7.2	65.7 ± 6.6	70.2 ± 7.9	65.5 ± 6.4
Standing	12	77.4 ± 6.9	70.6 ± 8.6	77.1 ± 7.3	70.5 ± 8.0

HR-ECG, heart rate-electrocardiogram; HR-ABP, heart rate-ambulatory blood pressure; bpm, beats-per-minute; SD, standard deviation.

Fig. 1



The course of the heart rate of one subject during cuff blood pressure measurement during three different postures: ● lying, ▲ sitting, ■ standing. Time 1: start of cuff inflation. Time 2: slow cuff deflation after inflation above systolic pressure. Time 3: rapid cuff deflation after diastolic pressure detection. bpm, beats per minute.

Study 2: ambulatory experiment

Participants

A total of 111 male, middle-aged (35–55 years; 45.2 ± 5.3) white-collar workers, all working at the same large computer company and performing mainly sedentary work, participated in a study on work stress and cardiovascular disease risk [20,21]. After the first measurement, two subjects complained that the measurements interfered too much with their work. They were excluded from the analysis. This left a total sample size of 109 male subjects for the ambulatory study. The study protocol was approved by the Ethics Committee of the Vrije Universiteit, and all subjects gave written consent before entrance to the study.

Procedure

Participants underwent ambulatory monitoring on 3 days of the same work-week. They attended the health department of the computer company, for the first time, on the Monday. After a short explanation of the experimental procedure, the experimenter showed them how to attach the equipment and electrodes and how to fill in the activity diary. After instrumentation, the subjects returned to their department to follow their normal working routines. After 24 h of registration, the subjects returned to the health department where the monitors were removed and the data downloaded. This procedure was repeated on the Thursday. On the Friday, the subjects took the ambulatory devices home for the non-workday registration. The non-workday registration was done on Saturday (50.9%) or on Sunday (49.1%), depending on the subject's preference. Subjects were encouraged to 'prefer' the most relaxing non-workday, in which they engaged in the least physical activity. Thus, subjects were measured on 2 workdays, Monday and Thursday, and 1 non-workday (Saturday or Sunday), always in that order.

Measures

Spacelabs ABP

HR and ABP were recorded with the same Spacelabs 90207 devices as during the laboratory study. Subjects were instructed to remove the BP device when they went to bed and to attach the device again the next morning when they woke up. Thus, HR and BP from the Spacelabs were only measured during waking hours, not during sleep. The subjects were asked not to change their actual posture while recordings were being obtained, and to keep the measured arm as still as possible. HR was determined from the number of pulses detected during cuff deflation. The monitor was programmed to record BP and HR at 30 min intervals, after a short warning beep. No BP or HR values were displayed after a recording.

VU-AMS

HR was measured by the VU-AMS (see Study 1) continuously for 24 h. To get an impression of the physical activity during the registration, the VU-AMS also monitors the amount of body movement of the subject by a vertical accelerometer. Continuous HR and average body movement over 30 s periods were stored throughout the 24 h recording time.

Diary information

The VU-AMS produced an audible alarm approximately every 30 min (±10 min randomized) to prompt the subject to fill out the activity diary. They were instructed to write down the time, activities and bodily postures during the last 30 min period, in chronological order.

Data reduction and analysis

The recommendations for excluding artefactual readings and outliers from ambulatory blood pressure records summarized by [22] were followed. All systolic blood pressure values of < 70 or > 200 mmHg, diastolic blood pressure values of < 40 or > 140 mmHg and pulse pressures of < 10 mmHg were eliminated. These ranges are similar to those adopted by Steptoe *et al.* [4]. Information about type of activity and (changes in) posture from the diary was combined with the vertical accelerometer information from the VU-AMS using an interactive graphical program. This program displayed the amount of body movement as a function of time, which made it possible to accurate specify the start and end times of the activities/posture changes that the subjects had recorded in the diary. Stationary fragments (same posture, same activity) of at least 3 min with non-conflicting information between diary and motility signal were coded for posture (lying, sitting, standing, physical activity), activity (household activities, desk work, meeting, dinner, etc.), period (work, leisure, sleep) and day (Monday, Thursday and non-workday). Travelling to and from work was considered to be the transition between work and leisure period on the workdays. Mean values for HR for these coded fragments were calculated by the program and stored simultaneously with start and end time, and duration of the period. Each blood pressure and heart rate value from the Spacelabs device was similarly coded for posture, activity, period and day, again using the combined information from diary and vertical accelerometer.

The activities were clustered in seven main groups: watching television, car driving, desk work (computer work, reading), talking at work (meeting, telephone calls, talking to colleagues), relaxing at home (talking, hobby, relaxing) light physical work (householding activities, walking, shopping, personal hygiene), moderate to heavy physical work (household activities, sports, bicycling, gardening). These were the activities that accounted for the largest part of the recording time and were done by most of the subjects. Average HR-ECG and HR-ABP were computed for each of these activities separately for work period and leisure periods on each of the three recording days. HR values from the Spacelabs and the VU-AMS were always based on the same activities. The important difference, of course, is that the average HR-ABP was based on a few HR measurements per activity, whereas HR-ECG was based on all continuous ECGs available during the entire time period of the activity. Cross instrument correlations were computed between HR-ECG and HR-ABP across all activities on all days for each subject to indicate how changes in HR were tracked by the two devices on an individual level. Two statistical approaches were used to analyse agreement on a group level. The mean difference between the two devices with the limits of agreement were computed as proposed by Bland and Altman [23]. These limits are calculated as mean difference ± 2(SD) and indicate the limits in which 95% of the differences fall. A positive value indicates that HR-ECG was higher compared to HR-ABP. MANOVA with the SPSS General Linear Models (GLM) was used to test for differences between the two devices and possible interaction. For these analyses, the activities were collapsed in three main categories: sitting, standing, and physical activity. These three activity categories, as well as time of day (work time, leisure time) and type of day (workday, non-workday) were entered as repeated measurement factors, in addition to the repeated measurement factor of device (HR-ABP, HR-ECG). Mild hypertensive status, defined as ambulatory diastolic blood pressure $\geqslant 85$ mmHg during all postures on all three measurement days, versus normotensives was entered as a between subject factor (see Table 2).

Results

The mean duration of the registrations on Monday, Thursday and the non-workday was 22:24 ± 1:32, 22:56 ± 2:01, 22:39 ± 2:44 h, respectively (16:00 ± 2:30, 17:00 ± 3:00, 16:00 ± 4:00 h for BP). Fragments that could not be coded due to ambiguous diary information resulted in data loss of 10.3% of the total registration time. Data loss due to temporary VU-AMS malfunction or loose electrodes occurred on 10 measurement days, which resulted in an additional 1.4% data loss. The percentage of invalid BP and HR recordings from the Spacelabs was 14.1%, which resulted in 28 ± 4, 29 ± 4 and 28 ± 7 valid BP/HR values on Monday, Thursday and the non-workday, respectively. There were no differences between the two workdays in activity patterns or in mean HR and BP during the work-related and non-work-related activities. In the analyses below, all data from the two workdays were averaged.

The mean duration of all labelled periods with the same codes, varied between 17 min (drinking/eating at work) and 2 h (light physical activities on a non-workday). This means that on average, during drinking/eating, one HR-ABP measurement was compared with a mean HR-ECG of 17 min. During longer labels, such as light physical activities, the mean of three or four HR-ABP values was compared to 2 h mean values for HR-ECG.

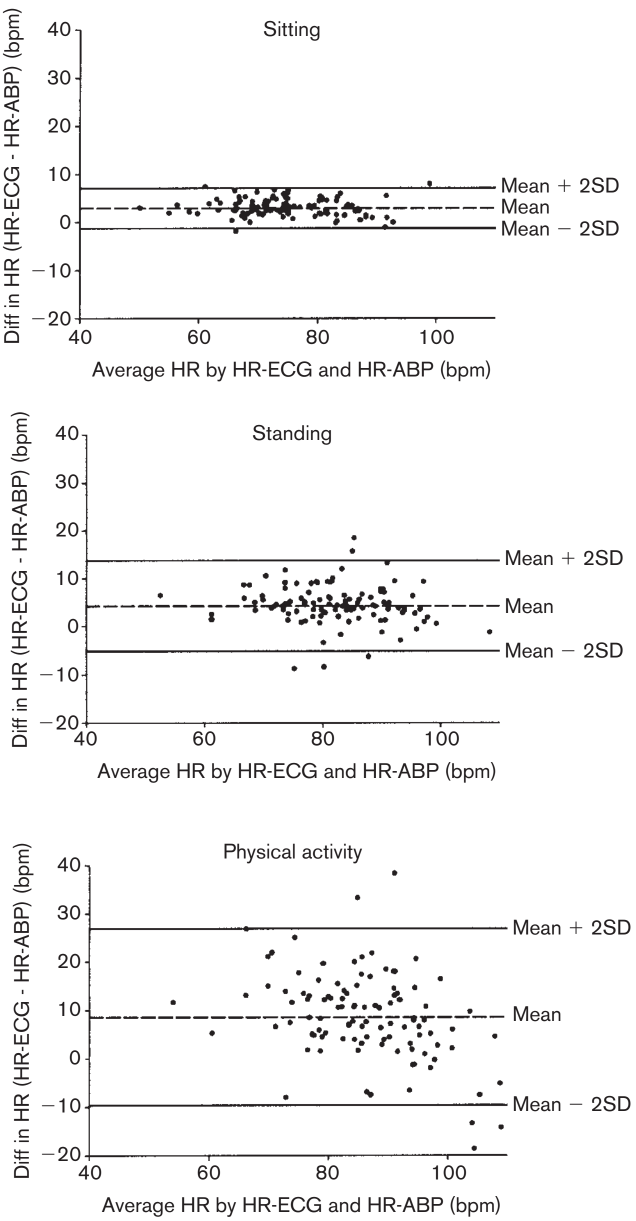
Comparison of HR-ABP and HR-ECG

The cross-instrument correlations varied between 0.45 and 0.97 with a median correlation of 0.81 for all 109 subjects. This means that increases and decreases in HR within an individual, can be tracked reliably by a cuff ABP device.

Figure 2 shows the plots of agreement between the two devices in the 109 subjects with all activities averaged over three main categories: sitting, standing and physical activity. The mean difference and the limits of agreement during sitting, standing and physical activity were respectively: 2.9 beats/minute (bpm) (−1.3 and 7.1), 4.3 (−5.1 and 13.7) and 9.1 (−9.1 and 27.3). These results indicate that across all three activity categories, the HR-ABP is clearly lower than HR-ECG. While subjects were sitting, the differences were small, but they increased and became more spread out when the subjects were involved in more physical activity. Multivariate analysis of variance (MANOVA) also revealed this highly significant device by activity interaction ($F = 20.05$; $P < 0.0001$). Table 2 shows this device offset in more detail, by tabulating the average HR measured by the two devices as well as the difference as a function of different activities on the workdays and the non-workday. The increased difference between the two devices with increasing activity reflected an incomplete increase in the HR-ABP in comparison to HR-ECG, strongly suggesting that the subjects ceased ongoing activity during the cuff-measurement.

Of the 109 subjects, 30 subjects showed mean ambulatory diastolic blood pressure ⩾ 85 mmHg during all postures on all three measurement days. These groups did not differ in the possible confounding factors age (45.2 ± 5.3 years), body mass index (25.3 ± 3.0 kg/m^2), percentage smokers (26%), alcohol consumption (15 ± 12 glasses/week) and physical habitual activity (1.4 ± 1.1 times/week exercise until sweating). The GLM analyses revealed that the underestimation of HR was not different for the normotensives and the mild hypertensives.

Fig. 2



Difference between heart rate (HR) measured by the ambulatory blood pressure (ABP) device and by continuous electrocardiography (ECG) during sitting, standing and physical active activities of all 109 subjects. Also the limits of agreement (mean ± 2SD) are plotted.

Discussion

In the ambulatory study, HR measurements obtained by an ABP device systematically underestimated the true HR for the type of activity in which the subjects were engaged, around the time of the BP measurement. Underestimation of HR became more severe if the subjects were engaged in physical activity, but was found when virtually no activity was required (e.g. quiet sitting, while watching television). The results from the laboratory experiment show that this underestimation reflects a real effect of cuff BP measurement on HR. This effect is partly due to the well-known bradycardia of the orientation reflex in response to cuff inflation [24,25], which is, however, short-lasting (seconds) and should decrease in amplitude after the first couple of measurements (habituation). A more likely explanation for the prolonged decrease in HR is an increase in total peripheral resistance during peak cuff inflation that occludes the entire vascular bed, distal

Table 2 **Mean and standard deviation of heart rate (bpm) measured continuously by ECG recordings and by an ambulatory blood pressure device and difference in heart rate (bpm) between the two devices as a function of activity**

	n	Heart rate ECG (bpm)	Heart rate ABP (bpm)	Δ Heart rate (beats/min)	DBP ABP (mmHg)	SBP ABP (mmHg)
Workdays						
Work period						
Deskwork, computer work, reading	109	77.3 ± 9.6	74.6 ± 10.1	2.7	87.4 ± 8.5	133.6 ± 11.4
Meeting, talking to colleagues, clients, congresses	107	78.3 ± 10.8	75.0 ± 11.4	3.3	89.3 ± 10.5	135.7 ± 14.3
Drinking/eating	107	80.8 ± 10.2	75.0 ± 10.0	5.8	89.6 ± 9.1	137.3 ± 12.8
Car driving	49	81.2 ± 9.6	78.7 ± 9.8	2.5	87.1 ± 9.06	135.3 ± 12.0
Light physical activities	108	88.3 ± 10.8	79.4 ± 12.7	8.9	89.6 ± 10.2	140.8 ± 14.1
Leisure period						
Watching television	92	71.3 ± 9.9	69.0 ± 10.4	2.3	81.2 ± 10.5	130.4 ± 13.2
Deskwork, computer work, reading	86	75.3 ± 9.2	71.7 ± 9.4	3.6	83.7 ± 11.0	130.9 ± 13.2
Relaxing, talking, hobby	109	79.2 ± 10.9	75.5 ± 11.5	3.7	86.5 ± 11.5	133.5 ± 14.6
Car driving	101	78.6 ± 11.5	75.6 ± 13.4	3.0	87.8 ± 10.4	136.7 ± 12.7
Drinking/eating	104	80.0 ± 10.0	76.8 ± 11.1	3.2	86.8 ± 10.3	134.2 ± 13.8
Light physical work	107	87.2 ± 10.5	81.3 ± 12.8	5.9	86.9 ± 9.2	137.0 ± 13.2
Sleep	109	63.8 ± 7.4				
Weekend day						
Leisure period						
Watching television	87	73.0 ± 9.3	70.9 ± 9.8	2.1	79.0 ± 10.7	127.8 ± 13.1
Deskwork, computer work, reading	93	74.4 ± 10.1	71.8 ± 10.4	2.6	81.8 ± 9.6	128.8 ± 13.0
Relaxing, talking, hobby	103	79.2 ± 10.0	75.2 ± 9.9	4.0	83.0 ± 11.0	130.3 ± 14.2
Car driving	77	80.3 ± 11.0	78.3 ± 10.2	2.0	83.5 ± 12.4	131.8 ± 17.2
Drinking/eating	102	78.1 ± 9.2	75.4 ± 10.2	2.7	83.6 ± 11.0	129.2 ± 14.3
Light physical activities	104	87.0 ± 10.2	80.6 ± 11.6	6.4	85.1 ± 10.1	133.7 ± 14.3
Moderate/heavy physical activities	53	97.4 ± 14.1	87.4 ± 13.8	10.0	90.4 ± 9.9	136.6 ± 13.7
Sleep	109	64.3 ± 7.3				

ECG, electrocardiogram; ABP, ambulatory blood pressure; DBP, diastolic blood pressure; SBP, systolic blood pressure; bpm, beats-per-minute.

from the brachial artery. The immediate increase in blood pressure is compensated for by the baroreflex, through vagal reduction of heart rate. As cuff inflation is the most likely explanation for this underestimation, we expect this finding not only be related to ambulatory devices measuring BP by oscillometry, but also to ambulatory auscultatory devices.

In addition to the physiological effects of cuff measurement, underestimation of HR is increased during physical activity, by a change in ongoing behaviour. In this study, as in all ambulatory studies, the subjects were explicitly instructed to hold their arm still at the time of a BP measurement. Apparently they ceased all activity. Our failure to get valid BP recordings during walking may offer an explanation for this behaviour. Invalid measurements are followed by a second cuff inflation after 3 min, and subjects may quickly learn that this unpleasant second measurement can be avoided, by complete 'freezing', i.e., stopping all arm movement as well as other body movement at the time of measurement. The idea that ongoing behaviour is modified during a BP measurement is confirmed by Shapiro and Goldstein [26], who using actigraph data, found that at the moment of measurement, the number of movements was less, compared with mean values taken 2, 5, or 10 min preceding the cuff inflation. Costa and coworkers [27], using accelerometer data, found a reduction in the total amount of energy expenditure during a day of ambulatory BP monitoring, and a specific lowering of physical activity during the 4 min surrounding each blood pressure. Our data support and extend these findings, by showing that the underestimation of ongoing HR increases linearly with physical activity at the time of measurement. Brigden *et al.* [28] reported underestimation of HR during BP measurements in two out of 13 hypertensive patients only, and concluded that activity was not reduced during cuff measurements. Apart from the small sample size, the contrast with the present and previous studies [26,27] may derive from the fact that the behaviour of intra-arterially cannulated patients in a hospital study, does not generalize to the population at large.

The importance of ambulatory HR monitoring is increasingly recognized. Resting HR is an independent predictor of hypertension [8] and cardiovascular disease [9,10] with detrimental effects becoming more apparent at values higher than 85 bpm [8,11]. Palatini and coworkers [11] showed that reproducibility of 24 h ambulatory HR is much better compared with office HR, and dubbed ambulatory HR a better prognostic indicator for cardiovascular disease. The results of large-scale longitudinal studies in hypertensive patient groups strengthened this idea. They found that a blunted reduction in HR from day-to-night, was associated with all-cause mortality and cardiovascular morbidity. Because we found a HR response to cuff inflation that may depend on baroreflex sensitivity, which is known to be impaired in subjects with high blood pressure [29], this finding might have been disqualified by the use of ABP-derived HR. However, we showed that the underestimation of HR is not dependent on the hypertensive state, i.e. no differences in the underestimation of HR were found between normotensives and mild hypertensives.

More generally, our results can be regarded as encouraging, in that they suggest high test–retest reliability of ABP derived HR, provided that the effects of physical activity are adequately controlled. For the development and use of clinical criteria for ambulatory HR, however, we strongly recommend the use of HR derived from an ECG tracing, rather than from a cuff-based ABP device. Even in this sedentary population, mean daytime HR was underestimated by 4.0 bpm, when obtained by HR-ABP (75.2 bpm), compared with HR-ECG (79.2 bpm). This increases in subjects that are more physically active.

Conclusion

The present study suggests that ambulatory HR is underestimated by an ABP device due to an effect of cuff inflation and changes in ongoing behavior, the effect of which becomes more apparent during physical activity. When these limitations are taken into account in the design and analyses of the study, for example, by group comparison after stratification for physical activity, ABP-derived ambulatory HR can still be considered a reliable and valid measure. Importantly, the underestimation was not found to be affected by the hypertensive state.

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