

ORIGINAL ARTICLE

Reproducibility of postexercise ambulatory blood pressure in Stage I hypertension

LAA Lehmkuhl¹, S Park², D Zakutansky², CA Jastremski² and JP Wallace²

¹Forschungsbereich Sport- und Bewegungsmedizin, Fachbereich Sportwissenschaft, Universität Hamburg, Hamburg, Germany; ²Clinical Exercise Physiology Laboratory, Indiana University, Bloomington, IN, USA

The accuracy and reproducibility of ambulatory blood pressure monitoring used in intervention and treatment studies is essential to assure the desired health outcomes. The reproducibility of ambulatory variables in pharmacological studies has been reported, however, the reproducibility of ambulatory blood pressure variables associated with exercise has not been reported. Thus, the purpose of this study was to investigate the reproducibility of the postexercise ambulatory blood pressure in Stage I hypertensive adults. It was hypothesized that the reproducibility of the ambulatory blood pressure variables would not be different following two corresponding exercise and control treatments. A total of 18 Stage I hypertensive adults ($142.1 \pm 3.15/91.6 \pm 1.80$ mmHg) performed four randomized, 24 h AMBP monitoring sessions: two following a 50 min treadmill walk (50% VO_2 peak) and two on control days.

Variables measured were: (1) average systolic and diastolic pressures for 24 h, daytime (06:00–22:00 h) and night time (22:00–06:00 h) and (2) systolic and diastolic load for the same time periods. Both a nonsignificant paired *t*-test and an excellent intraclass correlation were used to define reproducibility of the variables between the 1st and 2nd exercise trials and between the 1st and 2nd control trials. Reproducibility was found for all the control variables except for nighttime diastolic load. Reproducibility was found for all the systolic and diastolic exercise variables. Ambulatory blood pressure measurements, including average systolic and diastolic blood pressures and systolic and diastolic loads for 24 h, daytime and night time periods are reproducible following exercise.

Journal of Human Hypertension advance online publication, 19 May 2005; doi:10.1038/sj.jhh.1001848

Keywords: blood pressure reduction; exercise treatment; postexercise hypotension; physical activity

Introduction

Lifestyle modification is the primary recommendation given for the prevention of prehypertension progressing to hypertension as well as for the initial prescription for the treatment of hypertension.¹ Physical activity and exercise are among the more effective lifestyle treatments.¹ Even though the basic exercise prescription for hypertension is well established,^{2,3} several unanswered questions remain as to the efficacy of exercise treatment in hypertension. These include (1) the dose–response for physical activity and exercise,^{4,5} (2) the diurnal variation in blood pressure and the time of day for physical activity and exercise,⁶ (3) a comparison of physical activity and exercise treatments,^{7,8} and (4) the

fractionation of exercise treatments on health outcomes.⁹

All of these unanswered questions can be addressed using ambulatory blood pressure technology. Ambulatory blood pressure monitoring has been recommended as a valuable tool in the assessment of blood pressure under a variety of conditions.¹⁰ One of the benefits of ambulatory blood pressure monitoring is the ability to take several measurements under free-living conditions throughout the entire day and night.¹¹ In addition, ambulatory monitoring has (a) a higher accuracy,¹² (b) less variability,¹³ and (c) a higher correlation with end-organ damage¹³ compared to clinical blood pressure.

Whether ambulatory blood pressure monitoring is used in pharmacological or exercise treatment intervention, the accuracy and reproducibility of the measurement is essential to assure the desired health outcomes. Ambulatory blood pressure technology has been utilized in both long- and short-term pharmacological^{14–16} and exercise^{17–27} intervention studies. The dose–response as well as

Correspondence: Dr JP Wallace, Clinical Exercise Physiology, HPER 112-G, Department of Kinesiology, Indiana University, Bloomington, IN 47405, USA.

E-mail: wallacej@indiana.edu

Received 15 October 2004; revised 30 December 2004; accepted 19 January 2005

the effects of diurnal blood pressures has been the focus of these studies. The reproducibility of ambulatory variables in pharmacological studies has been reported.^{28,29} A high accuracy and reproducibility of ambulatory technology has been found for normo- and hypertensive adults during activities of daily living.^{28,30–33} Ambulatory monitoring has been utilized in the investigation of postexercise blood pressure–response.^{19,20,26} No literature exists, however, on the reproducibility of ambulatory blood pressures following exercise. Therefore, the purpose of this study was to investigate the reproducibility of the postexercise ambulatory blood pressure in Stage I hypertensive adults. As the response to a standard bout of exercise has been found to be reproducible for other cardiovascular variables, for example heart rate and blood pressure response to exercise, it was hypothesized that the reproducibility of the ambulatory blood pressure variables would not be different following exercise and control treatments.

Materials and methods

All methods and procedures were approved by the Committee for the Protection of Human Subjects at Indiana University. A test–retest design utilizing four randomized 24 h ambulatory blood pressure monitoring sessions was used to investigate reproducibility. Phases of this investigation included (1) a blood pressure screening, (2) a maximal graded exercise test, and (3) four 24 h ambulatory blood pressure monitoring trials, two following a submaximal exercise bout and two on a control day without exercise. Ambulatory data were analyzed for (1) average systolic and diastolic pressures for 24 h, daytime, and night time periods, and (2) systolic and diastolic blood pressure loads for 24 h, daytime and night time periods.

Subjects

Subjects were 18 hypertensive adults (seven women and 11 men) who had a previous diagnosis of hypertension by their primary physician and a mean screening systolic blood pressure between 140 and 160 mmHg and/or a diastolic blood pressure between 90 and 95 mmHg or a daytime ambulatory blood pressure $\geq 135/85$ mmHg.³⁴ Individuals having significant cardiovascular disease, significant arrhythmia, brachial artery bruits, and cardiac or renal transplants were excluded from the study. If subjects presented on antihypertensive medications, permission to discontinue medications for this study was obtained from their primary physician. A 2-week wash-out period with close blood pressure monitoring was provided for these subjects before participation in the study began. All subjects obtained their primary physician's authorization and agreed to participate following an oral and written informed consent.

Blood pressure screening

A total of six blood pressure measurements were taken according to standardized procedures and conditions presented by The Seventh Report of the Joint National Committee on Detection, Evaluation, and Treatment of High Blood Pressure.¹ Three measurements, at least 2 min apart, were taken on each of two separate days, 3 days apart with a random zero sphygmomanometer (Hawksley, England). On the first day of screening, blood pressure was taken on both arms. The arm with the higher blood pressure was used for the screening on the second day and for the calculation of the average of the six screening pressures.

Graded exercise test

The graded exercise test was performed on a motor-driven treadmill starting at a treadmill speed between 2.5 and 4 mph and 0% grade. The speed of the treadmill remained constant whereas the grade was increased 1% every minute until volitional fatigue (VO_2 peak). Expired gases were analysed breath by breath with a metabolic cart (Sensor Medics 2900, Sensor Medics, Yorba Linda, CA, USA).

Exercise stimulus

The exercise stimulus was a 50 min intermittent walk (five 10 min walks separated by 3 min rest periods) on a motor-driven treadmill at 50% of VO_2 peak. VO_2 was measured during the seventh through tenth minute of the first two or three stages to confirm the exercise intensity. If the VO_2 was not within 10% of the target oxygen uptake, the workload was adjusted accordingly. Heart rate was determined every minute during the exercise session via ECG (Electrocardiograph 1511A, Hewlett-Packard, Palo Alto, CA, USA) and blood pressure was measured via auscultation every 2–5 min.

Twenty-four hour ambulatory blood pressure monitoring

Two of the four 24 h ambulatory blood pressure monitoring sessions followed the exercise trials, whereas the other two were initiated on a control day without exercise. All monitoring sessions were scheduled to start at the same time of day, in the evening. The Accutracker II (Sun Tech Medical Instruments, Inc., Raleigh, NC, USA) automated noninvasive ambulatory blood pressure monitor was used for all ambulatory recordings after calibration with a mercury column sphygmomanometer. Taylor *et al*¹² have shown the Accutracker II to be valid in accordance to the standards of the British Hypertension Society and the American Association

for Medical Instrumentation. The device was programmed to take readings in 15 ± 5 min intervals during daytime hours (06:00–22:00 h) and every 45 ± 5 min during night time (22:00–06:00 h). In case of an unsuccessful reading, the monitor repeated a measurement once during the daytime and twice during night time. The inflation of the cuff for each reading was set to be 30 mmHg greater than the previous measurement. The deflation rate of the cuff was 3 mmHg/s.

Subjects were asked to follow similar daily routines during each monitoring session and to record (a) time of sleeping, (b) time at work, and (c) time at leisure activities throughout the 24 h monitoring period. Subjects were asked to refrain from exercise and/or shower during the 24 h monitoring period. During the actual measurement, while awake, they were asked to keep their arm steady and relaxed.

Individual blood pressure measurements were reviewed for missing and erroneous readings. Readings were purged (1) if data were missing, (2) if systolic blood pressure was lower than diastolic pressure or if >240 mmHg or <50 mmHg, (3) if diastolic pressure was >140 mmHg or <40 mmHg, or (4) if pulse rate was >150 or <40 per minute in accordance with Staessen *et al.*³⁵ System tagged data were purged (1) if systolic pressures deviated ± 50 mmHg, (2) if diastolic pressures deviate ± 20 mmHg, or (3) if heart rates deviated ± 30 beat from the surrounding values.

The data were analysed as (1) average systolic and diastolic pressures for the 24 h, daytime (06:00–22:00 h) and night time (22:00–06:00 h) periods and (2) systolic and diastolic load for the same time periods. Systolic blood pressure load was defined as the percentage of systolic blood pressures >140 mmHg during the daytime hours and >120 mmHg during the night time hours. Similarly, diastolic load was defined as the percentage of diastolic blood pressures >90 mmHg during the daytime hours and >80 mmHg during night time hours.³⁶

Statistical analysis

Demographics and ambulatory blood pressure data were expressed as mean \pm standard error of the mean. Both a paired *t*-test and intraclass correlation were used to test reproducibility. More specifically, the paired *t*-test confirming a nonsignificance difference between trials with an excellent intraclass correlation were used to define the reproducibility of ambulatory blood pressures for the control and exercise treatments. The excellent values for intraclass correlations have been defined by Landis and Koch.³⁷ Values of <0.40 , 0.40 – 0.75 , and >0.75 represent poor, fair to good, and excellent agreement, respectively. Significance was set at an $\alpha < 0.05$.

Results

Subjects

The characteristics of the 18 Stage I hypertensive adults, including their screening blood pressures, VO_2 peak, and average control 24 h ambulatory measurements are summarized in Table 1. Nine of the subjects were taken off antihypertensive medication; three subjects were taking diuretics, three were on beta-blockers, two on ACE inhibitors, and one on a calcium channel blocker. These subjects discontinued their blood pressure medication 21.4 ± 1.6 days prior to the treatment period. All subjects reached the target intensity (50% VO_2 peak) for each exercise trial (47.3 and 48.3% for trial 1 and 2, respectively). Exercise bouts were performed 5.4 ± 0.37 days apart.

Reproducibility of 24 h ambulatory blood pressure monitoring

From the four ambulatory trials, 95.6% of all readings met the editing criteria and were used for data analysis. The average duration of all trials was

Table 1 Subject demographics and blood pressure variables

	Whole group (n = 18) Mean \pm s.e.	Men (n = 11) Mean \pm s.e.	Women (n = 7) Mean \pm s.e.
<i>Demographics</i>			
Age	49.8 \pm 2.26	49.8 \pm 2.92	49.9 \pm 38.5
Weight (kg)	89.9 \pm 4.84	96.9 \pm 5.67	78.8 \pm 7.51
Height (cm)	173.7 \pm 2.11	175.9 \pm 2.20	165.6 \pm 1.97
Body mass index (kg/m ²)	29.6 \pm 1.41	30.1 \pm 1.46	28.8 \pm 1.84
VO_2 max (ml/min kg)	28.2 \pm 1.36	28.2 \pm 1.48	28.2 \pm 2.78
<i>Blood pressure variables</i>			
Systolic BP (mmHg) ^a	141.2 \pm 3.05	139.5 \pm 4.48	144.0 \pm 3.70
Diastolic BP (mmHg) ^a	92.2 \pm 1.72	93.1 \pm 2.76	90.7 \pm 1.20
MAP (mmHg)	108.1 \pm 2.07	107.8 \pm 3.29	108.6 \pm 1.76

Systolic BP = systolic blood pressure; Diastolic BP = diastolic blood pressure; MAP = mean arterial pressure.

^aAverage of six screening pressures.

23:38 ± 00:06 h. Ambulatory monitoring was started at 18:41 ± 00:13 h. The two postexercise trials started 30 min postexercise (18:43 ± 00:13 h). The two control sessions were started at 18:38 ± 00:23 h. All sessions were performed within 12.0 ± 1.1 days of each other.

The results of the 24 h ambulatory recordings are illustrated in Figures 1 and 2. Table 2 summarizes the paired *t*-tests and intraclass correlations for both control and exercise treatments. No significant differences in paired *t*-tests were found for any blood pressure variable for the control treatment or following exercise. For the control treatment, excellent intraclass correlations were found for all of the systolic and diastolic variables except for nighttime diastolic load. For the exercise treatment, excellent intraclass correlations were found for all of the systolic and diastolic variables.

For the control treatments, every ambulatory blood pressure variable except the diastolic night time load was found to be reproducible. Whereas, all the systolic and diastolic blood pressure variables following exercise, for 24 h, daytime, and night time periods were found to be reproducible.

Discussion

The purpose of this study was to investigate the reproducibility of the postexercise ambulatory blood pressure in Stage I hypertensive adults. It was hypothesized that the reproducibility of the ambulatory blood pressure variables would not be different following exercise and control treatments. As expected, the ambulatory blood pressure variables measured following exercise treatment were found to be reproducible for the 24 h, daytime and night time periods. Reproducibility was found for the control periods except nighttime diastolic load.

Statistical methods used to report reproducibility in ambulatory blood pressure monitoring have been simple correlations,^{11,28,30} paired *t*-tests,³³ or ANOVA.^{31–33} Both a nonsignificant paired *t*-test and an excellent intraclass correlation between trials were used in this study to define reproducibility. The intraclass correlation would establish a significant association between the two trials whereas the nonsignificant paired *t*-test would confirm no differences between the two trials. The intraclass

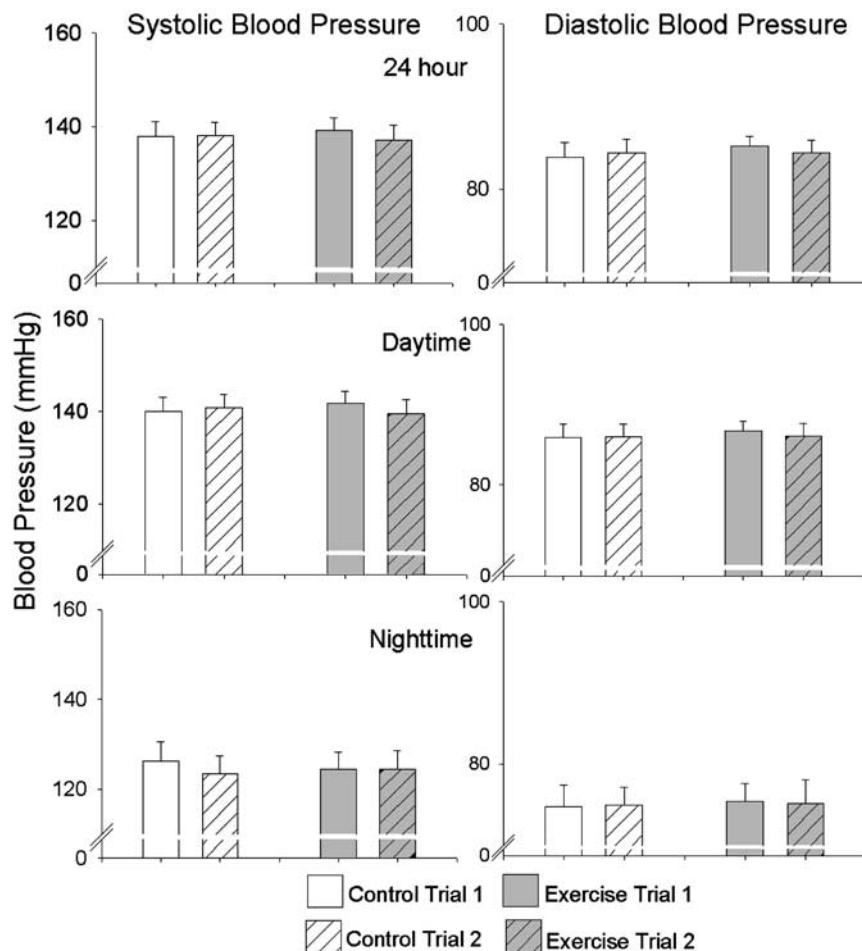


Figure 1 Reproducibility of average ambulatory blood pressures following control and exercise.

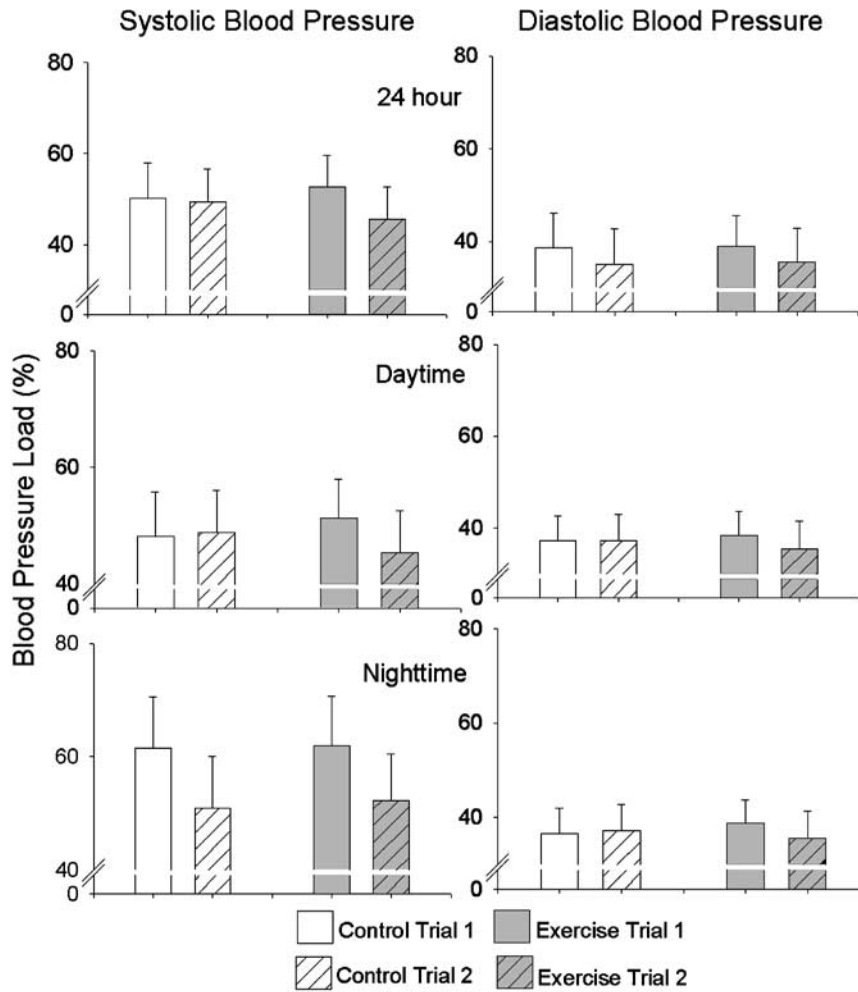


Figure 2 Reproducibility of ambulatory blood pressure loads following control and exercise.

correlation was chosen instead of simple correlations because intraclass correlations measure the relative homogeneity of the scores within the class in relation to the total variation. Simple correlations measure interclass relationships rather than intraclass relationships.

It is unclear why reproducibility was not found in the nighttime diastolic load for the control condition. Our findings were consistent with Omboni *et al*²⁹ who reported limited reproducibility for the nighttime fall in blood pressure for 180 hypertensive subjects. They speculated minor variations in the quality and depth of sleep could lead to marked changes in the blood pressure. These findings warrant further investigation.

The two categories of ambulatory blood pressure variables chosen for this study are those reported to have clinical significance. Average blood pressure variables have been used to diagnose hypertension³⁸ and to identify white coat syndrome.³⁹ Blood pressure loads have been associated with end-organ damage and to confirm the diagnosis of hypertension.³⁶

Subjects in this study were similar to subjects found in other reproducibility studies.^{11,31,32} In addition, the subject sample falls into the blood pressure range that would be expected to lower blood pressure with exercise.⁴⁰ Therefore, the subject sample was representative of a normal population of middle-aged Stage I hypertensive individuals and suitable to assess the reproducibility of post-exercise ambulatory blood pressure.^{19,20,26}

The study sample size was also large enough to demonstrate significant changes in blood pressure following exercise, yet this group of subjects did not exhibit a reduction in ambulatory blood pressures following exercise (2×2 ANOVA; $F = 0.000\text{--}1.940$; $P = 0.183\text{--}0.954$). Averaging the two control and the two exercise trials for systolic blood pressure and comparing the average control to the average exercise, no differences were found for 24 h average (control to exercise = 138.1 ± 2.13 to 138.2 ± 2.05 mmHg), daytime average (140.5 ± 2.05 to 140.7 ± 1.99 mmHg), night time average (124.9 ± 2.88 to 124.4 ± 2.77 mmHg), 24 h load (49.8 ± 5.21 to $49.6 \pm 4.89\%$ for systolic), daytime load (48.5 ± 5.20

Table 2 Reproducibility of ambulatory blood pressures on control days and following exercise

Group	Variable	Paired t-test criteria (P values)	Intraclass correlation	Reproducibility
Systolic blood pressure				
Control	Averages			
	24 h	0.93	0.95 ^a	Yes
	Daytime	0.54	0.96 ^a	Yes
Control	Loads			
	24 h	0.78	0.95 ^a	Yes
	Daytime	0.85	0.96 ^a	Yes
Exercise ^a	Averages			
	24 h	0.10	0.96 ^a	Yes
	Daytime	0.09	0.95 ^a	Yes
Exercise ^a	Loads			
	24 h	0.07	0.95 ^a	Yes
	Daytime	0.09	0.94 ^a	Yes
Exercise ^a	Night time			
	24 h	0.10	0.88 ^a	Yes
	Daytime	0.09	0.94 ^a	Yes
Diastolic blood pressure				
Control	Averages			
	24 h	0.65	0.90 ^a	Yes
	Daytime	0.95	0.90 ^a	Yes
Control	Loads			
	24 h	0.93	0.83 ^a	Yes
	Daytime	0.90	0.80 ^a	Yes
Exercise	Averages			
	24 h	0.61	0.72	No
	Daytime	0.87	0.79 ^a	Yes
Exercise	Loads			
	24 h	0.40	0.88 ^a	Yes
	Daytime	0.60	0.85 ^a	Yes
Exercise	Night time			
	24 h	0.86	0.75 ^a	Yes
	Daytime	0.39	0.87 ^a	Yes
Exercise	Night time			
	24 h	0.49	0.84 ^a	Yes
	Daytime	0.45	0.89 ^a	Yes

^aExcellent intraclass correlation.

to $48.3 \pm 4.86\%$ for systolic), and night time load (56.2 ± 6.39 to $57.1 \pm 5.95\%$ for systolic) as a result of exercise. The combination of the time of day for the exercise and nocturnal dipping status of the subject's hypertension may be why this subject sample did not respond to an exercise treatment. The exercise session was administered in the evening, between 17:00 and 19:00 h. If the duration of blood pressure reduction following exercise has been documented to be 11–12 h,^{19,26} the reduction for this group of subjects should have been detected in the night time hours rather than in the daytime hours. On the other hand, a significant night time reduction in blood pressure would be not expected for subjects with normal dipping nocturnal hypertension.^{6,41} Only five of the 18 subjects who presented with nondipping nocturnal hypertension should have exhibited a night time decrease in blood pressure. Indeed, a decrease in night time average systolic blood pressure was found for the nondipping subgroup (142.4 ± 7.56 to

136.8 ± 6.73 mmHg) following exercise. Therefore, as a group, the blood pressure response to exercise was normal authenticating the reproducibility findings. Ambulatory blood pressure measurements, including average systolic and diastolic blood pressures and systolic and diastolic loads for 24 h, daytime and night time periods are reproducible following exercise.

Acknowledgements

This research was supported by the Indiana University School of Health, Physical Education, and Recreation 'Research Grant-in-Aid' and the Adult Fitness Program.

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