JPFSM: Regular Article

Effect of time of exercise and posture on 24-h post-exercise blood pressure in young normotensive men

Ryoko Sone^{1*}, Manami Ozaki¹, Yuta Yamaguchi¹, Masato Fujimori¹,
Fumio Yamazaki² and Nobusuke Tan¹

¹Laboratory of Exercise Physiology, Faculty of Education, Yamaguchi University, 1677-1 Yoshida, Yamaguchi City, Yamaguchi 753-8513, Japan

²Exercise Physiology Laboratory, Faculty of Nursing and Human Nutrition, Yamaguchi Prefectural University, 3-2-1 Sakura-batake, Yamaguchi City, Yamaguchi 753-8502, Japan

Received: April 11, 2019 / Accepted: July 26, 2019

Abstract This study aimed to examine blood pressure (BP) response in sitting (daytime only) and supine positions for 24 h after moderate endurance exercise in the morning and afternoon in healthy and normotensive young men. Nine men with a moderate fitness level ran at 68%-69% maximal oxygen uptake for 30 min at 8:00 AM and 4:00 PM. Arterial BP was measured hourly for 24 h after each exercise and each control experiment. The positions during the measurement were supine during nighttime, and supine and sitting during daytime (7:00 AM-11:00 PM). The Profile of Mood States (POMS) test was performed before the sitting measurement. Post-exercise systolic BP (SBP) in the supine position decreased by 2-3 mmHg on average for 24 h in both exercise conditions compared to the control condition ($p < 0.05$). In both exercise conditions, the post-exercise SBP decrease tended to be smaller in the sitting than in the supine position, and a greater SBP decrease in the sitting position tended to relate linearly with a greater fatigue score increase. We conclude that, in young normotensive men, a bout of moderate endurance exercise both in the morning and afternoon decreases SBP in the supine position by a few mmHg on average over 24 h. In addition, post-exercise BP response during daytime appeared to vary with posture and relate to fatigue sensation.

Keywords : ambulatory blood pressure, endurance exercise, hypotension, POMS

Introduction

Post-exercise hypotension (PEH), characterized by a decrease in arterial blood pressure (BP) below the control level observed within minutes and hours following a bout of exercise^{1,2}, is frequently observed after moderate- and high-intensity endurance exercise^{2,3}. This phenomenon is also more markedly noted in hypertensive individuals than in normotensive individuals^{2,4-6}. However, a BP decrease of nearly 10 mmHg after exercise has been reported even in normotensive individuals². Based on these findings, the PEH has been energetically to utilize an exercise prescription in hypertension and to explore BP regulation after exercise^{1,2}.

Numerous studies on the PEH phenomenon have been performed in the laboratory, ranging from a short duration to a few hours. BP response for an extended period of more than half a day after moderate- to high-intensity endurance exercise was also examined using ambulatory monitoring. A prolonged post-exercise BP decrease below the control level is generally observed in hypertensive

individuals⁵⁻⁸. In contrast, in normotensive individuals, different findings were obtained such as decreases in systolic BP (SBP) during daytime, diastolic BP (DBP) and mean BP (MBP) during nighttime sleep, and all BP variables for 24 h⁹; a decrease only in MBP during nighttime after high-intensity exercise¹⁰; and no change in all BP variables^{3,5,6}. The inconsistency of findings might be related to less hypotension in normotensive individuals compared to hypertensive individuals^{2,5,6}. In addition, daytime physical activities and posture during BP measurement were strictly unregulated for examining daily life in previous studies^{2,10}. However, post-exercise BP response and its regulatory mechanism have been considered to be affected by posture^{11,12}. In all previous studies quoted above^{3,5,6,9,10} that assessed BP response over a long period after exercise in normotensive individuals, exercise was performed in the morning. However, post-exercise BP response has been observed to also depend on time of exercise - a greater decrease in BP after the afternoon (4:00 PM) exercise than after the morning (8:00 AM) exercise, although based on a relatively short examination period^{13,14}. Therefore, despite a longer examination period, the exercise time of day can possibly affect BP response.

*Correspondence: sone@yamaguchi-u.ac.jp

Also, higher BP at rest correlates negatively with emotional condition¹⁵. A significant relationship between the diurnal variation in BP and that in mood has also been reported¹⁶. Thus, a relationship may exist between mood and BP response after exercise.

In this study, we aimed to examine the BP response in the sitting (daytime only) and supine positions for 24 h after moderate endurance exercise in the morning and afternoon in healthy, normotensive, young men to clarify the effect of time of exercise and posture on post-exercise BP response, and also examine the relationship between post-exercise BP and mood response. The examination was performed by carefully regulating daytime physical activities in terms of quantity and timing during the experiments.

Methods

Subjects. The subjects included 9 healthy, nonsmoking, and normotensive young men. Subjects did not participate in any regular physical activity program at the time of the experiments. However, they were active people with baseball, tennis, and football training experience. The mean $\pm$ standard error (SE) of the subjects' age, height, and weight was 21.6 ± 0.2 years, 173.9 ± 2.2 cm, and 62.7 ± 1.6 kg, respectively. The institutional ethics committee approved this study (2011-2), and the subjects provided written informed consent before participating. The subjects abstained from performing severe exercise, as well as ingesting alcohol for 24 h before the experiment and caffeine for 12 h before the experiment. They rested as much as they could on the day of the experiment.

Experimental protocol. A maximal exercise test was initially performed. Two exercise experiments in which BP was monitored for 24 h after the exercise in the morning and afternoon (ExAM and ExPM, respectively) and each control experiment (ContAM and ContPM) were then performed randomly. The interval period between the two experiments was more than 4 days.

Maximal test. After a 2-min walk on the treadmill at 118 m/min, the treadmill speed was increased incrementally to 13 m/min every 1 min until exhaustion (treadmill angle: 0°). The expired gas during the exercise was collected continuously in a Douglas bag every 30 s. O₂ and CO₂ gas concentrations were measured with a calibrated portable gas monitor (AR-10; Arco Systems, Chiba, Japan). Expired gas volume was measured using a dry gas meter, and oxygen consumption per min ($\dot{V}O_2$) was calculated. Based on the maximal value of $\dot{V}O_2$ during the exercise ($\dot{V}O_{2max}$) and the relationship between the treadmill speed and $\dot{V}O_2$, the speed at 60% $\dot{V}O_{2max}$ was then calculated. After the exercise test, the subjects measured their BP by themselves for 24 h using a portable automatic manometer (TM-2431; A&D Company, Tokyo, Japan) on the non-dominant arm.

AM and PM experiments

Protocol. After the subjects visited the laboratory (room temperature: $\sim 25^\circ\text{C}$, relative humidity: $\sim 50\%$), body mass was measured and bipolar electrocardiograph (ECG) electrodes were placed on the chest. Exercises in the ExAM and ExPM were started at 8:00 AM and 4:00 PM, respectively. The exercises were composed of walking at 80 m/min for 2 min and running at 118 m/min for 2 min as a warm-up exercise, followed by running at the specified speed calculated above (147 ± 6 m/min) for 30 min and running at 118 m/min for 3 min as a cool-down exercise. After the exercise, BP was measured for 24 h using the portable manometer starting at 9:00 AM and at 5:00 PM. In the ContAM and ContPM, the subjects sat in a chair on the treadmill and rested instead of exercising.

The subjects went home after the measurement at 5:00 PM on the first day and measured their BP at home until 8:00 or 9:00 AM on the second day. Thereafter, the subjects re-visited the laboratory, and the measurement was finished in the ExAM and ContAM. In the ExPM and ContPM, the subjects stayed at the laboratory and continued the measurement until 4:00 PM. Throughout the 24-h measurement period, the subjects performed only activities of daily living and rested as much as they could. We instructed the participants about the times they could awaken (6:30 AM), go to bed (11:30 PM), bathe (9:15 PM–9:45 PM), and eat meals (breakfast: 6:30 AM–7:00 AM, lunch: 12:15 PM–12:45 PM, dinner: 6:15 PM–6:45 PM). The same meals were provided to each participant in all experiments, in accordance with the Japanese dietary intake reference. Intake of any food or drink was prohibited from 1.5 h before exercise to the end of the first post-exercise BP measurement, and the participants were then allowed to drink water freely, excluding the time just before each BP measurement. The subjects recorded the volume and time of water intake each time.

Measurement and analysis. ECG was continuously monitored (BioView 1000; NEC, Tokyo, Japan) during the exercise, and heart rate (HR) was registered for the last 10 s of each minute. The rating of perceived exertion (RPE) was also measured at the end of each minute. The $\dot{V}O_2$ was measured for 2 min from 8, 18, and 28 min after the start of the main exercise using the method mentioned above. The $\dot{V}O_2$, HR, and RPE during exercise were averaged for the time the $\dot{V}O_2$ was measured.

Twenty-four hour BP and pulse rate (conveniently called HR). The posture during the measurement was supine during nighttime (12:00 midnight–6:00 AM), and supine and sitting during the daytime (7:00 AM–11:00 PM). The order of posture during the daytime measurement was the same in all experiments for a subject, and the order was reversed for about half of the subjects. The measurement for each posture was performed after holding that posture for 5 min. For the measurements while sitting, subjects

sat on a chair with the soles of their feet touching the floor and putting their arms on the table set at heart level for the BP measurement. BP was measured automatically once every hour for the first posture and manually for the second posture. In the daytime period, when the fluctuation of the measured value was large, BP was measured thrice. Results of the BP measurement were analyzed after the experiment using the single purpose DoctorPro 3 Lite software (A&D Company, Tokyo, Japan). Additional BP measurements were basically averaged.

Profile of mood states (POMS). The POMS test was performed before the sitting measurement during the daytime. Based on results of the POMS test, which was composed of 65 questions, six factors (tension, suppression, anger, activity, fatigue, and confusion) were estimated¹⁷⁾.

Statistical analysis. All data are shown as mean $\pm$ SE. The $\dot{V}O_2$, HR, and RPE during exercise were compared between exercise conditions using paired t-test. The BP, HR, and POMS data for ContAM and ContPM were averaged because of similarity (Cont). The time course of each parameter in the Cont was tested, using one-way repeated measures analysis of variance (ANOVA) to examine the original diurnal variation, and compared with each exercise condition using two-way repeated measures ANOVA. The Tukey test was then used for multiple comparisons. For each parameter, the average values for 24 h (24 h, supine only), daytime of the first and/or second day [Daytime (Days 1 & 2), Day 1, and Day 2], and night sleeping time (Nighttime, supine only) were calculated, and the differences between each exercise condition and the Cont condition (Δ) also calculated. Comparisons of those values (except for the Δ value of Daytime) between the two conditions, between the two postures, and between Daytime (supine) and Nighttime in the Cont were performed with a paired t-test. The Δ value of Daytime for BP and HR were tested as factors of posture and time of exercise (ExAM and ExPM) using two-way repeated measures ANOVA. The total water intake calculated for each experiment was compared among conditions using one-way ANOVA. For each parameter, the difference between the average values every hour in each exercise condition and in the Cont was calculated in the supine and sitting postures (Δ sit and Δ sup). The relationship between the two variables was tested using Pearson's correlation. We used JSTAT for Windows and Stat View 5.0 (SAS Institute, Cary, NC, USA) for the statistical analysis. P-values < 0.05 were considered statistically significant.

Results

Exercise results. In the maximal exercise test, the HR and RPE at exhaustion were 207 ± 3 bpm and 19.2 ± 0.4 , respectively, and the $\dot{V}O_{2\max}$ was 48.2 ± 1.4 ml/kg/min. The $\dot{V}O_2$, HR, and RPE during the exercise were $32.9 \pm$

1.3 ml/kg/min ($68 \pm 3\%$ $\dot{V}O_{2\max}$), 168 ± 5 bpm, and 13.9 ± 0.8 , respectively, in the ExAM; and 33.5 ± 1.5 ml/kg/min ($69 \pm 3\%$ $\dot{V}O_{2\max}$), 170 ± 5 bpm, and 13.9 ± 0.4 , respectively, in the ExPM; they were not significantly different between the two exercise conditions.

Responses of BP and HR. Fig. 1 shows the time courses of BP and HR in the supine position for 24 h. Those from 12:00 midnight to 8:00 AM for the ExAM and from 12:00 midnight to 4:00 PM for the ExPM are on the second day. The averages of each parameter for the 24-h, daytime, and nighttime periods in the supine position, and the daytime period in the sitting position are shown in Table 1 for each condition.

Cont condition. In the Cont, the time course for the SBP was significantly changed in the supine position (Fig. 1, $p < 0.05$), but no significant difference was found between the Daytime and Nighttime values in the supine position (Table 1). DBP and HR in the Cont were significantly affected by time (Fig. 1, $p < 0.05$), and their Nighttime values were significantly lower than their Daytime values in the supine position (Table 1, $p < 0.05$). Comparing the Daytime values between both postures for each parameter (Table 1), SBP was significantly lower in the sitting position than in the supine position ($p < 0.05$), DBP was not significantly different, and HR was significantly higher in the sitting position than in the supine position ($p < 0.05$).

Comparison between Cont and ExAM. The time course for SBP was not significantly different between Cont and ExAM in both postures, but the 24-h value, and Daytime and Day-1 values in both postures were significantly lower in the ExAM than in the Cont (Table 1, $p < 0.05$). Day 2 values in both postures and the Nighttime value were not significantly different between Cont and ExAM. DBP was not significantly different between Cont and ExAM, regardless of posture and time course or average value (Fig. 1 and Table 1). HR in the supine position was significantly higher in the ExAM than in the Cont between 9:00 AM and 10:00 AM, immediately after exercise (Fig. 1, $p < 0.05$) (9:00 AM in the sitting position). Average HR value, the 24-h value, and Daytime and Day-1 values in both postures were significantly higher in the ExAM than in the Cont (Table 1; $p < 0.05$). Day 2 values in both postures and the Nighttime value were not significantly different between Cont and ExAM.

Comparison between Cont and ExPM. The time course for SBP was not significantly different between Cont and ExPM in either posture, but the 24-h value, the Daytime and Day-1 values in both postures, and Day 2 value in the supine position tended to be significantly lower in the ExPM than in the Cont (Table 1; Daytime in the sitting position, $p = 0.057$; others, $p < 0.05$). The Day 2 value in the sitting position and the Nighttime value were not sig-

Table 1. BP and HR in the 24-h, daytime, and nighttime periods in the control and exercise conditions.

	Supine			Sitting		
	SBP(mmHg)	DBP(mmHg)	HR(bpm)	SBP(mmHg)	DBP(mmHg)	HR(bpm)
24hr						
Cont	119 ± 3	66 ± 2	57 ± 2			
ExAM	116 ± 3 *	66 ± 2	61 ± 2 *			
ExPM	117 ± 3 *	66 ± 2	63 ± 2 *			
Daytime						
Cont(7-23)	120 ± 3	67 ± 2	60 ± 2	116 ± 3 \$	68 ± 2	67 ± 2 \$
ExAM(7-23)	116 ± 3 *	67 ± 2	64 ± 2 *	114 ± 3 *	67 ± 2	73 ± 3 *
ExPM(7-23)	116 ± 3 *	66 ± 2	67 ± 3 *	114 ± 3	68 ± 2	77 ± 3 *#
Day 1						
Cont(9-23)	120 ± 3	67 ± 2	60 ± 2	116 ± 3	68 ± 2	68 ± 2
ExAM(9-23)	116 ± 3 *	66 ± 2	65 ± 2 *	113 ± 3 *	67 ± 2	74 ± 3 *
Cont(17-23)	120 ± 4	67 ± 3	58 ± 2	116 ± 3	68 ± 2	66 ± 2
ExPM(17-23)	114 ± 3 *	66 ± 2	72 ± 4 *	112 ± 3 *	68 ± 2	83 ± 5 *
Day 2						
Cont(7-8)	119 ± 3	67 ± 2	57 ± 2	116 ± 2	68 ± 2	65 ± 2
ExAM(7-8)	121 ± 4	68 ± 2	59 ± 2	118 ± 3	68 ± 3	66 ± 3
Cont(7-16)	120 ± 3	67 ± 2	60 ± 2	116 ± 3	68 ± 2	68 ± 3
ExPM(7-16)	117 ± 3 *	66 ± 2	64 ± 2 *	116 ± 3	69 ± 2	74 ± 3 *
Nighttime						
Cont(0-6)	117 ± 3	64 ± 2 \$	51 ± 2 \$			
ExAM(0-6)	115 ± 3	63 ± 1	53 ± 2			
ExPM(0-6)	118 ± 3	66 ± 2	54 ± 1 *			

Number in parentheses following condition name presents time range. * and #: vs Cont and vs ExAM in the same time range, respectively, $p < 0.05$, \$: vs Cont (7-23) in the supine position, $p < 0.05$

Fig. 1 Hourly systolic (SBP) and diastolic (DBP) blood pressures and heart rate (HR) in the supine position over 24 h for each condition. Exercise periods are illustrated by shaded areas. Data are shown as mean $\pm$ SE. *: vs Cont, $p < 0.05$

nificantly different between Cont and ExPM. DBP was not significantly different between Cont and ExPM, regardless of posture and time course or average value (Fig. 1 and Table 1). HR in the supine position was significantly higher between 5:00 PM and 7:00 PM, immediately after exercise, in the ExPM than in the Cont (Fig. 1, $p < 0.05$) (5:00 PM–8:00 PM in the sitting position). All average HR values in either posture were significantly higher in the ExPM than in the Cont (Table 1, $p < 0.05$).

Comparison between ExAM and ExPM. For SBP and DBP, the 24-h, Daytime, Nighttime, and the Δ values were not significantly different between ExAM and ExPM (Table 1 and Fig. 2). For HR, the Daytime value in the sitting position and the Δ values of the Daytime in both postures were significantly higher in the ExPM than in the ExAM (Table 1 and Fig. 2, $p < 0.05$), whereas the other average values were not significantly different between ExAM and ExPM.

Comparison of BP response between supine and sitting positions. The Δ value of the Daytime only for SBP tended to be smaller in the sitting than in the supine position in both exercise conditions (Fig. 2; posture factor: $p = 0.092$, condition factor: $p = 0.957$, interaction: $p = 0.678$), and the effect of posture on Δ SBP of the Daytime was significant in the average of the two conditions (paired t -test, $p < 0.01$). A linear relationship tended to be found between Δ SBP_{sit} and Δ SBP_{sup}, in which the slope and the intercept were ~ 0.6 and ~ 0 , respectively, in the ExAM and ExPM ($r = 0.666$ [$p < 0.01$] and $r = 0.460$ [$p = 0.063$], respectively) (Fig. 3). Such a relationship was not found between

Δ DBP_{sit} and Δ DBP_{sup} in both exercise conditions.

Response of POMS factors. The time course and average value of each POMS factor score were compared between the Cont and ExAM and ExPM; only fatigue was significantly different. The time course for fatigue score was not significantly different between the Cont and ExAM, but the fatigue score was significantly higher in the ExPM than in the Cont at 5:00 PM (Fig. 4; $p < 0.05$). For the average fatigue score (Table 2), the Day 1 and Daytime values were significantly higher in the ExAM and ExPM than in the Cont ($p < 0.05$), and the Day 2 value was significantly higher in the ExAM only than in the Cont ($p < 0.05$).

Relationship between the change of mood and BP response.

The relationship between the Δ fatigue score and Δ SBP_{sit} is shown in Fig. 5. Smaller Δ SBP_{sit} tended to relate linearly with greater Δ fatigue score in the ExAM and ExPM ($r = -0.459$ [$p = 0.064$] and $r = -0.669$ [$p = 0.003$], respectively). The Δ DBP_{sit} was not clearly related to the Δ fatigue score in both exercise conditions.

Water intake. The total water intake per day (except for food inclusion) was $1,026 \pm 72$ ml in the Cont, $1,083 \pm 203$ ml in the ExAM, and $1,234 \pm 157$ ml in the ExPM, and no significant difference was found among the conditions.

Discussion

Main findings. In this study, after a moderate endurance exercise at 8:00 AM and 4:00 PM, the BP response

Table 2. Score of POMS factor during the daytime period in the control and exercise conditions.

	Tension	Depression	Anger	Vigor	Fatigue	Confusion
Daytime						
Cont(7–23)	7.2 $\pm$ 1.6	5.5 $\pm$ 2.5	4.6 $\pm$ 2.0	12.8 $\pm$ 1.5	4.7 $\pm$ 1.5	6.3 $\pm$ 1.1
ExAM(7–23)	6.7 $\pm$ 1.6	4.8 $\pm$ 2.3	3.4 $\pm$ 1.4	13.3 $\pm$ 1.8	8.4 $\pm$ 1.5 *	6.2 $\pm$ 1.1
ExPM(7–23)	7.1 $\pm$ 1.8	5.8 $\pm$ 2.8	4.8 $\pm$ 2.2	12.6 $\pm$ 2.1	7.2 $\pm$ 1.4 *	6.6 $\pm$ 1.4
Day 1						
Cont(9–23)	7.2 $\pm$ 1.7	5.5 $\pm$ 2.5	4.6 $\pm$ 2.0	12.9 $\pm$ 1.5	4.8 $\pm$ 1.6	6.4 $\pm$ 1.1
ExAM(9–23)	6.8 $\pm$ 1.6	4.8 $\pm$ 2.3	3.5 $\pm$ 1.5	13.5 $\pm$ 1.8	8.7 $\pm$ 1.6 *	6.3 $\pm$ 1.1
Cont(17–23)	7.2 $\pm$ 1.8	6.2 $\pm$ 2.6	5.2 $\pm$ 2.2	12.3 $\pm$ 1.6	5.4 $\pm$ 1.7	6.5 $\pm$ 1.2
ExPM(17–23)	7.3 $\pm$ 2.0	5.8 $\pm$ 2.9	5.0 $\pm$ 2.5	12.5 $\pm$ 1.9	10.5 $\pm$ 1.7 *	6.7 $\pm$ 1.4
Day 2						
Cont(7–8)	7.0 $\pm$ 1.6	5.6 $\pm$ 2.4	4.5 $\pm$ 2.0	12.0 $\pm$ 1.5	3.7 $\pm$ 1.3	6.2 $\pm$ 1.0
ExAM(7–8)	6.6 $\pm$ 1.5	4.8 $\pm$ 2.7	2.7 $\pm$ 1.2	12.6 $\pm$ 1.7	6.5 $\pm$ 1.2 *	5.6 $\pm$ 1.2
Cont(7–16)	7.2 $\pm$ 1.5	5.1 $\pm$ 2.4	4.2 $\pm$ 1.9	13.1 $\pm$ 1.4	4.2 $\pm$ 1.4	6.3 $\pm$ 1.0
ExPM(7–16)	7.0 $\pm$ 1.8	5.8 $\pm$ 2.8	4.6 $\pm$ 2.1	12.7 $\pm$ 2.2	4.9 $\pm$ 1.4	6.6 $\pm$ 1.3

Number in parentheses following condition name presents time range. *: vs Cont in the same time range, $p < 0.05$

Fig. 2 Net effect of exercise in the morning and afternoon on the 24-h, daytime, and nighttime periods for systolic (SBP) and diastolic (DBP) blood pressures and heart rate (HR). For each parameter, the Δ value was calculated by subtracting the absolute value in the control condition from that in the exercise condition. Data are shown as mean $\pm$ SE. #: vs ExAM, $p < 0.05$

Fig. 3 Relationship between hourly exercise-induced changes in the sitting (ΔSBP_{sit}) and supine (ΔSBP_{sup}) positions in the daytime period for systolic blood pressure (SBP). The ΔSBP in each position was calculated by subtracting the hourly averaged absolute value ($n = 9$) in the control condition from that in the exercise condition.

Fig. 4 Hourly fatigue score during the daytime period for each condition. Exercise periods are illustrated by shaded areas. Data are shown as mean $\pm$ SE. *: vs Cont, $p < 0.05$

Fig. 5 Relationship between hourly exercise-induced changes for fatigue score (Δ fatigue) and for systolic blood pressure in the sitting position (Δ SBP_{sit}). The Δ value for each parameter was calculated by subtracting the hourly averaged absolute value ($n = 9$) in the control condition from that in the exercise condition.

was examined over 24 h in young normotensive men with a moderate fitness level ($\dot{V}O_{2\max}$: 48.2 ± 1.4 ml/kg/min). Because there are diurnal variations in cardiovascular variables^{18,19}, we compared the post-exercise response of each variable with non-exercise (Cont) response, as generally performed in previous studies^{3,5-7,9,10,20,21}. We found that the post-exercise average SBPs for 24 h in the supine position, and during daytime (7:00 AM-11:00 PM) in both postures tended to significantly decrease independently of time of exercise. The decrease in SBP was 2-3 mmHg for 24 h and tended to be smaller during daytime in the sitting than in the supine position. We also observed that the decrease in SBP after exercise may be related to increased fatigue.

Diurnal variation of BP and HR in the non-exercise condition.

BP and HR are known to be generally high during daytime and low during nighttime^{18,19}. We found that the nighttime DBP and HR values were significantly lower than the daytime DBP and HR values in the supine position, but the differences were modest. The difference between both values in SBP was not significant in the Cont condition (Table 1). Although the diurnal variations in BP and HR were not necessarily marked in this study, they might be attributed to the same posture during measurement and the restricted, less physical activities in this study. Comparison between the two positions in this study (Table 1) showed that SBP was lower and HR was higher in the sitting than in the supine position during daytime, and such an effect of posture on BP and HR was also observed previously^{22,23}. In addition, the diurnal variations in BP and HR were similar between the two Cont experiments for the morning and afternoon exercise conditions. Therefore, in our participants, BP and HR responses to posture were normal, and their diurnal variations were reproducible. It is conceivable that a comparison of response of each variable at the same time of day between the exercise and Cont conditions, in which the activities of daily living and posture during BP measurement were carefully regulated to be the same, is proper.

BP response after exercise in the morning and afternoon.

The post-exercise average SBPs for 24 h in the supine position and during daytime (7:00 AM-11:00 PM) in the supine and sitting positions tended to significantly decrease in the morning and afternoon exercises. It did not significantly change during nighttime sleep in both exercises (Table 1). In contrast, DBP did not significantly change at all. Previous studies^{3,5,6,9,10}, which have examined BP response for 13 or 24 h after moderate endurance exercise in the morning in normotensive individuals, reported a decrease or no change during daytime and night-

time. A possible cause of such inconsistent findings is the difficulty to clarify the effect of exercise in normotensive individuals, since a smaller BP decrease after exercise is observed at lower baseline BP^{2,6,9,11}. In addition, sleep and posture clearly change the BP value as shown in this study, and a bout of exercise may induce a more sedentary post-exercise period in free living conditions². Daily activities and posture during BP measurement in previous studies were not strictly the same in all experimental conditions, which might have contributed to the failure to truly clarify the effect of exercise. A study²⁰ that examined BP response after exercise for half a day in normotensive individuals, allowing them to rest as much as possible in the laboratory, did not find a significant BP decrease in contrast to the findings of the present study. However, the posture during BP measurement in the previous study was either the semi-supine or sitting position. In this study, to clarify the post-exercise BP response more accurately, the participants were instructed to rest as much as they possibly could for 24 h in the laboratory or at home, and the time of activities of daily living and posture during BP measurement were made uniform in all experimental conditions. Therefore, the difference in BP response among experimental conditions should be caused by time of exercise. It can be concluded that moderate endurance exercise in the morning and afternoon was associated with similar decreases in SBP during the daytime, but not in DBP, in normotensive individuals. A greater effect on post-exercise SBP than DBP was also observed previously^{8,20,21}. The DBP decrease may be more likely to be observed after more intense exercise and in individuals with higher fitness²⁴.

The consistent decrease in SBP during the daytime after exercise may be attributed to decreases in stroke volume (SV) and cardiac output (CO), which were observed in the supine and sitting positions in young and active normotensive men^{11,25}. Muscular vasodilation caused by decreased muscular sympathetic nervous activity and metabolites after exercise decreases cardiac preload due to blood pooling in the vasodilated vessel¹. The decreased preload is postulated to be a major cause of SV and CO decreases^{11,12}. In this study, water intake was basically free, but the volume of water intake for 24 h was not significantly different among the experimental conditions. Therefore, inadequate compensation for water loss due to exercise-induced sweating might also decrease the plasma volume, preload, CO, and thus SBP²⁶. Furthermore, it is possible that the post-exercise BP decrease may be attributed to decreased SVR^{4,25,27} and increased arterial compliance²⁸. However, in this study, the CO, SVR, and arterial compliance were not measured, and the mechanism could not be clarified.

The present study found that in normotensive individuals, the post-exercise SBP decrease during the daytime tended to be smaller in the sitting than in the supine position. The ratio of post-exercise SBP decrease in the sitting

position to that in the supine position was ~ 0.6 . In contrast to the findings of this study, post-exercise SBP and MBP responses were reported to not differ significantly between the different postures^{25,29,30}. However, previous studies only examined time courses until 1 h after exercise. The present study also showed that the SBP decrease after the afternoon exercise was still significant on the second day in the supine position, but not in the sitting position. These findings indicate that the post-exercise BP decrease is less in the sitting than in the supine position in young normotensive individuals. This study did not examine BP response in the standing position, which is another posture frequently used during daytime²¹. However, based on the findings of this study, the inconsistent results of previous studies examining daily life^{3,5,6,9,10} should be at least partially related to the different postures of the participants during BP measurement. In this study, the net effect of exercise for HR (Fig. 2) averaged for two exercise conditions, such as in the case of SBP, was significantly greater in the sitting position than in the supine position (paired t-test, $p < 0.05$). In addition, a higher SVR after exercise is observed in the sitting than in the supine position²⁹. The HR and SVR response might be associated with the smaller post-exercise SBP decrease in the sitting position. Such regulation of BP after exercise appears to be important in maintaining normal BP, since the CO is distributed more to the lower extremities because of gravitational force³¹ and SBP at rest is lower originally in the sitting than in the supine position. The post-exercise BP regulatory mechanism, including the influence of posture, should be investigated in the future.

In this study, post-exercise SBP decreased significantly during daytime on the first day, but not thereafter in the morning exercise. It decreased significantly during daytime both on the first and second days, but not during nighttime in the afternoon exercise. Change in nighttime SBP was also not found in a previous study⁹, which might be related to the original low BP level, because the lowering effect on post-exercise BP is difficult to observe at low baseline BP^{2,6,11}. In hypertensive individuals, nighttime SBP decreased when the original value was high, but not when it was normal in the afternoon exercise⁷. Additionally, a previous study¹⁰ reported that nighttime MBP decreased after exercise at higher intensity, but not at moderate intensity. Thus, it may decrease at higher intensity and with more daytime physical activities².

The time dependence of post-exercise BP response, that is, the greater BP decrease in the afternoon than in the morning, has been supposed to be related to the baseline BP level and circadian mechanism of the cardiovascular system in normotensive individuals^{13,14}. However, previous findings are based on the results of an examination for 20 or 90 min after exercise. The present study found that the average SBP decrease for 24 h and during daytime (7:00 AM-11:00 PM) did not differ depending on the time of day. The time dependence of post-exercise

BP response might occur immediately after exercise. The difference in the findings of the 24-h and short-period observations is not surprising, as indicated also in the effect of exercise intensity³⁾. However, the baseline level in SBP was higher (>10 mmHg) at 4:00 PM than at 8:00 AM in previous studies. In this study, the difference between both values was less (~4 mmHg). As described above, diurnal variation in cardiovascular variables was modest, probably because of the restricted and less physical activities and the posture adopted in the present study, resulting in less difference between morning and afternoon baseline BPs. Thus, the BP responses after exercise might not change the time dependence with a less diurnal cardiovascular variation, and vice versa, in normotensive individuals. However, in this study, a significantly greater HR increase was observed in the afternoon exercise than in the morning exercise (Fig. 2), and therefore, the mechanisms contributing to a BP decrease in the morning and afternoon exercise might not be the same. The greater HR response in the afternoon exercise is possible because of a greater baroreflex-mediated increase in cardiac sympathetic activation produced by greater post-afternoon exercise vasodilatory responsiveness³²⁾.

Relationship between BP response and mood change.

BP at rest is related to mood, that is, anxiety and emotional distress are stronger at higher BP at rest¹⁵⁾. Thus, lower BP at rest after exercise might be accompanied by a change in mood, but neither POMS negative mood scores, except for fatigue (tension, depression, anger, and confusion), nor positive mood score (vigor) changed significantly in the morning or afternoon exercises despite a post-exercise significant decrease in SBP at rest. Therefore, at least in normotensive individuals, a bout of moderate endurance exercise itself would not markedly change the mood during daytime on the first and second days after exercise, despite a BP lowering effect. For the fatigue score, its increase was observed until the second day in the morning exercise and only the first day in the afternoon exercise; and the reason for this is unknown. However, the exercise-induced SBP change in the sitting position tended to negatively correlate with the exercise-induced fatigue score change for every hour in both the morning and afternoon exercises (Fig. 5). This indicates that a greater BP decrease after exercise may be accompanied by greater fatigue. In essential hypotension, cerebral blood flow velocity is decreased, and regarding the physiological process that mediates the relationship between hypotension and subjective symptoms (fatigue, dizziness, etc.), alterations in central hemodynamics in terms of a decreased cerebral blood perfusion are thought to play an important role³³⁻³⁵⁾. On this basis, cerebral blood perfusion may be causing subjective symptoms at the time of the post-exercise BP decrease. However, no change or decrease in cerebral blood flow is seen in the short time after exercise^{36,37)}, and any previous studies that included

mood could not be found. Therefore, further studies on monitoring the BP, cerebral blood flow, and mood after exercise are necessary to clarify the mechanism.

Limitations. This study has some limitations. First, prior 24-h BP monitoring was performed once or more until the participants were familiar with the measurement, and BP was measured once every hour to decrease stress and avoid sleep disturbance. Nevertheless, the hourly BP during nighttime fluctuated (Fig. 1), and the effect of exercise on nighttime BP was not observed. Although there were a few reports from the participants that they could not sleep easily or that they awoke at the measurement, validation of the post-exercise BP response during nighttime might be necessary. Second, in this study, the BP responses up to 24 hours after exercise were considered, and the daytime measurements on the second day in the morning exercise condition were performed for only 2 hours. Therefore, according to the results of this study, although there was no significant effect on daytime BP response on the second day of the morning exercise, the effect of exercise when examined over a longer period is unclear. Such an examination is considered necessary in the future. Third, baseline measurements of BP were not performed under uniform conditions prior to exercise. However, the subjects prepared for this experiment/study from the day prior, rested as much as possible on the day, and worked on the experiments in good health. In addition, the calculated net exercise effect on HR was significantly greater in the afternoon exercise than in the morning exercise as in the previous study³²⁾. Therefore, we believe that the comparison between the conditions was properly performed.

Conclusion

In young normotensive individuals with a moderate fitness level, the decrease in SBP after moderate endurance exercise was a few mmHg on average for 24 h in both the morning and afternoon exercises. In addition, the decrease in SBP in the sitting position was smaller than that in the supine position (~0.6), and greater SBP decrease was related to greater fatigue. Therefore, to truly elucidate post-exercise BP response, a uniform posture during BP measurement is necessary, as well as careful regulation of daytime physical activities. Even in daily life examination, it is necessary to make a note of the posture at the time of measurement and consider the effects to avoid misinterpretation. Additionally, based on the possible relationship between BP decrease and fatigue after exercise, interventions, such as performing lighter exercise, that are less likely to cause hypotension^{3,24)} are important to achieve a quality life according to the circumstances.

Acknowledgments

The authors thank the subjects who participated in this experiment. This study was supported by Grant-in-Aid for Scientific Research (C) from the Japan Society for the Promotion of Science (Grant No. 23500676).

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this manuscript.

References

- Halliwill JR, Buck TM, Lacewell AN and Romero SA. 2013. Postexercise hypotension and sustained postexercise vasodilatation: what happens after we exercise? *Exp Physiol* 98: 7-18. doi: 10.1113/expphysiol.2011.058065.
- MacDonald JR. 2002. Potential causes, mechanisms, and implications of post exercise hypotension. *J Hum Hypertens* 16: 225-236.
- Forjaz CLM, Cardoso CG Jr, Rezk CC, Santaella DF and Tinucci T. 2004. Postexercise hypotension and hemodynamics: the role of exercise intensity. *J Sports Med Phys Fitness* 44: 54-62.
- Clroux J, Kouam N, Nadeau A, Coulombe D and Lacourcire Y. 1992. Aftereffects of exercise on regional and systemic hemodynamics in hypertension. *Hypertension* 19: 183-191.
- Pescatello LS, Fargo AE, Leach CN Jr and Scherzer HH. 1991. Short-term effect of dynamic exercise on arterial blood pressure. *Circulation* 83: 1557-1561.
- Wallace JP, Bogle PG, King BA, Krasnoff JB and Jastremski CA. 1999. The magnitude and duration of ambulatory blood pressure reduction following acute exercise. *J Hum Hypertens* 13: 361-366.
- Park S, Jastremski CA and Wallace JP. 2005. Time of day for exercise on blood pressure reduction in dipping and nondipping hypertension. *J Hum Hypertens* 19: 597-605.
- Terblanche E and Millen AM. 2012. The magnitude and duration of post-exercise hypotension after land and water exercises. *Eur J Appl Physiol* 112: 4111-4118. doi: 10.1007/s00421-012-2398-5.
- Forjaz CLM, Tinucci T, Ortega KC, Santaella DF, Mion D Jr and Negro CE. 2000. Factors affecting post-exercise hypotension in normotensive and hypertensive humans. *Blood Press Monit* 5: 255-262.
- Jones H, George K, Edwards B and Atkinson G. 2009. Exercise intensity and blood pressure during sleep. *Int J Sports Med* 30: 94-99.
- Duji Z, Ivancev V, Valic Z, Bakovic D, Marinovi-Terzi I, Eterovi D and Wislff U. 2006. Postexercise hypotension in moderately trained athletes after maximal exercise. *Med Sci Sports Exerc* 38: 318-322.
- Teixeira L, Ritti-Dias RM, Tinucci T, Mion Jnior D and Forjaz CL. 2011. Post-concurrent exercise hemodynamics and cardiac autonomic modulation. *Eur J Appl Physiol* 111: 2069-2078.
- Jones H, Pritchard C, George K, Edwards B and Atkinson G. 2008. The acute post-exercise response of blood pressure varies with time of day. *Eur J Appl Physiol* 104: 481-489. doi: 10.1007/s00421-008-0797-4.
- Jones H, Taylor CE, Lewis NCS, George K and Atkinson G. 2009. Post-exercise blood pressure reduction is greater following intermittent than continuous exercise and influenced less by diurnal variation. *Chronobiol Int* 26: 293-306.
- Dimens ES, Wiklund IK, Dahlf CG, Lindvall KG, Olofsson BK and De Faire UH. 1989. Differences in the subjective well-being and symptoms of normotensives, borderline hypertensives and hypertensives. *J Hypertens* 7: 885-890.
- Mitsutake G, Otsuka K, Cornlissen G, Herold M, Gnther R, Dawes C, Burch JB, Watson D and Halberg F. 2001. Circadian and infradian rhythms in mood. *Biomed Pharmacother* 55 Suppl 1: 94s-100s.
- Ohnishi A, Mori K, Kohriyama K, Miyata M, Murai Y and Ikeda M. 1993. Japanese translation of Profile of Mood States (POMS) - interpretation of the fifty six items of mood factors and their application in a manufacturing automotive parts factory -. *Sangyo Ikadaigaku Zasshi (J UOEH)* 15: 147-154 (in Japanese).
- Mancia G, Ferrari A, Gregorini L, Parati G, Pomidossi G, Bertinieri G, Grassi G, di Rienzo M, Pedotti A and Zanchetti A. 1993. Blood pressure and heart rate variabilities in normotensive and hypertensive human beings. *Circ Res* 53: 96-104.
- Millar-Craig MW, Bishop CN and Raftery EB. 1978. Circadian variation of blood-pressure. *Lancet* 15: 795-797.
- Angadi SS, Weltman A, Watson-Winfield D, Weltman J, Frick K, Patrie J and Gaesser GA. 2010. Effect of fractionized vs continuous, single-session exercise on blood pressure in adults. *J Hum Hypertens* 24: 300-302. doi: 10.1038/jhh.2009.110.
- Bhammar DM, Angadi SS and Gaesser GA. 2012. Effects of fractionized and continuous exercise on 24-h ambulatory blood pressure. *Med Sci Sports Exerc* 44: 2270-2276.
- Netea RT, Lenders JW, Smits P and Thien T. 2003. Both body and arm position significantly influence blood pressure measurement. *J Hum Hypertens* 17: 459-462.
- Ternt A and Breig-Asberg E. 1994. Epidemiological perspective of body position and arm level in blood pressure measurement. *Blood Press* 3: 156-163.
- Eicher JD, Maresch CM, Tsongalis GJ, Thompson PD and Pescatello LS. 2010. The additive blood pressure lowering effects of exercise intensity on post-exercise hypotension. *Am Heart J* 160: 513-520. doi: 10.1016/j.ahj.2010.06.005.
- Senitko AN, Charkoudian N and Halliwill JR. 2002. Influence of endurance exercise training status and gender on postexercise hypotension. *J Appl Physiol* 92: 2368-2374.
- Gagnon D, Lynn AG, Binder K, Boushel RC and Kenny GP. 2012. Mean arterial pressure following prolonged exercise in the heat: influence of training status and fluid replacement. *Scand J Med Sci Sports* 22: e99-e107. doi: 10.1111/j.1600-0838.2012.01506.x.
- Coats AJS, Conway J, Isea JE, Pannarale G, Sleight P and Somers VK. 1989. Systemic and forearm vascular resistance changes after upright bicycle exercise in man. *J Physiol* 413: 289-298.
- Kingwell BA, Berry KL, Cameron JD, Jennings GL and Dart AM. 1997. Arterial compliance increases after moderate-intensity cycling. *Am J Physiol* 273: H2186-H2191. doi: 10.1152/ajpheart.1997.273.5.H2186.
- Raine NM, Cable NT, George KP and Campbell IG. 2001.

- The influence of recovery posture on post-exercise hypotension in normotensive men. *Med Sci Sports Exerc* 33: 404-412.
- 30) Mendonca GV and Fernhall B. 2016. The influence of water ingestion on postexercise hypotension and standing haemodynamics. *Clin Physiol Funct Imaging* 36: 447-456. doi: 10.1111/cpf.12249.
 - 31) Rowell LB. 1993. Reflex control during orthostasis. In: *Human cardiovascular control* (Rowell LB, ed.), 37-80, Oxford University Press, NYC, USA.
 - 32) de Brito LC, Rezende RA, da Silva Junior ND, Tinucci T, Casarini DE, Cipolla-Neto J and Forjaz CL. 2015. Post-exercise hypotension and its mechanisms differ after morning and evening exercise: a randomized crossover study. *PLoS One* 10: e0132458. doi: 10.1371/journal.pone.0132458.
 - 33) Duschek S and Schandry R. 2004. Cognitive performance and cerebral blood flow in essential hypotension. *Psychophysiology* 41: 905-913.
 - 34) Owens PE and O'Brien ET. 1997. Hypotension: a forgotten illness? *Blood Press Monit* 2: 3-14.
 - 35) Pilgrim JA, Stansfeld S and Marmot M. 1992. Low blood pressure, low mood? *BMJ* 304: 75-78.
 - 36) Willie CK, Ainslie PN, Taylor CE, Eves ND and Tzeng YC. 2013. Maintained cerebrovascular function during post-exercise hypotension. *Eur J Appl Physiol* 113: 1597-1604. doi: 10.1007/s00421-012-2578-3.
 - 37) Williamson JW, Querry R, McColl R and Mathews D. 2009. Are decreases in insular regional cerebral blood flow sustained during postexercise hypotension? *Med Sci Sports Exerc* 41: 574-580. doi: 10.1249/MSS.0b013e31818b98c8.