

ORIGINAL ARTICLE

Time of day for exercise on blood pressure reduction in dipping and nondipping hypertension

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Time of day (TOD) for exercise may influence blood pressure (BP) reduction in hypertension because of the diurnal variation of BP and the duration of BP reduction following a single bout of exercise. The purpose of this study was to observe the effects of TOD for exercise on ambulatory blood pressure reduction in dipping ($n=5$) and nondipping ($n=9$) hypertension ($<10\%$ drop in nighttime BP (BP_{night})). Hypotheses: (1) evening exercise (PM_{ex}) would exhibit a greater BP_{night} reduction in Non-Dippers than Dippers, (2) morning exercise (AM_{ex}) would exhibit similar daytime BP (BP_{day}) reduction in Dippers and Non-Dippers, (3) AM_{ex} would exhibit greater 24 h BP ($BP_{24\text{h}}$) reduction than PM_{ex} in Dippers, and (4) AM_{ex} and PM_{ex} would exhibit similar $BP_{24\text{h}}$ reduction in Non-Dippers. BP responses to AM_{ex} (0600–0800 h; 30 min at $50\% VO_{2\text{peak}}$) and PM_{ex} (1700–1900 h) were compared to

each control day in a randomized design. Systolic (S) and diastolic (D) BP were averaged for $BP_{24\text{h}}$, BP_{day} , and BP_{night} . A two-way ANOVA (dipping X time of exercise) using BP reduction with repeated measures were performed at $P<0.05$. Findings: (1) Non-Dippers respond to exercise despite of TOD for exercise, (2) PM_{ex} exhibited a greater SBP_{night} reduction in Non-Dippers than Dippers, (3) AM_{ex} exhibited similar SBP_{day} reductions in Dippers and Non-Dippers, and (4) AM_{ex} and PM_{ex} exhibited similar $SBP_{24\text{h}}$ reduction in Dippers and Non-Dippers. Dippers and Non-Dippers respond differently to TOD for exercise. The duration of the BP reduction persists up to 24 h after exercise.

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Introduction

Hypertension, a major modifiable risk factor for stroke,¹ coronary artery disease,¹ congestive heart failure,² and end-stage renal disease,³ is the most common primary diagnosis in the US. Healthy lifestyle modification, including physical activity and exercise, is recommended as the initial treatment option to control hypertension.^{4–7}

Even though endurance exercise training lowers blood pressures in hypertensive patients,^{8–10} approximately 25% of the hypertensive patients do not exhibit blood pressure reduction associated with exercise training.⁸ Hypertensive patients who do not exhibit nocturnal dipping (Non-Dippers: defined as $<10\%$ reduction in average nighttime blood pressure compared to average daytime blood pressure)¹¹ have been identified among the nonresponders to

exercise training.¹² Nami *et al*¹² reported that aerobic exercise training failed to reduce blood pressure in Non-Dippers while it did reduce blood pressure in hypertensive patients who exhibited nocturnal dipping (Dippers). The unresponsiveness of the Non-Dippers to exercise treatment could not be attributed to salt intake and other metabolic factors.¹² Nondipping hypertension is associated with a higher degree of cardiovascular complications and more serious end-organ damage than Dipping hypertension.¹¹ Thus, a more effective exercise programme for Non-Dippers may be warranted.

The reduction in blood pressure following a single bout of exercise has been reported to persist for up to 11–12 h under free-living conditions for systolic blood pressure (5–8 mmHg) and/or up to 4–8 h for diastolic blood pressure (6–8 mmHg).^{13–17} Presenting an exercise treatment prior to the period of highest blood pressure elevation may result in a more attenuated response because greater blood pressure reductions can be found in higher pressures.¹⁸ Given this fact, morning exercise may be more effective in reducing the elevated daytime pressures in dipping and nondipping hypertension whereas evening

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exercise may be more effective in reducing the elevated nighttime pressures in nondipping hypertension. Thus, the study of the time of day (TOD) for exercise may be a conceptual approach for a more individualized exercise prescription in nondipping hypertension.

The purpose of this study was to observe the effects of the TOD for exercise on the reduction of ambulatory blood pressure in dipping and non-dipping hypertension. It was hypothesized that (1) evening exercise would exhibit a greater reduction in nighttime blood pressure in nondipping hypertension than in dipping hypertension, (2) morning exercise would exhibit a similar daytime blood pressure reduction in dipping and non-dipping hypertension, (3) morning exercise would exhibit greater 24 h blood pressure reduction in dipping hypertension than evening exercise, and (4) morning and evening exercise would exhibit similar reductions in 24 h blood pressure in nondipping hypertension.

Materials and methods

Procedures included (1) blood pressure screening, (2) maximal graded exercise testing, and (3) four 24 h ambulatory blood pressure monitoring trials following: (a) morning and evening exercise treatments (30 min walk at 50% of the peak oxygen uptake or VO_{2peak}), and (b) the corresponding morning and evening control treatments. The first level of randomization was the TOD. The second level of randomization was the order of exercise and control within the corresponding TOD treatment. All procedures were approved by the Committee for protection of Human Subjects at Indiana University. Written informed consent was obtained prior to participation.

Subjects

Hypertensive middle-aged adults were recruited for this study. Hypertensive subjects were defined by one of the following: (1) having had a previous diagnosis of hypertension by a primary physician; (2) having a mean screening systolic blood pressure ≥ 140 mmHg and/or a mean diastolic blood pressure ≥ 90 mmHg taken from at least two readings on two days, three days apart;¹⁹ or (3) exhibiting a mean daytime ambulatory blood pressure of $\geq 135/85$ mmHg.⁵ To be classified as Dippers or Non-Dippers, the subject had to exhibit the nocturnal blood pressure pattern on both control treatments. Non-Dippers were defined as hypertensive adults who exhibited $<10\%$ decrease in average nighttime systolic blood pressure compared to average daytime blood pressure. Dippers were defined as $\geq 10\%$ decrease in average nighttime systolic blood pressure. Subject exclusion criteria included (1) significant cardiovascular or renal disease, (2) significant

dysrhythmia, (3) brachial artery bruits, (4) cardiac or renal transplant patients, and (5) treatment with antihypertensive medications. A physician clearance by the subject's primary physician was required for every subject prior to participation in the study. With approval of their primary physician, hypertensive subjects who were taking antihypertensive medications discontinued the medications 2 weeks prior to maximal graded exercise test. Antihypertensive medications were discontinued for the duration of the study which was approximately 4–5 weeks. Blood pressures were closely monitored during this withdrawal period.

Blood pressure screening

For all subjects, three blood pressure measurements were taken by auscultation on two separate days, three days apart (a total of six measurements). On the first day, blood pressure measurements were taken in both arms. The arm with the highest blood pressure was used for both screening periods. The screening blood pressure was an average of six measurements. Ambulatory blood pressure monitoring was also conducted to confirm high blood pressure in selected subjects who did not meet the clinical screening criteria.

Maximal graded exercise test

The graded exercise test began between 2.5 and 4.0 mph at 0% grade. The speed remained constant while the grade increased 1.0% every minute until a maximal voluntary effort was achieved or limited by symptoms.^{15,20} Blood pressure (by auscultation) and heart rate (by electrocardiogram) were measured every minute. VO_{2peak} was obtained by on-line breath-by-breath using a Sensor Medics 2900 metabolic cart during the symptom-limited graded exercise test.

Exercise treatment

Morning and evening exercise treatments were conducted between 0600 and 0800 h and between 1700 and 1900 h respectively. The exercise stimulus was a 30 min walk on a motor driven treadmill at 50% of VO_{2peak} . Each exercise treatment consisted of three sets of alternating 10 min exercise and 3 min rest period. Oxygen uptake (VO_2) was measured during the 7th–10th minutes of the first set of exercise to confirm the exercise intensity. The speed and/or grade of the treadmill was adjusted if it was not within $\pm 10\%$ of the target VO_2 . VO_2 was then measured during the 7th–10th minutes of the next work interval to confirm the new exercise intensity. Heart rate was measured every minute and blood pressure was measured every 2–5 min during the exercise.

Nonexercise control treatment

Morning and evening control treatments were conducted between 0600 and 0800 h and between 1700 and 1900 h, respectively. The control treatments were defined as nonexercise treatments beginning at the same TOD corresponding to each exercise treatment. The subject reported to the lab approximately 15 min before the time when the ambulatory blood pressure monitor would have been activated for the exercise treatments. Control data were collected for the same time period as for the exercise treatments. No sham rest period was used for the control treatments to simulate the time of attention given to the subject during the exercise treatments because rest is considered as an intervention itself.

Twenty- four hour ambulatory blood pressure monitoring

A total of four ambulatory blood pressure monitoring sessions were performed; two beginning in the morning (0700–0900 h) and two beginning in the evening (1700–1900 h). The respective control and exercise treatments were no further apart than four days for each subject, however, the two exercise treatments were greater than seven days apart to avoid a training effect.

The Accutracker II (SunTech Medical Instruments, Inc., Morrisville, NC, USA) was used for ambulatory blood pressure measurements. The sampling interval was randomized to take a reading on the average of every 15 ± 5 min for daytime hours (0600–2200 h) and on the average of every 30 ± 5 min for nighttime hours (2200–0600 h).²¹ One repeat measurement was taken if the first measurement was unsuccessful during the daytime hours and two repeat measurements were taken during the nighttime hours. The inflation of the cuff for each measurement was programmed to inflate 30 mmHg greater than the previous reading. The cuff deflation rate was programmed at 3 mmHg/s. Subjects were asked to document time of sleeping. Subjects were asked to go to bed between 2000 and 2400 h and get up between 0600 and 1000 h. Subjects were instructed (1) not to exercise, (2) not to take a shower, and (3) to relax and straighten out the arm during each recording interval for the entire 24 h period.

Individual ambulatory blood pressure measurements were reviewed for missing and erroneous readings. Readings were purged if (1) data was missing, (2) systolic blood pressure was lower than diastolic blood pressure or if systolic blood pressure was >240 or <50 mmHg, (3) if diastolic blood pressure was >140 or <40 mmHg, or (4) if heart rate was >150 or <40 beats per minute. System tagged data were purged if (1) systolic blood pressure deviated ± 50 mmHg, (2) diastolic blood pressure deviate ± 20 mmHg, or (3) heart rates deviated ± 30 beats from the surrounding values.²² Systolic and diastolic blood pressure were averaged for 24 h,

daytime (0600–2200 h), and nighttime (2200–0600 h).

The area of blood pressure reduction was calculated to determine the duration of blood pressure reduction. The area of blood pressure reduction was defined as the area between the control and exercise blood pressure curves.²³ The area between the blood pressure curve and the time axis (x-axis) was calculated by summing the area of successive trapezoids, corresponding to each blood pressure reading. The total area below the treatment curve was subtracted from the total area under the control curve to obtain the area between the curves.

Statistical methods

Values were expressed as means \pm standard errors of the means (s.e.m.). The level of significance was set at $P < 0.05$. Independent *t*-tests were performed to compare the demographics of subjects between non-dipping and dipping hypertensive groups. The demographic variables were sex, age, body mass index, screening systolic and diastolic blood pressure and VO_{2peak} . A two-way ANOVA (Dipping Status \times Time of Exercise) with repeated measures was performed using the blood pressure reduction as dependent ambulatory blood pressure variables: difference between control and exercise systolic and diastolic blood pressure (mmHg) for daytime, nighttime and 24 h. Paired *t*-tests were used to compare the first and last 12 h period of the area of the blood pressure reduction for Dippers and Non-Dippers. All statistical analyses were performed using SPSS software (SPSS 11.0).

Results

Subjects

In all, 19 hypertensive adults were screened; five were found to be ineligible during the screening process. A total of 14 hypertensive adults who were qualified based on screening blood pressures, ambulatory blood pressures, exercise testing, and nocturnal patterns participated in the study. Subjects were classified as Dippers ($n = 9$) or Non-Dippers ($n = 5$) based on the control ambulatory blood pressure monitoring sessions. All of Dippers and Non-Dippers exhibited the nocturnal requirements for their respective groups.

Demographics of the subjects are summarized in Table 1. None of the demographic variables were different between Dippers and Non-Dippers except for average 24 h and nighttime blood pressure. Both of these variables were higher in the Non-Dippers because of the elevated nocturnal blood pressure. Two of subjects were taking combinations of anti-hypertensive medications (angiotensin converting enzyme inhibitor, calcium channel blocker, and beta blocker), and six of subjects were taking a single

Table 1 Demographics of subjects

	Dippers (n = 9)	Non-dippers (n = 5)	t-values/P-values
Sex (men/women)	6/3	2/3	
Race	8 Caucasian 1 Asian	3 Caucasian 1 Asian 1 Native American	
Age (years)	55.6 ± 1.47	58.2 ± 3.32	-0.85 0.41
Weight (kg)	80.3 ± 6.09	78.5 ± 7.13	0.19 0.86
Height (cm)	172.6 ± 2.30	166.4 ± 5.49	1.24 0.24
Body mass index (kg/m ²)	26.7 ± 1.47	28.2 ± 1.87	-0.63 0.54
VO _{2peak} (ml/kg ¹ /min ¹)	29.6 ± 1.28	25.0 ± 2.37	1.91 0.08
Activity level (active/sedentary)	7/2	4/1	0.09 0.93
Screening systolic/diastolic blood pressure (mmHg)	144.4 ± 3.50/ 88.0 ± 2.08	141.6 ± 4.17/ 91.2 ± 1.20	0.50/-1.08 0.62/0.30
24-h systolic/diastolic blood pressure (mmHg)	143.1 ± 2.41 ^a / 83.4 ± 1.01	150.4 ± 1.29/ 83.5 ± 1.71	-2.16/-0.30 0.04/0.98
Daytime systolic /diastolic blood pressure (mmHg)	147.5 ± 2.53/ 86.1 ± 1.23	151.3 ± 1.29/ 85.4 ± 1.71	-1.07/0.31 0.30/ 0.76
Nighttime systolic/diastolic blood pressure (mmHg)	123.4 ± 2.18 ^a / 73.1 ± 1.47	146.3 ± 2.68/ 76.7 ± 2.50	-6.47/-1.34 0.001/0.19

Values were expressed as means ± s.e.

^aDenotes significant differences at $P < 0.05$.

antihypertensive medication (angiotensin converting enzyme inhibitor, calcium channel blocker and beta blocker).

As part of the screening process, all of the subjects performed a maximal exercise test. One of the subjects who did not meet the screening criteria was disqualified with the exercise test by exercise-induced headache. The 14 subjects who were qualified for the study performed a maximal voluntary effort on the exercise test as verified by reaching $103.4 \pm 2.09\%$ predicted maximal heart rate.

Exercise stimulus

Each exercise session was separated by 9.8 ± 0.26 days. Exercise intensities were similar between morning ($52.0 \pm 0.21\%$ of VO_{2peak}) and evening exercise ($54.3 \pm 0.26\%$ of VO_{2peak}). Both Dippers and Non-Dippers also exhibited similar exercise intensities for both morning ($52.4 \pm 0.87\%$; $51.5 \pm 1.88\%$ of VO_{2peak}) and evening ($53.7 \pm 0.93\%$; $54.8 \pm 2.55\%$ of VO_{2peak}) exercise, respectively.

Ambulatory blood pressure

Table 2 summarizes the ambulatory blood pressure monitoring sessions for each group and each treatment. The duration of the ambulatory blood pressure monitoring sessions averaged 24.1 ± 0.9 h for

Table 2 Ambulatory monitoring

Group	Morning control	Morning exercise	Evening control	Evening exercise
<i>Duration of monitoring session (h)</i>				
Dippers	24.3 ± 1.19	24.6 ± 1.33	24.1 ± 0.64	24.1 ± 0.6
Non-Dippers	23.8 ± 0.24	23.7 ± 0.43	23.7 ± 0.23	23.9 ± 0.29
<i>Number of blood pressure measurements</i>				
Dippers	102.4 ± 14.65	104.3 ± 12.34	98.8 ± 8.66	101.4 ± 6.87
Non-Dippers	100.2 ± 5.17	96.2 ± 6.30	96.4 ± 5.03	108.8 ± 32.1
<i>Percent of blood pressure measurements analysed</i>				
Dippers	80.3 ± 12.82	85.7 ± 8.83	88.5 ± 8.47	84.7 ± 5.60
Non-Dippers	85.9 ± 9.08	87.2 ± 10.5	85.8 ± 4.59	92.3 ± 3.00

Values were expressed as mean ± s.e.

both groups for all the treatment conditions. An average of 101.0 ± 12.2 blood pressures were taken for each ambulatory monitoring session; $85.8 \pm 8.7\%$ of the pressures were used in the analysis. Dippers and Non-Dippers did not differ in the number of pressures taken and the percent analysed for each of the four monitoring sessions. Even though the average duration of sleep was 6.5 ± 1.1 h for both groups for all four treatment conditions, the time to go to bed ranged from 2100 to 0200 and the time to wake-up ranged from 0320 to 0900. These times and

duration of sleep did not differ among the treatments or between the groups.

The hourly reductions in blood pressure associated with morning and evening exercise are illustrated in Figure 1 for dipping (Panel A) and nondipping hypertension (Panel B) for the 24 h clock. A two-way ANOVA (dipping status × time of

exercise) with repeated measures using the blood pressure reduction reveals that a significant two-way interaction between dipping status and time of exercise was found for the reduction in nighttime systolic blood pressure (see Table 3). Simple effects found that Non-Dippers exhibited a significantly greater reduction in average nighttime systolic blood pressure than Dippers following both morning ($F=13.43$; $P=0.001$) and evening exercise ($F=7.13$; $P=0.013$). No significant two-way interaction was found in either 24 h or daytime systolic blood pressure reductions (Table 3) as well as for any diastolic blood pressure reductions.

The data presented in Table 4 address the first two hypotheses. In Table 4 daytime and nighttime systolic blood pressure reductions following morning and evening exercise were compared between dipping and nondipping hypertension. Non-Dippers exhibited a significantly greater reduction in average nighttime systolic blood pressure than Dippers following evening exercise ($F=7.13$; $P=0.013$). No statistical difference was found between dipping status and time of exercise for average daytime blood pressure reductions following exercise ($F=0.001$; $P=0.991$).

The data presented in Table 5 address the last two hypotheses. Table 5 illustrates the reduction in average 24 h blood pressure for Dippers and Non-Dippers following morning and evening exercise. The reduction in 24 h systolic blood pressure was not affected by interaction between the time exercise and dipping status ($F=0.08$; $P=0.778$).

Figure 2 illustrates the areas for the 24 h blood pressure reduction starting from the end of exercise.

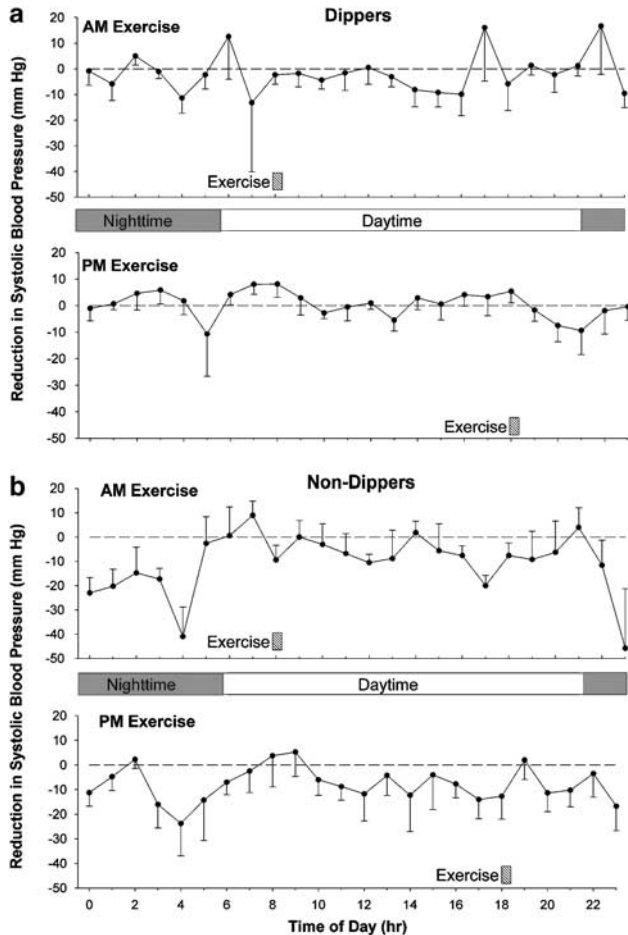


Figure 1 Hourly blood pressure reduction associated with morning (AM) and evening (PM) exercise in dipping (a) and nondipping (b) hypertension for the 24 h clock. Values are expressed as mean ± s.e. Exercise periods are illustrated by shaded areas. Nighttime and daytime periods are also illustrated based on TOD. The data points following the shaded exercise included only those blood pressures that followed the treatment.

Table 4 Daytime and nighttime reduction in systolic blood pressure following morning and evening exercise in dipping and nondipping hypertension

	Dippers	Non-Dippers
Nighttime average following evening exercise (mmHg)	-0.30 ± 1.7^a	-11.50 ± 3.85
Daytime average following morning exercise (mmHg)	-5.67 ± 2.59	-6.00 ± 1.23

Values were expressed as means ± s.e.

^aDenotes significant group differences at $P < 0.05$.

Table 3 A two-way ANOVA (dipping status × time of exercise) with repeated measures using the blood pressure reduction

	Daytime SBP		Nighttime SBP		24 h SBP	
Dipping status	$F=0.07$	$P=0.790$	$F=3.19$	$P=0.100$	$F=0.38$	$P=0.547$
Time of exercise	$F=0.65$	$P=0.434$	$F=9.22$	$P=0.010$	$F=1.85$	$P=0.199$
Dipping status × time of exercise	$F=0.001$	$P=0.991$	$F=4.84^a$	$P=0.048$	$F=0.08$	$P=0.778$

SBP: systolic blood pressure.

^aDenotes significant group differences at $P < 0.05$.

Table 5 The 24 h reduction in systolic blood pressure following morning and evening exercise in dipping and nondipping hypertension

	Morning exercise (mmHg)	Evening exercise (mmHg)
Dippers	-5.56 ± 2.27	0.11 ± 2.29
Non-Dippers	-7.22 ± 2.10	-7.00 ± 3.16

Values were expressed as means \pm s.e.

For the Non-Dippers, both 12 h periods contributed to the average 24 h reduction in blood pressure because the area of the reduction from the first 12 h period following morning ($t = -0.41$; $P = 0.700$) and evening ($t = 0.61$; $P = 0.583$) exercise was similar to the last 12 h period. Similar findings were exhibited for the Dippers who exercised in the morning ($t = -3.58$; $P = 0.730$). For the Dippers who exercised in the evening, however, the contribution of the two 12 h periods is not as clear. The second 12 h period actually exhibited a higher systolic blood pressure following exercise although it is not statistically higher ($t = 0.68$; $P = 0.583$).

Discussion

The purpose of this study was to observe the effects of TOD for exercise on the reduction of ambulatory blood pressure in dipping and nondipping hypertension. We found that (1) evening exercise exhibited a greater reduction in nighttime systolic blood pressure for Non-Dippers than for Dippers, (2) morning exercise exhibited similar daytime systolic blood pressure reductions for Dippers and Non-Dippers, and (3) morning and evening exercise treatments exhibited similar 24 h systolic blood pressure reduction for both dipping and nondipping hypertension. The additional important findings in this study include: (1) Non-Dippers respond to exercise treatment, (ie both morning and evening exercise produced a reduction in nighttime systolic blood pressure in Non-Dippers) and (2) the duration of the blood pressure reduction appears to be greater than 12 h. Table 6 summarizes these findings in relationship to the literature.

Non-Dippers were investigated in the study because (1) they have been identified as nonresponders to exercise¹² and (2) non-dipping hypertension is associated with more serious end-organ damage and higher incidence of cardiovascular complications than Dippers.¹¹ A single bout of exercise was chosen for this study because it may be the initial step to investigate the effectiveness of exercise on blood pressure reduction in populations previously identified as nonresponders.²⁴ Training studies may not be justified without demonstrating an acute response first. Furthermore, the utilization of acute

exercise responses allows for more efficacious study into possible variations in the exercise prescription for nonresponders. One of the possible variations in the exercise prescription for the nondipping hypertensive patients was considered to be the TOD for exercise.

Subjects

The subjects in this investigation were similar to subjects found in exercise and blood pressure reduction studies.⁸ The nocturnal dipping status in hypertension was confirmed by the two control ambulatory blood pressure monitoring sessions. The reproducibility of the dipping and nondipping hypertension is consistent with the study by Nami and colleagues.¹² Systolic blood pressure reductions were found in average 24 h, daytime and nighttime systolic blood pressure. No significant reduction was found for diastolic blood pressure. The blood pressure reductions of the subjects are consistent with other studies utilizing a single bout of exercise.^{15,25} The number of subjects were adequate for all of significant findings with >0.94 of power and >0.32 of effect size (ω^2). Null findings of this study could be due in part to the number of subjects and, as such, a high likelihood of Type II error could exist.

Ambulatory blood pressure monitoring

Control ambulatory blood pressure monitoring was performed twice, once in the morning and once in the evening corresponding to the two exercise sessions. In our laboratory, we have found the TOD to begin ambulatory blood pressure monitoring affects blood pressure outcomes.²⁶ The control monitoring sessions starting the morning have been found to have higher average blood pressures and blood pressure than monitoring sessions starting in the evening. A similar trend was seen in these data, however, no significant difference in the three average blood pressure variables was found between the two control sessions in this study.

There are several important findings from this study. Not only were Non-Dippers found to respond to exercise treatment, but also Non-Dippers reduced their nighttime systolic blood pressure (-10.1 ± 2.70 mmHg) despite the TOD for exercise. The reduction in systolic blood pressure in Non-Dippers contradicts the findings of Nami and colleagues,¹² who reported aerobic exercise training failed to reduce blood pressure in nondipping hypertension.

In the study,¹² Nami and colleagues investigated salt intake and other metabolic variables and found no relationship among the inability to reduce blood pressure with exercise and the other confounding variables. They reported good subject adherence to their study protocol. Our studies differed in the

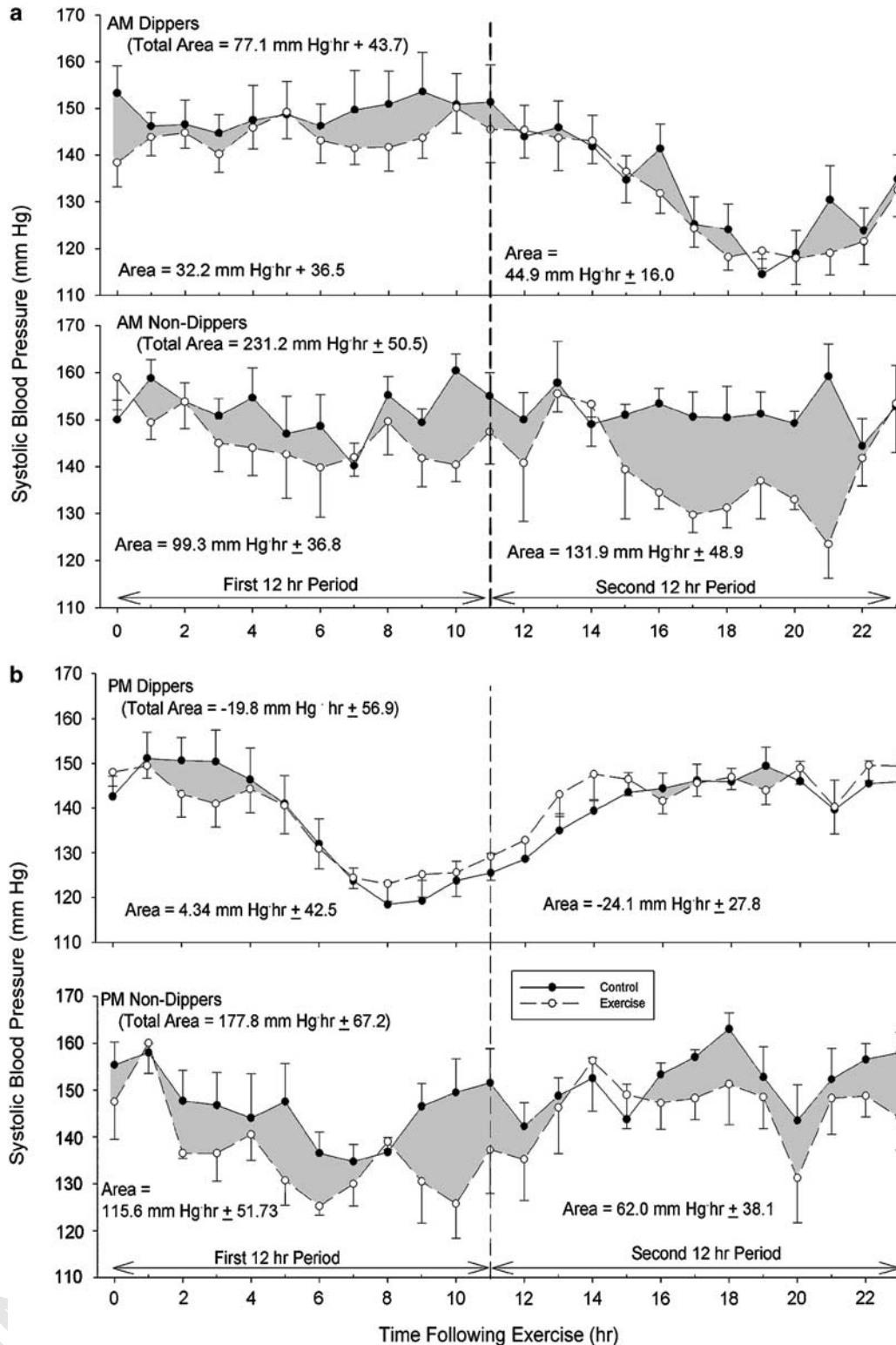


Figure 2 Area of blood pressure reduction (shaded) following morning (AM; a) and evening (PM; b) exercise in dipping and nondipping hypertension. Values are expressed as mean ± s.e.

subject demography, exercise treatment, and use of a control group. Our subjects had higher blood pressures, were older, and some had been treated

with antihypertensive medications. It would seem obvious that our subject would exhibit a greater reduction in blood pressure because higher blood

Table 6 A summary of current literature and contributions of this study*What is known on this topic*

1. Endurance exercise training lowers blood pressures in hypertensive patients^{8–10}
2. Nocturnal nondipping hypertensive patients (Non-Dippers: defined as <10% reduction in average nighttime blood pressure compared to average daytime blood pressure)¹¹ have been identified among the nonresponders to exercise training¹²
3. A more effective exercise programme for Non-Dippers may be warranted
4. The reduction in blood pressure following a single bout of exercise has been reported to persist for up to 11–12 h under free-living conditions for systolic blood pressure (5–8 mmHg) and/or up to 4–8 h for diastolic blood pressure (6–8 mmHg)^{13–17}
5. Exercise treatment prior to the period of highest blood pressure elevation may result in a more attenuated response because greater blood pressure reductions can be found in higher pressures¹⁸

What this study adds

1. This study observed the effects of the TOD for exercise on the reduction of ambulatory blood pressure in dipping and nondipping hypertension
 - (a) Evening exercise exhibited a greater reduction in nighttime systolic blood pressure for Non-Dippers than for Dippers
 - (b) Morning exercise exhibited similar daytime systolic blood pressure reductions for Dippers and Non-Dippers
 - (c) Morning and evening exercise treatments exhibited similar 24 h systolic blood pressure reduction for both dipping and nondipping hypertension
2. The additional important findings in this study include:
 - (a) Non-Dippers respond to exercise treatments. Nighttime systolic blood pressure for Non-Dippers was reduced despite of time of day for exercise—that is either morning or evening exercise
 - (b) The duration of the blood pressure reduction appears to be greater than 12 h

pressures exhibit greater reductions.⁹ On the other hand, Nami and colleagues found a blood pressure reduction in their Dippers (24 h, daytime and nighttime systolic blood pressures: 130.6 ± 1.8 , 135.9 ± 0.8 , and 120.0 ± 0.8 mmHg) who also had lower pressures than our Dipping subjects. Our subjects were approximately 25 years older than Nami's (Dippers = 29.5 ± 1.16 years; Non-Dippers = 31.4 ± 1.9 years). Middle-aged hypertensive subjects have a tendency to decrease blood pressure somewhat more and somewhat more consistently than younger hypertensive subjects.⁸

Different exercise stimuli can produce different blood pressure responses.⁹ The mode (cardiovascular), duration (60 min) and intensity (40–60%) of Nami's stimulus¹² were not only similar to ours, but within the guidelines for appropriate exercise treatment.⁴ Our exercise treatment differed from Nami's in that ours was acute and Nami's was training. Yet, our results cannot be attributed to these differences because in blood pressure, the acute response reflects the training response.²⁴ On the other hand, Nami and colleagues did not include the control group in their study, which made it hard to interpret the effects of exercise training on blood pressure. Our subjects served as their own controls.

Another significant finding in our study was the nature of the blood pressure reduction in Dippers and Non-Dippers. Not only did the Non-Dippers exhibit a greater nighttime reduction in systolic blood pressure than the Dippers following evening exercise, but the Non-Dippers exhibited similar daytime systolic blood pressure reduction as the Dippers despite morning or evening exercise, as illustrated in Tables 3 and 4. Dippers were not expected to reduce average nighttime blood pressure following evening exercise in the same magnitude as

the Non-Dippers because the average nighttime blood pressure for the Dippers was near normal (124.4 ± 3.30 mmHg). It is well documented that higher blood pressures exhibit greater reductions following exercise.^{17,27} In this study, a significant correlation ($r=0.58$; $P=0.002$) was also found between baseline blood pressure and daytime and nighttime blood pressure reduction following exercise. Furthermore, the average nighttime blood pressure reduction was greater in the Non-Dippers who presented with higher pressures (143.5 ± 1.68 – 132.0 ± 2.60 mmHg) than in the Dippers who presented with near normal nighttime blood pressures (124.4 ± 3.12 – 124.1 ± 1.68 mmHg).

The nighttime reduction in blood pressure for Non-Dippers who exercised in the morning was not expected because the primary reduction in blood pressure following exercise had been reported to be 12 h.^{13–17} It appears, however, as though the reduction in blood pressures found in this study exceeded this 12 h period, similar to the findings of Brandao-Randon and colleagues^{4,25} who reported the 22 h postexercise blood pressure reduction in elderly hypertensive patients. Most investigators may not have detected a reduction in blood pressure beyond the first 12 h because of the criteria used to estimate the duration of postexercise hypotension. In these studies, the duration of the blood pressure reduction was determined to be the time where the hourly blood pressures were no longer significantly different (control vs exercise, or pre- vs exercise). Whereas, Brandao-Randon *et al*^{4,25} reported significant differences for average pressures for specific periods of the day (ie daytime and nighttime) which accounted for the entire 22 h. We found similar reductions for average 24 h (-5.3 ± 1.12 mmHg; $F=9.78$; $P=0.009$), daytime (-4.4 ± 1.02 mmHg;

$F = 7.81$; $P = 0.016$), and nighttime (-5.9 ± 1.62 mmHg; $F = 10.72$; $P = 0.004$). It is possible for total 24 h average blood pressures to be significantly lower because of the magnitude of the first 12 h period of reduction even though the second 12 h period is not significantly different.

To investigate this effect further, we compared the first 12 h period and the last 12 h period blood pressure reduction by comparing the area between the control and exercise blood pressure curves (Figure 2). The 24 h reduction in systolic blood pressure following exercise appears to be a true phenomenon and not influenced by the magnitude of the reduction during the first 12 h period. The extension of the reduction beyond the first 12 h period may explain why the reductions in 24 h systolic blood pressure were not affected by the TOD for exercise in both Dippers and Non-Dippers.

In conclusion, Non-Dippers responded to exercise treatment. Dippers and Non-Dippers, however, responded differently to exercise treatments presented at different times of day. Non-Dippers decreased nighttime systolic blood pressure following exercise whereas Dippers did not. Morning exercise produced a greater magnitude and longer duration of blood pressure reduction in Dippers than evening exercise. Finally, the reduction in systolic blood pressure found in this study persisted up to 24 h after exercise in Non-Dippers who exercised in the morning or the evening and in Dippers who exercised in the morning.

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