

TIMING OF EXERCISE WITHIN THE WAKING PERIOD DOES NOT ALTER BLOOD PRESSURE DURING SUBSEQUENT NOCTURNAL SLEEP IN NORMOTENSIVE INDIVIDUALS

Helen Jones, Keith George, Greg Atkinson

Research Institute for Sport and Exercise Sciences, Liverpool John Moores University, Liverpool, UK

Exercise can cause a reduction in blood pressure (BP) that is prolonged enough to extend into nocturnal sleep. This post-exercise hypotension has been found to be less apparent in the morning when the immediate (during the 20 minutes after exercise) responses are considered. However, it is currently unknown if the timing of exercise (morning vs. afternoon) mediates different BP responses during a longer follow-up period of everyday habits and nocturnal sleep. Therefore, we aimed to examine BP for up to 24 hours following exercise in the morning and afternoon. After 45 minutes of supine rest, 12 male normotensives completed 30 minutes of cycling at 70% $\dot{V}O_{2\text{peak}}$, which began at either 08:00 or 16:00 hours. Between 20 minutes and 24 hours after exercise, ambulatory BP, heart rate and wrist-activity were monitored and compared between trials using general linear models. Participants slept normally at night. Systolic, diastolic and mean arterial BP did not differ between trials from 20 minutes after exercise until nocturnal sleep onset ($p > 0.23$) or during the nocturnal sleep period ($p > 0.20$). During the daytime period, heart rate was 5 beats \cdot min⁻¹ higher following morning exercise compared with the afternoon trial ($p = 0.05$), and physical activity was also greater following morning exercise ($p = 0.01$). Nocturnal measurements of heart rate and physical activity were unaffected by the timing of exercise ($p > 0.63$). We conclude that the timing of exercise does not moderate subsequent BP responses during everyday activity and nocturnal sleep in normotensive individuals. These findings suggest that the diurnal variation in BP immediately after exercise is relatively short-lived and does not extend into the nocturnal sleep period. [*J Exerc Sci Fit* • Vol 7 • No 2 (Suppl) • S42–S50 • 2009]

Keywords: ambulatory blood pressure, exercise and diurnal rhythm

Introduction

Regular exercise has the potential to be a key non-pharmacological tool in the management of blood pressure (BP). After exercise, BP is normally reduced below pre-exercise levels—a well-known phenomenon termed

“post-exercise hypotension” (PEH; Kenney & Seals 1993). Post-exercise BP reductions begin immediately following an exercise bout (MacDonald 2002) and can persist for up to 22 hours in hypertensive individuals (Pescatello et al. 2004). Such a prolonged reduction in BP is important if exercise is to be used as an intervention for hypertension. Therefore, the identification of the optimal conditions and moderating factors (e.g. time of day for exercise) for this prolonged PEH is also important.

Recently, diurnal variation in the acute (up to 20 minutes) response of BP following a bout of exercise has been described in a series of interrelated studies (Jones et al. 2008a,b, 2006). The data from these studies indicated that the PEH phenomenon is absent or even



Corresponding Author
Helen Jones, Research Institute for Sport and Exercise Sciences, Liverpool John Moores University, Henry Cotton Campus, Webster Street, Liverpool L3 2ET, UK.
Tel: (44) (0)151 231 4120
Fax: (44) (0)151 231 4353
E-mail: h.jones1@ljmu.ac.uk

reversed when exercise is taken specifically between 04:00 and 08:00 hours (Jones et al. 2008b) compared with exercise at other times of the waking period. This unusual response of BP in the morning was found to be robust even when posture and the amount of sleep were tightly controlled prior to exercise (Jones et al. 2008a). As well as having implications for exercise prescription in the management of BP, these observations support the notion that the characteristic morning surge in ambulatory BP (Hermida 2007; Millar-Craig et al. 1978) is, in part, explained by a greater reactivity of BP to a given change in physical activity at this time of day (Jones et al. 2006). These data, taken together with the fact that sudden cardiovascular events peak in the morning (Muller et al. 1989), raise concerns about the safety of early morning exercise for individuals at risk of these events, such as hypertensive patients (Jones et al. 2008a,b; Atkinson et al. 2006). The main mechanism for the relationship between time of day variations in BP and sudden cardiac events is thought to be due to within-day increases in BP, superimposed on values already indicative of hypertension, leading to the rupture of vulnerable arterial plaques, which in turn can precipitate an acute cardiac event (Muller 1999).

Knowledge about the longer term (i.e. 24 hours) response of BP following exercise at different times of day is limited. In one of the few relevant studies, Park et al. (2005) examined the responses of ambulatory BP following a bout of exercise in the morning (between 06:00 and 08:00 hours) and the afternoon (17:00–19:00 hours). The aim of that study was to investigate how exercise in the morning and afternoon affected the magnitude of BP “dipping” during sleep in medicated hypertensive individuals. Park et al. (2005) reported that afternoon exercise exhibited a greater reduction in systolic BP during sleep in participants who did not normally exhibit a $\geq 10\%$ reduction in average night time BP (i.e. “non-dippers”) compared to participants who did normally exhibit this reduction (i.e. “dippers”). Nevertheless, in that study, the authors did not compare morning and afternoon exercise BP responses directly to establish which time of day for exercise mediates the greatest reduction. Therefore, the aim of the present study was to compare BP responses for up to 24 hours following exercise at two times of day. The BP follow-up period included measurements during everyday activities and nocturnal sleep. We have shown previously that morning exercise can cause a physiologically significant reduction in BP during nocturnal sleep (Jones et al. 2009), and since BP reductions are greater immediately after exercise in the afternoon

(Jones et al. 2008a,b), we hypothesize that the greater BP reductions evident following afternoon exercise will persist and extend into nocturnal sleep.

Methods

Participants

Following an estimation of the sample size required for the primary comparisons in our study (see statistical analysis), 12 normotensive (mean systolic/diastolic BP, $124 \pm 8/73 \pm 8$ mmHg) physically active males participated in the study. Participants were aged 26 ± 5 years, had a body mass of 74 ± 6 kg, were 1.78 ± 0.4 m in height, and had a $\dot{V}O_{2\text{peak}}$ of 47.5 ± 7.3 mL \cdot kg⁻¹ \cdot min⁻¹. All were nonsmokers, had no history of cardiovascular disease and were not taking any medication. They engaged in regular physical activity for more than 2 hours per week. Participants were instructed to abstain from strenuous exercise and the consumption of alcohol for 24 hours, caffeine for 12 hours and food for at least 6 hours prior to each trial. The study conformed to the Declaration of Helsinki and was approved by the Institutional Ethics Committee; all participants were informed of the methods before providing written consent.

Research design

Each participant was required to attend the laboratory on four separate occasions, with the first visit for familiarization purposes, the second visit for measurement of peak oxygen uptake, and then two visits for completion of the main experimental conditions, morning exercise and afternoon exercise. The two trials were administered in a counterbalanced order, and were separated by 7–10 days. The light intensity in the laboratory was controlled at ~ 200 lux, and temperature was maintained at 21 °C. At both times of day, the protocol began after a 12-hour abstinence from caffeine, 24-hour abstinence from alcohol and strenuous exercise, and at least a 4-hour fast (participants ate a standard carbohydrate breakfast only prior to the afternoon test).

Familiarization

During their first visit to the laboratory, participants were familiarized with the equipment and exercise protocol, and anthropometric measurements were recorded. Height (m), body mass (kg) and resting BP (three serial measurements with a mercury manual sphygmomanometer) were determined.

Measurement of peak oxygen uptake

On the second visit to the laboratory, $\dot{V}O_{2\text{peak}}$ was determined using a progressive continuous protocol (Bird & Davidson 1997). As a standard warm-up, participants performed 10 minutes of submaximal cycling on an ergometer (Kettler Sport, Worcestershire, UK). Power output was set initially at 50 W and was increased in 25-W increments every 2 minutes until volitional exhaustion or the point at which the subject could no longer maintain the required pedal cadence ($\geq 60 \text{ rev} \cdot \text{min}^{-1}$). Expired gases were collected using an online collection system that sampled every 10 seconds (MetaMax 1; Cortex Biophysic GmbH, Leipzig, Germany). Oxygen uptake was then plotted against work rate, and the exercise work rate (i.e. watts) corresponding to 70% $\dot{V}O_{2\text{peak}}$ was interpolated using a linear regression equation.

Experimental protocol

Participants reported to the laboratory at 07:00 hours ready to begin exercise at 08:00 hours in the morning exercise condition, and at 15:00 hours ready to begin exercise at 16:00 hours in the afternoon exercise condition. Participants remained resting in the supine position for 45 minutes to control for posture prior to the exercise bout and ensure equilibration of blood pressure throughout the body. The participants then moved to the cycle ergometer ready to begin exercise. The exercise protocol consisted of a 30-minute bout of semi-supine cycling at 70% $\dot{V}O_{2\text{peak}}$. To ensure that the participants were cycling at the correct intensity, the mechanical resistance (watts) was constant during each exercise bout. At the end of the exercise bout in the laboratory, participants remained on the cycle ergometer for 20 minutes for post-exercise measurements (the acute post-exercise measurements have been reported previously [Jones et al. 2008b]). Following this period, participants were allowed a time period (about 10 minutes) to shower and change clothing before being fitted with the ambulatory equipment and leaving the laboratory. Participants were instructed to leave the laboratory and follow their normal daily routine and return the following day at 09:00 hours for removal of the equipment. Therefore, 24 hours of data were recorded following morning exercise, whilst 16 hours of data were recorded following afternoon exercise.

Measurement procedures

A TM-2430 ambulatory BP monitor (A&D Company Ltd., Gloucestershire, UK) was fitted to the upper arm of each participant according to the practical guidelines

outlined by the European Society of Hypertension (O'Brien et al. 2005). The non-dominant arm was used for measurement using an appropriate sized cuff. If the arm circumference was $> 31 \text{ cm}$, a large cuff was used. Participants were asked to keep the arm still during the recording of each measurement. The monitor was calibrated by direct comparison with 3 BP readings by a trained observer using a mercury sphygmomanometer in the sitting position according to British Hypertension Society guidelines (O'Brien et al. 1990). The monitor was programmed to record systolic and diastolic BP and heart rate via oscillation every 15 minutes except between the hours of 23:00 and 06:00, when it recorded every hour to minimize sleep disturbance. The display on the monitor was switched off to prevent feedback to the participants. All BP readings rejected by the TM-2430 software as being artefacts (e.g. reading $> 250 \text{ mmHg}$) were excluded from analyses. Data sets with $< 80\%$ of BP recordings present were excluded from the study. The analysis software also provided mean arterial pressure (MAP) values, calculated as: $\text{MAP} = \text{diastolic BP} + (\text{systolic BP} - \text{diastolic BP})/3$.

After the ambulatory BP monitor was attached, a model AW4 Actiwatch (Cambridge Neurotechnology Ltd., Cambridge, UK) was placed on the participant's dominant wrist. This site was chosen because the results of previous research have shown that motor activity measured at the dominant wrist is the most appropriate (Middelkoop et al. 1997) and also correlates best with general physical activity (Gretler et al. 1993). The Actiwatch is a compact, light weight, wrist-worn electronic device that measures and records physical movements. Activity is measured by the means of a piezoelectric accelerometer that is set up to record the integration of intensity, amount and duration of movements in all directions. The Actiwatch records movement over $0.05g$ and has a sampling frequency of 32 Hz. The voltage produced is converted and stored as an activity count in the memory unit of the watch. The watch was programmed to record every minute on an arbitrary scale that ranged from 0 to 2000 units. The activity scores from the watch were transferred to a PC via the custom-designed Actiwatch software (Actiwatch Activity and Sleep Analysis 5; Cambridge Neurotechnology Ltd.). A logarithmic transformation was then applied to the activity values to reduce the positive skew of the distribution and to make it more symmetrical; activity units are expressed in arbitrary units ($\log_e \text{AU}$).

All participants were given a standardized activity diary to complete during the 24-hour monitoring period.

Participants were required to record significant actions (e.g. driving) around the time of each automated BP reading. This information was compared to the actimetry data as a general cross-validation of the measurements. Participants also used the diary to record the time of going to bed at night and time of waking in the morning. Waking time was defined as the time closest to diary wake time at which there was onset of regular activity scores of more than zero. The point of falling asleep was considered to be the time closest to diary sleep time, when there was onset of a series of at least 10 minutes of activity scores, of which at least 90% were zero. Such definitions of waking and sleep time have been adopted in previous studies (Jones et al. 2009, 2006; Leary et al. 2002). Participants were then instructed to leave the laboratory and follow their normal daily routine and return the following day at 09:00 hours for removal of the equipment.

Statistical analysis

The primary outcome variables were systolic BP, diastolic BP and MAP averaged over the daytime and sleep period. The primary comparison was between the morning and afternoon exercise. A sample size estimation was performed using nQuery Advisor[®] (Statistical Solutions Ltd., Cork, Ireland). It was deemed that a post-exercise average daytime or nocturnal sleep period difference of 5 mmHg in systolic BP, diastolic BP or MAP between the two trials was physiologically important, and it was estimated that six participants would allow this difference to be deemed statistically significant (statistical power, 80%; standard deviation of differences ≤ 4 mmHg using a one-tailed paired *t* test). Clinically, a 5 mmHg reduction in systolic BP in the population would be predicted to result in a 14% overall reduction in mortality due to stroke, a 9% reduction in mortality due to coronary heart disease, and a 7% decrease in all-cause mortality (Whelton et al. 2002).

All data were averaged into 1-hour periods and expressed relative to the end of exercise. A general linear model with repeated measures analysis was performed for the daytime period (duration, 5 hours). All 1-hour averaged data were also expressed relative to the time of sleep to control for differing sleep patterns and to ensure that all participants were sleeping during the sleep period. A general linear model with repeated measures analysis was also performed for the sleep period (duration, 5 hours). The nocturnal dip was calculated as “average daytime – average sleep/average sleep $\times 100$ ” and compared using a paired *t* test. All data were analysed using SPSS version 14 (SPSS Inc., Chicago, IL,

USA). Data are presented in the text as mean \pm standard error (SE), and 90% confidence intervals (CI; Sterne & Davey Smith 2001) exact *p* values are cited (values of *p* of “0.000” provided by SPSS are recorded as “ <0.0005 ”).

Results

Daytime period

Post-exercise systolic BP, diastolic BP, and MAP responses did not show any interactive effects between time of day and post-exercise time ($p > 0.234$). The post-exercise responses of systolic BP, diastolic BP and MAP were not affected by the time of day for exercise from the 20 minutes after exercise until the time of sleep ($p > 0.322$). The mean \pm SE values when averaged over the whole 5-hour daytime period were similar between times of day (Figure 1). Post-exercise heart rate was higher following the 08:00 hours bout of exercise compared to the 16:00 hours bout of exercise during the daytime period ($p = 0.056$). The mean difference in heart rate between morning and afternoon exercise was 5 beats \cdot min⁻¹, and the 90% CI for the difference was -9.0 to -0.7 beats \cdot min⁻¹. There was a general trend for heart rate values to show a gradual reduction throughout the daytime period at both times of day (Figure 1), the main effect of post-exercise time being significant ($p = 0.007$). Following exercise at 08:00 hours, heart rate began to increase towards the end of the daytime period (5 hours post-exercise). Nevertheless, these differences in the time course of the post-exercise responses did not reach statistical significance (interaction between time of day and post-exercise time, $p = 0.290$).

Nocturnal sleep period

Post-exercise systolic BP, diastolic BP, MAP and heart rate did not show any interactive effects between time of day and post-exercise time ($p > 0.206$). There was no main effect of time of day in the post-exercise systolic BP, diastolic BP and MAP during nocturnal sleep ($p > 0.126$). The mean values when averaged over the whole 5-hour nocturnal sleep period were similar between both times of day (Figure 2). Post-exercise heart rate was not affected by the time of day for exercise during nocturnal sleep ($p = 0.633$). However, heart rate during sleep demonstrated a significant effect of post-exercise time ($p = 0.048$). The trend for heart rate during sleep was a gradual reduction throughout the 5-hour nocturnal sleep period (Figure 2).

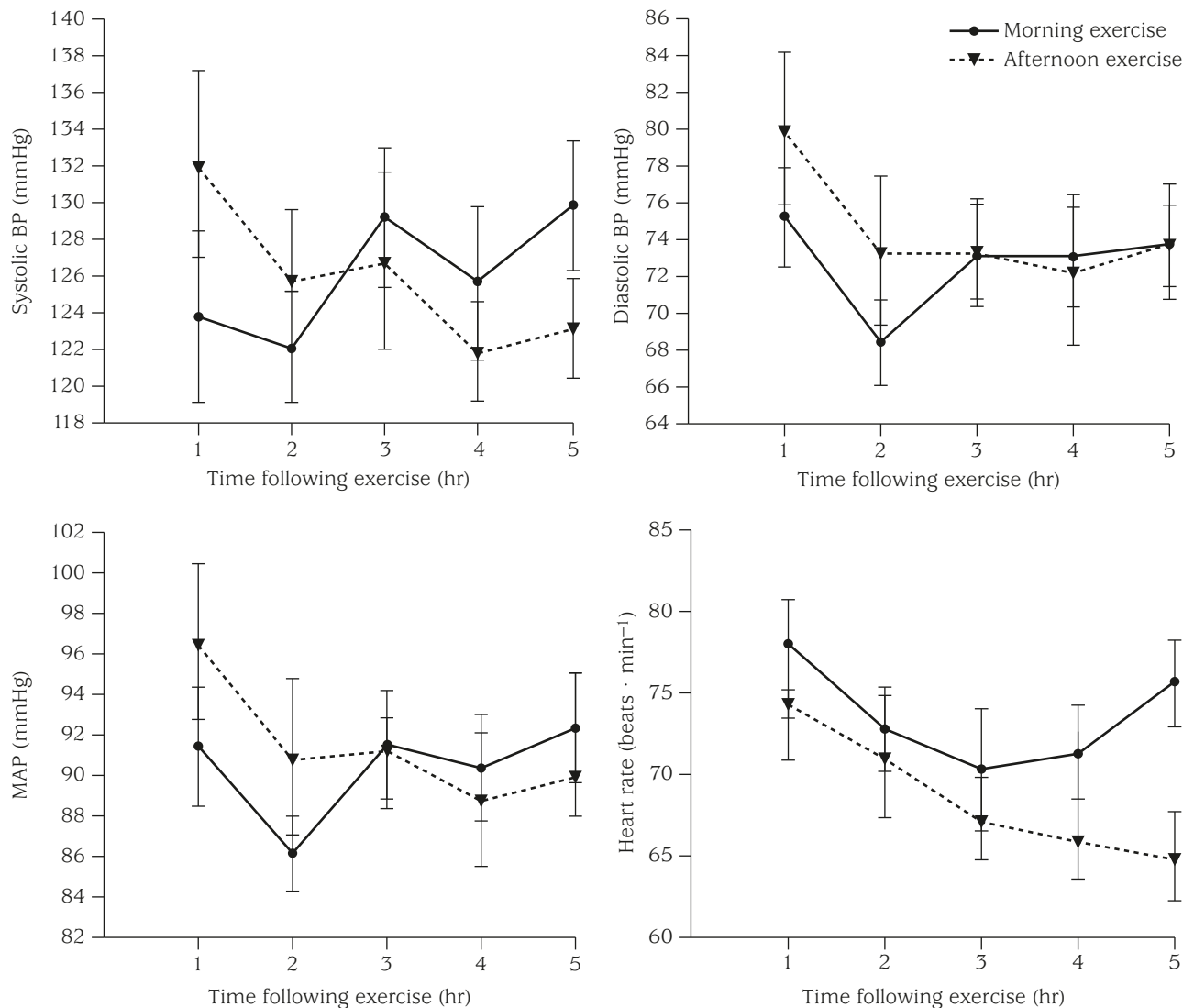


Fig. 1 Blood pressure (BP) and heart rate responses from the 20 minutes after exercise until the time of sleep. MAP=mean arterial pressure.

Post-exercise activity levels

Post-exercise activity levels were significantly greater following exercise at 08:00 hours compared to 16:00 hours from the 20 minutes after exercise until the time of sleep ($p=0.010$; 90% CI, -0.56 to -0.15 \log_e AU for the difference in activity between 08:00 vs. 16:00 hours).

There was a significant effect of post-exercise time for both times of day ($p=0.016$). The trend for the activity values was a gradual decrease throughout the 5-hour daytime period following exercise in the afternoon. However, following exercise in the morning, activity levels remained consistent throughout the 5-hour daytime period. These differences in time course showed a significant interaction between time of day

and post-exercise time ($p=0.005$). The difference in responses between both times of day was greater at 5 hours post-exercise compared to 1 hour post-exercise (Figure 3). The mean \pm SE difference was -0.33 ± 0.11 and -1.17 ± 0.38 \log_e AU for 1- and 5-hour post-exercise time points.

Post-exercise activity levels were not affected by time of day during nocturnal sleep ($p=0.850$). Mean \pm SE activity values when averaged over the whole 5-hour sleep period are shown in Figure 3. The general trend for activity during sleep was a gradual increase throughout the 5-hour period. Activity values during sleep showed a significant effect of post-exercise time ($p=0.01$). There were no interaction effects between time of day and post-exercise time ($p=0.839$).

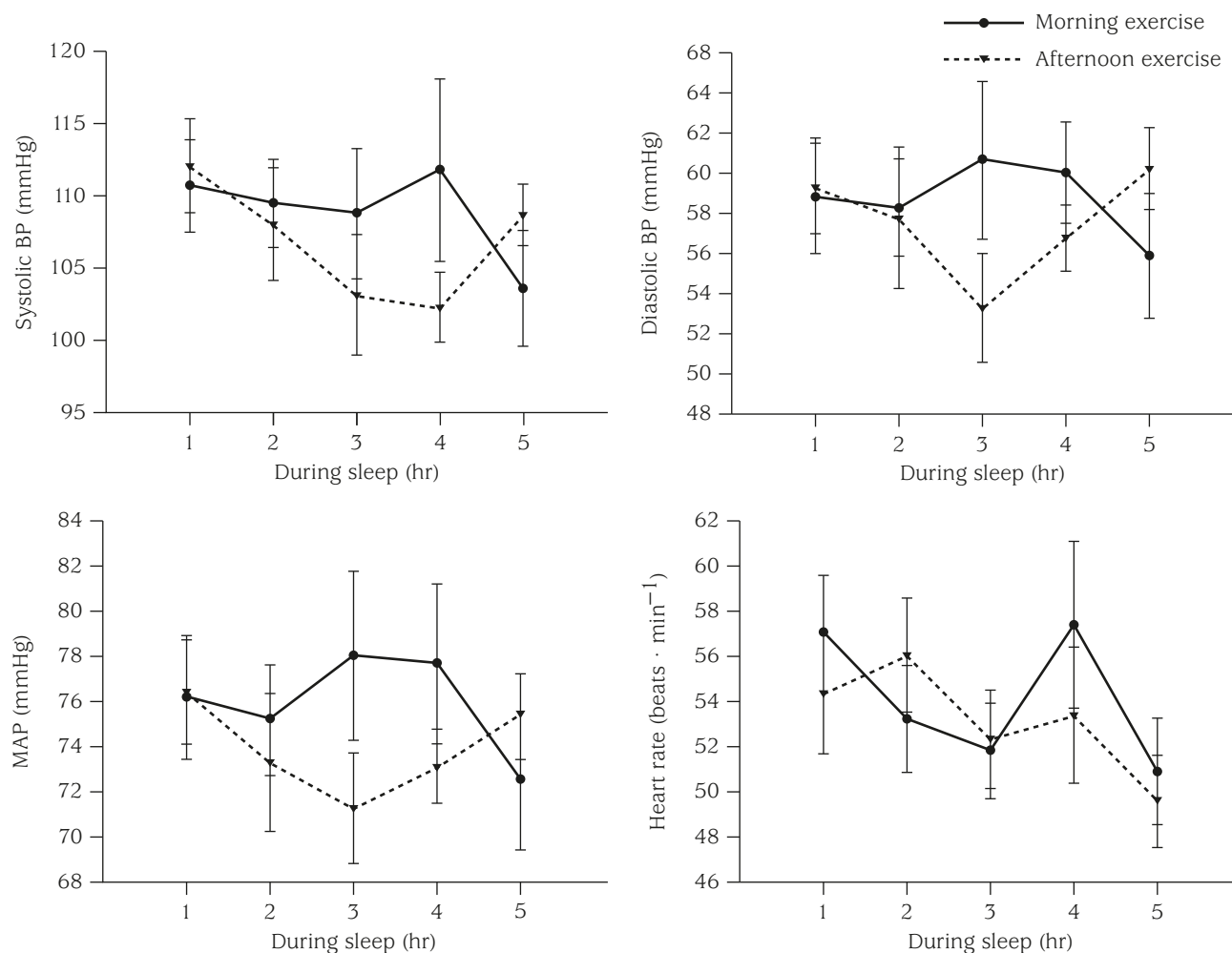


Fig. 2 Blood pressure (BP) and heart rate response during the 5-hour nocturnal sleep period. MAP = mean arterial pressure.

The nocturnal dip

The nocturnal dip in systolic BP, diastolic BP, MAP and heart rate were not different following morning and afternoon exercise bouts. The 90% CIs were -6.5 to 3.8% , 9.8 to 1.1% , -7.5 to 0.8% and -0.6 to 9.9% for nocturnal dip between morning versus afternoon exercise bouts for systolic BP, diastolic BP, MAP and heart rate, respectively. Mean \pm SE systolic BP, diastolic BP, MAP and heart rate during the nocturnal dip are shown in Figure 4. A positive percentage change indicates that the mean value recording during the waking period is higher than that recorded during sleep.

Discussion

In the present study, we employed ambulatory BP techniques to examine whether variation in the timing of an exercise bout yields differing effects on the magnitude

and time course of BP during subsequent everyday physical activities and nocturnal sleep. Since acute BP reductions (up to ~ 90 minutes post-exercise) have been shown to be greatest following afternoon exercise (Jones et al. 2008b), we hypothesized that BP would be lower following afternoon exercise and that this pattern would persist during everyday physical activities and extend into nocturnal sleep. Nevertheless, our data indicate that post-exercise systolic BP, diastolic BP and MAP responses during the 5-hour daytime period and nocturnal sleep period following exercise are not appreciably different when exercise is performed in the morning or afternoon in normotensive individuals. The results of this study suggest that the diurnal variation in acute PEH (Jones et al. 2008a,b) does not persist for a long period of time (< 90 minutes) and does not affect BP during sleep in normotensive individuals with a normal BP rhythm. The lack of difference in BP during everyday activities and nocturnal sleep in normotensive

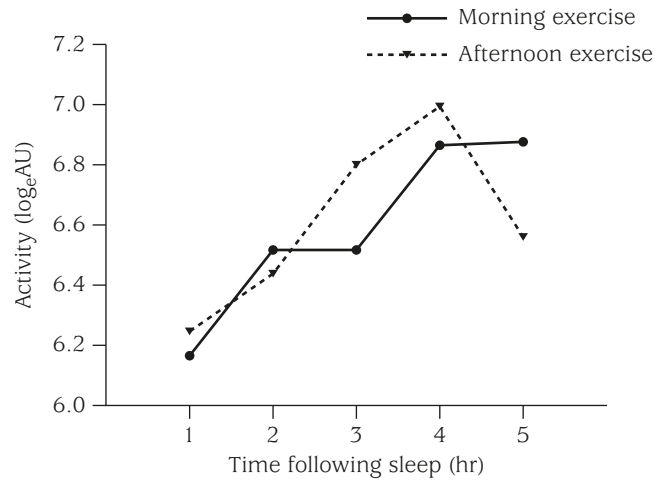
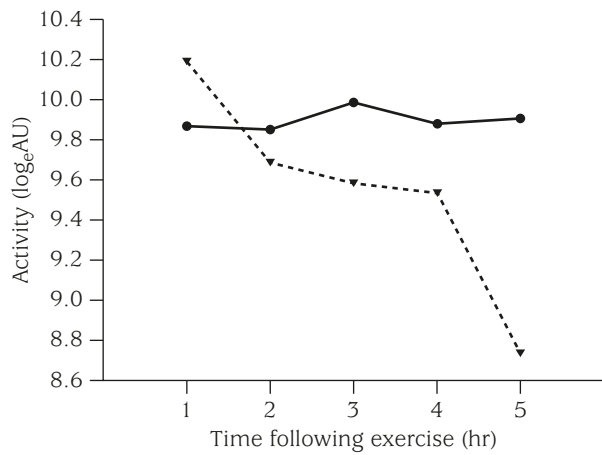


Fig. 3 Activity levels from the 20 minutes after exercise until the time of sleep and during nocturnal sleep.

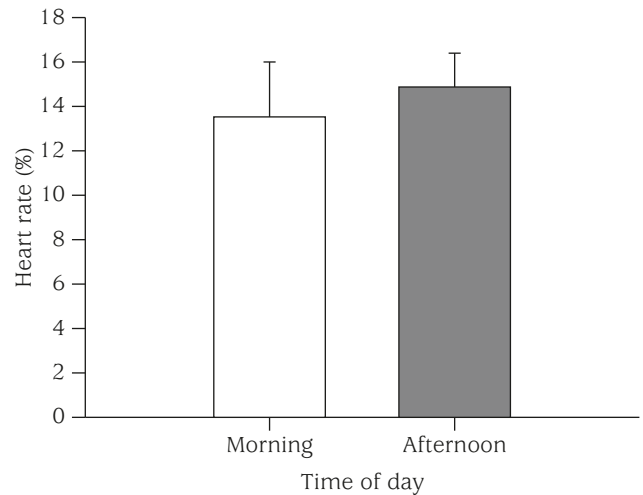
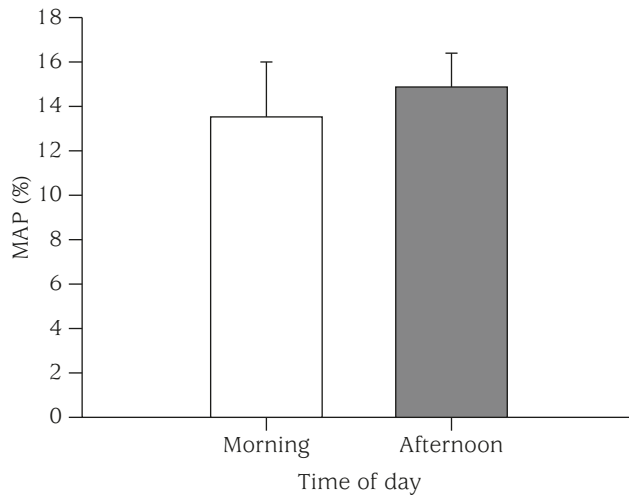
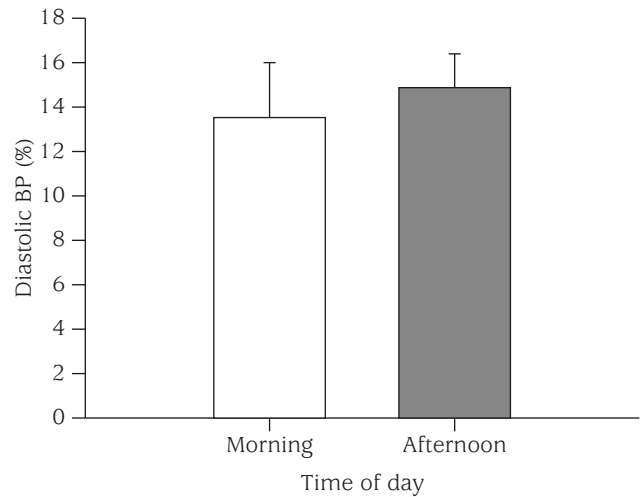
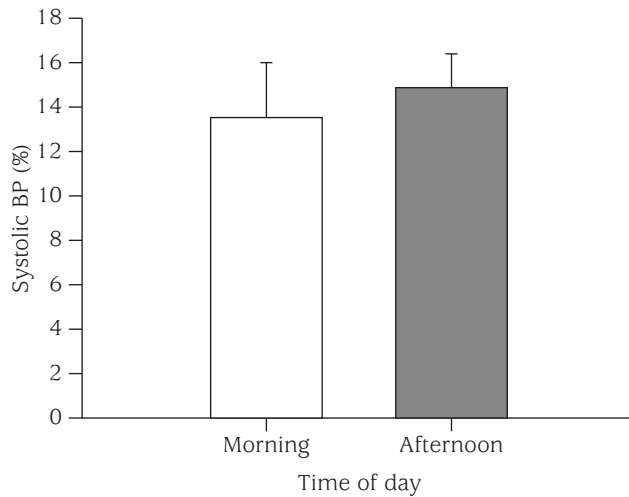


Fig. 4 Mean \pm standard error of sleep-wake differences in blood pressure (BP) and heart rate for morning and afternoon exercise bouts. MAP=mean arterial pressure.

individuals suggests that scheduling exercise in the morning or afternoon will have the same effects on BP in the longer term (i.e. < 90 minutes), including during the nocturnal sleep period.

Post-exercise daytime period

The lack of diurnal variation in systolic BP, diastolic BP and MAP during the 5-hour daytime period following exercise was evident despite greater physical activity levels and heart rate values after exercise in the morning. The differences in heart rate during this daytime period could be explained by the physical activity levels, because activity patterns differ with time of day due to work and rest schedules (Pickering 1988). In the current study, the participants were instructed to go about their everyday lives following the exercise bout. This involved a daytime work and night time rest schedule. Therefore, following the morning exercise bout, participants went to work, whereas participants were more likely to go home and rest in the evening following the afternoon exercise bout. Nevertheless, there was a general trend of a transient increase in systolic BP in the 5-hour daytime period following exercise in the morning. In the afternoon, systolic BP displayed a transient reduction. This trend cannot be totally explained by changes in activity as daytime activity levels did not transiently increase. Conversely, the trend in systolic BP could reflect the circadian rhythm of BP in that systolic BP had not reached the highest point of the day.

Nocturnal sleep period

The similar BP values during the nocturnal sleep period suggest that the longer-term ambulatory BP reduction following morning exercise observed in our previous study (Jones et al. 2009) is evident despite the time of day that exercise is scheduled. Heart rate during nocturnal sleep was also not different following morning or afternoon exercise. Nevertheless, heart rate displayed a gradual decrease during sleep following both exercise bouts. Somewhat surprisingly, the trend in general physical activity did not mirror that of heart rate. Rather, activity gradually increased during nocturnal sleep.

There was a general trend for systolic BP, diastolic BP and MAP to display lower values following afternoon exercise. This trend supports the findings of Park et al. (2005) who found the greatest BP reductions in “non-dippers” following evening exercise. It is noted that Park et al. (2005) studied people with hypertension and borderline hypertension rather than the normotensive people we studied. It could be that the individuals

with the highest BP values demonstrate the greatest BP lowering effects following exercise (Pescatello et al. 2004). Interstudy differences in research design could be another factor, especially in terms of the duration of the follow-up period and how this period relates to the timing of the sleep-wake cycle. Indeed, an important factor could be the delimitation of the nocturnal sleep period in each study. Park et al. (2005) defined a specific clock time (i.e. 22:00 to 06:00 hours for sleep period) to separate the daytime period from the sleep period. Conversely, we analyzed our data in terms of the specific sleep period of each participant, thereby controlling for individual sleep patterns and durations.

The nocturnal dip

The circadian rhythm in BP is characterized by a nocturnal fall that is commonly used to classify individuals as dippers (a BP reduction during sleep compared to daytime values) or non-dippers (no BP reduction during sleep). A normal BP reduction at night is defined as a BP reduction $\geq 10\%$ of average daytime values (Parati 2000). In the current study, no significant differences in the nocturnal dip were observed in systolic BP, diastolic BP, MAP or heart rate. Nevertheless, it is important to note that this does not indicate that an exercise bout has no effect on the nocturnal dip. We have reported previously that morning exercise at a similar intensity elicits a significant increase in the nocturnal dip (Jones et al. 2009), and the present findings simply suggest that the time of day exercise is performed does not affect this magnitude of the nocturnal dip.

Conclusion

Daytime BP during everyday physical activities and nocturnal sleep are not affected by the timing of prior exercise in the waking period for normotensive individuals. This finding is in contrast with the acute exercise data in our previous study (Jones et al. 2008b), suggesting that the diurnal variation in post-exercise BP is relatively short-lived, definitely not extending into the nocturnal sleep period.

References

- Atkinson G, Drust B, George K, Reilly T, Waterhouse J (2006). Chronobiological considerations for exercise and heart disease. *Sports Med* 36:487–500.
- Bird S, Davison R (1997). *Physiological Testing Guidelines*. The British Association of Sport and Exercise Sciences, Leeds.

-
- Gretler DD, Carlson GF, Montano AV, Murphy MB (1993). Diurnal blood pressure variability and physical activity measured electronically and by diary. *Am J Hypertens* 6:127-33.
- Hermida RC (2007). Ambulatory blood pressure monitoring in the prediction of cardiovascular events and effects of chronotherapy: rationale and design of the MAPEC study. *Chronobiol Int* 24:749-75.
- Jones H, Atkinson G, Leary A, George K, Murphy M, Waterhouse J (2006). The reactivity of ambulatory blood pressure to physical activity varies with time of day. *Hypertension* 47:778-84.
- Jones H, George K, Edwards B, Atkinson G (2008a). Effects of time of day on post-exercise blood pressure: circadian or sleep-related influences? *Chronobiol Int* 25:987-98.
- Jones H, Pritchard C, George K, Edwards B, Atkinson G (2008b). The acute post-exercise response of blood pressure varies with time of day. *Eur J Appl Physiol* 104:481-9.
- Jones H, Pritchard C, George K, Edwards B, Atkinson G (2009). Exercise intensity and blood pressure during sleep. *Int J Sports Med* 30:94-9.
- Kenney MJ, Seals DR (1993). Postexercise hypotension. Key features, mechanisms and clinical significance. *Hypertension* 22:653-64.
- Leary AC, Struthers AD, Donnan PT, MacDonald MT, Murphy MB (2002). The morning surge in blood pressure and heart rate is dependent on levels of physical activity after waking. *J Hypertens* 20:865-70.
- MacDonald JR (2002). Potential causes, mechanisms, and implications of post exercise hypotension. *J Hum Hypertens* 16:225-36.
- Middelkoop HA, van Dam EM, Smilde-van den Doel DA, Van Dijk G (1997). 45-hour continuous quintuple-site actimetry: relations between trunk and limb movements and effects of circadian sleep-wake rhythmicity. *Psychophysiology* 34:199-203.
- Millar-Craig MW, Bishop CN, Raftery EB (1978). Circadian variation of blood pressure. *Lancet* 1:795-7.
- Muller JE (1999). Circadian variation in cardiovascular events. *Am J Hypertens* 12:35S-42S.
- Muller JE, Tofler GH, Stone PH (1989). Circadian variation and triggers of onset of acute cardiovascular disease. *Circulation* 79:733-43.
- O'Brien E, Asmar R, Beilin L, Imai Y, Mancia G, Mengden T, Myers M, Padfield P, Palatini P, Parati G, Pickering T, Redon J, Staessen J, Stergiou G, Verdecchia P; European Society of Hypertension Working Group on Blood Pressure Monitoring (2005). Practice guidelines of the European Society of Hypertension for clinic, ambulatory and self blood pressure measurement. *J Hypertens* 23:697-701.
- O'Brien E, Petrie J, Littler W, de Swiet M, Padfield PL, O'Malley K, Jamieson M, Altman D, Bland M, Atkins N (1990). The British Hypertension Society protocol for the evaluation of automated and semi-automated blood pressure measuring devices with special reference to ambulatory systems. *J Hypertens* 8:607-19.
- Parati G (2000). Blood pressure reduction at night: sleep and beyond. *J Hypertens* 18:1725-9.
- Park S, Jastremski CA, Wallace JP (2005). Time of day for exercise on blood pressure reduction in dipping and nondipping hypertension. *J Hum Hypertens* 19:597-605.
- Pescatello LS, Franklin BA, Fagard R, Farquhar WB, Kelley GA, Ray CA; American College of Sports Medicine (2004). American College of Sports Medicine position stand. Exercise and hypertension. *Med Sci Sports Exerc* 36:533-53.
- Pickering TG (1988). The influence of daily activity on ambulatory blood pressure. *Am Heart J* 116:1141-5.
- Sterne JA, Davey Smith G (2001). Sifting the evidence—what's wrong with significance tests? *BMJ* 322:226-31.
- Whelton SP, Chin A, Xin X, He J (2002). Effect of aerobic exercise on blood pressure: a meta-analysis of randomized, controlled trials. *Ann Intern Med* 136:493-503.