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Abstract

Purpose: We aimed to identify circannual variations in physiological responses during unsteady-workload exercise. ***Methods:*** The study included 18 healthy men who provided written informed consent before participation. The study was performed in summer and winter. Heart rate (HR), blood pressure (BP), oral temperature, and cardiac autonomic nervous system modulation expressed as the natural logarithm of the high-frequency band of HR variability (lnHF) were measured at rest. All subjects performed a two-part cycling exercise (with steady and unsteady workload) for a total of 32 min, followed by recovery in the supine position for 10 min. The steady-state exercise test consisted of three 4-min bouts of exercise at 20%, 60%, and 40% of maximal oxygen intake ($\dot{V}O_2$max). The unsteady-workload exercise test consisted of five 4-min bouts of exercise with gradual increase and decrease in workload between 20% and 60% of $\dot{V}O_2$max. HR, systolic BP, diastolic BP, and rating of perceived exertion (RPE) were measured under both conditions. The HR maximal values, minimal values, amplitude, and phase lag (response to maximal/minimal workload) during unsteady-workload exercise were calculated. ***Results:*** Resting systolic and diastolic BP, as well as lnHF were significantly lower in summer than in winter, whereas no significant differences in HR or oral temperature were noted. During exercise, summer was associated with significantly higher HR, RPE, and HR amplitude, but significantly lower diastolic BP, and significantly longer HR phase lag during minimum and maximum workload. Post-exercise HR was significantly lower in winter than in the summer. There was no significant difference in systolic BP between the two seasons, but diastolic BP and lnHF were significantly higher in winter. ***Conclusion:*** Exercise prescriptions should take into consideration the human circannual rhythm to avoid adverse cardiac and cerebrovascular events during exercise.

Key words: circannual rhythm, heart rate amplitude, phase lag, parasympathetic nervous system

Introduction

Seasonal variations in climate occur in most regions of our planet (Atkinson & Drust, 2005) and are reflected in humans as the circannual rhythm, which affects physiological responses. For example, blood circulation volume is lower in winter than in summer, whereas basal metabolism, the level of activity in the autonomic nervous system, and systolic blood pressure (BP) are higher in winter than in summer (Japanese Society of Biometeorology, 1992). These responses are considered compensatory actions to maintain homeostasis of body temperature, since they were observed only in areas with substantial temperature differences between summer and winter (Japanese Society of Biometeorology, 1992). However, certain aspects, such as the characteristics and physiological mechanisms of the circannual rhythm remain unclear (Miyazaki, Nishimura, & Numata, 2016). Hiroshima city in Japan, where the present study was performed, has a warm and wet climate, characterized by distinguishable climatic differences across the seasons. In 2016, Hiroshima had a rainfall of 2,124 mm, average temperature of 17.2°C, and average humidity of 65.2% (Japan Meteorological Agency, 2017b). In winter (February), the average highest temperature was 11.0°C, the average lowest temperature was 2.7°C, and the average minimum humidity was 23%. In summer (August), the average highest temperature was 34.3°C, the average lowest temperature was 25.5°C, and the average minimum humidity was 16% (Japan Meteorological Agency, 2017a).

The circannual rhythm affects physiological response during exercise as well as at rest. Previous studies that observed seasonal changes in physiological response during Mountain climbing on the same route reported increased heart rate (HR), dehydration rate, and perspiration volume, as well as increased body temperature in summer than in winter (Nishimura, Takagi, & Onodera, 2012). Therefore, it is recognized that seasonal changes affect the exercise workload and, consequently, physiological response during exercise. For most individuals living away from the equator, the levels of leisure-time physical fitness and physical activity are generally lower during winter than during summer months (Atkinson & Drust, 2005). On the other hand, empirical evidence indicates that there is a decrease in aerobic exercise capacity and training effects in the summer (Japanese Society of Biometeorology, 1992). However, the relevance of certain aspects potentially affecting the seasonal changes in physiological response at rest or during exercise have not been clarified, including physical strength level, lifestyle, or diet (Japanese Society of Biometeorology, 1992).

Human adaptability to exercise can be evaluated through unsteady-workload exercise tests during which sinusoidal exercise workload is applied (Bakker, Struikenkamp, & De Vries, 1980; Fukuoka, Gwon, Sone, & Ikegami, 1995; Fukuoka, Nakagawa, Ogoh, Shiojiri, & Fukuba, 2002; Nabekura, Yoshioka, Nakagaki, Tsujimura, & Sengoku, 2007; Sone, Yamazaki, Fujii, Fukuoka, & Ikegami, 1997), or the workload is gradually increased and decreased (Nishimura et al., 2016; Nishimura et al., 2010; Nishimura et al., 2011). The HR amplitude, which reflects the relative burden on the body, and the HR phase lag, which reflects the temporal delay of the physiological response to workload fluctuations, as well as oxygen uptake have been shown to be affected by cardiopulmonary fitness (Fukuoka et al., 1995), physical fitness status (Fukuoka et al., 1995), and low-intensity aerobic training (Nabekura et al., 2007).

Because both competitive sports and sports club activities are commonly performed both outdoors and indoors without control of room temperature or humidity, it is important to clarify potential circannual variations in physiological response during exercise. Such information is meaningful not only for improving exercise performance (e.g., in terms of training effects) but also for devising strategies to prevent injury during exercise. The purpose of the present study was to identify potential circannual variations in human adaptability to exercise using an unsteady-workload exercise test. We hypothesized that exercise in winter would enhance physiological responses, such as HR amplitude and phase lag during unsteady-workload exercise, and HR and RPE during exercise would be higher in summer than in winter, bur diastolic BP during exercise would be higher in winter.

Methods

Study design

Eighteen healthy men volunteered to participate in the study. All experiments (exercises and measurements) were performed indoors in a dedicated exercise room in the city of Hiroshima, Japan. We established two experimental conditions for each participant: bicycle exercise in summer (August) and bicycle exercise in winter (February). Each subject participated in the experiment conducted under both conditions, in random order. All subjects were tested after they had controlled their sleeping hours, diet, and physical activity. The HR amplitude and phase lag were calculated as indicators of human adaptability. All procedures were reviewed and approved by the Ethics Committee, and the study protocol conformed to the Helsinki Declaration.

Subjects

Eighteen healthy men (mean age, 23.4 ± 1.9 years; height, 171.0 ± 4.7 cm; body weight, 67.6 ± 5.4 kg; body mass index, 23.2 ± 2.2 kg/m^2; and maximum oxygen consumption [$\dot{V}O_2$max]: relative, 47.4 ± 8.1 mL/kg/min; absolute, 3.38 ± 0.47 L/min) volunteered to participate in the study. All subjects were normotensive, non-obese, non-smokers with no evidence of cardiovascular disease based on medical history and resting electrocardiogram. The subjects reported performing physical exercise activities regularly. All subjects were informed of the benefits and risks of the present study, and all provided written informed consent for participation prior to being included in the study.

Measurements

Before the experiment, each subject performed a graded exercise test for calculating $\dot{V}O_2$max in summer. The cycling exercise consisted of 90 seconds of pedalling during each exercise stage at a rate of 60 rpm on an electrically-braked cycle ergometer (Aerobike 75XL II; Combi Wellness Corp., Tokyo, Japan). The initial exercise intensity was 20 W, which was increased by 20 W for each stage. The subjects were instructed to stop the exercise at the rating of perceived exertion (RPE) of 20 (Borg scale) or when the HR reached 100% of the predicted maximum HR.

We established two experimental conditions for each participant, exercise in summer (August) and winter (February). All subjects performed a cycling exercise for 32 min. The exercise tests had two parts, namely a 12-min calibration test (steady-state exercise) and a 20-min unsteady-workload exercise test (Nishimura et al., 2015; Nishimura et al., 2016; Nishimura et al., 2010; Nishimura et al., 2011). The workload during cycling exercise was the same for both conditions. The steady-state exercise consisted of three 4-min bouts of exercise at 20%, 60%, and 40% $\dot{V}O_2$max and steady load. The unsteady-workload exercise consisted of five exercise bouts with gradual increase and decrease in workload between 20% and 60% $\dot{V}O_2$max. During a single bout of exercise, the workload of 40% was increased gradually in increments of 5% of $\dot{V}O_2$max every 15 seconds; similarly, from an intensity corresponding to 60% of $\dot{V}O_2$max, gradual reduction was carried out in increments of 5% of $\dot{V}O_2$max every 15 seconds until an intensity corresponding to 20% of $\dot{V}O_2$max was reached. After exercise, the participants remained at rest in the supine position for 10 min (post-exercise recovery).

Each subject participated in the summer and winter exercise, in random order. The trials were performed between 9:00 and 11:00 h under both conditions. The subjects did not have breakfast before the trial, and no caffeine-containing products were allowed for 3 hours before the trials.

Measurements of HR, BP, cardiovascular autonomic nervous system (ANS) activity, and oral temperature were performed with the participant at rest in the supine position. HR was defined as the number of R waves noted in 1 min on electrocardiogram waveforms, which were obtained using bipolar chest leads (LRR-033 memory heart rate monitor; Arm Electronics, Tokyo, Japan). HR was recorded over a 5-min interval, and the mean value was retained for analysis. BP was measured with the auscultatory method. The same investigator measured BP in all experiments. Resting BP was recorded as the mean value of the measurements taken at 4 and 5 min. Cardiovascular ANS activity was measured via the maximum entropy calculation method, using the MemCalc/Tarawa software system (GMS, Tokyo, Japan) for real-time analysis of HR fluctuation. The electrocardiogram data obtained and amplified from bipolar chest leads were digitized using a 12-bit analogue-to-digital converter (AD12-8(PM); Contec, Qinhuangdao, China) and uploaded on a personal computer (IBM, Armonk, NY, USA) running on Microsoft Windows XP, where the frequency analysis of R-R interval variability over the last 30 s was performed using MemCalc. The powers of the low-frequency (LF; 0.04–0.15 Hz) and high-frequency (HF; 0.15–0.40 Hz) bands of the variability spectrum were calculated via a protocol described in detail elsewhere (Pomeranz et al., 1985). In addition, the HF component, which was converted to a natural logarithm (lnHF) to ensure a normal distribution, was used as an indicator of cardiovascular parasympathetic nervous system activity (Nishimura et al., 2015; Nishimura et al., 2014; Nishimura et al., 2016; Nishimura et al., 2010; Nishimura et al., 2011). In order to exclude the effect of respiratory rate on cardiovascular parameters, an electronic metronome was used to pace the respiratory rate at one breath every 4 s (2 s of inspiration and 2 s of expiration) (Brown, Beightol, Koh, & Eckberg, 1993; Hayano et al., 1994). Oral temperature was measured using a digital thermometer (MC-672; Omron Healthcare, Kyoto, Japan).

HR, BP, and RPE were measured during the exercise tests. During the steady-state exercise, HR was recorded over each 4-min exercise bout, and the mean values at 3 and 4 min were retained for analysis. During the unsteady-workload exercise test, the maximum and minimum values of HR were calculated using a quadratic function to plot HR as a function of exercise duration (Nishimura et al., 2015; Nishimura et al., 2016; Nishimura et al., 2010; Nishimura et al., 2011). The HR amplitude was calculated as the ratio between the value recorded during the unsteady-workload exercise test (maximum value minus minimum value) and the value recorded during the steady-state exercise (value at 60% of $\dot{V}O_2$max minus value at 20% of $\dot{V}O_2$max) (Nishimura et al., 2015; Nishimura et al., 2016; Nishimura et al., 2010; Nishimura et al., 2011). The HR phase lag was calculated as the time required for the maximum (or minimum) workload to be reflected into the maximum (or minimum) value of the HR (Nishimura et al., 2015; Nishimura et al., 2016; Nishimura et al., 2010; Nishimura et al., 2011). BP was measured at 150–210 s into each steady-state exercise bout. During the unsteady-workload exercise test, BP was recorded as the mean value of measurements taken during maximum and minimum workload. The subjects were asked to demonstrate their RPE during maximum and minimum workload. HR, BP, and ANS activity were measured during the post-exercise recovery period. Specifically, HR was obtained for every 1-min interval; BP was taken at 1, 3, 6, and 11 min post-exercise; cardiovascular ANS activity was recorded over a 5-min interval (minutes 6–11 post-exercise), and the mean value was retained for analysis. During minutes 6–11 of the post-exercise recovery period, an electronic metronome was used to pace the respiratory rate at one breath every 4 s (2 s of inspiration and 2 s of expiration).

The body weight was measured before and after the experiment. The body weight loss and rate of body weight loss were calculated. The wet-bulb globe temperature (WBGT), ambient temperature (Ta), and humidity were measured for each experimental condition.

Statistical analysis

Data were expressed as mean ± standard deviation. The RPE was expressed as median ±interquartile range. First, the summer and winter distribution of values for each parameter were tested using the F-test of equality of variances. Normality analysis indicated that none of the data sets were distributed normally, and therefore the Wilcoxon Signed-Rank test was used for comparing the values of each parameter recorded during the summer and winter trials. **The environmental parameter was tested using the unpaired-samples t-test.** The level of statistical significance was set at $p < 0.05$. All calculations were performed using the Statistical Package for Social Science (SPSS) version 20 for Windows (IBM, Armonk, NY, USA).

Results

Table 1 provides information regarding the environmental conditions during summer and winter. The WBGT, Ta, and humidity were significantly lower in winter (all, $p < 0.0001$). There were no significant differences in age, height, body weight, or body mass index between summer and winter. Table 2 provides an overview of the physiological parameters recorded at rest in the supine position, during the summer and winter. The parameters of lnHF, systolic BP, and diastolic BP were significantly higher in winter (all, $p < 0.05$). There were no significant differences in HR or oral temperature between the two seasons.

Table 3 provides an overview of the physiological parameters recorded during the exercise in winter and summer. HR at 20%, 60%, and 40% of $\dot{V}O_2$max were significantly lower in winter (**p = 0.0002, p = 0.0038, and p = 0.0021**, respectively). The maximum and minimum values of HR were significantly lower in winter than in summer (maximum HR, **p = 0.0009; minimum HR; p = 0.0018**, respectively). Systolic BP did not differ significantly between the two conditions, regardless of exercise intensity (20%, 60%, or 40% of $\dot{V}O_2$max, maximum or minimum workload). However, diastolic BP was significantly higher in winter at 20%, 60%, and 40% of $\dot{V}O_2$max (**p = 0.0065, p = 0.0121, and p = 0.0012, respectively**). Diastolic BP was significantly higher in summer for both maximum and minimum workload (**p = 0.0012 and p = 0.0009**, respectively). RPE at 20%, 60%, or 40% of $\dot{V}O_2$max did not differ significantly between the two conditions. RPE was significantly lower in winter at both maximum and minimum workload (**p = 0.0294 and p = 0.0231**, respectively).

Table 4 shows the HR amplitude and phase lag recorded during unsteady-workload exercise in summer and winter. The HR amplitude was significantly lower in winter (**p = 0.0249**). Additionally, the HR phase lag was significantly shorter in winter, both for maximum and minimum workload (**p = 0.0038 and p = 0.0303**, respectively).

Figure 1 displays the evolution of physiological parameters during recovery after exercise. Post-exercise HR was significantly lower in winter than in summer (all, $p < 0.005$). There was no significant difference in systolic BP between the two conditions, but diastolic BP was significantly higher in winter at 1 and 3 min post-exercise ($p = 0.0053$ and $p = 0.0092$, respectively). Winter was also associated with significantly higher lnHF ($p = 0.0382$). Table 5 shows the body weight loss in summer and winter. Body weight loss was significantly lower in winter than in summer (**p = 0.0077**).

Discussion

The results of the present study can be summarized as follows: 1) systolic BP, diastolic BP, and cardiovascular parasympathetic nervous system activity at rest were significantly higher in winter than in summer; 2) HR and RPE during exercise were significantly higher but the diastolic BP was significantly lower in summer; 3) HR phase lag was significantly shorter in winter; 4) during recovery after exercise, HR was significantly higher, whereas diastolic BP and cardiovascular parasympathetic nervous system activity were significantly lower in summer. These results demonstrate that, compared to summer, winter results in a reduction in the relative exercise intensity at the same workloads, potentially leading to enhanced physiological response, such as HR phase lag, which supports the original hypothesis of our study.

In the present study, $\dot{V}O_2$max values were measured in summer, under laboratory conditions, in an air-conditioned environment. Previous studies on seasonal variations have suggested that oxygen intake is not sensitive to the season (Japanese Society of Biometeorology, 1992). The reason for the seasonal variation in $\dot{V}O_2$max observed in the subjects of our present study remains unknown because we did not perform equivalent measurements in winter.

At rest, systolic BP, diastolic BP, and lnHF differed significantly between winter and summer, whereas no such differences were noted for HR or oral temperature. Previous studies on the seasonal variation of physiological response at rest have reported that, in winter, the compensatory mechanisms achieve homeostasis of the body temperature by the following cascade of actions: increase in basal metabolism, reduction in blood circulation volume, enhancement of ANS activity, elevation in systolic BP, and reduction in respiratory volume (Japanese Society of Biometeorology, 1992). The findings of the present study confirm the existence of the circannual rhythm in humans, in agreement with the results of previous studies on the same subject.

During exercise, HR and RPE were significantly higher in summer than in winter, suggesting that summer was associated with higher relative burden for the same workload. These findings are in agreement with previous observations that the season (summer vs. winter) influences HR and RPE during climbing (Nishimura et al., 2012). In the present study, the rate and range of increase in exercise intensity based on HR was 8.6 ± 7.4% and 8.5 ± 7.1 bpm. Taking this difference into account may help prevent cardiovascular events during exercise. In addition, the relative increase in exercise intensity in the summer might have been caused by other factors such as increase in body temperature, haemoconcentration accompanying perspiration (which represents a decrease in the burden of the cardiovascular system), and decrease in ventilation efficiency (Japanese Society of Biometeorology, 1992). We found systolic and diastolic BP at rest to be significantly higher in the winter than in summer, which might contribute to reduced vascular compliance in winter. However, during exercise, there was no significant difference in systolic BP, while HR and diastolic BP were higher in winter, suggesting a circannual variation in baroreflex sensitivity. The circannual variation in systolic and diastolic BP during exercise were the novel findings of this study.

The HR phase lag during maximum and minimum workload were significantly shorter in winter than in summer, suggesting that the index of adaptability to exercise was greater in winter, and that the adaptability to exercise might have seasonal variation in humans. The HR phase lag reflects the temporal delay in physiological response, and has been shown to be affected by cardiopulmonary fitness, physical fitness status, and low-intensity aerobic training (Fukuoka et al., 1995; Nabekura et al., 2007). The HR phase lag is controlled by modulation of the cardiac parasympathetic nervous system (Sone et al., 1997). Therefore, the higher activity level of the cardiac parasympathetic nervous system at rest in winter may result in shorter HR phase lag during exercise. In the present study, the ANS dynamics during exercise were not investigated; however, we found that the activity level of the cardiac parasympathetic nervous system at rest and post-exercise was significantly higher in winter than in summer, which suggests that the winter activity level of the cardiac parasympathetic nervous system might also be higher during exercise. Since parasympathetic withdrawal is faster than sympathetic activation, these findings suggest that there may be seasonal changes in the rate of decrease in parasympathetic nervous system activity during exercise. If winter conditions suppresse the decline of the cardiac parasympathetic nervous system, then it might be preferable for individuals with low cardiac parasympathetic nervous system modulation (e.g., elderly individuals or diabetic patients) to perform exercise in winter rather than in summer. However, systolic and diastolic BP at rest were higher in winter; moreover, cardiovascular events, such as myocardial infarction or cerebral infarction, occur more frequently in winter, so it is necessary to consider the effect of other aspects including exercise intensity. We observed that HR amplitude was significantly lower in winter, which is likely related to the fact that, during summer, HR was higher at low intensities (20% of VO_2max).

During recovery after exercise, HR was significantly higher in summer than in winter, whereas the reactivation of the cardiac parasympathetic nervous was significantly delayed in summer. Additionally, physiological responses similar to those noted during exercise were observed for at least 10 minutes after exercise. Finally, diastolic BP was significantly lower in summer than in winter, suggesting that, when planning exercise routines that are to be performed in summer, one should consider that longer rest periods are required between exercise bouts because cardiovascular response is delayed. In winter, cardiovascular response during post-exercise recovery is greater, and when exercise is accompanied by sweating, the rate of decrease in body temperature (which was increased by the influence of low environmental temperature) and the heat of vaporization caused by perspiration increase (Japanese Society of Biometeorology, 1992). In other words, during exercise after rest, exercise performance might decline and the risk of injury associated with exercise increases.

The present study had several limitations. All subjects were male, normotensive, non-obese, non-smokers with no evidence of cardiovascular disease, who performed exercise regularly. Therefore, there is a possibility that our conclusions are not applicable to the general population. In order to generalize the findings of the present study, it might be necessary to consider age, sex, underlying diseases, and lifestyle factors such as smoking and exercising habits. In this study, the exercise workload was calculated based on the maximum oxygen uptake during the summer exercise, while the physiological responses during cycling exercise with the same workload were observed for summer and winter. The present study did not measure the cardiac ANS activity during exercise because we could not adequately control respiratory rate and volume. For this reason, we evaluated ANS activity at rest and during the recovery period, when respiratory adjustment could be made using the metronome. The dynamics of the cardiac ANS during exercise were not assessed, which represents a limitation of this study. Furthermore, the present study measured BP using the auscultatory method, and the time for BP measurements was 30 seconds. Because of this, it is possible that the BP measured during the unsteady-workload exercise test was not actually a maximum or minimum value, which is another limitation of this study. Further studies are warranted to determine the dynamics of the cardiac ANS and the BP trend during exercise.

In the present study, we demonstrated that there are seasonal fluctuations in physiological response not only at rest but also during exercise. Interestingly, compared to the summer, the winter resulted in a reduction in the relative exercise intensity at the same workloads, which may have resulted in improved physiological response such as HR phase lag. Moreover, physiological responses similar to those recorded during exercise were observed for at least 10 minutes after exercise. These represent novel findings of the present study. Thus, not only does the adaptability to exercise exhibit circannual variation in humans, but the index of adaptability to exercise is likely greater in winter than in summer. Therefore, when exercising in summer, it is necessary to keep in mind that the relative exercise intensity is higher. Specifically, the burden on the cardiovascular system at the same load increases, and the break time between exercise bouts should be longer. In winter, the BP responses at rest were high; therefore, low-to-medium intensity exercise is considered optimal to avoid cardiovascular events.

Public interest statement

This experimental study enrolled 18 men who performed cycling exercises in summer and winter, with steady and unsteady workload. We monitored various physiological parameters at rest, during steady-state exercise, during unsteady-workload exercise, and during the post-exercise period. Our findings indicate that there are seasonal fluctuations in physiological responses not only at rest, but also during exercise. Furthermore, compared to summer, winter results in reduced relative exercise intensity at the same workloads, which may have resulted in improved physiological responses. This improvement persisted for at least 10 minutes after exercise. We believe that our study makes a significant contribution to the literature because it not only confirms that physiological response to exercise reflects the circannual rhythm in humans, but also explains the advantages and disadvantages of exercising during summer and during winter for various target populations.

About the author

The author belongs to the Department of Global Environment Studies, Hiroshima Institute of Technology, Japan. The author’s specialty is exercise physiology, and papers are mostly published on unsteady workload exercise and human adaptability and followability (*Journal of Strength and Conditioning Research, 30, 2016, 1735–1742.*). In addition, we have developed a research that combines chronobiology and exercise physiology; we have also published papers on circadian variations and physiological responses during exercise (*Kinesiology, 46, 2014, 164–170.*). It has won the Grants-in-Aid for Scientific Research in the context of the chronobiology and mental health.

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Table 1. The environmental parameters

	Summer	Winter	P value	Effects size
WBGT (ºC)	25.1 ± 1.0	8.7 ± 0.7	< 0.0001	1.00
Ta (ºC)	28.2 ± 0.8	13.2 ± 1.2	< 0.0001	0.99
Humidity (%)	69.0 ± 10.5	39.1 ± 4.9	< 0.0001	0.90

Data are expressed as mean ± standard deviation.

WBGT, wet bulb globe temperature; Ta, ambient temperature

Table 2. Physiological parameters recorded at rest in the supine position

Parameter	Summer	Winter	***p***-value	Effects size
HR (bpm)	64.4 ± 10.0	62.5 ± 11.0	0.1446	-0.34
lnHF	6.00 ± 1.11	6.49 ± 0.98	0.0231	-0.58
SBP (mmHg)	110.1 ± 12.5	118.7 ± 11.7	0.0009	-0.79
DBP (mmHg)	59.6 ± 10.7	67.1 ± 10.6	0.0451	-0.47
Oral temperature (ºC)	36.76 ± 0.18	36.45 ± 0.46	0.2477	-0.27

Each experiment was performed under two conditions (winter vs. summer).

Data are expressed as mean ± standard deviation.

lnHF, natural logarithm of the high-frequency bands of HR variability; HR, heart rate; SBP, systolic blood pressure; DBP, diastolic blood pressure

Table 3. Physiological parameters recorded during exercise

Heart rate	Summer (bpm)	Winter (bpm)	***p***-value	Effects size
20% of $\dot{V}O_2$max	96.0 ± 10.8	86.8 ± 9.0	0.0002	-0.87
60% of $\dot{V}O_2$max	138.3 ± 10.9	132.4 ± 9.8	0.0038	-0.68
40% of $\dot{V}O_2$max	126.9 ± 13.0	118.6 ± 10.4	0.0021	-0.72
Maximum value	143.1 ± 13.7	132.4 ± 11.0	0.0009	-0.79
Minimum value	123.6 ± 14.7	113.7 ± 11.9	0.0018	-0.73

Data are expressed as mean ± standard deviation.

Systolic blood pressure	Summer (mmHg)	Winter (mmHg)	***p***-value	Effects size
20% of $\dot{V}O_2$max	120 ± 15	120 ± 16	0.9321	-0.02
60% of $\dot{V}O_2$max	163 ± 18	164 ± 20	0.9479	-0.02
40% of $\dot{V}O_2$max	141 ± 11	143 ± 14	0.7439	-0.08
Maximum workload	150 ± 15	151 ± 14	0.8961	-0.03
Minimum workload	135 ± 13	133 ± 12	0. 5713	-0.13

Data are expressed as mean ± standard deviation.

Diastolic blood pressure	Summer (mmHg)	Winter (mmHg)	***p***-value	Effects size
20% of $\dot{V}O_2$max	56 ± 10	66 ± 12	0.0065	-0.64
60% of $\dot{V}O_2$max	48 ± 18	58 ± 18	0.0121	-0.59
40% of $\dot{V}O_2$max	44 ± 9	56 ± 14	0.0012	-0.76
Maximum workload	44 ± 7	53 ± 11	0.0012	-0.76
Minimum workload	47 ± 10	59 ± 13	0.0009	-0.79

Data are expressed as mean ± standard deviation.

Rating of perceived exertion	Summer	Winter	***p***-value	Effects size
20% of $\dot{V}O_2$max	7 (7-8)	7 (7-7)	0.4469	-0.18
60% of $\dot{V}O_2$max	11 (8-13)	11.5 (9-13)	0.3863	-0.21
40% of $\dot{V}O_2$max	10.5 (8-12)	9.5 (8-11)	0.1263	-0.36
Maximum workload	12.1 (8.5-13.3)	11.6 (8.0-12.8)	0.0294	-0.51
Minimum workload	9.5 (8.0-11.9)	8.7 (7.9-10.4)	0.0231	-0.54

Data are expressed as median ±interquartile range.

Table 4. Heart rate amplitude and phase lag (response to workload fluctuations) during unsteady-workload exercise

Parameter	Summer (%)	Winter (%)	***p***-value	Effects size
Amplitude	46.2 ± 8.4	41.4 ± 8.7	0.0249	-0.53

Phase lag	Summer (sec)	Winter (sec)	***p***-value	Effects size
Maximum workload	48.9 ± 6.3	43.3 ± 7.6	0.0038	-0.68
Minimum workload	43.8 ± 7.8	39.8 ± 7.5	0.0303	-0.51

Data are expressed as mean ± standard deviation.

Table 5. The comparison of body weight loss

	Summer	Winter	P value	Effect size
Body weight loss (kg)	0.43 ± 0.17	0.13 ± 0.08	0.0077	-0.89

Data are expressed as mean ± standard deviation.

Figure legends

Figure 1. Physiological parameters during recovery after exercise. Heart rate (a), blood pressure (b), and the natural logarithm of the high-frequency band of heart rate variability (lnHF, c) are shown.

W, winter; S, summer

(a) ○▽: Winter, ●▼: Summer

(b) ○●**:** systolic blood pressure**,** ▽▼**:** diastolic blood pressure

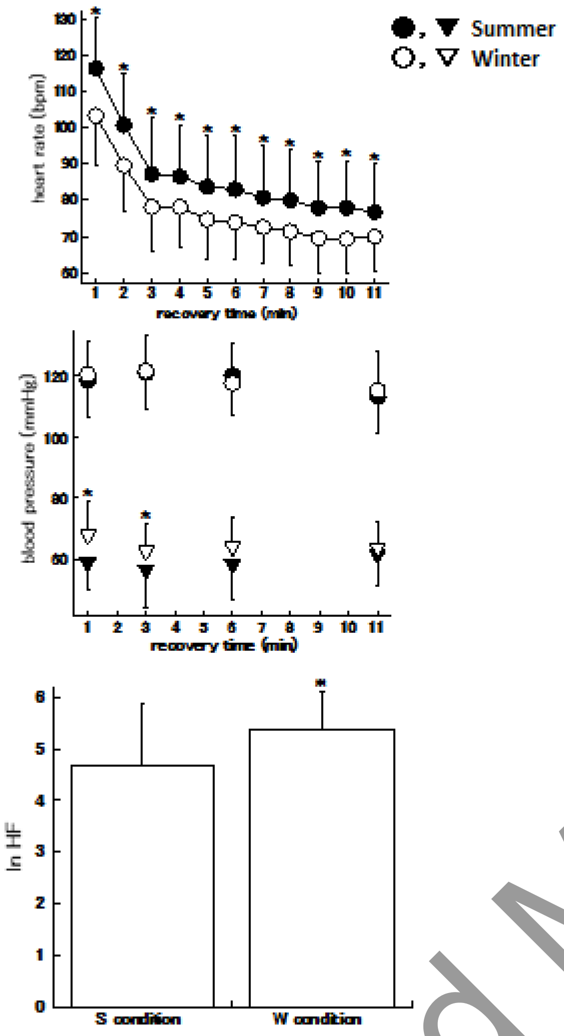
●, ▼ Summer
○, ▽ Winter
heart rate (bpm)
130
120
110
100
90
80
70
60
*
1 2 3 4 5 6 7 8 9 10 11
recovery time (min)
blood pressure (mmHg)
120
100
80
60
1 2 3 4 5 6 7 8 9 10 11
recovery time (min)
ln HF
6
5
4
3
2
1
0
S condition
W condition

Figure 1