The influence of short-term sedentary behavior on circadian rhythm of heart rate and heart rate variability

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ABSTRACT

The notion that sedentary behavior is harmful to human health is widespread. Little is known about the short term influence of sedentary behavior on heart rate (HR) and heart rate variability (HRV) circadian rhythms. Therefore the purpose of the present study was to examine the influence of short term sedentary behavior on the circadian rhythms of HR and HRV using cosine periodic regression analysis. Sixteen healthy young students were included in a randomized crossover study. All subjects underwent 24-h ECG Holter monitoring in two different states of physical activity, an active condition (more than 15,000 steps per day) and a sedentary condition (less than 1,000 steps per day). Hourly mean values were calculated for HR and HRV, and then were evaluated using cosine periodic regression analysis. The circadian rhythm parameters, amplitude, mesor, and acrophase for HR and HRV variables were obtained. As a result, the significance of the circadian rhythm was confirmed for all variables in each condition. The measure of fit R^2 value was decreased in sedentary condition. The amplitude of the sedentary condition was significantly smaller than that of the active condition with respect to HR (7.94 ± 1.91 bpm vs. 15.4 ± 3.93 bpm, $p < 0.001$), natural log of the high frequency measurement (lnHF) (0.38 ± 0.21 ms^2 vs. 0.80 ± 0.28 ms^2, $p < 0.001$), and low frequency/high frequency ratio (LF/HF) (0.75 ± 0.54 vs. 1.24 ± 0.69, $p = 0.008$). We found that sedentary behavior not only significantly lowered the amplitude of HR and HRV variables, but also might have led to weakness of the circadian rhythm of the HR and HRV variables.

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The Influence of short term sedentary behavior on circadian rhythm of heart rate and heart rate variability.

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Introduction

Public health recommendations state that every adult should perform moderate-to-vigorous physical activity regularly (Haskell et al. 2007). Physical activity is known to reduce the risk of type 2 diabetes (Gill & Cooper 2008), cardiovascular disease (Erlichman et al. 2002; Thompson 2003; Wannamethee & Shaper 2002), and premature mortality (Lollgen et al. 2009; Erlichman et al. 2002). On the contrary, several studies have reported that sedentary behavior is associated with an increased risk of all-cause and cardiovascular disease mortality, independent of leisure-time exercise levels (Dunstan 2010; Pinto et al. 2012). The term sedentary behavior is characterized by any waking behavior while in a seated or reclined posture with an energy expenditure range of 1.0 - 1.5 METs (multiples of the basal metabolic rate) (Ainsworth et al. 2000; Owen et al. 2010). It is estimated that adults spend an average of 51-68% of their waking life in sedentary behavior (Matthews et al. 2008; Healy et al. 2008). Even in physically active adults, reducing the overall time spent sitting is likely to confer health benefits (Dunstan et al. 2012). In mammals, a master circadian pacemaker, located in the suprachiasmatic nucleus (SCN), is affected by light and darkness, feeding patterns, and physical activity (Lax et al. 1998; Lall et al. 2012). Heart rate (HR) and heart rate variability (HRV), which reflect the activity of the cardiac autonomic nervous system, are the representative indices that indicate the circadian rhythm. The relationship between physical activity and HRV (Buchheit et al. 2004; Melo et al. 2005), and the influence of the duration of walking on HRV (James et al. 2010) have been investigated. However, to our knowledge, no studies have assessed the influence of sedentary behavior on the circadian rhythm with respect to the HR and HRV variables. Therefore the purpose of the present study was to examine the influence of short term sedentary behavior on the circadian rhythms of HR and HRV using cosine periodic regression analysis.

Methods

Subjects

Sixteen healthy young volunteers were recruited from Kobe University by way of a bulletin board notice. We confirmed that the volunteers had generally similar lifestyles. No one had a history of any cardiovascular or other diseases, nor long-term use of any medications. There were no occupational shift works, no one had history of smoking, and no one performed regular exercise routines. This study was approved by Ethics Committee of Kobe University. All subjects were informed about the nature of the study and gave written consent to participate.

Study protocol

We performed a randomized crossover study involving altered physical activity for one day ~~only~~ with 2 to 3 days interval. Subjects were enrolled and randomized into two groups and conditions: one group of 8 participants followed an active condition first, while the other 8 participants followed a sedentary condition. After 2 to 3 days, each group underwent the opposite condition. According to the Ministry of Health, Labor and Welfare of Japan, a Japanese individual walks about 6,000 steps / day on average and they are recommended to walk more than 10,000 steps / day to maintain a healthy condition. In the active condition group, subjects were instructed to walk more than 15,000 steps from 11:00 to 19:00 (meal times were excluded) in order to maintain a high physical activity level. In the sedentary condition group, the subjects remained seated and walked less than 1,000 steps.

All participants underwent 24-h ECG monitoring using a two-channel Holter recorder (FM-800; Fukuda Denshi Co., Ltd., Tokyo, Japan) during each pattern. Bipolar leads were attached to the electrodes at CC5 and NASA. The participants' physical activity levels were recorded by an ambulatory accelerometer (Lifecorder EX; Suzuken Co., Ltd., Nagoya, Japan), which has been validated by Kumahara et al. (2004). To ensure a similar recording environment for each condition, all participants were required to go to bed at 0:00 and wake up at 7:00 on recording days. They were asked to eat their meals at 8:00, 12:00 and 19:00. All participants, regardless of conditions, consumed the same meals and the total energy level was around 1,800 calories per day. Additionally, all participants were asked to avoid ingesting caffeine and alcohol and were encouraged to avoid eating anything other than what was provided during the experiment.

Heart rate variability analysis

To obtain the HR and frequency-domain HRV, we conducted the following process. First, the 24-h ambulatory ECG recordings, were automatically detected by using a Fluclet WT version 4.0 (Dainippon Sumitomo Pharma Co., Ltd., Osaka, Japan) for R wave and R-R interval measurements. Second, careful manual editing was performed by visually inspecting the R-R intervals to exclude ventricular ectopy and artifacts. After editing the R-R intervals, the HR was calculated from consecutive ECG data using the formula: 60,000 / R-R intervals (milliseconds) for every beat. From this, the hourly mean values were determined. Subsequently, the time series or the R-R intervals were spline-interpolated and re-sampled at 2.5 Hz for the spectral analysis. The spectral analyses were performed using the fast Fourier transformation. The power of the low frequency (LF) (LF; 0.04 Hz to 0.15 Hz) and high frequency (HF) components (HF; 0.15 Hz to 0.60 Hz) were calculated from the power spectrum and expressed as ms^2. The natural log of the high frequency measurement (lnHF) is considered to be an index of parasympathetic activity, and the LF/HF ratio, which was also calculated, is considered to be an index of sympathetic activity. The hourly mean values were calculated for lnHF and LF/HF in each subject.

Cosine periodic regression analysis

We applied a cosine periodic regression analysis. First, we used the single cosinor method by the least squares procedure (Nelson et al. 1979). The hourly mean value for each parameter was fitted to the cosine curve, and the significance of the circadian rhythm in the cosine periodic regression curve was analyzed using a zero-amplitude test (Nelson et al. 1979; Vandewalle et al. 2007). Subsequently, significance was confirmed. We then calculated R^2 values as regression of the sum of the squares ~~by~~ divided by the sum of squares. We considered R^2 values > 0.80 as a good curve fit.

Finally, the cosine curve was presented as $y = M + A \cos(\omega t - \varphi)$, and the circadian rhythm was defined by three parameters: mesor (M) which was the mean value; amplitude (A) which was one half of the difference between the highest and the lowest values; acrophase (φ) which was the phase angle of the maximum value on the cosine curve (Massin et al. 2000).

Statistical analysis

The ~~conditions represents~~ parameters are presented as means±SD. We obtained the parameters using both the individual participants' hourly mean data, and the groups' hourly mean data. We then compared these parameters using the paired t-test or Wilcoxon singed-rank sum test based on the individuals' data. A p-value of less than 0.05 was considered statistically significant.

Result

General characteristics

The study included 3 men and 13 women with age ranging from 19 to 24 years. The mean age, height, weight, and body mass index (BMI) of the sixteen subjects were 22.0 ± 1.2 years, 1.6 ± 0.1 m, 53.8 ± 7.0 kg, and 20.3 ± 1.6 kg/m^2, respectively. The average number of steps was about 16,000 in the active condition, about 650 in the sedentary condition. The average calories consumed were about 1800 kcal per day.

Circadian rhythm of HR and HRV

Significance of the circadian rhythm was confirmed for all variables during sedentary and active conditions. Figures 1-3 show the cosine periodic regression curve for each variable in both conditions. Regarding HR, there was a small reduction in R^2 under the sedentary condition compared to the active one (0.64 vs. 0.80). However, the R^2 of lnHF in the sedentary condition was markedly decreased compared to the active one (0.47 vs. 0.84) and the LF/HF were markedly reduced to 0.31 in the sedentary condition compared 0.81 in the active one. Each parameter of the cosine curve in both conditions is shown in Table 1. There were significant differences in the mesor of the HR (73.8 ± 7.2~~3~~ bpm for the active condition vs. 66.2 ± 7.3 bpm for the sedentary one, $p < 0.001$), in lnHF (6.36 ± 0.60 ms^2 for the active condition vs. 6.83 ± 0.77 ms^2 for the sedentary condition, $p < 0.001$) and in LF/HF (2.36 ±1.01 for the active condition vs. 1.93 ± 1.12 for the sedentary one, $p = 0.034$). The amplitude of the sedentary condition was significantly smaller than that of the active one for HR (7.9 ± 1.9 bpm vs. 15.4 ± 3.9 bpm, $p < 0.001$), lnHF (0.38 ± 0.21 ms^2 vs. 0.80 ± 0.28 ms^2, $p < 0.001$) and LF/HF (0.75 ± 0.54 vs. 1.24 ± 0.69, $p = 0.008$).

There were no significant differences in any values under the two conditions with respect to acrophase.

Discussion

In this crossover study, we revealed for the first time that a short term sedentary condition weakened the circadian activity rhythms of HR and HRV compared to an active condition. The effect was determined by the coefficient in the cosine regression curve analysis. Additionally, the amplitude of the circadian curve ~~was~~ significantly decreased in the sedentary condition.

Besides light exposure (Scheer & Buijs 1999) and diet (Fuller et al. 2008), physical exercise is thought to be a key factor affecting the circadian rhythm (Van Reeth et al. 1994). Epidemiological studies indicate that regular exercise is associated with better nocturnal sleep and lower daytime tiredness (Driver & Taylor 2000). However, the relationship between sedentary behavior and the circadian rhythm has not been fully studied in the past. In this study, by using the zero-amplitude test, the significance of the circadian rhythm was confirmed for HR, lnHF, and LF/HF in both the active and sedentary conditions.

However, with respect to the coefficient determination, there were significant differences between the active and sedentary conditions. The coefficient determination describes how well the model fits the data in the regression analysis, but there are no set criteria as to what universally represents a good R^2 value (Saunders et al. 2012). We considered an R^2 value > 0.80 as a good curve fit. In the present study, the R^2 values were greater than 0.8 in all the variables in the active condition (HR: 0.80, lnHF: 0.84, and LF/HF: 0.81), however, they were markedly decreased in the sedentary condition (HR: 0.64, lnHF: 0.47, and LF/HF: 0.31). Taken together, the sedentary behavior did not disturb the circadian rhythms completely but showed adverse influences as observed in the not so good fitting of the curves.

The circadian activity rhythm parameters such as mesor, amplitude, acrophase, and circadian quotient (Levin et al. 2005) have been evaluated in some studies. However, when evaluating such parameters, the zero-amplitude test as well as the R^2 in the periodic regression analysis has usually been disregarded. When evaluating the circadian activity rhythm parameters, a fundamental examination of the periodic regression analysis is needed, as emphasized in the present study. In our study, there was no difference in the measurement procedure for each condition. We think that the circadian rhythms of the HR and HRV variables might have been weakened mainly by sedentary behavior.

Furthermore, in our study, we demonstrated that the amplitudes of HR, lnHF, and LF/HF were significantly smaller in the sedentary condition than in the active one. The decrease of amplitude in the sedentary condition might be due to the difference of the condition during the daytime, since the HR, lnHF and LF/HF were quite similar between two conditions during night time (Figure 1-3). Cross-sectional studies have revealed that sympathetic modulation is increased and cardiac parasympathetic modulation is decreased during exercise or as an acute effect seen after exercise (Lima et al. 2011; Hautala et al. 2009). Callard showed accentuation of the HR amplitude resulting from exercise (Callard et al. 2001). Our study is in accordance with that study showing that the lack of exercise during ~~the~~ daytime in the sedentary condition might have led to a flattening of the circadian rhythm of HR and HRV with smaller amplitudes of HR, lnHF, and LF/HF. Similarly, in terms of the mesor, lack of exercise during the daytime might have caused a higher lnHF in the sedentary condition and a higher LF/HF in the active condition.

Light is the most important factor in adjustment of the circadian rhythm (Zee et al. 2013). In this study, subjects in the active pattern walked outside, and thus had exposure to natural light. However, in the sedentary pattern, the subjects remained in a room with exposure to artificial light. These differences in exposure to light may have affected the circadian rhythm. However, no significant differences were observed in acrophase between the active and sedentary conditions. This might be due to similar eating and sleeping conditions.

Therefore, we believe that the influence of light exposure during day-time on the circadian rhythm of HR and HRV is probably small.

We investigated the influence of only one day's sedentary behavior, which had a significant impact on the amplitude and mesor of the circadian rhythms of the HR, ln HF and LF/HF, suggesting that continuation of such behavior is likely have a continuous adverse influence. However, further research is needed to determine the long-term influence of low amplitudes of HR and HRV variables caused by sedentary behavior.

Limitation

We recognize that there were some limitations in our study. Our study included healthy young adults aged 19 -24 years. Therefore, our results can not be applied directly to middle aged or elderly persons. The subjects included mostly women, however, none of them had their menstrual period during this study. Thus, we do not consider this as a major limitation.

We did not measure daily average steps of our subjects prior to the study. Therefore, we could not compare normal unregulated behavior with sedentary or active behavior. Further investigation will be necessary to compare the influence of sedentary behavior with various conditions.

As for the interpretation of our results, we have to be careful regarding the effect of the sedentary behavior. No significant differences were observed in the acrophase between the active and sedentary conditions. In addition, the HR, ln HF and LF/HF were quite similar between the two conditions during night time. However, during daytime the amplitude of the circadian curve decreased in the sedentary condition. Therefore, the results observed for HR and HRV could be due to an effect of physical activity per se because other factors like eating and sleeping were kept similar during our study conditions. Taken together, physical activity is considered ~~a major~~ one contributor determining circadian rhythms of the HR and HRV, and we believe our results showing at least a partial negative effect in sedentary behavior is in accordance with this notion.

Conclusions

Our findings indicated that the amplitude of HR and HRV was significantly decreased by sedentary behavior, and it also might have led to alterations of the circadian rhythm of the HR and HRV.

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Conflict of interest

The authors declare that they have no conflict of interest.

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Table 1. Mesor, amplitude and acrophase of heart rate variability

			active pattern	sedentary pattern	P-value
HR	Mesor [b]	[bpm]	73.8 ± 7.23	66.2 ± 7.26	<0.001**
	Amplitude [a]	[bpm]	15.4 ± 3.93	7.94 ± 1.91	<0.001**
	Acrophase [a]	[h]	14.5 ± 0.97	15.1 ± 1.06	0.063
lnHF	Mesor [a]	[ms^2]	6.36 ± 0.60	6.83 ± 0.77	<0.001**
	Amplitude [b]	[ms^2]	0.80 ± 0.28	0.38 ± 0.21	<0.001**
	Acrophase [b]	[h]	2.98 ± 1.78	2.76 ± 4.14	0.379
LF/HF	Mesor [b]		2.36 ± 1.01	1.93 ± 1.12	0.034*
	Amplitude [b]		1.24 ± 0.69	0.75 ± 0.54	0.008**
	Acrophase [b]	[h]	13.8 ± 1.91	13.5 ± 3.66	0.056

[a] paired t test ; [b] Wilcoxon singed-rank sum test; * $P < 0.05$; ** $P < 0.01$

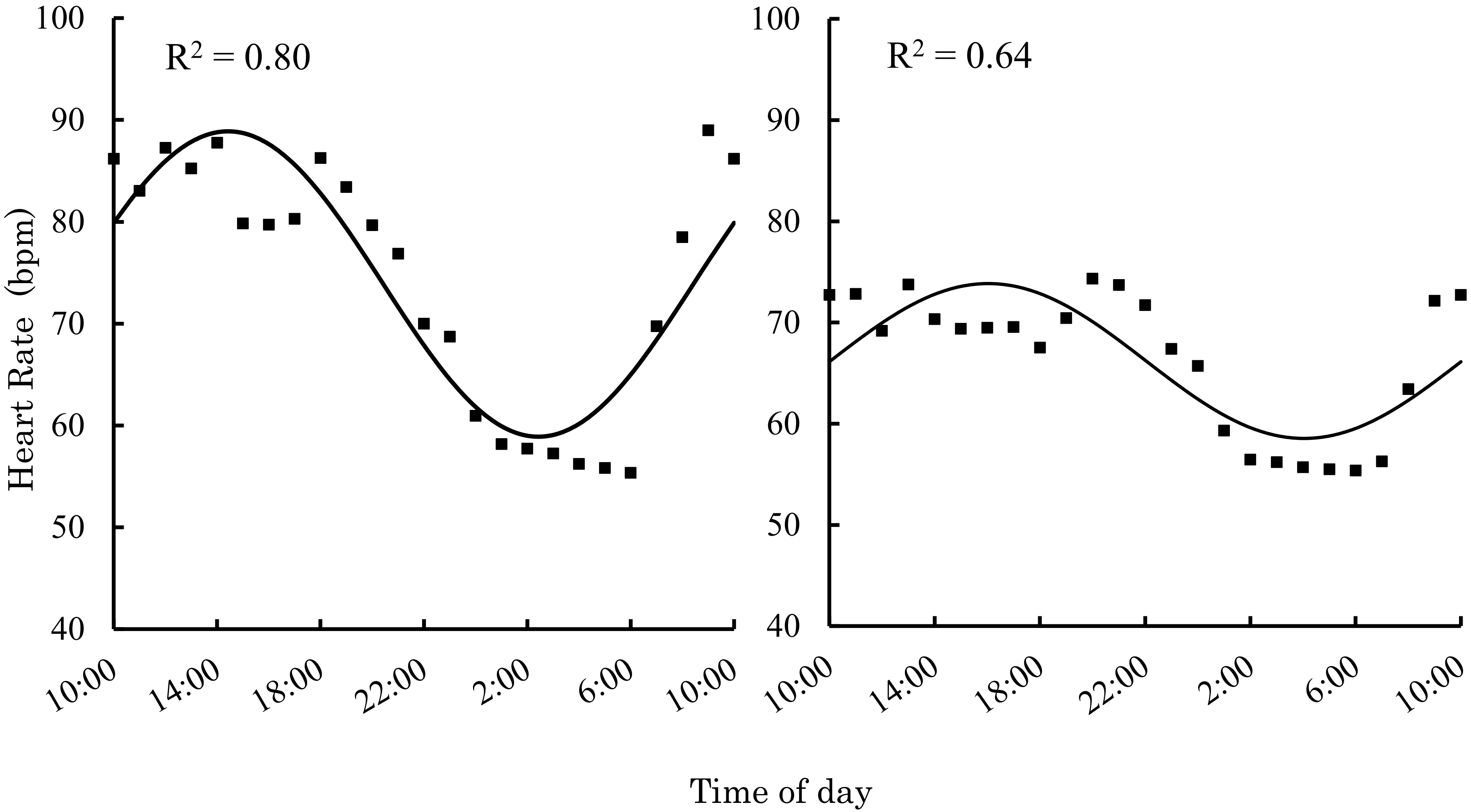

Fig1. HR in active condition (left) and sedentary condition (right).

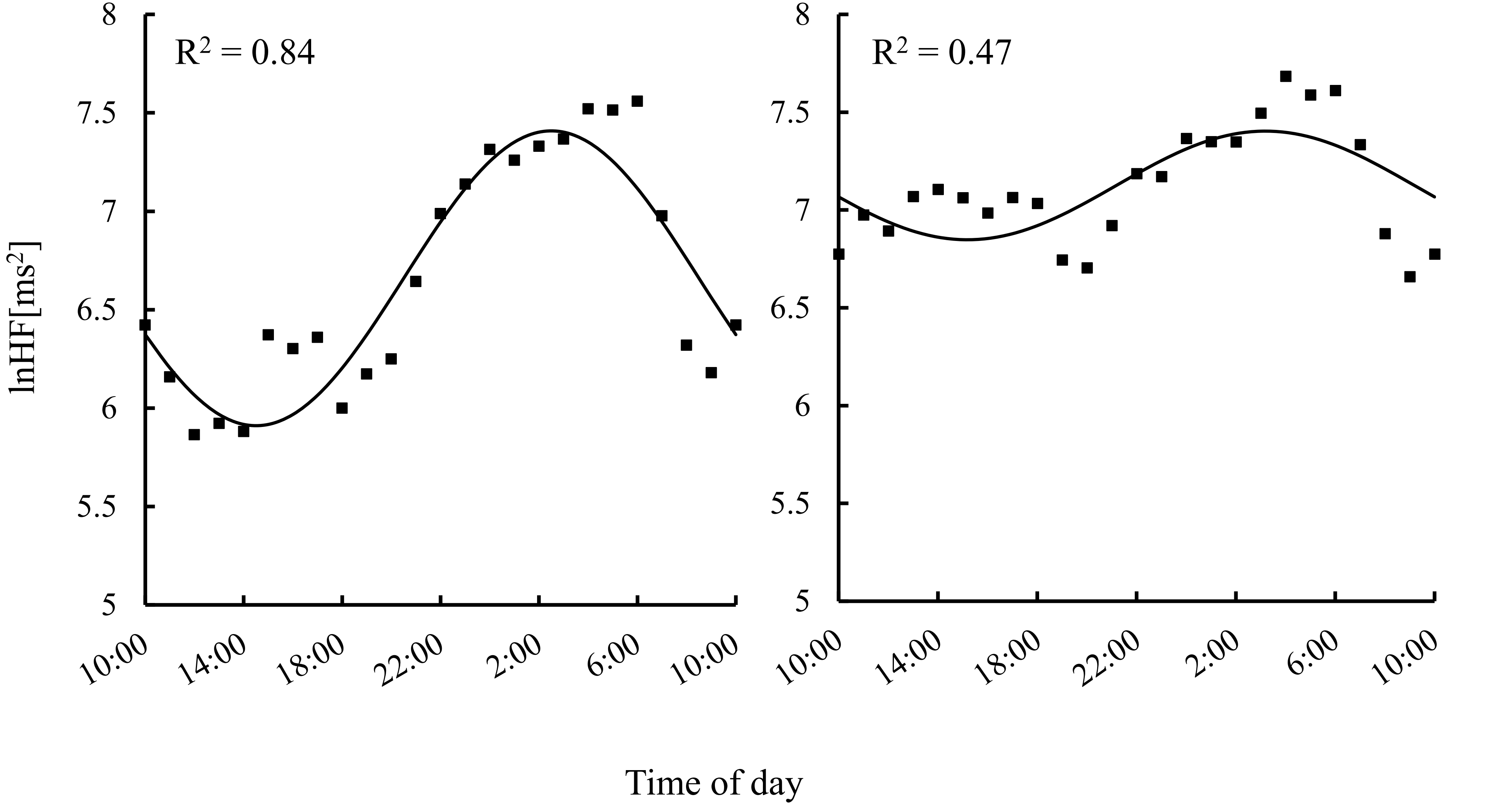

Fig2. lnHF in active condition (left) and sedentary condition (right).

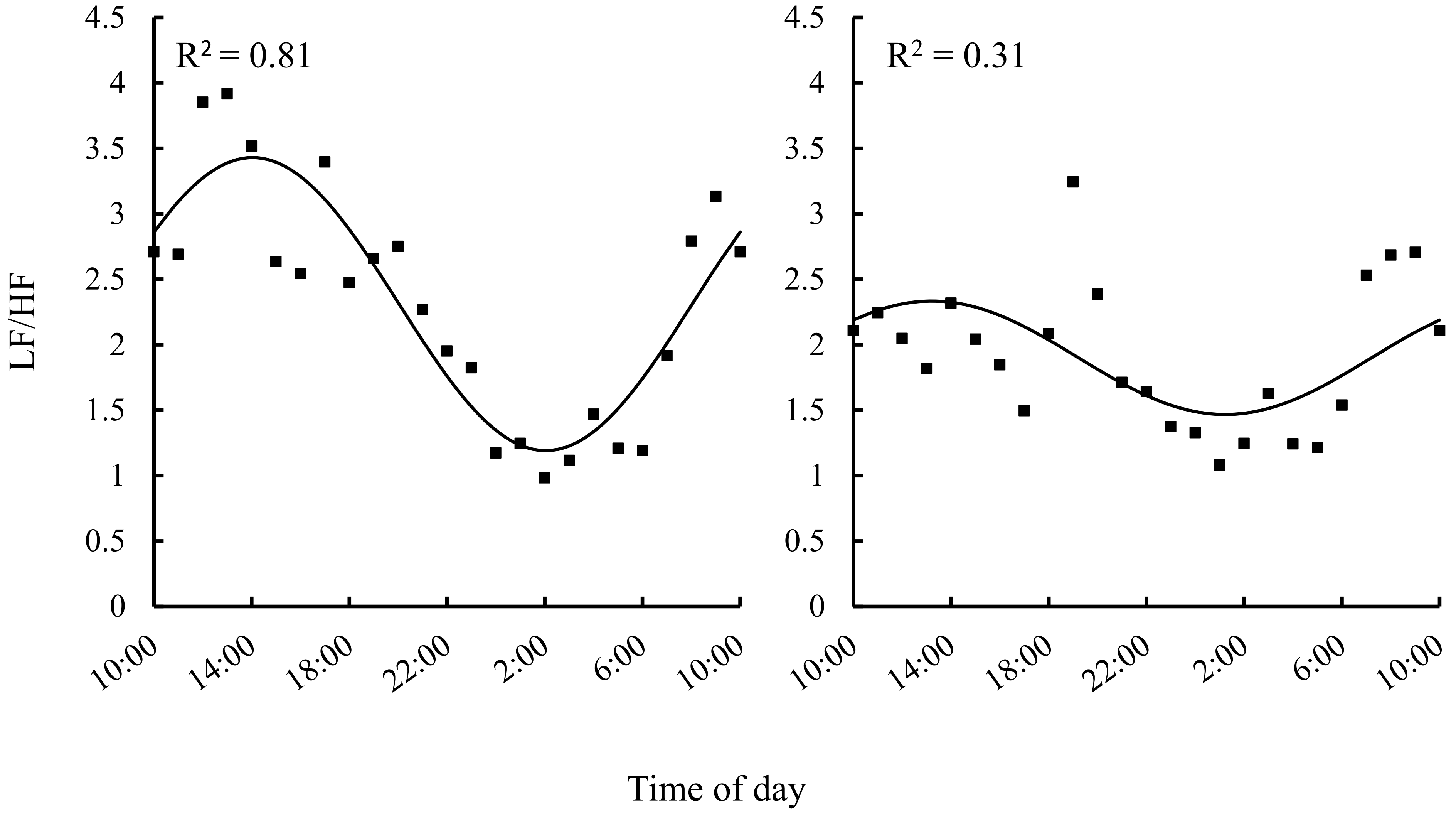

Fig3. LF/HF in active condition (left) and sedentary condition (right).