

The Effects of Exercise in Forest and Urban Environments on Sympathetic Nervous Activity of Normal Young Adults

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In Japan, forest-air bathing and walking (shinrin-yoku) has been proposed as a health-facilitating activity in which people spend a short period of time in a forest environment. Initially, we examined the usefulness of salivary amylase activity as an indicator of an individual's stress levels in a forest environment. The circadian rhythm of salivary amylase activity was measured in healthy young male subjects under stress-free conditions. The salivary amylase activity remained relatively constant throughout the day. Salivary

amylase activity was then measured before and after walking in both urban and forest environments using a hand-held monitor. Our results indicated that (i) the circadian rhythm fluctuations in salivary amylase activity were much smaller than the stressor-induced variations; (ii) salivary amylase activity was an excellent indicator of the changes in sympathetic nervous activity; and (iii) the forest was a good environment in which people could experience much less environment-derived stress.

KEY WORDS: SYMPATHETIC NERVOUS ACTIVITY; AMYLASE; EXERCISE; CIRCADIAN RHYTHM; FOREST ENVIRONMENT; URBAN ENVIRONMENT; HEALTH-FACILITATING ACTIVITY

Introduction

During the 5 million years of human history, humans evolved to live in forest environments and it was only around 2000 years ago that we started living in urban environments. It is well known that forest environments have favourable effects on human physiological functions, and sanatoria are often built on plateaus in forest environments. There have been reports that the forest environment has excellent physiological effects on patients with allergies or respiratory diseases.^{1,2} Factors in the forest environment that might provide good

physiological effects include the aroma of the plants,³ various environmental factors such as temperature, humidity, light intensity, wind and oxygen concentrations, and exercise performed within that environment.

In contrast, people who live in an urban environment often develop diseases such as chronic fatigue syndrome. Otherwise normal healthy subjects might develop chronic fatigue syndrome due to increased fatigue and stress if they are not appropriately treated.⁴ To improve the quality of life of those who live in cities, it has been suggested that society develops better methods to

facilitate and promote healthy activities, which can be performed in a very short period of time, are not expensive and are also enjoyable. In Japan, one such health-promoting activity is called 'shinrin-yoku' or 'forest-air bathing and walking' in which people attempt to spend a short period of time in a forest environment performing certain recreational activities including exercise.^{5,6} This health-promoting activity is expected to induce psychological relaxation in those who experience the atmosphere of the forest. However, this theory has not yet been studied scientifically with regard to the physiological effects of forest-air bathing and walking on healthy city-dwellers.

In an attempt to measure quantitatively the physical and psychological status of healthy people, a variety of methods have been studied that have evaluated the activity of the autonomic nervous system using electroencephalograms (EEG), electrocardiograms (ECG), skin conductance and heart rate. However, these physical measurements have some limitations as they not only require the subjects to be restricted physically, but also require equipment that is difficult to transport. Except for heart rate monitoring, these methods cannot be used in a forest environment. The measurement of the heart rate observes the sympathetic nervous activity of the cardiovascular system and it is strongly influenced by homeostasis.

In contrast, a method for measuring the sympathetic nervous system based on a biochemical marker in saliva has been investigated.⁷ Saliva sampling is non-invasive, making multiple sampling easy and stress free. It has been suggested that salivary amylase activity can be a useful index of plasma noradrenaline levels under a variety of stressful conditions, since it

appears that increased sympathetic nervous activity is a major stimulator of amylase secretion.^{8,9} We have previously proposed a new method to quantify salivary amylase activity and have manufactured a hand-held salivary amylase activity monitor.^{10,11}

We investigated the physiological effects of forest-air bathing and walking as one health-promoting activity that could be used for preventive medicine. In this present study, we initially examined the circadian rhythm of salivary amylase activity in regulated stress-free conditions in healthy young male university students. We then measured the time-course changes of the salivary amylase activity before and after walking in both forest and urban environments using the hand-held monitor in the same healthy male subjects.

Subjects and methods

SUBJECTS

This study enrolled healthy young male university students without any oral disease from Shinshu University (Matsumoto, Japan) and Tsukuba University (Tsukuba, Japan). The study protocol was approved by the Ethical Committee of the Forestry and Forest Products Research Institute (Tsukuba, Japan). It was also fully explained to all of the subjects in both spoken and written forms, specifically focusing on the purpose of the study, the precise procedures that would be used and any possible adverse events. Signed informed consent was obtained for each subject who enrolled in the study.

SALIVARY AMYLASE ACTIVITY MONITOR

A hand-held monitor was manufactured, consisting of a disposable test-strip and an optical analyser (126 × 130 × 48 mm; 350 g).^{10,11} To cancel out the effects of

variations in the environmental temperature and pH of an individual's saliva, temperature- and pH-adjusted equations were determined experimentally. The theoretical value for each parameter was entered into the memory of the hand-held monitor. The hand-held monitor enabled a user to measure automatically the salivary amylase activity (37 °C and pH 6.5) with high accuracy, using a dry-chemical system and a 30- μ l sample of saliva, within 1 min from collection to completion of the measurement.

CIRCADIAN RHYTHM OF SALIVARY AMYLASE ACTIVITY

Subjects stayed in a hotel (Nagano, Japan) for 3 days and the circadian rhythm of salivary amylase activity was measured on the second day. On the day of the experiment, the following schedule was used: wake up: 07:00; breakfast: 08:00 – 09:00; lunch: 12:30 – 13:30; dinner: 19:00 – 20:00; bed: 22:00. During the daytime, subjects were permitted to walk around within the hotel, converse with other people, read books or watch TV, but they were instructed not to do any physical or mental work that might cause them stress. During the period between 07:00 and 22:00, salivary amylase activity was measured every 1 – 4 h using the hand-held monitor. Salivary amylase activity was not measured within 1 h of a meal. Since salivary amylase activity showed variations in individuals, all the measured values were converted into logarithmic values.

EFFECT OF EXERCISE IN THE FOREST AND URBAN ENVIRONMENTS

The experiments were conducted in the forest environment of Kimitsu woodland (Chiba Prefecture, Japan) and in the urban environment around Chiba City railway station (Chiba Prefecture, Japan). The

Kimitsu woodland has a total area of 3200 hectares (1 ha = 10⁴ m²) and 2 hectares of flat land. The woodland has wild trees and was not a man-made environment. There is also a footpath (580 m) surrounded by trees (approximately 77 trees/hectare). In contrast, Chiba City has a population of 922 000 and a total area of 272.1 km², resulting in a population density of 3388.5 people/km². The distance between Kimitsu woodland and Chiba City is 55 km and people can drive from Chiba City to the forest environment within 1 h.

The subjects stayed in a hotel (Kimitsu, Japan) for 3 days and took a 20-min walk as an exercise during the daytime on days 2 and 3. An experimental protocol for the exercise schedule in the forest and urban environments is shown in Fig. 1. Subjects were divided into two groups ($n = 5$ /group) and the experimental environments (forest versus urban) were switched each day. On the day of the experiment, the following schedule was used: wake up: 06:00; breakfast: 07:30 – 08:30, lunch: 12:30 – 01:30, dinner: 19:00 – 20:00; bed: 23:00.

Salivary amylase activity was measured six times in total: immediately after waking up (07:00 \pm 0:30); before walking (11:05 \pm 0:50); after walking (11:25 \pm 0:50); before sitting and watching (14:35 \pm 0:50); after sitting and watching (14:55 \pm 0:50); and before dinner (18:30 \pm 0:30) (Fig.1). Salivary amylase activity was not measured within 1 h of a meal. The measured values were converted into logarithmic values.

STATISTICAL ANALYSIS

The correlation between the salivary amylase activities was analysed statistically by a one sample *t*-test and $P < 0.05$ was considered significant. Proprietary statistical software (Excel 2003, Microsoft, Tokyo, Japan) was used for the calculation.

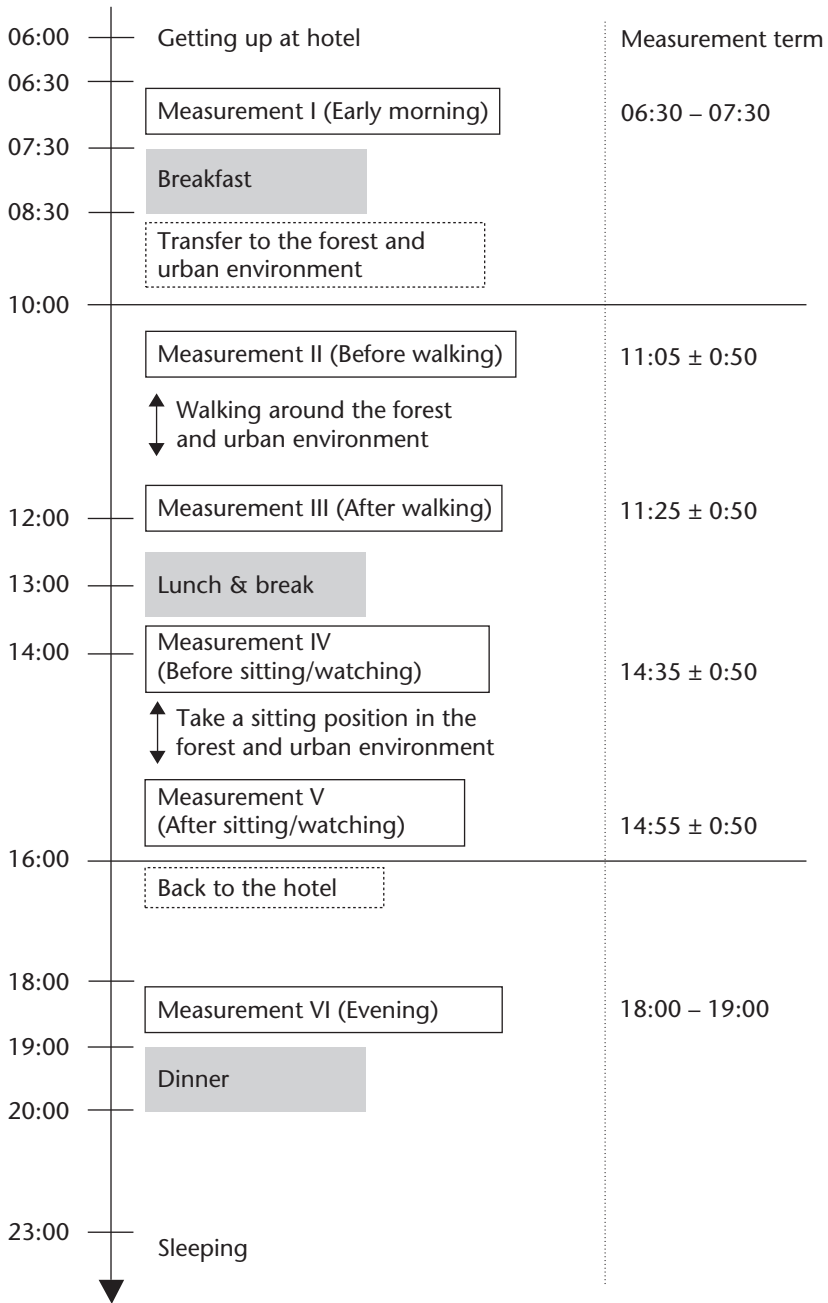


FIGURE 1: The experimental protocol for the assessment of the effects of exercise on salivary amylase levels in subjects exercising in a forest or urban environment

Results

CIRCADIAN RHYTHM OF SALIVARY AMYLASE ACTIVITY

The subjects were 15 healthy young male university students (22.2 ± 0.47 y; mean \pm SD). The circadian rhythm of the salivary amylase activity is shown in Fig. 2. The individual salivary amylase activities ranged from 9 kU/l to 89 kU/l. The mean salivary amylase activity showed a minimum of 19.0 ± 8.0 kU/l immediately after waking up and a maximum of 32.7 ± 16.1 kU/l at 20:30. The salivary amylase activity was shown to be relatively stable and constant throughout the day. When salivary amylase activity at each time-point was analysed statistically by a one-sample *t*-test, data from adjacent time-points showed no statistically significant differences. However, the salivary amylase activity just before the bed time-point was higher than the activity at some of the other time-points, for example the activity immediately after waking up ($P < 0.05$).

EFFECT OF EXERCISE IN THE FOREST AND URBAN ENVIRONMENTS

The subjects were 10 healthy young male university students (23.2 ± 1.1 y; mean \pm SD). When the salivary amylase activity from the two groups ($n = 5$) who exercised in the forest and the urban environments on alternate days was analysed statistically by a one-sample *t*-test, there was no significant difference between the two groups depending upon the order in which they were assessed in each environment.

The effects of exercise on the time-course changes of the salivary amylase activity in the forest and urban environments are shown in Fig. 3. The mean salivary amylase activity after exercise in the forest environment was 18.8% lower compared with that observed in subjects who exercised in the urban environment. The salivary amylase activity in the forest environment was 55.8 ± 31.5 kU/l after walking and 45.2 ± 27.7 kU/l after sitting/watching, showing a marked but

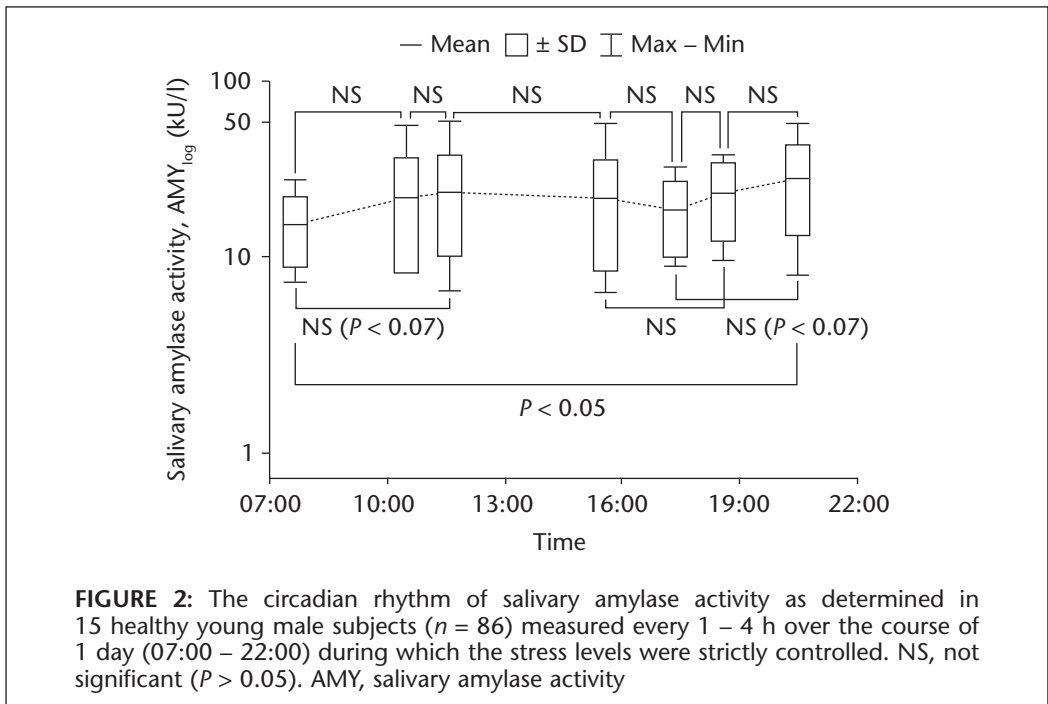


FIGURE 2: The circadian rhythm of salivary amylase activity as determined in 15 healthy young male subjects ($n = 86$) measured every 1 – 4 h over the course of 1 day (07:00 – 22:00) during which the stress levels were strictly controlled. NS, not significant ($P > 0.05$). AMY, salivary amylase activity

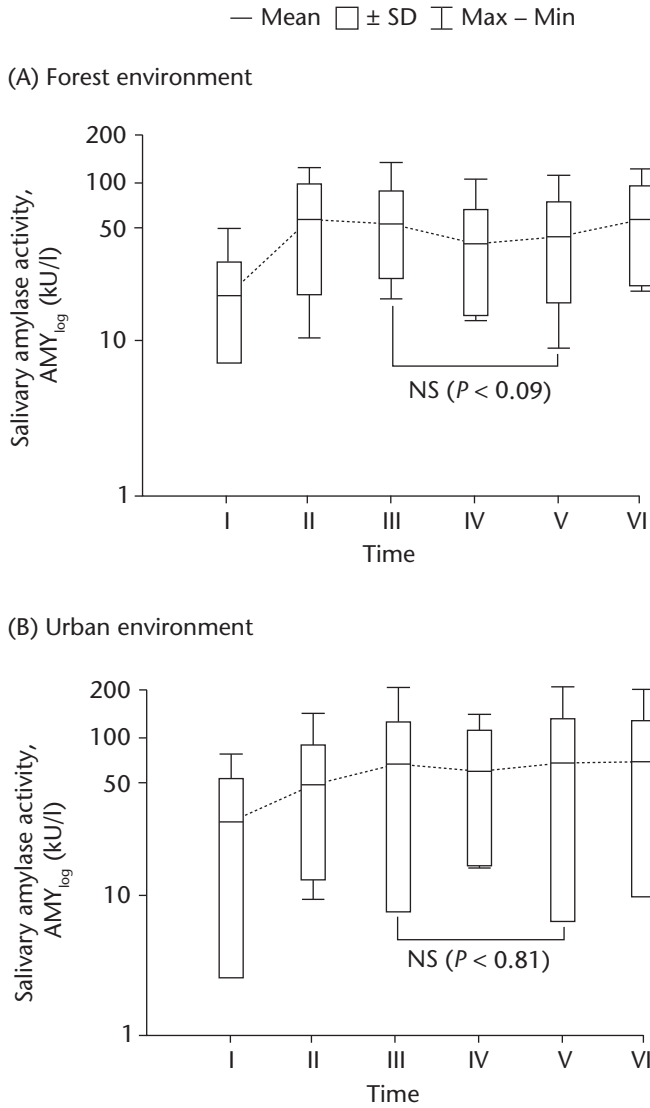


FIGURE 3: The effects of exercise on the salivary amylase activity of 10 healthy male subjects who exercised in a forest environment (A) and an urban environment (B). NS, not significant ($P > 0.05$). AMY, salivary amylase activity. I, waking up: $07:00 \pm 0:30$; II, before walking: $11:05 \pm 0:50$; III, after walking: $11:25 \pm 0:50$; IV, before sitting/watching: $14:35 \pm 0:50$; V, after sitting/watching: $14:55 \pm 0:50$; VI, before dinner: $18:30 \pm 0:30$

non-significant decrease in the activity after sitting/watching compared with walking. In the urban environment, there was no significant

difference in the mean salivary amylase activities after walking (65.6 ± 57.8 kU/l) and after sitting/watching (68.2 ± 61.5 kU/l).

Discussion

The circadian rhythm of salivary amylase activity was examined in order to investigate the use of salivary amylase activity as an indicator of sympathetic nervous activity in healthy subjects. The lowest salivary amylase activity was measured immediately after waking. This result was consistent with the findings of Parkkila *et al.*,¹² who reported circadian rhythms in salivary amylase activity, and Chatterton *et al.*,¹³ who demonstrated that the salivary amylase activity was under the influence of the sympathetic nervous system. However, our study found that the salivary amylase activity just before the bed time-point was higher than the other earlier time-points and this was not consistent with the previous reports. We speculate that this was due, in part, to the fact that most university students would normally go to bed around 23:00 to 02:00 and would therefore still be quite alert at 20:30, when the final salivary amylase activity measurement was made.

Although it was extremely difficult to maintain completely stress-free conditions in the subjects over an entire day of monitoring, there was only a small difference (13.7 kU/l) between the mean values at each time-point. We have previously reported that only a 10-min application of a mental stressor using the Uchida-Kraepelin psychodiagnostic test increased salivary amylase activity by 79% compared with the pre-stress status.¹⁰ When the stressor-induced change in salivary amylase activity was compared, it was estimated that daily variations in salivary amylase activity were small. These results suggested that measuring salivary amylase activity might be an excellent method of evaluating any changes in sympathetic nervous activity over time.

We divided the subjects into two groups whose experimental conditions were switched

daily between the forest and urban environments (cross-over test) and our results showed that the experimental order had no significant effect on the amylase activity. The salivary amylase activity of the healthy subjects was reduced in the forest environment compared with the urban environment, indicating that the sympathetic nervous system might be less active in subjects when they are in a forest environment. One explanation for this phenomenon could be that the environment-derived stressor might be relatively small in the forest environment compared with the urban environment. However, the major reasons for the difference between the two environments need to be investigated further. It was observed that the sympathetic nervous activity after sitting/watching was reduced markedly compared with that measured after walking only in the forest environment.

We conclude that our results indicate that (i) the circadian rhythm fluctuations in salivary amylase activity were much smaller than the stressor-induced variations; (ii) salivary amylase activity was an excellent indicator of changes in sympathetic nervous activity over time; and (iii) the forest was a good environment in which people experienced much less environment-derived stress, which enabled observations of exercise-induced physiological effects to be made. To establish whether the development of footpaths in forests located in suburbs within 1 h of cities would be justified in terms of promoting health, a long-term trial to evaluate any health-promoting effects of forest-air bathing and walking would need to be undertaken.

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Conflicts of interest

No conflicts of interest were declared in relation to this article.

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References

- 1 Loureiro G, Rabaca MA, Blanco B, Andrade S, Chieira C, Pereira C: Urban versus rural environment – any differences in aeroallergens sensitization in an allergic population of Cova da Beira, Portugal? *Allerg Immunol (Paris)* 2005; **37**: 187 – 193.
- 2 Namdeo A, Bell MC: Characteristics and health implications of fine and coarse particulates at roadside, urban background and rural sites in UK. *Environ Int* 2005; **31**: 565 – 573.
- 3 Kawakami K, Kawamoto M, Nomura M, Otani H, Nabika T, Gonda T: Effects of phytoncides on blood pressure under restraint stress in SHRSP. *Clin Exp Pharmacol Physiol* 2004; **31**: S27 – S28.
- 4 Shephard RJ: Chronic fatigue syndrome: an update. *Sports Med* 2001; **31**: 167 – 194.
- 5 Miyazaki Y, Motohashi Y: Forest environment and physiological response. In: *New Frontiers in Health Resort Medicine* (Agishi Y, Ohtsuka Y, eds). Sapporo: Kokoku, 1996; pp67 – 77.
- 6 Ohtsuka Y, Yabunaka N, Takayama S: Shinrin-yoku (forest-air bathing and walking) effectively decreases blood glucose levels in diabetic patients. *Int J Biometeorol* 1998; **41**: 125 – 127.
- 7 Morse DR, Schacterle GR, Furst ML, Esposito JV, Zaydenburg M: Stress, relaxation and saliva: relationship to dental caries and its prevention, with a literature review. *Ann Dent* 1983; **42**: 47 – 54.
- 8 Skosnik DP, Chatterton RT, Swisher T, Park S: Modulation of attentional inhibition by norepinephrine and cortisol after psychological stress. *Int J Psychophysiol* 2000; **36**: 59 – 68.
- 9 Li TL, Gleeson M: The effect of single and repeated bouts of prolonged cycling and circadian variation on saliva flow rate, immunoglobulin A and α -amylase responses. *J Sports Sci* 2004; **22**: 1015 – 1024.
- 10 Yamaguchi M, Kanemori T, Kanemaru M, Takai N, Mizuno Y, Yoshida H: Performance evaluation of salivary amylase activity monitor. *Biosens Bioelectron* 2004; **20**: 491 – 497.
- 11 Yamaguchi M, Deguchi M, Wakasugi J, Ono S, Takai N, Higashi T, *et al*: Hand-held monitor of sympathetic nervous system using salivary amylase activity and its validation by driver fatigue assessment. *Biosens Bioelectron* 2006; **21**: 1007 – 1014.
- 12 Parkkila S, Parkkila AK, Rajaniemi H: Circadian periodicity in salivary carbonic anhydrase VI concentration. *Acta Physiol Scand* 1995; **154**: 205 – 211.
- 13 Chatterton RT, Jr, Vogelsong KM, Lu YC, Ellman AB, Hudgens GA: Salivary α -amylase as a measure of endogenous adrenergic activity. *Clin Physiol* 1996; **16**: 433 – 448.

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