Hypertension Research (2023) 46:231–235
https://doi.org/10.1038/s41440-022-01020-0

BRIEF COMMUNICATION

Fast track – ISH2022 KYOTO

Morning surge in sympathetic nervous activity in the indoor environment during the cold winter season

Hironori Nakagami[1] · Hitoshi Akiyama[2] · Hiroki Otsuka[2] · Sho Adnas Takahashi[3] · Katsutoshi Sawada[3] · Nobutoshi Kobayashi[3] · Atsushi Iwamae[4] · Hidekazu Yamada[5]

Received: 13 August 2022 / Revised: 24 August 2022 / Accepted: 30 August 2022 / Published online: 13 October 2022

Abstract

We addressed to the sympathetic nervous activation of the same people in both their houses and a highly insulated and airtight model house (model house) during the cold winter season. Eight subjects (4 males and 4 females) stayed two nights at each house and were continuously monitored for sympathetic nerve system by calculating LF (low frequency)/HF (high frequency) in the analysis of heart rate variability using a wearable electrocardiography equipment. The room temperatures were kept constant at 20 °C or more in model house, but much lower in their houses. In all subjects, the sleeping duration is longer in model house compared with that in the participants' houses. Four subjects showed a morning surge in sympathetic activity that were more intense at their houses. This morning surge in sympathetic activity in a residential setting suggests the importance of the indoor environment in the management of early morning hypertension.

Keywords Morning surge · Indoor environment · Winter season

Introduction

Blood pressure (BP) fluctuations including morning surges can be triggered by combination of several stressors, such as physical exertion, and severe emotional and environmental stress. Morning BP surge are augmented in cold seasons, and cold temperature has an impact on the BP surge. We and others have reported that indoor temperature showed increased blood pressure with fluctuation, which might lead to high cardiovascular mortality in the winter season [1–4]. Activation of the sympathetic nervous system in response to cold temperature increases vascular tone in resistance arteries, and bedtime administration of an α-adrenergic blocker suppresses morning BP surge by reducing resistance [5]. The rhythmic components of heart rate variability can be separated and quantitatively assessed by means of power spectral analysis, which can be associated with autonomic nervous system activity [6, 7]. In this study, we focused on the real time analysis of sympathetic nervous system by frequency domain analysis of heart rate variability signals using wearable electrocardiography devices, when the same subjects spent 2 days each at their home and in a highly insulated, airtight model house (model house). We also measured the accurate and continuous indoor temperature using fixed thermos sensor at living room, bedroom and dressing room.

Methods

Study protocol

This study protocol was approved by the Faculty of Architecture, Kindai University Ethics Committee

Supplementary information The online version contains supplementary material available at https://doi.org/10.1038/s41440-022-01020-0.

✉ Hironori Nakagami
nakagami@gts.med.osaka-u.ac.jp

1 Department of Health Development and Medicine, Graduate School of Medicine, Osaka University, 2-2 Yamada-oka, Suita, Osaka, Japan

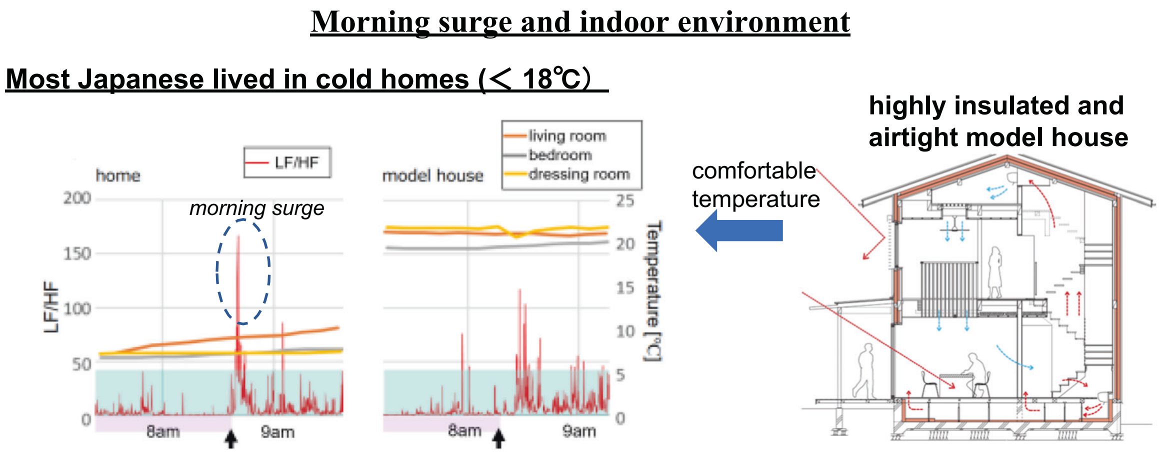
2 Asahi Kasei Construction Materials Corporation, 1-105 Kanda Jimbocho, Chiyoda Ward, Tokyo, Japan

3 JSR corporation, 1-9-2 Higashi-Shimbashi, Minato Ward, Tokyo, Japan

4 Department of Architecture, Kindai University Faculty of Architecture, Higashi Osaka, Osaka, Japan

5 Department of Dermatology, Nara Hospital, Kindai University Faculty of Medicine, Nara, Japan

Graphical Abstract



(2020–1). All subjects were enrolled in this study from Dec 2021 to Feb 2022 during winter season. Four subjects (1–4) stayed at their homes for 2 days and then stayed at the model house for 2 days, and the other four subjects (5–8) did the opposite. Basically, they stayed in the indoor environment all day. Because the participants could not be relaxed in a new environment on the first day, we focused on the analysis from the second day in both houses, except for the case of Subject 8 at their house. Subject 8 did not sleep in their home at all on the second day.

The highly insulated and airtight model house (model house) and temperature measurements

The model house is a two-story wooden detached house with a total floor area of 130.08 m^2 located in Sakaimachi, Sashima-gun, Ibaraki Prefecture in Japan (Asahi Kasei Construction Materials Corporation). The house has a UA value of 0.20 W/(m^2-K) and a C-value of 0.12 cm^2/m2. The UA value indicates the exterior skin average heat transfer coefficient, a standard that indicates the heat insulation performance of a building, with smaller values indicating higher performance; the C-value is the equivalent clearance area, an indicator of the airtightness of a building: the smaller the value is, the higher the performance, which is an index of the degree of high heat insulation and airtightness. This house achieves a comfortable temperature environment by combining a performance that far exceeds the national heat insulation standard with energy-saving equipment. The indoor environments in the subjects' homes and the model house were recorded by installing data loggers equipped with temperature and humidity sensors in various rooms and taking continuous measurements at 10 min intervals.

Sympathetic nervous activity by frequency domain analysis of heart rate variability

The rhythmic components of heart rate variability can be separated and quantitatively assessed by means of power spectral analysis. The powers of high frequency (HF) and low frequency (LF) components of heart rate variability have been shown to estimate cardiac vagal and sympathetic activities, and LF/HF ratio is a marker of sympathetic nervous system activity [6, 7]. Eight subjects (four males and four females) carried portable electrocardiography (Heartnote, JSR corporation, Tokyo) devices that were capable of simultaneously measuring heart rate, CVRR (coefficient of variation of R-R interval), LF, HF and physical activity throughout the day. Sleeping duration was determined by the monitoring of continuous physical activity. Sympathetic activation was defined as showing more than +2 SDs for distribution within an individual in terms of the LF/HF ratio calculated every 10 s. The sympathetic activity analysis of Subject 7 and 8 at first day (model house) was incomplete due to accidental reasons.

Results and discussion

Regarding indoor temperature measurements, room temperatures were kept constant at 20 °C or more in the model house. However, in the participants' houses, temperatures were low with large temperature differences between rooms, and in one case, the room temperature in the bedroom was recorded at 6.3 °C (Fig. 1). Interestingly, sleeping duration in model house was longer than that in the participants' houses for all subjects (Table 1 and Supplementary Figs. 1 and 2). This suggests that the room temperature in model house was comfortable for sleeping.

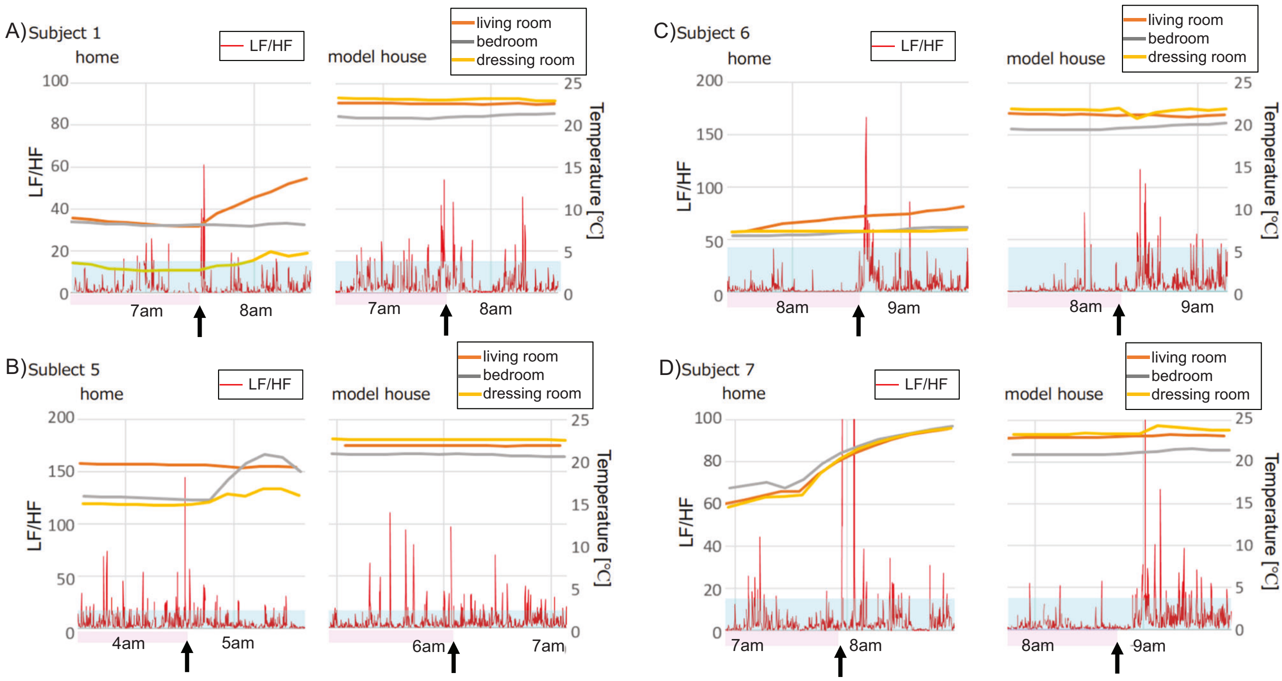


Fig. 1 LF/HF ratio (sympathetic nerve system) and indoor temperature during 2 h after/before waking. Four subjects (Subject 1(**A**), 5(**B**), 6(**C**), and 7(**D**)). showed the rapid increase of LF/HF ration immediately after waking. LF/HF ratio was shown in red line, and the indoor temperature of living room (0.1 m height), bedroom (1.1 m height) and dressing room (1.1 m height) was shown in orange, gray and yellow line, respectively. Blue marker was defined to show +2SD for distribution within an individual in LF/HF calculated every 10 s. Pink marker indicates the sleeping time and black arrow indicates the waking time

Table 1 Sleeping duration and frequency domain analysis of heart rate variability signals for 24 h at the second day

Age, Gender, height/weight/BMI			Sleep duration	HR(bpm)	HF(ms2)	LF/HF	CVRR(%)
Current disease (drug)							
1. 56M	170 cm /90 kg/31.1	(home)	6 h 17 min	63 ± 12	312 ± 298	2.8 ± 2.0	3.3 ± 0.9
	none	(model house)	7 h 53 min	63 ± 9	347 ± 378	2.9 ± 2.1	3.4 ± 0.9
2. 51F	163 cm /56 kg/21.1	(home)	(not available)	74 ± 15	453 ± 320	2.0 ± 1.5	4.3 ± 1.1
	anemia	(model house)	6 h 32 min	71 ± 13	365 ± 238	2.1 ± 1.4	4.1 ± 1.1
3. 53F	162 cm /60 kg/22.9	(home)	5 h 2 min	63 ± 8	429 ± 347	1.5 ± 1.3	3.3 ± 0.7
	none	(model house)	7 h 7 min	66 ± 8	490 ± 388	1.3 ± 1.2	3.5 ± 0.9
4. 77F	150 cm /53 kg/23.6	(home)	7 h 26 min	63 ± 6	423 ± 291	1.0 ± 0.8	3.4 ± 0.9
	HT (ARB)	(model house)	8 h 39 min	69 ± 9	234 ± 164	1.5 ± 1.1	3.0 ± 0.9
5. 63M	178 cm /77 kg/24.3	(home)	5 h 50 min	86 ± 10	58 ± 69	4.0 ± 3.2	2.4 ± 0.8
	HT(CCB + ARB)	(model house)	6 h 42 min	87 ± 7	48 ± 64	3.7 ± 3.2	2.2 ± 0.7
6. 33M	177 cm /83 kg/26.5	(home)	5 h 50 min	74 ± 12	192 ± 211	7.5 ± 7.1	3.8 ± 1.2
	none	(model house)	9 h 4 min	77 ± 14	165 ± 198	9.6 ± 9.4	3.8 ± 1.2
7. 29M	174 cm /68 kg/22.5	[a](home)	5 h 40 min	80 ± 20	449 ± 300	2.6 ± 2.0	4.8 ± 1.8
	Crohn's disease	[a](model house)	7 h 44 min	80 ± 20	308 ± 321	3.4 ± 2.6	3.9 ± 1.0
8. 30F	157 cm /49 kg/19.9	[ab](home)	6 h 13 min	67 ± 15	1220 ± 951	1.9 ± 1.9	5.5 ± 1.3
	none	[a](model house)	7 h 2 min	75 ± 18	760 ± 659	1.7 ± 1.9	4.6 ± 1.1

HR heart rate, *HF* absolute power of high frequency band, *LF/HF* ratio of LF (low frequency) band power to HF band power,

HT hypertension, *ARB* angiotensin receptor blockade, *CCB* calcium channel blockade

[a]The results were obtained for 12 h due at the second day

[b]The results were obtained at the first day

In the analysis of sympathetic nerve system, the average heart rate, HF, LF/HF and CVRR scores on the second day at the participants' houses were not different from that at the model house (Table 1 and Supplementary Figs. 1 and 2) We further focused on the time windows of waking hours. Waking hours are the time when most cardiovascular events occur due to the morning surge in blood pressure, which might be caused by the activation of sympathetic nervous system. As shown in Fig. 1, four subjects showed a morning surge in the sympathetic nervous system immediately after waking up. Subject 5 (hypertensive patient taking anti-hypertensive drug) and 7 (Crohn's disease patient) showed a morning surge at their houses. Subject 1 (obese) and 6 (no current disease) showed the morning surge at both houses and greater sympathetic nervous activity at their home. The physical activity was not correlated with the morning surge (Supplementary Fig. 3). These results suggest that a comfortable temperature may attenuate the morning surge immediately after waking.

The WHO Housing and Health Guidelines recommend a minimum indoor temperature of 18 °C to prevent cold-related diseases. In a recent cross-sectional analysis in Japan, the average temperature in living rooms and bedrooms was 16.8 °C and 12.8 °C, respectively [8]. In contrast, in UK homes, the average living room and bedroom temperatures in the winter were 19.3 °C and 18.9 °C, respectively [9]. Furthermore, in New York, the average room living room temperature in the winter was 23.3 °C [10]. Interestingly, countries with severe winter climates (i.e., Finland or Sweden) tend to have warmer indoor temperatures, which are associated with lower excess mortality during the winter [1]. These findings suggest associations between better housing quality and lower winter excess mortality. A few recent reports showed the relationship between indoor temperatures and BP in Japan [11–13]. Saeki et al. reported that the indoor temperature showed strong associations with daytime SBP, nocturnal BP and morning BP surge [11]. Umishio et al. also showed that systolic blood pressure in the morning had a significantly higher sensitivity to changes in the indoor temperature (8.2 mm Hg increase/10 °C decrease) than that in the evening (6.5 mm Hg increase/10 °C decrease) [12]. They also suggest that the low indoor temperature in Japan might be a risk of morning surge of BP.

This study has the following limitations. First, the sample size was small and had large individual differences of sympathetic nerve activity. We cannot form conclusions from the results, however, a confirmatory study will be designed based on this exploratory result. Second, BP is affected by sleep duration and psychological factors. In this study, sleeping duration was longer in the model house for all subjects, which might be directly associated with the extent of morning surge. This can be further evaluated in the future. Third, we cannot conclude the association of morning BP surge with sympathetic activation because we did not have BP data. A wearable device that monitors both BP and HR will help us to evaluate this association.

During the COVID-19 pandemic, people stayed home and were stressed throughout these 2 years [14]. To prevent cardiovascular events at home, a suitable indoor thermal environment should be implemented society-wide, especially in the winter season.

Author contributions HN, HA, HO, AI, and HY: Study design and concept analysis. HA, HO, ST, KS, and NK.: Data collection and support for analysis. HN wrote the paper. All authors drafted the paper and approved the final version for submission.

Funding This study was partially supported by a collaboration research fund from the Asahi Kasei Construction Materials Corporation.

Compliance with ethical standards

Conflict of interest The Department of Health Development and Medicine is an endowed department supported by Anges, Daicel, and FunPep. Hiroshi Akiyama and Hiroki Otsuka are employees of the Asahi Kasei Construction Materials Corporation. These organization did not have any additional role in the data analysis, decision to publish, or description of Results section of the paper.

References

1. The Eurowinter Group. Cold exposure and winter mortality from ischaemic heart disease, cerebrovascular disease, respiratory disease, and all causes in warm and cold regions of Europe. Lancet. 1997;349:1341–6.
2. Yano Y, Kario K. The risk of cold temperature: an important aspect of the determination of morning blood pressure surge. Hypertens Res. 2011;34:36–8.
3. Narita K, Hoshide S, Kario K. Seasonal Variation in Day-by-Day Home Blood Pressure Variability and Effect on Cardiovascular Disease Incidence. Hypertension. 2022;79:2062–70.
4. Nakagami H, Akiyama H, Otsuka H, Iwamae A, Yamada H. Blood pressure fluctuations and the indoor environment in a highly insulated and airtight model house during the cold winter season. Hypertens Res. 2022;45:1217–9.
5. Kario K, Pickering TG, Hoshide S, Eguchi K, Ishikawa J, Morinari M, et al. Morning blood pressure surge and hypertensive cerebrovascular disease: role of the alpha adrenergic sympathetic nervous system. Am J Hypertens. 2004;17:668–75.
6. Akselrod S, Gordon D, Ubel FA, Shannon DC, Berger AC, Cohen RJ. Power spectrum analysis of heart rate fluctuation: a quantitative probe of beat-to-beat cardiovascular control. Science. 1981;213:220–2.
7. Task force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology. Heart rate variability: standards of measurement, physiological interpretation and clinical use. Circulation. 1996;93:1043–65.
8. Umishio W, Ikaga T, Kario K, Fujino Y, Hoshi T, Ando S, et al. Cross-Sectional Analysis of the Relationship Between Home Blood Pressure and Indoor Temperature in Winter: a Nationwide Smart Wellness Housing Survey in Japan. Hypertension 2019;74:756–66.
9. Building Research Establishment. Energy Follow-Up Survey 2011: Report 2: Mean household temperatures; BRE report

number 283078, Dec 2013. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/274770/2_Mean_Household_Temperatures.pdf.
10. Quinn A, Shaman J. Indoor temperature and humidity in New York city apartments during winter. Sci Total Environ. 2017;583:29–35.
11. Saeki K, Obayashi K, Iwamoto J, Tone N, Okamoto N, Tomioka K, et al. Stronger association of indoor temperature than outdoor temperature with blood pressure in colder months. J Hypertens. 2014;32:1582–9.
12. Umishio W, Ikaga T, Kario K, Fujino Y, Suzuki M, Ando S, et al. Impact of indoor temperature instability on diurnal and day-by-day variability of home blood pressure in winter: a nationwide Smart Wellness Housing survey in Japan. Hypertens Res. 2021;44:1406–16.
13. Kubozono T, Akasaki Y, Kawasoe S, Ojima S, Kawabata T, Makizako H, et al. The relationship between home blood pressure measurement and room temperature in a Japanese general population. Hypertens Res. 2021;44:454–63.
14. Zhang S, Zhong Y, Wang L, Yin X, Li Y, Liu Y, et al. Anxiety, home blood pressure monitoring, and cardiovascular events among older hypertension patients during the COVID-19 pandemic. Hypertens Res. 2022;45:856–65.