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On Human Autonomic Nervous Activity Related to Weather Conditions Based on Big Data Measurement via Smartphone

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Abstract

This research uses our previously-developed smartphone camera-based heart rate change analysis system to survey the correlation between weather patterns and the autonomic nervous activity across a big data set of approximately 200,000 entries. The results showed a trend in which a significant decrease was seen in sympathetic nervous activity in both males and females—the higher the temperature. In addition, a significant increase was seen in the sympathetic nervous system in both males and females—the higher the atmospheric pressure. Lastly, a significant decrease was seen in the sympathetic nervous system in both males and females—the more precipitation there was. These results accord with prior research and with human biological phenomena, and we were able to use a data set of approximately 200,000 entries to statistically demonstrate our hypothesis. We believe this represents a valuable set of reference data for use in the health care.

Keywords

Heart Rate Variability, Autonomic Nervous System, Large Amount of Measurement Data, Weather

1. Introduction

It has long been recognized that modern society is stressful. If human beings are subjected to stress for a long period, the functions of autonomic nervous system and the endocrine system, which control the adrenocortical hormone, will be seriously influenced [1]. The autonomic nervous system controls the balance between the

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sympathetic nerve activity, which responses for maintaining the tension and excitement, and the parasympathetic nerve activity, which responses for maintaining relaxation. Therefore, it is very important for self-management to routinely recognize the state of our autonomic nervous system during everyday life [2].

The typical non-invasive technique for measuring autonomic nervous system uses a small, specialized heart rate sensor [3], or a fingertip pulse wave sensor [4]. These devices are used to measure RR interval (heartbeat interval) and peak interval (a value corresponding to the RR interval that is detected from the pulse waveform) [5], whereupon heart rate variability analysis is performed to calculate sympathetic nervous and parasympathetic nervous activity indicators [6]. These systems use Fast Fourier Transform (FFT) [7] to calculate the autonomic nervous activity from RR interval data in one to five minutes.

However, all these products use extremely expensive, specialized sensors and systems to measure RR intervals and pulse wave peak intervals. Thus, the hurdles to their use by the general public are high. Because of this, measurement of autonomic nervous system conditions has been limited to specialized facilities such as hospitals.

During previous research, authors developed a simple and precise measurement system that does not rely on specialized devices, but utilizes the camera of smartphones sold on the general market [8]. In this system, the device camera is placed on the tip of the finger for a short amount of time (just over 30 seconds), where it detects the pulse waveform peak interval from luminance changes in blood flow. Then, heart rate variability analysis is performed to measure the detailed conditions of the autonomic nervous system, namely, its balance and amount of activity (total power).

This system is currently being put to use by approximately 1,000,000 users (as of March 2016) [9] as an App for their iPhone (Apple Inc.) [10] or Android device (Google Inc.) [11].

Up to this point, autonomic nervous system measurements have been mainly conducted at hospitals, laboratories, and other facilities, using specialized sensors and equipment. Thus, the number of possible measurement subjects was limited to few hundred people at most. And as measurements were conducted under a particular set of circumstances, they cannot be considered an accurate representation of autonomic nervous system in daily life.

The system utilized in this study, however, is able to easily measure a large amount of data at any time, any location, and after any activity, giving researchers an understanding of autonomic nervous system conditions under everyday circumstances.

The authors used this system in previous research to investigate the relationship between autonomic nervous system and age and BMI, based on approximately 100,000 entries of autonomic nervous system data. This study found that the autonomic nervous activity decreases significantly as age and BMI increase [12]. The authors also published a study on the diurnal variation of autonomic nervous system, based on approximately 100,000 entries of autonomic nervous system data [13]. The results of these studies are consistent with results obtained using specialized sensors and measurement equipment.

While there is a comparatively high volume of research [14] [15] on the correlation between atmospheric temperature (one aspect of weather) and changes in the human body, there remains little research into other factors like atmospheric pressure and precipitation.

Studies on all of these factors have involved small samples sizes, so there was as yet no research that utilized a big data set of several hundreds of thousands of entries to analyze the relationship of weather to the autonomic nervous system.

This research uses an unprecedented set of approximately 200,000 entries of data on the autonomic nervous system and analyzes it according to the three parameters below.

- The relationship between autonomic nervous system and atmospheric temperature
- The relationship between autonomic nervous system and atmospheric pressure
- The relationship between autonomic nervous system and precipitation

2. Methods

This study employed a heart rate variability analysis system utilizing the camera of smartphones [8]. In this system, the smartphone camera is placed against the tip of the finger, where it continuously acquires data on the luminance of the skin. If the finger is lifted from the camera, the system displays a warning message. A pulse wave is derived from the changes in luminance, and the peak interval (corresponds to the RR interval) is detected from that pulse waveform. Then, frequency analysis is performed on peak interval fluctuations to calculate the autonomic nervous system indicator. This system is outlined in **Figure 1**.

The frequency analysis conformed to the procedure described in [6], with the low frequency component (LF) calculated as 0.04 Hz - 0.15 Hz, and the high frequency component (HF) calculated as 0.15 Hz - 0.4 Hz.

LF/HF values are used as indicators of sympathetic nervous activity, as well as indicators of tension, stimulation, and stress [6].

This paper analyzes the autonomic nervous system data of 53,800 subjects (17,474 males and 36,326 females). Measurement data was used with the consent of the subjects, in accordance with the ethics regulations of WIN Frontier Co., Ltd.

Subject age (in tens of years) and sex are displayed in **Table 1**. IBM SPSS Statics Version 22 was used for this study's statistical processing. The significance level was set to 5%.

3. The Relation between Autonomic Nervous System and Atmospheric Temperature

This research surveys the relationship of atmospheric pressure to autonomic nervous system. Data on atmospheric temperature averages was downloaded from the Japan Meteorological Agency's website [16] and the date of measurements and data from each prefecture tied to measured values by city as grouped by ordinance-designated city. The temperature intervals were grouped around days measuring 25 degrees Celsius, or what is called a "summer's day" [17], with categories for days below 25 degrees and above 25 degrees, respectively. Data by

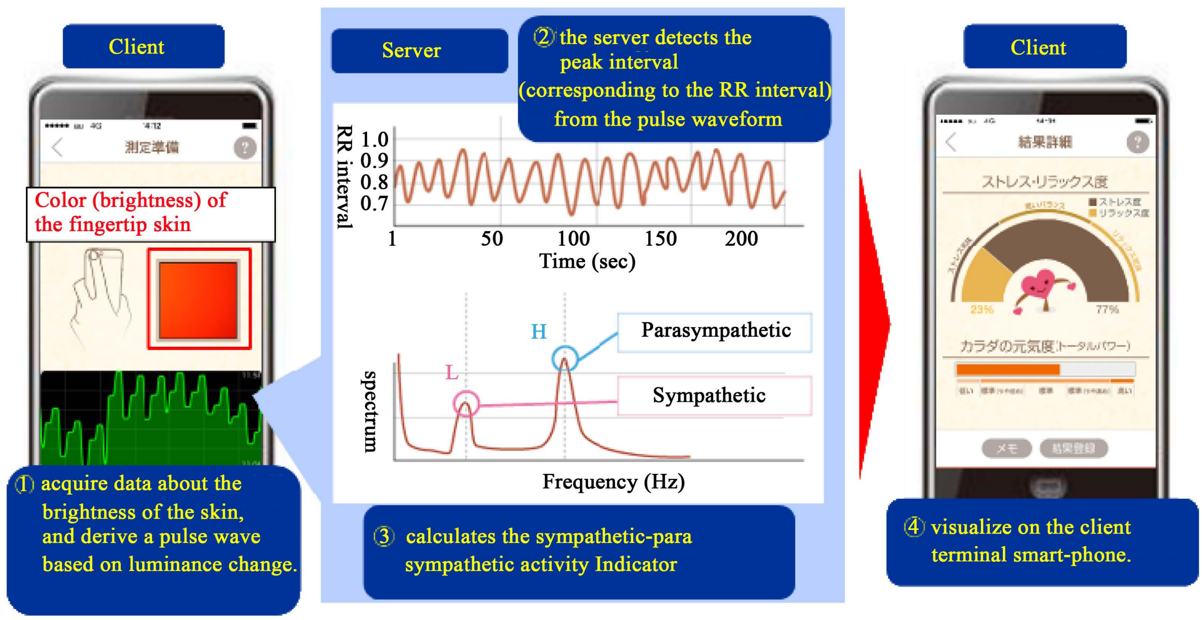

Figure 1. System outline.

Table 1. Subject age (in tens of years) and sex.

Age	Man	Female	Total
10's	1890	6333	8223
20's	2530	8746	11,276
30's	2326	4862	7188
40's	4584	8723	13,307
50's	4633	6524	11,157
Over 60's	1511	1138	2649
Total	17,474	36,326	53,800

temperature category is seen in **Table 2**.

It has been reported that treating LF/HF, an index of sympathetic nervous activity, as a logarithm normalizes data [18], so LF/HF for each data entry was converted to the LnLF/HF logarithm, and the difference in population mean between each was analyzed. Results for males are seen in **Table 3** and **Figure 2**, and those for females in **Table 4** and **Figure 3**.

The results show a trend in which there is a significant drop in sympathetic nervous activity in both males and females the higher the temperature is (P value: <statistical significance 0.05).

In general, it is understood that in cold weather, the effects of the sympathetic nervous system constrict the blood vessels and prevent the body from dispersing heat; in warm weather, the parasympathetic nervous system expands the blood vessels and causes the body to perspire, thereby decreasing body temperature [19]. This research hypothesized that a similar biological phenomenon would be present in the autonomic nervous system and manifest similar heat- and cold-prevention mechanisms. We were able to utilize a large set of 200,000 entries of data to statistically demonstrate this.

We believe this represents an extremely useful set of reference data that can be used for adjusting day-to-day lifestyles to account for temperature increases, to control health, et cetera.

4. The Relation between Autonomic Nervous System and Atmospheric Pressure

In this section, we examine the relationship between atmospheric pressure and the autonomic nervous system. Data on atmospheric pressure averages was downloaded from the Japan Meteorological Agency's website [16] and the date of measurements and data from each prefecture tied to measured values by city as grouped by ordinance-designated city. The pressure intervals were grouped around readings of 1013 hPa for one unit of pressure,

Table 2. Data by temperature category.

Temperature	Man	Female	Total
Under 25˚C	74,100	150,767	224,867
Over 25˚C	3818	12,500	16,318
Total	77,918	163,267	241,185

Table 3. T-test results: atmospheric temperature and LnLF/HF (male).

Group Statistics					
	Temperature_flag	N	Mean	Std Deviation	Sid Error Mean
LnLF/HF	Under 25˚C	74,100	0.5041853460	0.9161316994	0.003365494
	Over 25˚C	3818	0.4466678728	0.8858146424	0.0143358977

		Levene's Test for Equality of Variances	
		F	Sig.
LnLF/HF	Equal variances assumed	7.66	0.006
	Equal variances not assumed		

Independent Samples Test

t-test for Equality of Means						
			Mean	St < J. Error	95% Confidence Interval of the Difference	
t	df	3lg. (2-talled)	Difference	Difference	Lower	Upper
3.789	77,916	0.000	0.0575174732	0.0151794567	0.0277658320	0.0872691143
3.906	4248.655	0.000	0.0575174732	0.0147256413	0.0286475221	0.0863874242

Table 4. T-test results: atmospheric temperature and LnLF/HF (female).

Temperature_flag	N	Mean	Std. Deviation	Std. Error Mean
LnLF/HF Under 25˚C	150,767	0.3745794716	0.9287018287	0.0023917906
Over 25˚C	12,500	0.3520963961	0.8932121169	0.0079891320

		Levene's Test for Equality of Variances	
		F	Sig.
LnLF/HF	Equal variances assumed	25.065	0.000
	Equal variances not assumed		

Independent Samples Test

Test for Equality of Means						
t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
					Lower	Upper
2.608	163,265	0.009	0.0224830755	0.0086192105	0.0055896134	0.0393765376
2.696	14,830.070	0.007	0.0224830755	0.0083394780	0.0061366649	0.0388294861

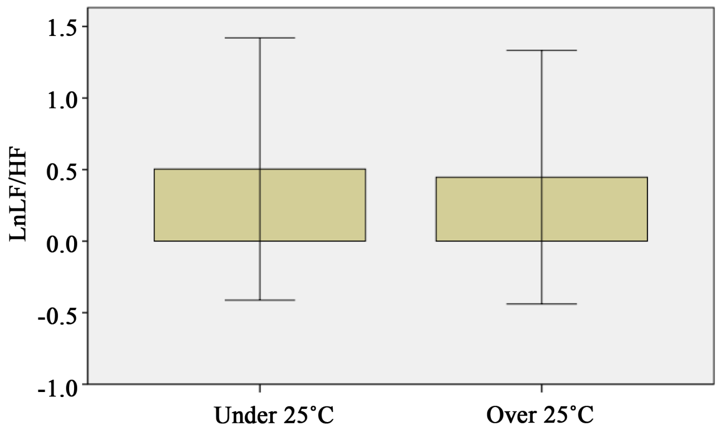

Figure 2. Relation between atmospheric temperature and LnLF/HF (male).

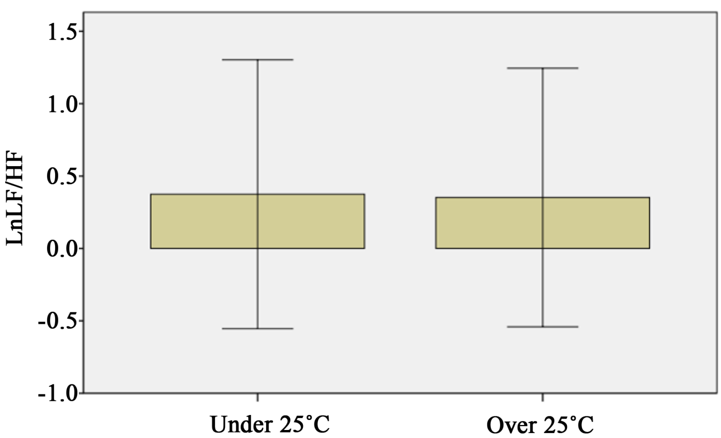

Figure 3. Relation between atmospheric temperature and LnLF/HF (female).

with categories for days below 1013 Hpa and above 1013 Hpa, respectively. Data by pressure category is shown in **Table 5**.

LF/HF for each entry was converted to the LnLF/HF logarithm, and the difference in population mean between each was analyzed. Results for males are seen in **Table 6** and **Figure 4**, and those for females in **Table 7** and **Figure 5**.

The results show a trend in which there is a significant increase in sympathetic nervous activity in both males and females the higher the pressure is (P value < statistical significance 0.0.5)

According to prior research, low pressure systems associated with weather irregularity increase parasympathetic nervous activity, such as in bradycardia, decreased granulocytes, increased lymphocytes, decreased urinary adrenaline, et cetera. The body becomes sluggish and one feels depressed [20] [21] in high pressure systems associated with fair weather, there is increased sympathetic nervous activity, with exacerbated release of dopamine in the corpus striatum, exacerbated release of peripheral catecholamine, et cetera, causing one to feel comfortable and at ease [20] [22]. In this way, this research shows similar trends to those found in prior research, and we were able to successfully use the data set of approximately 200,000 entries to statistically demonstrate this autonomic nervous system function. We believe this represents an extremely useful set of reference data that can be used for adjusting day-to-day lifestyles to account for atmospheric pressure changes, to control health, et cetera.

5. The Relation between Autonomic Nervous System and Precipitation

In this section, we examine the relationship between precipitation and the autonomic nervous system. Data on atmospheric pressure averages was downloaded from the Japan Meteorological Agency's website [16] and the

Table 5. Data by atmospheric pressure category.

Pressure	Man	Female	Total
Under 1013 Hpa	40,984	87,558	128,542
Over 1013 Mpa	36,934	75,709	112,643
Total	77,918	163,267	241,185

Table 6. T-test data: atmospheric pressure and LnLF/HF (male).

Group Statistics

HPAJag		N	Mean	Std. Deviation	Std. Error Mean
LnLF/HF	Under 1013 Hpa	40,964	0.4836457632	0.9072410738	0.0044814188
	Over 1013 Hpa	36,934	0.5210314105	0.9226212556	0.0048007632

		Levene's Test for Equality of Variances	
		F	Slg.
LnLF/HF	Equal variances assumed	8.402	0.004
	Equal variances not assumed		

Independent Samples Test

Test for Equality of Means						
t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
					Lower	Upper
−5.698	77,916	0.000	−0.037385647	0.0065616416	−0.050246424	−0.024524870
−5.693	76,794.088	0.000	−0.037385647	0.0065673771	−0.050257669	−0.024513626

Table 7. T-test data: atmospheric pressure and LnLF/HF (female).

Group Statistics

HPA_flag		N	Mean	Std. Deviation	Std. Error Mean
LnLF/HF	Under 1013 Hpa	87,558	0.362064544	0.917884073	0.003101987
	Over 1013 Hpa	75,709	0.385340987	0.935254525	0.003399038

		Levene's Test for Equality of Variances	
		F	Sig.
LnLF/HF	Equal variances assumed	22.594	0.000
	Equal variances not assumed		

Independent Samples Test

t-test for Equality of Means						
t	df	Sig (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
					Lower	Upper
−5.065	163,265	0.000	−0.023276443	0.0045954590	−0.032283441	−0.014269445
−5.058	158,978.471	0.000	−0.023276443	0.0046017152	−0.032295705	−0.014257181

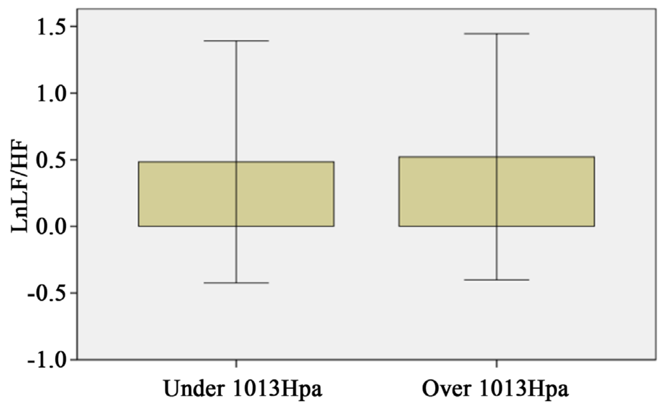

Figure 4. Relation between atmospheric pressure and LnLF/HF (male).

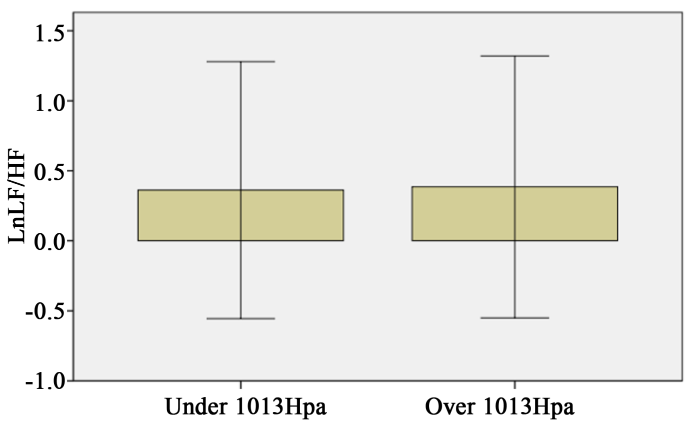

Figure 5. Relation between atmospheric pressure and LnLF/HF (female).

date of measurements and data from each prefecture tied to measured values by city as grouped by ordinance-designated city.

The precipitation intervals were grouped around 10 mm of precipitation in a 24-hour period, with categories for days below 10 mm and above 10 mm, respectively. Data by precipitation is shown in **Table 8**.

LF/HF for each entry was converted to the LnLF/HF algorithm, and the difference in population mean between each was analyzed. Results for males are seen in **Table 9** and **Figure 6**, and those for females in **Table 10** and **Figure 7**.

The results show a trend in which there is a significant increase in sympathetic nervous activity in both males and females the more rain there is (P value < statistical significance 0.05).

In general, it is understood that on days with fair weather, there is more oxygen in the atmosphere, and this increases oxygen pressure in the bloodstream, causing the body to prioritize sympathetic nervous activity; by contrast, on cloudy days with poor weather, there is less oxygen, and this decreases oxygen pressure in the bloodstream, causing the body to prioritize parasympathetic nervous activity [20]-[22]. This research hypothesized that a similar biological phenomenon would be present in the autonomic nervous system. We believe this represents an extremely useful set of reference data that can be used for adjusting day-to-day lifestyles to account for precipitation changes, to control health, et cetera.

6. Conclusions

In this research, we used our previously-developed smartphone camera-based heart rate change analysis system [8] to survey the correlation between weather patterns and the autonomic nervous system across a big data set of approximately 200,000 entries.

Table 8. Data by precipitation volume.

Precipitation	Man	Female	Total
Under 10 mm	74,536	153,634	228,170
Over 10 mm	3382	9633	13,015
Total	77,918	163,267	241,185

Table 9. T-test data: precipitation and LnLF/HF (male).

Group Statistics

Precipitation_Flag		N	Mean	Std. Deviation	Sid. Error Mean
LnLF/HF	Under 10 mm	74,536	0.503473688	0.9158507122	0.0033546070
	Over 10 mm	3382	0.4549370943	0.8889709991	0.0152862441

		Levene's Test for Equality of Variances	
		F	Sig.
LnLF/HF	Equal variances assumed	2.923	0.087
	Equal variances not assumed		

Independent Samples Test

t-test for Equality of Means						
t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
					Lower	Upper
3.018	77,916	0.003	0.0485365939	0.0160815563	0.0170168431	0.0800563447
3.101	3714.105	0.002	0.0485365939	0.0156500047	0.0178531491	0.0792200387

Table 10. T-test data: precipitation and LnLF/HF (female).

Group Statistics

Precipitation_Flag		N	Mean	Std. Deviation	Std. Error Mean
LnLF/HF	Under 10 mm	153,634	0.3762990589	0.9268479336	0.0023646388
	Over 10 mm	9633	0.3179797096	0.9115128369	0.0092871404

		Levene's Test for Equality of Variances	
		F	Sig.
LnLF/HF	Equal variances assumed Equal variances not assumed	3.302	0.069

Independent Samples Test

t-test for Equality of Means						
t	(Jf)	Sig (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
					Lower	Upper
5.997	163,265	0.000	0.0583193492	0.0097255108	0.0392575630	0.0773811354
6.085	10,918.459	0.000	0.0583193492	0.0095834489	0.0395340521	0.0771046464

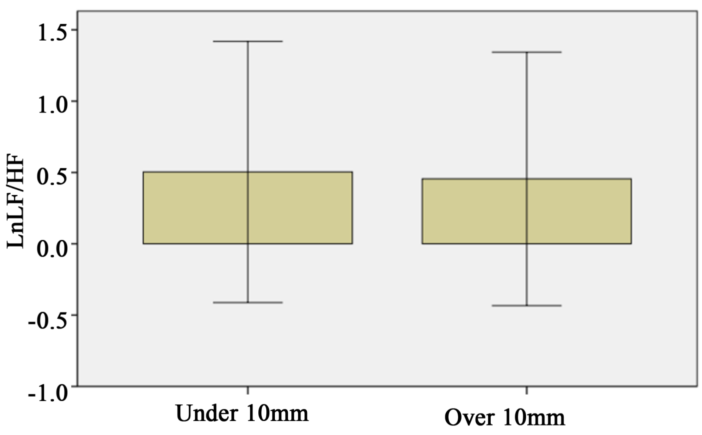

Figure 6. Relation between precipitation and LnLF/HF (male).

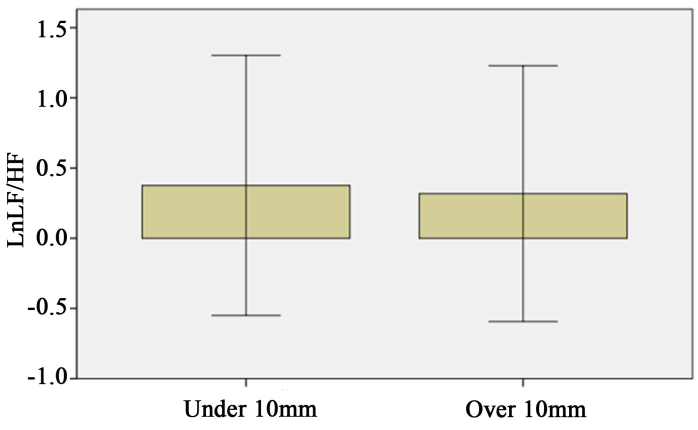

Figure 7. Relation between precipitation and LnLF/HF (female).

The results showed a trend in which a significant decrease was seen in sympathetic nervous activity in both males and females—the higher the temperature. In addition, a significant increase was seen in the sympathetic nervous system in both males and females—the higher the atmospheric pressure. Lastly, a significant decrease was seen in the sympathetic nervous system in both males and females—the more precipitation there was. These results accord with prior research and with human biological phenomena, and we were able to use a data set of approximately 200,000 entries to statistically demonstrate our hypothesis. We believe this represents a valuable set of reference data for use in the health care.

Our smartphone camera-based heart rate change analysis system [8] is accreting several tens of thousands of new data points on the autonomic nervous system daily. Once the data exceeds one million entries, we believe we will be in a position to conduct a more fine-grained analysis of the impact of autonomic nervous system function in daily life.

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