Analysis of Human Autonomic Nervous Activity Based on Big Data Measurement Via SmartPhone

Makoto KOMAZAWA
Graduate School of System Informatics, Kobe University
Rokkodai-cho, Nada-ku, Kobe 657-8501 Japan
makoto.komazawa@winfrontier.com

Hiroyuki KOBAYASHI
JUNTENDO University
2-1-1 , Hongou, Bunkyou-ku, Tokyo, 113 – 8421 , Japan

Kenichi ITAO
WINFrontier Co., Ltd.
247 Shin-Yurakucho Building, 1-12-1 Yurakucho, Chiyoda-ku, Tokyo, 100-0006 Japan

Zhiwei LUO
Organization of Advanced Science and Technology
Kobe University
Nada-ku, Kobe 657-8501 Japan

***Abstract*—This study used a large amount of autonomic nervous system data to investigate the relationship between autonomic nervous system and activity, day of the week, and region. Data was measured via a heart rate variability analysis system that utilizes the camera of smartphones [8]. This system was developed by the authors during previous research. As for as the relationship between autonomic nervous system and activity, total power and sympathetic nervous activity were found to rise after waking, while during leisure time, it was found that total power rises and sympathetic nervous activity is inhibited. Concerning the relationship between autonomic nervous system and day of the week, it was found that total power decreases from the middle through the latter part of the week (namely, Wednesday, Thursday, and Friday), while it rises on Saturday. What's more, sympathetic nervous activity is suppressed on Saturday. Regarding the relationship between autonomic nervous system and region, it was found that total power is lower in the Kanto region than in others. Regarding weather conditions, the results showed a trend in which a significant decrease was seen in sympathetic nervous activity the higher the temperature. In addition, a significant increase was seen in the sympathetic nervous system the higher the atmospheric pressure. Lastly, a significant decrease was seen in the sympathetic nervous system the more precipitation there was. These results accord with prior research and with human biological phenomena, and we were able to use big data to statistically demonstrate our hypothesis.**

Keywords-Heart rate variability; Autonomic nervous system; Big Data Measurement; Activity; Day of the Week; Region; Wether Conditons

I. 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, that controls the adrenocortical hormone, will be seriously influenced [1]. The autonomic nervous system controls the balance between the 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 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 increases [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 big data on the autonomic nervous system and analyzes it according to the six parameters below.

- The relationship between autonomic nervous system and activity
- The relationship between autonomic nervous system and day of the week
- The relationship between autonomic nervous system and region
- 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

II. METHODS

This study used 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. 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].The sum of the LF and HF values are called the total power (TP), and it serves as an indicator of the autonomic nervous activity [6]. The total power is said to be correlated with fatigue, with smaller values indicating higher levels of fatigue [16].

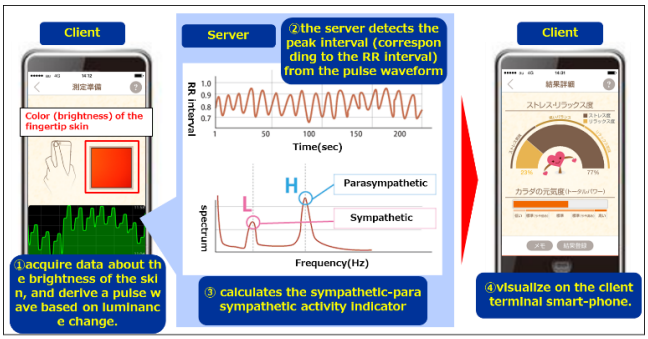


Figure 1. System Outline

This paper analyzes the autonomic nervous system data of 27,307 subjects, 130,648 data about behavior, daily and reginal changes and analyzes the autonomic nervous system data of 53,800 subjects, 241,185 data about weather conditions.

Measurement data was used with the consent of the subjects, in accordance with the ethics regulations of WIN Frontier Co., Ltd.

IBM SPSS Statics Version 22 was used for this study's statistical processing. The significance level was set to 5%.

III. THE RELATIONSHIP BETWEEN AUTONOMIC NERVOUS SYSTEM AND ACTIVITY

In this section, a relationship (under everyday circumstances) between autonomic nervous system and activity is shown. In the research conducted up to this point, there have been few reports analyzing trends (based on a large amount of data) in autonomic nervous system for different activities of everyday life.

A. The Relationship between Total Power and Activity

In this section, the relationship between total power and activity is investigated. It is said that performing logarithmic transformation on total power (an indicator of autonomic nervous system) increases its normality [17], so logarithmic transformation was performed on the total power values (LnTP) for all the measurement data. The resulting values were then divided into eight groups based on activity, and the differences between groups were investigated by performing a Games-Howell multiple comparison procedure. The results are given in Figure 2. Total power was found to be significantly higher after waking and during leisure time, a trend that was also observed when analyzing data separately by sex.

It has been observed in previous research that the amount of autonomic nervous system rises before and after waking due to diurnal variation in autonomic nervous system [18], a trend that is consistent with observations made in this study. What's more, total power was found to rise during leisure

time, suggesting that leisure is effective in increasing autonomic nervous system and function. Conversely, total power was found to be low during housework.

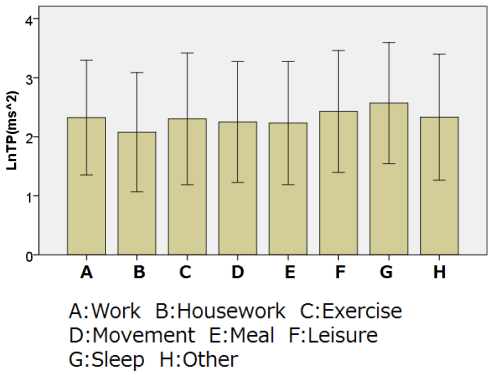


Figure 2. The Relationship between LnTP and Activity

B. *The Relationship between LF/HF and Activity*

In this section, the relationship between LF/HF (an indicator of sympathetic nervous activity) and region is investigated. It is said that performing logarithmic transformation on LF/HF increases its normality [17], so logarithmic transformation was performed on the LF/HF values (LnLF/HF) for all the measurement data. A Games-Howell multiple comparison procedure was then performed on these values, the results of which are given in Figure 3.

Sympathetic nervous activity was found to rise significantly after waking and during work, while during leisure time, it was found that sympathetic nervous activity is inhibited. These trends were also observed when analyzing data separately by sex.

It has been observed in previous research that sympathetic nervous activity rises before and after waking [18], a trend that is consistent with observations made in this study.

It was also observed that during leisure time, sympathetic nervous activity is inhibited and subjects are relaxed.

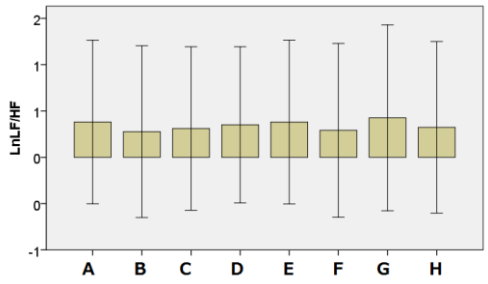


Figure 3. The Relationship between LnLF/HF and Activity

IV. THE RELATIONSHIP BETWEEN AUTONOMIC NERVOUS SYSTEM AND DAY OF THE WEEK

In this section, a relationship (under everyday circumstances) between autonomic nervous system and activity is shown. In the research conducted up to this point, there have been few reports analyzing trends (based on a large amount of data) in autonomic nervous system (under everyday circumstances) for different days of the week.

A. *The Relationship between Total Power and Day of the Week*

In this section, the relationship between total power and day of the week is investigated. .

Data was divided into seven groups based on day of the week, and the differences between groups were analyzed by performing logarithmic transformation on the TP values (LnTP) for all the measurement data, and then performing a Games-Howell multiple comparison procedure. The results are given in Figure 4.

Total power was found to significantly decrease from the middle through the latter part of the week (namely, Wednesday, Thursday, and Friday), while it significantly increases on Saturday. These trends were also observed when analyzing data separately by sex.

While there is believed to be some dispersion based on region and workplace, according to information reported by the Ministry of Health, Labour, and Welfare on industrial accident occurrence by day of the week [19], accumulating fatigue, decreasing concentration, and other factors contribute to a high incidence of industrial accidents around Thursday (with the weekend approaching). In the report, the work week starts on Monday.

Most people have likely experienced increasing fatigue from the middle through the latter part of the week, a trend that is consistent with the current study's finding that total power decreases during the same period of the week.

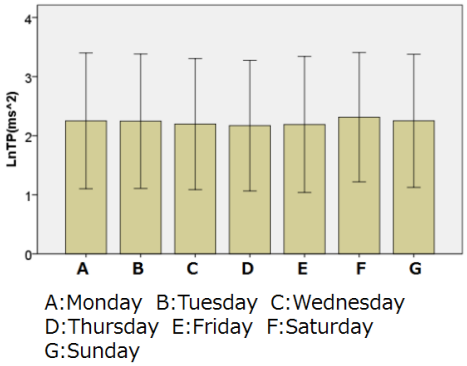


Figure 4. The Relationship between LnTP and Day of the Week

B. *The Relationship between LF/HF and Day of the Week*

In this section, the relationship between LF/HF (an indicator of sympathetic nervous activity) and day of the week is investigated. Logarithmic transformation was performed on the LF/HF values (LnLF/HF) for all the measurement data, and then a Games-Howell multiple comparison procedure was performed. The results are given in Figure 5. Sympathetic nervous activity was found to decrease significantly on Saturday, a trend that was also observed when analyzing data separately by sex. As mentioned previously, total power was found to be high on

Saturday. It can be said that, compared to other days of the week, autonomic nervous system is extremely good on Saturday.

This may be influenced by the cycle of the days of the week. the sympathetic nervous activity of many people increases during weekdays as they are kept busy with work, housework, and other duties, and this increase is seen again on Sunday as peoples' tension and emotions rise in anticipation of the coming week.

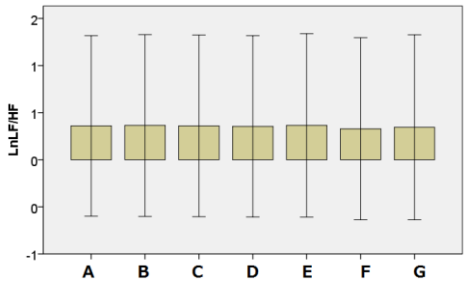


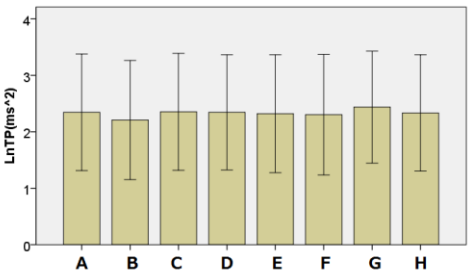
Figure 5. The Relationship between LnLF/HF and Day of the Week

V. THE RELATIONSHIP BETWEEN AUTONOMIC NERVOUS SYSTEM AND REGION

In this section, a relationship (under everyday circumstances) between autonomic nervous system and region is shown. In the research conducted up to this point, there have been few reports analyzing regional trends (based on a large amount of data) in autonomic nervous system under everyday circumstances.

A. The Relationship between Total Power and Regions

In this section, the relationship between total power and region is investigated. Data was divided into eight groups based on prefecture, and the differences between groups were analyzed by performing logarithmic transformation on the TP values (LnTP) for all the measurement data, and then performing a Games-Howell multiple comparison procedure. The results are given in Figure 6. The total power of the Kanto region was found to be significantly lower than in other regions, a trend that was also observed when analyzing data separately by sex. In general, the incidence of autonomic neuropathy is said to be higher in the capital (with its higher stress levels) than in the provinces. This may be correlated with the results of this study.



A:Hokkaido and Tohoku B:Kanto
C:Koshinetsu D:Chubu E:Kinki
F:Chugoku G:Shikoku
H:Kyushu and Okinawa

Figure 6. The Relationship between LnTP and Region

B. The Relationship between LF/HF and Region

In this section, the relationship between LF/HF and region is investigated. Logarithmic transformation was performed on the LF/HF values (LnLF/HF) for all the measurement data, and then a Games-Howell multiple comparison procedure was performed. The results are given in Figure 7. No significant difference in LF/HF was observed between regions.

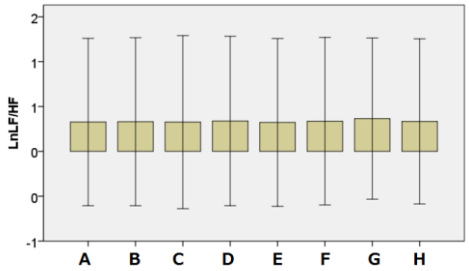


Figure 7. The Relationship between LnLF/HF and Region

VI. THE RELATIONSIP BETWEEN AUTONOMIC NERVOUS SYSTEM AND ATMOSPHERIC TEMPERATURE

In this section, we surveys the relationship of atmospheric pressure to autonomic nervous system. Data on atmospheric temperature averages was downloaded from the Japan Meteorological Agency's website [20] 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" [21], with categories for days below 25 degrees and above 25 degrees, respectively.

It has been reported that treating LF/HF, an index of sympathetic nervous activity, as a logarithm normalizes data [17], 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 are seen in Figure 8.

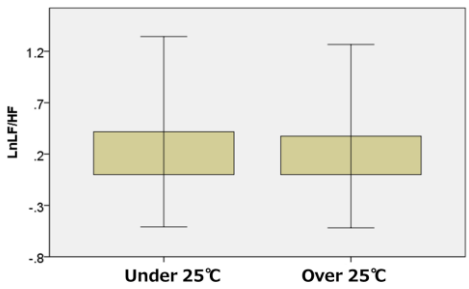


Figure 8. The Relationship between LnLF/HF and Atmospheric Temperature

The results show a trend in which there is a significant drop in sympathetic nervous activity 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.[22] 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.

VII. THE RELATIONSIP 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 [20] 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 1013hPa for one unit of pressure, with categories for days below 1013Hpa and above 1013Hpa, respectively.

LF/HF for each entry was converted to the LnLF/HF logarithm, and the difference in population mean between each was analyzed. Results are seen in Figure 9.

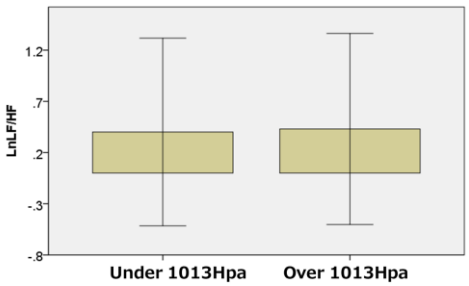


Figure 9. The Relationship between LnLF/HF and Atmospheric Pressure

The results show a trend in which there is a significant increase in sympathetic nervous activity 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 [23] [24]; 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. [23] [25] 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.

VIII. THE RELATIONSIP 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 [20] and the 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 10mm of precipitation in a 24-hour period, with categories for days below 10mm and above 10mm, respectively.

LF/HF for each entry was converted to the LnLF/HF algorithm, and the difference in population mean between each was analyzed. Results are seen in Figure 10.

The results show a trend in which there is a significant increase in sympathetic nervous activity 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. [23] [24] [25]. 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.

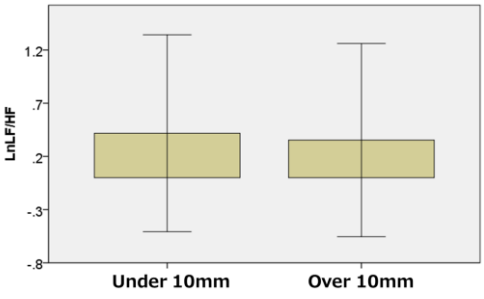


Figure 10. The Relationship between LnLF/HF and Precipitation

IX. CONCLUSION

This study used a large amount of autonomic nervous system data to investigate the relationship between autonomic nervous system and activity, day of the week, and region. Data was measured via a heart rate variability analysis system that utilizes the camera of smartphones [8]. This system was developed by the authors during previous research. As for as the relationship between autonomic nervous system and activity, total power and sympathetic nervous activity were found to rise after waking, while during leisure time, it was found that total power rises and sympathetic nervous activity is inhibited.

Concerning the relationship between autonomic nervous system and day of the week, it was found that total power decreases from the middle through the latter part of the week (namely, Wednesday, Thursday, and Friday), while it rises on Saturday. What's more, sympathetic nervous activity is suppressed on Saturday. Regarding the relationship between autonomic nervous system and region, it was found that total power is lower in the Kanto region than in others.

Regarding weather conditions, the results showed a trend in which a significant decrease was seen in sympathetic nervous activity the higher the temperature. In addition, a significant increase was seen in the sympathetic nervous system the higher the atmospheric pressure. Lastly, a significant decrease was seen in the sympathetic nervous system the more precipitation there was. These results accord with prior research and with human biological phenomena, and we were able to use big data to statistically demonstrate our hypothesis.

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