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On Human Autonomic Nervous Activity Related to Behavior, Daily and Regional Changes Based on Big Data Measurement via Smartphone

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Abstract

This research uses a large amount of autonomic nervous system data (approximately 100,000 entries) to investigate the relationship between human autonomic nervous activity and behaviors, daily and regional changes. Data were measured via a heart rate variability analysis system that utilizes the camera of smartphones. This system was developed by the authors during previous research. The relations between autonomic nervous system and behaviors, total power and sympathetic nervous activity were found to rise after waking, while during leisure time, the 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, while the 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 of Japan than in others. This study also shows statistical proof (using a large amount of measurement data) to ideas held by the public for years. Thus, the data can be considered meaningful to the society, and the authors hope that it helps to improve work-life balance.

Keywords

Heart Rate Variability, Autonomic Nervous System, Large Amount of Measurement Data, Activity, Day of the Week, Region

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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 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) [11] as an App for their iPhone (Apple Inc.) [9] or Android device (Google Inc.) [10].

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.

This research uses an unprecedented set of approximately 100,000 entries of data on the autonomic nervous system and analyzes it according to the three parameters below.

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

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**.

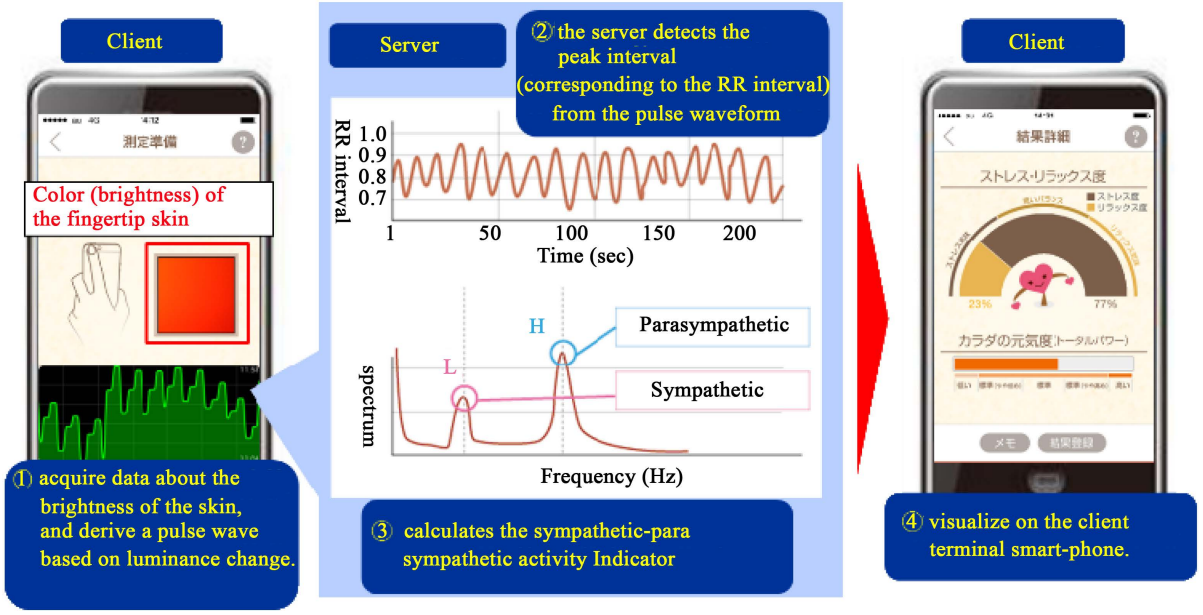

Figure 1. System outline.

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 [14].

This paper analyzes the autonomic nervous system data of 27,307 subjects (6394 males and 20,913 females). Measurement data was used with the consent of the subjects, in accordance with the ethics regulations of WIN Frontier Co., Ltd. The data was measured during April 2015 to September 2015.

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 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.

3.1. The Relationship between Total Power and Activity

In this section, the relationship between total power and activity is investigated. Information on the measurement data used in the study's analysis is given in **Table 2**. It is said that performing logarithmic transformation on total power (an indicator of autonomic nervous system) increases its normality [15], 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** and **Table 3**. 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 [16], 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 ef-

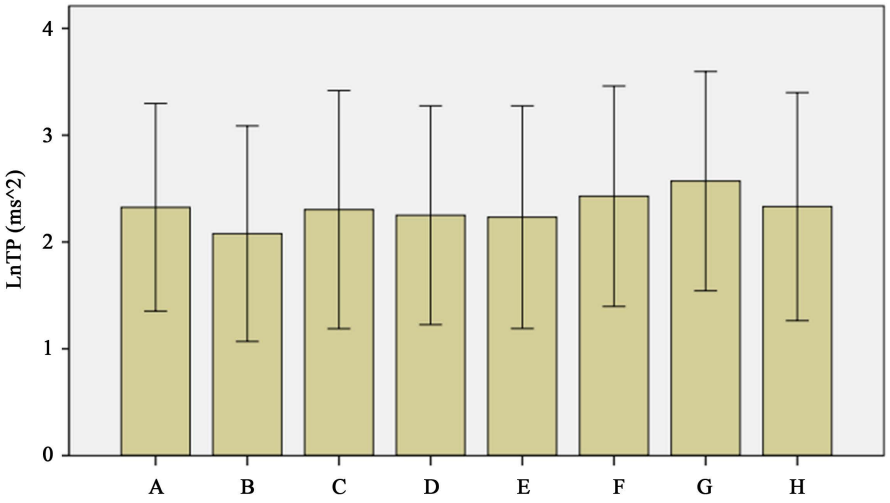

Figure 2. The relationship between LnTP and activity.

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

Age	Man	Female	Total
10’s	1058	9448	10,506
20rs	1433	7621	9054
30rs	1342	1856	3198
40’s	1406	1404	2810
50rs	884	528	1412
Over 60’s	271	56	327
Total	6394	20,913	27,307

Table 2. Data by activity.

Action	Man	Female	Total
A	5356	13,043	18,399
B	1371	3338	4709
C	837	2039	2876
D	2641	6431	9072
E	5034	12,260	17,294
F	12,661	30,834	43,495
G	4587	11,171	15,759
H	5544	13,501	19,045
Total	38,030	92,618	130,648

A: Work; B: Housework; C: Exercise; D: Movement; E: Meal; F: Leisure; G: Sleep; H: Other.

Table 3. Multiple comparison results (LnTP and activity).

Multiple Comparisons						
Dependent Variable: LnTP						
Games-Howell						
(1) AcN	(J) AcN	Mean Difference (1-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Work	Housework	0.2470*	0.0223	0.000	0.179	0.315
	Exercise	0.0218	0.0301	0.996	−0.069	0.113
	Movement	0.0747*	0.0177	0.001	0.021	0.128
	Meal	0.0928*	0.0146	0.000	0.049	0.137
	Leisure	−0.1038*	0.0119	0.000	−0.140	−0.068
	Sleep	−0.2452*	0.0149	0.000	−0.290	−0.200
	Other	−0.0062	0.0144	1.000	−0.050	0.037
Housework	Work	−0.2470*	0.0223	0.000	−0.315	−0.179
	Exercise	−0.2252*	0.0348	0.000	−0.331	−0.120
	Movement	−0.1723*	0.0249	0.000	−0.248	−0.097
	Meal	−0.1542*	0.0228	0.000	−0.223	−0.085
	Leisure	−0.3507*	0.0212	0.000	−0.415	−0.286
	Sleep	−0.4922*	0.023	0.000	−0.562	−0.422
	Other	−0.2532*	0.0227	0.000	−0.322	−0.184
Exercise	Work	−0.0218	0.0301	0.996	−0.113	0.069
	Housework	0.2252*	0.0348	0.000	00.12	0.331
	Movement	0.0529	0.032	0.717	−0.044	0.150
	Meal	0.0711	0.0304	0.274	−0.021	0.163
	Leisure	−0.1255*	0.0292	0.000	−0.214	−0.037
	Sleep	−0.2669*	0.0305	0.000	−0.360	−0.174
	Other	−0.0279	0.0303	0.984	−0.120	0.064
Movement	Work	−0.0747*	0.0177	0.001	−0.128	−0.021
	Housework	0.1723*	0.0249	0.000	0.097	0.248
	Exercise	−0.0529	0.032	0.717	−0.150	0.044
	Meal	0.0181	0.0182	0.975	−0.037	0.073
	Leisure	−0.1784*	0.0162	0.000	−0.227	−0.129
	Sleep	−0.3199*	0.0185	0.000	−0.376	−0.264
	Other	−0.0809	0.0181	0.000	−0.136	−0.026
Meal	Work	−0.0928'	0.0146	0.000	−0.137	−0.049
	Housework	0.1542*	0.0228	0.000	0.085	0.223
	Exercise	−0.0711	0.0304	0.274	−0.163	0.021
	Movement	−0.0181	0.0182	0.975	−0.073	0.037
	Leisure	−0.1966*	0.0128	0.000	−0.235	−0.158
	Sleep	−0.3380*	0.0156	0.000	−0.385	−0.291
	Other	−0.0990'	0.0151	0.000	−0.145	−0.053

Continued

Leisure	Work	0.1038*	0.0119	0.000	0.068	0.140
	Housework	0.3507*	0.0212	0.000	0.286	0.415
	Exercise	0.1255*	0.0292	0.000	0.037	0.214
	Movement	0.1784*	0.0162	0.000	0.129	0.227
	Meal	0.1966*	0.0128	0.000	0.158	0.235
	Sleep	−0.1414*	0.0131	0.000	−0.181	−0.102
	Other	0.0976	0.0125	0.000	0.060	0.136
Sleep	Work	0.2452*	0.0149	0.000	0.200	0.290
	Housework	0.4922*	0.023	0.000	0.422	0.562
	Exercise	0.2669*	0.0305	0.000	0.174	0.360
	Movement	0.3199*	0.0185	0.000	0.264	0.376
	Meal	0.3380*	0.0156	0.000	00.291	00.385
	Leisure	0.1414*	0.0131	0.000	0.102	0.181
	Other	0.2390*	0.0154	0.000	0.192	0.286
Other	Work	0.0062	0.0144	1.000	−0.037	0.050
	Housework	0.2532*	0.0227	0.000	00.184	0.322
	Exercise	0.0279	0.0303	0.984	−0.064	0.120
	Movement	0.0809	0.0181	0.000	0.026	0.136
	Meal	0.0990'	0.0151	0.000	0.053	0.145
	Leisure	−0.0976	0.0125	0.000	−0.136	−0.060
	Sleep	−0.2390'	0.0154	0.000	−0.286	−0.192

*The mean difference is significant at the 0.05 level.

fective in increasing autonomic nervous system and function. Conversely, total power was found to be low during housework.

3.2. 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 [15], 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** and **Table 4**. 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 [16], 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.

3.3. Summary

As part of the relationship between autonomic nervous system and activity, it was found that during leisure time, sympathetic nervous activity is inhibited, total power is high, and autonomic nervous system is good. It is said

Table 4. Multiple comparison results (LnLF/HF and activity).

Multiple Comparisons						
Dependent Variable: LnLF.HF						
Games-Howell						
(1) AcN	(J) AcN	Mean Difference (1-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Work	Housework	0.1036*	0.0205	0.000	0.041	0.166
	Exercise	0.0704	0.0242	00.071	−0.003	0.144
	Movement	0.0301	0.0150	0.479	−0.015	0.076
	Meal	0.0007	0.0128	1.000	−0.038	0.039
	Leisure	0.0895	0.0108	0.000	0.057	0.122
	Sleep	−0.0457*	0.0141	0.026	−0.088	−0.003
	Other	0.0574'	0.0128	0.000	0.019	0.096
Housework	Work	−0.1036*	0.0205	0.000	−0.166	−0.041
	Exercise	−0.0332	0.0291	0.948	−0.121	0.055
	Movement	−0.0735*	0.0221	0.020	−0.140	−0.007
	Meal	−0.1029*	0.0206	0.000	−0.165	−0.040
	Leisure	−0.0141	0.0195	0.996	−0.073	0.045
	Sleep	−0.1493*	0.0215	0.000	−0.214	−0.084
	Other	−0.0462	0.0206	0.328	−0.109	0.016
Exercise	Work	−0.0704	0.0242	0.071	−0.144	0.003
	Housework	00.0332	0.0291	0.948	−0.055	0.121
	Movement	−0.0404	0.0255	0.762	−0.118	0.037
	Meal	−0.0697	0.0243	0.080	−0.143	0.004
	Leisure	0.0191	0.0233	0.992	−0.052	0.090
	Sleep	−0.1161*	0.0250	0.000	−0.192	−0.040
	Other	−0.0130	0.0243	0.999	−0.087	00.061
Movement	Work	−0.0301	0.0150	0.479	−0.076	0.015
	Housework	0.0735'	0.0221	0.020	0.007	0.140
	Exercise	0.0404	0.0255	0.762	−0.037	0.118
	Meal	−0.0293	0.0152	0.528	−0.075	0.017
	Leisure	0.0594*	0.0136	0.000	0.018	0.101
	Sleep	−0.0757*	0.0163	0.000	−0.125	−0.026
	Other	0.0273	0.0152	0.619	−0.019	0.073
Meal	Work	−0.0007	0.0128	1.000	−0.039	0.038
	Housework	0.10290.	0.0206	0.000	0.040	0.165
	Exercise	0.0697	0.0243	0.080	−0.004	0.143
	Movement	0.0293	0.0152	0.528	−0.017	0.075
	Leisure	0.0887	0.0111	0.000	0.055	0.122
	Sleep	−0.0464'	0.0143	0.025	−0.090	−0.003
	Other	0.0567	0.0130	0.000	0.017	0.096

Continued

	Work	−0.0895*	0.0108	0.000	−0.122	−0.057
	Housework	0.0141	0.0195	0.996	−0.045	0.073
	Exercise	−0.0191	0.0233	0.992	−0.090	0.052
Leisure	Movement	0.0594	0.0136	0.000	−0.101	−0.018
	Meal	−0.0887	0.0111	0.000	−0.122	−0.055
	Sleep	−0.1351*	0.0125	0.000	−0.173	−0.097
	Other	−0.0321	0.0110	0.071	−0.066	0.001
	Work	0.0457*	0.0141	0.026	0.003	0.088
	Housework	0.1493*	0.0215	0.000	0.084	0.214
	Exercise	0.1161*	0.0250	0.000	0.040	0.192
Sleep	Movement	0.0757*	0.0163	0.000	0.026	0.125
	Meal	0.0464*	0.0143	0.025	0.003	0.090
	Leisure	0.1351*	0.0125	0.000	0.097	0.173
	Other	0.1031*	0.0143	0.000	0.060	0.146
	Work	−0.0574*	0.0128	0.000	−0.096	−0.019
	Housework	0.0462	0.0206	0.328	−0.016	0.109
	Exercise	0.013	0.0243	0.999	−0.061	0.087
Other	Movement	−0.0273	0.0152	0.619	−0.073	0.019
	Meal	−0.0567*	0.0130	0.000	−0.096	−0.017
	Leisure	0.0321	0.0110	0.071	−0.001	0.066
	Sleep	−0.1031*	0.0143	0.000	−0.146	−0.060

*The mean difference is significant at the 0.05 level.

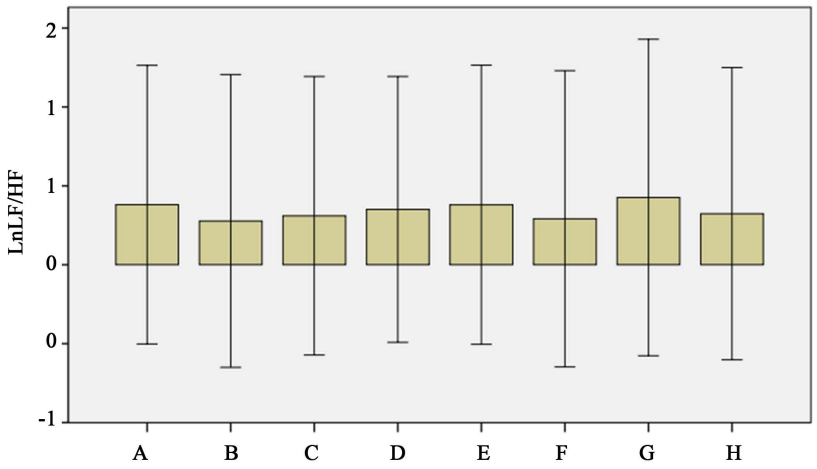

Figure 3. The relationship between LnLF/HF and activity.

that in our lives as members of society, it is important to set aside a moderate amount of time for leisure. The current study managed to demonstrate this usefulness (using a large amount of data) statistically, a valuable contribution to society.

It was also found that during work, sympathetic nervous activity is high and subjects are in a state of tension. In addition to its other applications, this data could serve useful to companies in their promotion of healthy business activities (taking into consideration employee care, etc.).

Additionally, it was found that during housework, sympathetic function is inhibited, but total power is lower. The study results reveal statistically (using a large amount of data) that while housework is not as tense as work, it is nonetheless a physically fatiguing activity.

Thus, this data could contribute to the increased societal recognition of the difficulties of housework, and the advancement in social status of stay-at-home wives (and husbands).

4. 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.

4.1. 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. Information on the measurement data used in the study's analysis is given in **Table 5**.

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** and **Table 6**.

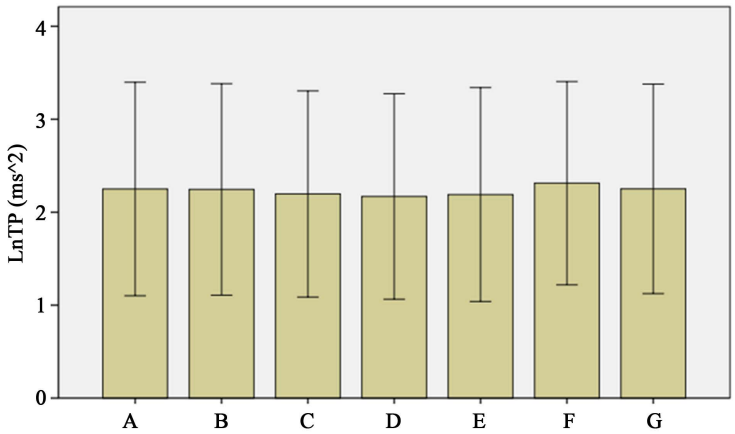

Figure 4. The relationship between LnTP and day of the week.

Table 5. Data by day of the week.

Day of week	Man	Female	Total
A	5787	14,093	19,880
B	5340	13,006	18,346
C	4696	11,436	16,132
D	4812	11,719	16,531
E	4859	11,834	16,693
F	6570	16,000	22,569
G	5966	14,530	20,497
Total	38,030	92,618	130,648

A: Monday; B: Tuesday; C: Wednesday; D: Thursday; E: Friday; F: Saturday; G: Sunday.

Table 6. Multiple comparison results (LnTP and day of the week).

Multiple Comparisons						
Dependent Variable: LnTP						
Games-Howell						
(1) WDN	(J) WDN	Mean Difference (1-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Monday	Tuesday	0.0052	0.0137	1.000	−0.035	0.046
	Wednesday	0.0539*	0.014	0.002	0.013	0.095
	Thursday	0.0804*	0.0139	0.000	0.039	0.121
	Friday	0.0600*	0.0141	0.000	0.018	0.102
	Saturday	−0.0624'	0.0128	0.000	−0.100	−0.025
	Sunday	−0.0014	0.0133	1.000	−0.040	0.038
Tuesday	Monday	−0.0052	0.0137	1.000	−0.046	0.035
	Wednesday	0.0487*	0.0142	0.011	0.007	0.091
	Thursday	0.0752*	0.0141	0.000	0.034	0.117
	Friday	0.0548*	0.0143	0.003	0.013	0.097
	Saturday	0.0676	0.0130	0.000	−0.106	−0.029
	Sunday	−0.0066	0.0135	0.999	−0.046	0.033
Wednesday	Monday	−0.0539*	0.014	0.002	−0.095	−0.013
	Tuesday	−0.0487*	0.0142	0.011	−0.091	−0.007
	Thursday	0.0265	0.0143	0.517	−0.016	0.069
	Friday	0.0061	0.0146	1.000	−0.037	0.049
	Saturday	−0.1163*	0.0133	0.000	−0.156	−0.077
	Sunday	−0.0553*	0.0138	0.001	−0.096	−0.015
Thursday	Monday	−0.0804	0.0139	0.000	−0.121	−0.039
	Tuesday	−0.0752*	0.0141	0.000	−0.117	−0.034
	Wednesday	−0.0265	0.0143	0.517	−0.069	0.016
	Friday	−0.0204	0.0145	0.799	−0.063	0.022
	Saturday	−0.1428*	0.0132	0.000	−0.182	−0.104
	Sunday	−0.0818*	0.0136	0.000	−0.122	−0.042
Friday	Monday	−0.0600*	0.0141	0.000	−0.102	−0.018
	Tuesday	−0.0548*	0.0143	0.003	−0.097	−0.013
	Wednesday	−0.0061	0.0146	1.000	−0.049	0.037
	Thursday	0.0204	0.0145	0.799	−0.022	0.063
	Saturday	−0.1224*	0.0135	0.000	−0.162	−0.083
	Sunday	−0.0614*	0.0139	0.000	−0.102	−0.020

Continued

Saturday	Monday	0.0624*	0.0128	0.000	0.025	0.100
	Tuesday	0.0676*	0.013	0.000	0.029	0.106
	Wednesday	0.1163*	0.0133	0.000	0.077	0.156
	Thursday	0.1428*	0.0132	0.000	0.104	0.182
	Friday	0.1224*	0.0135	0.000	0.083	0.162
	Sunday	0.0610*	0.0125	0.000	0.024	0.098
Sunday	Monday	0.0014	0.0133	1.000	−0.038	0.040
	Tuesday	0.0066	0.0135	0.999	−0.033	0.046
	Wednesday	0.0553*	0.0138	0.001	0.015	0.096
	Thursday	0.0818*	0.0136	0.000	0.042	0.122
	Friday	0.0614*	0.0139	0.000	0.020	0.102
	Saturday	−0.0610*	0.0125	0.000	−0.098	−0.024

*The mean difference is significant at the 0.05 level.

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 [17], 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.

4.2. 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** and **Table 7**. 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.

4.3. Summary

As part of the relationship between autonomic nervous system and day of the week, it was found that from the latter half of the week, total power decreases and subjects fatigue slightly. This data should prove extremely beneficial to companies.

For instance, by changing "no overtime day" from Wednesday (as it is usually scheduled) to Thursday, company productivity may increase.

What's more, this study (using a large amount of data) has managed to give statistical proof to what is commonly referred to in Japan as "Sazae-san Syndrome", a phenomenon in which people become quite depressed on Sunday as they think about work or school starting up again the following day. This will likely prove very valu-

Table 7. Multiple comparison results (Lnlf/Hf and day of the week).

Multiple Comparisons						
Dependent Variable: LnLF.HF						
Games-Howell						
(1) WDN	(J) WDN	Mean Difference (1-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Monday	Tuesday	−0.0045	0.0119	1.000	−0.040	0.031
	Wednesday	−0.0005	0.0123	1.000	−0.037	0.036
	Thursday	0.0047	0.0122	1.000	−0.031	0.041
	Friday	−0.0052	0.0122	1.000	−0.041	0.031
	Saturday	0.0307	0.0113	0.094	−0.003	0.064
	Sunday	0.0152	0.0117	0.852	−0.019	0.050
Tuesday	Monday	0.0045	0.0119	1.000	−0.031	0.040
	Wednesday	0.0040	0.0125	1.000	−0.033	0.041
	Thursday	0.0091	0.0125	0.991	−0.028	0.046
	Friday	−0.0007	0.0125	1.000	−0.038	0.036
	Saturday	0.0352*	0.0116	0.039	0.001	0.069
	Sunday	0.0196	0.0119	0.653	−0.016	0.055
Wednesday	Monday	0.0005	0.0123	1.000	−0.036	0.037
	Tuesday	−0.0040	0.0125	1.000	−0.041	0.033
	Thursday	0.0051	0.0129	1.000	−0.033	0.043
	Friday	−0.0048	0.0129	1.000	−0.043	0.033
	Saturday	0.0311	0.0120	0.126	−0.004	0.066
	Sunday	0.0156	0.0123	0.867	−0.021	0.052
Thursday	Monday	−0.0047	0.0122	1.000	−0.041	00.031
	Tuesday	0.0091	0.0125	0.991	−0.046	0.028
	Wednesday	−0.0051	0.0129	1.000	−0.043	0.033
	Friday	−0.0099	0.0128	0.988	−0.048	0.028
	Saturday	0.0260	0.0119	0.304	−0.009	0.061
	Sunday	0.0105	0.0123	0.979	−0.026	0.047
Friday	Monday	0.0052	0.0122	1.000	−0.031	00.041
	Tuesday	0.0007	0.0125	1.000	−0.036	0.038
	Wednesday	0.0048	0.0129	1.000	−0.033	0.043
	Thursday	0.0099	0.0128	0.988	−0.028	0.048
	Saturday	0.0359*	0.0120	0.043	0.001	0.071
	Sunday	0.0204	0.0123	0.645	−0.016	00.057

Continued

Saturday	Monday	−0.0307	0.0113	0.094	−0.064	0.003
	Tuesday	−0.0352*	0.0116	0.039	−0.069	−0.001
	Wednesday	−0.0311	0.0120	00.126	−0.066	0.004
	Thursday	−0.0260	0.0119	0.304	−0.061	0.009
	Friday	−0.0359*	0.0120	0.043	−0.071	−0.001
	Sunday	−0.0155	0.0114	0.820	−0.049	0.018
Sunday	Monday	−0.0152	0.0117	0.852	−0.050	0.019
	Tuesday	−0.0196	0.0119	0.653	−0.055	0.016
	Wednesday	−0.0156	0.0123	0.867	−0.052	00.021
	Thursday	−0.0105	0.0123	0.979	−0.047	0.026
	Friday	−0.0204	0.0123	0.645	−0.057	0.016
	Saturday	0.0155	0.0114	0.820	−0.018	0.049

*The mean difference is significant at the 0.05 level.

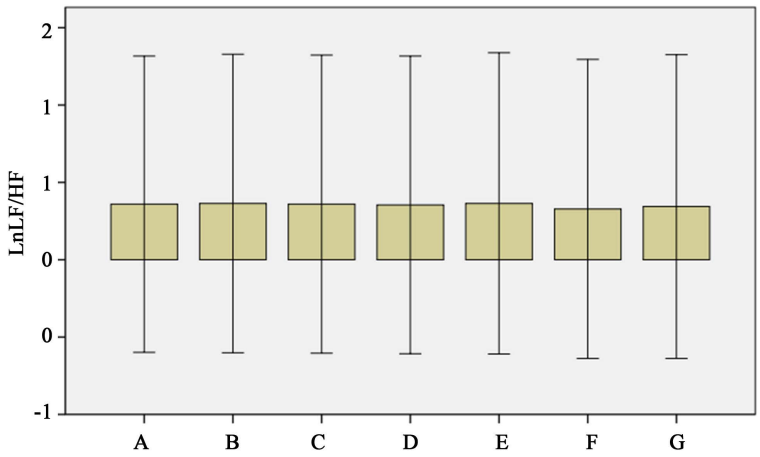

Figure 5. The relationship between LnLF/HF and day of the week.

able to society. By spreading awareness of such weekly cycles in autonomic nervous system, this study's data could serve useful in the adjustment of work/housework load across the week, as well as other facets of health preservation and promotion.

5. 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.

5.1. The Relationship between Total Power and Regions

In this section, the relationship between total power and region is investigated. Information on the study subjects and the measurement data used in the study's analysis is given in **Table 8** and **Table 9**. 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** and **Table 10**. The total power of the Kanto

Table 8. Region of residence for subjects.

Area	Man	Female	Total
A	459	1833	2292
B	3276	7396	10,672
C	272	1040	1312
D	600	2345	2945
E	983	4066	5049
F	213	1128	1341
G	101	580	681
H	490	2525	3015
Total	6394	20,913	27,307

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

Table 9. Data by region.

Area	Man	Female	Total
A	2942	7983	10,925
B	20,738	35,881	56,619
C	1789	4563	6352
D	3462	10,778	14,240
E	5058	15,955	21,013
F	1276	4797	6073
G	525	2341	2866
H	2240	10,320	12,560
Total	38,030	92,618	130,648

Table 10. Multiple comparison results (LnTP and region).

Multiple Comparisons						
Dependent Variable: LnTP						
Games-Howell						
(1) AN	(J) AN	Mean Difference (1-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Hokkaido and Tohoku	Kanto	0.1369*	0.0108	0.000	0.104	0.170
	Koshinetsu	−0.0092	0.0163	0.999	−0.059	0.040
	Chubu	0.0003	0.0131	1.000	−0.039	0.040
	Kinki	0.0242	0.0122	0.494	−0.013	00.061
	Chugoku	0.0420	0.0169	0.203	−0.009	0.093
	Shikoku	−0.0922*	0.0210	0.000	−0.156	−0.028
	Kyushu and Okinawa	0.0114	0.0135	0.991	−0.030	0.052
Kanto	Hokkaido and Tohoku	−0.1369*	0.0108	0.000	−0.170	−0.104
	Koshinetsu	−0.1461*	0.0137	0.000	−0.188	−0.104
	Chubu	−0.1366*	0.0096	0.000	−0.166	−0.107
	Kinki	−0.1127*	0.0085	0.000	−0.138	−0.087
	Chugoku	−0.0949*	0.0144	0.000	−0.139	−0.051
	Shikoku	−0.2291*	0.0191	0.000	−0.287	−0.171
	Kyushu and Okinawa	−0.1255*	0.0102	0.000	−0.156	−0.095

Continued

Koshinetsu	Hokkaido and Tohoku	0.0092	0.0163	0.999	−0.040	0.059
	Kanto	0.1461*	0.0137	0.000	0.104	0.188
	Chubu	0.0094	0.0156	0.999	−0.038	00.057
	Kinki	0.0334	0.0149	0.323	−0.012	0.078
	Chugoku	0.0511	0.0189	0.121	−0.006	0.108
	Shikoku	−0.0831*	0.0226	0.006	−0.152	−0.014
	Kyushu and Okinawa	0.0206	0.0159	0.902	−0.028	0.069
Chubu	Hokkaido and Tohoku	−0.0003	0.0131	1.000	−0.040	0.039
	Kanto	0.1366*	0.0096	0.000	0.107	0.166
	Koshinetsu	−0.0094	0.0156	0.999	−0.057	0.038
	Kinki	0.0240	0.0112	0.388	−0.010	0.058
	Chugoku	0.0417	0.0162	00.163	−0.007	0.091
	Shikoku	0.0925	0.0204	0.000	−0.154	−0.031
	Kyushu and Okinawa	0.0111	0.0126	0.987	−0.027	0.049
Kinki	Hokkaido and Tohoku	−0.0242	0.0122	0.494	−0.061	0.013
	Kanto	0.1127*	0.0085	0.000	0.087	0.138
	Koshinetsu	−0.0334	0.0149	0.323	−0.078	0.012
	Chubu	−0.0240	0.0112	0.388	−0.058	0.010
	Chugoku	0.0177	0.0155	0.947	−0.029	0.065
	Shikoku	−0.1164*	0.0199	0.000	−0.177	−0.056
	Kyushu and Okinawa	0.0128	0.0117	0.958	−0.048	0.023
Chugoku	Hokkaido and Tohoku	−0.0420	0.0169	0.203	−0.093	0.009
	Kanto	0.0949*	0.0144	0.000	00.051	0.139
	Koshinetsu	−0.0511	0.0189	0.121	−0.108	0.006
	Chubu	−0.0417	0.0162	00.163	−0.091	0.007
	Kinki	−0.0177	0.0155	0.947	−0.065	0.029
	Shikoku	−0.1342*	0.0231	0.000	−0.204	−0.064
	Kyushu and Okinawa	−0.0306	0.0165	0.585	−0.081	0.020
Shikoku	Hokkaido and Tohoku	0.0922*	0.0210	0.000	0.028	0.156
	Kanto	0.2291*	0.0191	0.000	0.171	0.287
	Koshinetsu	0.0831*	0.0226	0.006	0.014	0.152
	Chubu	0.0925.	0.0204	0.000	0.031	0.154
	Kinki	0.1164*	0.0199	0.000	0.056	0.177
	Chugoku	0.1342*	0.0231	0.000	0.064	0.204
	Kyushu and Okinawa	0.1036*	0.0207	0.000	0.041	0.166
Kyushu and Okinawa	Hokkaido and Tohoku	−0.0114	0.0135	0.991	−0.052	0.030
	Kanto	0.1255*	0.0102	0.000	0.095	0.156
	Koshinetsu	−0.0206	0.0159	0.902	−0.069	0.028
	Chubu	−0.0111	0.0126	0.987	−0.049	0.027
	Kinki	0.0128	0.0117	0.958	−0.023	0.048
	Chugoku	0.0306	0.0165	0.585	−0.020	0.081
	Shikoku	−0.1036*	0.0207	0.000	−0.166	−0.041

*The mean difference is significant at the 0.05 level.

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.

5.2. 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** and **Table 11**. No significant difference in LF/HF was observed between regions.

5.3. Summary

As part of the relationship between autonomic nervous system and region, it was found that the capital has a lower total power than the provinces, as well as more people who are slightly fatigued. Centralization of Japan's capital, resources, and activities in Tokyo continues to this day, but perhaps pointing out (as this study does) that people living in the provinces have high total power and energy will lead to the provinces' revitalization.

6. Conclusions

This study used a large amount of autonomic nervous system data (approximately 100,000 entries) to investigate the relationship between autonomic nervous system and activity, day of the week, and region. Data were meas-

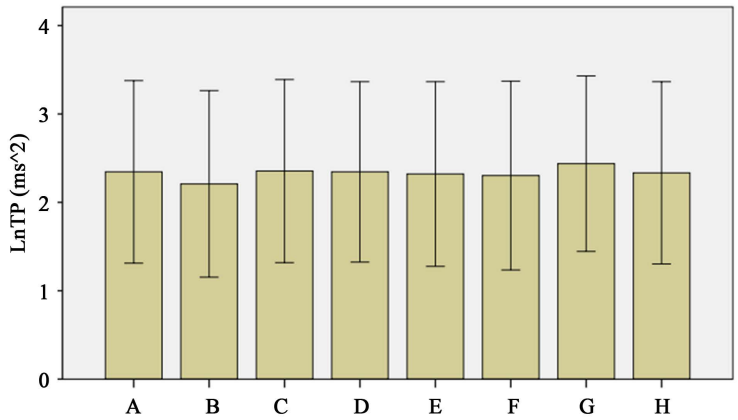

Figure 6. The relationship between LnTP and region.

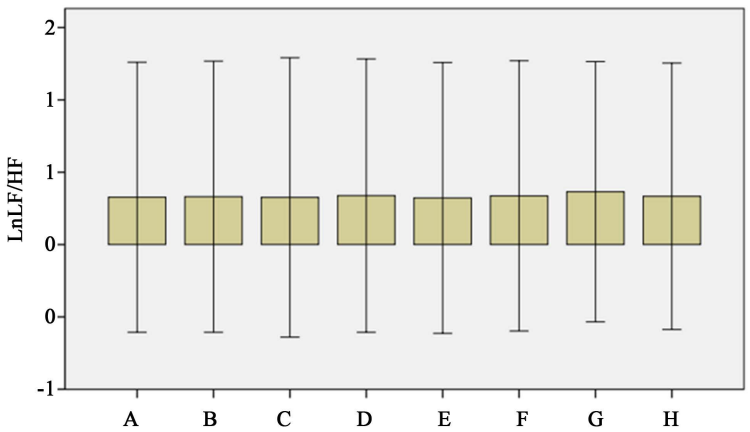

Figure 7. The relationship between LnLF/HF and region.

Table 11. Multiple comparison results (LnLF/HF and region).

Multiple Comparisons						
Dependent Variable: LnLF.HF						
Games-Howell						
(1) AN	(J) AN	Mean Difference (1-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Hokkaido and Tohoku	Kanto	−0.0034	0.0098	10.000	−0.033	0.026
	Koshinetsu	0.0014	0.0150	10.000	−0.044	0.047
	Chubu	−0.0108	0.0119	0.986	−0.047	0.025
	KinKi	0.0050	0.011	1.000	−0.028	0.038
	Chugoku	−0.0096	0.0149	0.998	−0.055	0.036
	Shikoku	0.0377	0.0190	0.493	−0.095	0.020
	Kyushu and Okinawa	0.0063	0.0121	1.000	−0.043	0.030
Kanto	Hokkaido and Tohoku	0.0034	0.0098	1.000	−0.026	0.033
	Koshinetsu	0.0048	0.0127	10.000	−0.034	0.043
	Chubu	0.0074	0.0088	0.991	−0.034	0.019
	Kinki	0.0084	0.0076	0.955	−0.015	0.031
	Chugoku	−0.0062	0.0126	1.000	−0.044	0.032
	Shikoku	0.0344	0.0173	0.488	−0.087	0.018
	Kyushu and Okinawa	0.0029	0.0091	1.000	−0.031	0.025
Koshinetsu	Hokkaido and Tohoku	−0.0014	0.0150	1.000	−0.047	0.044
	Kanto	−0.0048	0.0127	1.000	−0.043	0.034
	Chubu	−0.0122	0.0145	0.991	−0.056	0.032
	Kinki	0.0036	0.0137	1.000	−0.038	0.045
	Chugoku	−0.0111	0.0170	0.998	−0.063	0.041
	Shikoku	−0.0392	0.0207	0.557	−0.102	0.024
	Kyushu and Okinawa	0.0077	0.0146	1.000	−0.052	0.037
Chubu	Hokkaido and Tohoku	0.0108	0.0119	0.986	−0.025	0.047
	Kanto	0.0074	0.0088	0.991	−0.019	0.034
	Koshinetsu	0.0122	0.0145	0.991	−0.032	0.056
	Kinki	0.0158	0.0102	0.782	−0.015	0.047
	Chugoku	0.0011	0.0144	1.000	−0.042	0.045
	Shikoku	0.0270	0.0186	0.833	−0.083	0.029
	Kyushu and Okinawa	0.0045	0.0114	1.000	−0.030	0.039
Kinki	Hokkaido and Tohoku	0.0050	0.0110	1.000	−0.038	0.028
	Kanto	−0.0084	0.0076	0.955	−0.031	0.015
	Koshinetsu	0.0036	0.0137	1.000	−0.045	0.038
	Chubu	−0.0158	0.0102	0.782	−0.047	0.015
	Chugoku	−0.0146	0.0136	0.962	−0.056	0.027
	Shikoku	−0.0428	0.0180	0.254	−0.097	0.012
	Kyushu and Okinawa	0.0113	0.0104	0.960	−0.043	0.020

Continued

	Hokkaido and Tohoku	0.0096	0.0149	0.998	−0.036	0.055
	Kanto	0.0062	0.0126	1.000	−0.032	0.044
	Koshinetsu	0.0111	0.0170	0.998	−0.041	0.063
Chugoku	Chubu	0011	0.0144	1.000	−0.045	0.042
	Kinki	0.0146	0.0136	0.962	−0.027	0.056
	Shikoku	−0.0281	0.0206	0.874	−0.091	0.034
	Kyushu and Okinawa	0.0033	0.0145	1.000	−0.041	0.047
	Hokkaido and Tohoku	0.0377	0.0190	0.493	−0.020	0.095
	Kanto	0.0344	0.0173	0.488	−0.018	0.087
	Koshinetsu	0.0392	0.0207	0.557	−0.024	0.102
Shikoku	Chubu	0.0270	0.0186	0.833	−0.029	0.083
	Kinki	0.0428	0.0180	0.254	−0.012	0.097
	Chugoku	0.0281	0.0206	0.874	−0.034	0.091
	Kyushu and Okinawa	0.0314	0.0187	0.700	−0.025	0.088
	Hokkaido and Tohoku	0.0063	0.0121	1.000	−0.030	0.043
	Kanto	0.0029	0.0091	1.000	−0.025	0.031
	Koshinetsu	0.0077	0.0146	1.000	−0.037	0.052
Kyushu and Okinawa	Chubu	−0.0045	0.0114	1.000	−0.039	0.030
	Kinki	0.0113	0.0104	0.960	−0.020	0.043
	Chugoku	0.0033	0.0145	1.000	−0.047	0.041
	Shikoku	0.0314	0.0187	0.700	−0.088	0.025

*The mean difference is significant at the 0.05 level.

ured 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 far 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. This study has managed to give statistical proof (using a large amount of measurement data) to ideas held by the public for years. Thus, the data can be considered meaningful to society, and the authors hope that it helps to improve work-life balance.

References

[1] Onaka, T. (2005) Stress and Its Neural Mechanisms. *Journal of Pharmacological Sciences*, **126**, 170-173.

[2] Itao, K. and Komazawa, M. (2015) Wearable Device Applications and Technology Tends. *Japan Institute of Electronics Packaging, Special Issue*, **18**, 384-389.

[3] Union Tool Co. (2013) Wearable Heart Rate Sensor WHS-1. http://uniontool.co.jp/product/sensor/index_02.html

[4] WIN Frontier Co. Ltd. (2013) Lifescore Quick. http://www.winfrontier.com/lifescorequick.html

[5] Fumio, M., *et al.* (2001) Basic Research to Estimate Athlete's Psychological Stress Responses by Digital Plethysmo-

graphy. *Research Bulletin*, **29**, 87/102

[6] Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology. (1996) Heart Rate Variability: Standards of Measurement, Physiological Interpretation, and Clinical Use. *Circulation*, **93**, 1043-1065. http://dx.doi.org/10.1161/01.CIR.93.5.1043

[7] Mikio, H. (2010) Spectral Analysis. AsakuraPub, Tokyo.

[8] Komazawa, M., Itao, K. and Luo, Z. (2015) Development of Heart Rate Variability Analysis System Using a Smart-Phone Camera. 20*th Poster Presentation Collection of the Academy of Human Informatics*, 19-20.

[9] WIN Frontier Co., Ltd. (2015r) COCOLOLO—Check 8 Types of Feelings with the Fluctuation of the Heart Rate. https://itunes.apple.com/jp/app/cocololo-cafe-kimochishea/id973325431?mt=8&ign-mpt=uo%3D4

[10] WIN Frontier Co., Ltd. (2015) COCOLOLO ♥ Heart Furnace-Stress Check Using the Fluctuation of Heart Rate. https://play.google.com/store/apps/details?id=com.winfrontier.COCOLOLO&hl=ja

[11] Kobayashi, H. (2016) COCOLOLO: Autonomic Nervous System Are Complete by the Stress Check of the Heart in 30 Seconds. GOMA BOOK Co., Ltd. http://www.goma-books.com/archives/36436

[12] Komazawa, M., Itao, K. and Luo, Z. (2015) The Relationship between Autonomic Nervous System and Age, BMI Based on about 100,000 of Measurement Data. 21st *Poster Presentation Collection of the Academy of Human Informatics*, 24-25.

[13] Komazawa, M., Itao, K. and Luo, Z. (2015) The Relationship between Autonomic Nervous System and Circadian rhythm Based on about 100,000 of Measurement Data. 22*nd Poster Presentation Collection of the Academy of Human Informatics*, 14-15.

[14] Kuratsune, H. (2011) Creation of Chronic Fatigue Diagnosis Guidelines and the Establishment of Objective Fatigue Diagnostic Methods for Patients Complaining of Chronic Fatigue Accompanied by Autonomic Abnormalities. *Health, Labor and Welfare Ministry Scientific Research, Disability Measures Research Department* (*Mental Disorders and Nerve and Muscle Disease Areas*) 2009-2011 *General Research Report*, 1-114.

[15] Yukishita, T., Lee, K., Kim, S., Yumoto, Y., Kobayashi, A., Shirasawa, T. and Kobayashi, H. (2010) Age and Sex-Dependent Alterations in Heart Rate Variability: Profiling the Characteristics of Men and Women in Their 30s. *Anti-Aging Medicine*, **7**, 94-100. http://dx.doi.org/10.3793/jaam.7.94

[16] Shimizu, T. (2008) The Autonomic Function around the Clock. *Japanese Society for Medical and Biological Engineering*, **46**, 154-159.

[17] Ministry of Health, Labour and Welfare. http://ibaraki-roudoukyoku.jsite.mhlw.go.jp/library/ibaraki-roudoukyoku/corner_kantoku/kantoku12_02.pdf