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A Preliminary Study on Autonomic Nervous System Assessment during Aerobic Exercise using TEMPV

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Abstract— **The purpose of this study is to monitor the autonomic nervous system with average skin temperature and its variability, of which both are compared with heart rate variability. Six healthy male college students participated in a test which is composed of rest for 5 min., exercise for 20 min. and recovery for 10 min. to measure their ECG and skin temperature with BIOPACK. The test found similarity between HRV's total power and peak amplitude of skin temperature variability towards physical stress. Furthermore, the constant fall of mean temperature during exercise and recovery capacity during recovery stage also proved that subjects differ in their autonomic nervous system activities to maintain homeostasis.**

Keywords— skin temperature, heart rate variability, aerobic exercise

I. INTRODUCTION

The autonomic nervous system constantly operates during exercise to maintain homeostasis. In particular, the autonomic nervous system raises core temperature, which maintains a certain level during exercise and returns to the normal level after exercise. As such, the sympathetic nervous system controls blood flow on the body surface. Core temperature rise during exercise raises skin blood flow, which helps release heat from the body. Core temperature fall, on the other hand, stimulates the peripheral nerves and constricts blood vessels, which lowers skin blood flow and thus keeps heat from being released. (e.g. [1]). The core temperature can be measured via rectum, oral cavity or axilla but they are all seriously limited ways of measurement during exercise. Hence, this study measured STEMP as an alternative to monitor the autonomic nervous system and suggested Heart Rate Variability (HRV) signal, which is the leading parameter representing autonomic nervous system, as the reference for comparison [3].

A recent study revealed the interrelationship between STEMP variability and HRV, which represents the autonomic nervous system. Blood vessel dilation or constriction has more to do with temperature variability than with average temperature, which makes it possible to predict stress-triggered blood vessel constriction and relaxation by observing it. In addition, that S-TEMPV is controlled by the autonomic nervous system as HRV is also verified by the fact that HRV and S-TEMPV of subjects under mental stress fall at low frequency band only to rebound after the stress is removed [2].

This study set aerobic exercise as stress factor to compare HRV and S-TEMPV affected by physical stress and assumed that HRV and S-TEMPV under physical stress will also exhibit similar patterns as in the case under mental stress in which STEMP variability and HRV showed interrelation, and that the physical stress during exercise will bring about differences in autonomic nervous system activities to maintain homeostasis.

Hence, this study proposes S-TEMPV as the new alternative parameter to replace core temperature measurement during exercise and represent the autonomic nervous system by making a comparison between HRV and S-TEMPV during the aerobic exercise.

II. METHODS

A. Subjects

For the test, six male students with no athletic career, medical history and cardiovascular disease were chosen as subjects and their physical characteristics are shown in Table1.

TABLE I. PHYSICAL CHARACTERISTICS OF SUBJECTS

Variables	Mean±SD
Age (year)	24.50±1.22
Height (cm)	176.17±6.17
Weight (kg)	69.42±7.42
Systolic blood Pressure (mmHg)	120±9.14
Diastolic blood Pressure (mmHg)	70±4.15

B. Test Conditions

Temperature and relative humidity of the test room during measurement was kept at 23±1℃ and 30±5%, respectively, by turning on the air conditioner. The subjects took the test topless and wearing only a knee-length shorts.

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ECG was measured at 1000 samples/sec. by using the measuring instrument in Table2. For convenience, the temperature of the lower arm was measured at 1000 samples/sec. and 0.0001℃ resolution to track the delicate S-TEMPV [5].

TABLE II. EXPERIMENTAL INSTRUMENTS

Instrument	Manufacturer
Electrocardiogram	Bio-pack (ECG100C)
Thermistor Data Logger	Bio-pack (SKT100C)
Treadmill	TAEHA Mechatronics (STEX8020T)
Computer	Dell (OPTIPLEX GX620)
Software	National Instrument (Labview 8.6)

C. Test Method

The test employed Balke Protocol in Table 3 to put physical stress to the body by taking aerobic exercise. The Balke Protocol suits the test conditions demanding moderate exercise stress. Compared to Bruce Protocol, which is a major exercise protocols using a treadmill, The Balke Protocol adds only gradual load and less intensity. The exercise started off by setting the treadmill speed at 5.4km/hr (3.4mph) and slope at 0°. The slope was raised by 1° every minute reaching 20° throughout the 20 min. period. The exercise at 21° and steeper was dropped off from the test as such is a highly intense exercise used to estimate maximum oxygen consumption by producing more than 80% of [220-age], which is ACSM's maximum heart rate formula.

ECG electrode and temperature sensor were attached to the subjects in the test, which lasted for 35 minutes with 5 min. in resting stage, 20 min. in exercise stage and 10 min. in recovery stage. The subjects sat on their seats for 5 min. prior to exercise to relax followed by 20 min. of walking on the treadmill at 5.4km/h as shown in Fig. 1 as per the Balke Protocol. After the aerobic exercise, the subjects returned to their seats and took a rest for 10 min. all throughout which the changes in their bodies were observed.

TABLE III. BALKE PROTOCOL

Time (min)	Speed (km/h)	Elevation (°)
1	5.4	0
2	5.4	2
3	5.4	3
4	5.4	4
5	5.4	5
6	5.4	6
7	5.4	7
8	5.4	8
9	5.4	9
10	5.4	10
11	5.4	11
12	5.4	12
13	5.4	13
14	5.4	14
15	5.4	15
16	5.4	16
17	5.4	17
18	5.4	18
19	5.4	19
20	5.4	20

Figure 1. Data obtained during aerobic exercise

D. Data Analysis

Data during resting stage (5 min.), exercise stage (20 min.) and recovery stage (10 min.) were used for HRV and TEMPV analysis. The physical status of subjects during the resting stage for 5 min., variations in autonomic nervous system triggered by physical stress during exercise for 5 min. and recovery stage were analyzed. The final 5 min. data in exercise stage out of the total 20 min. period, which is of high intensity with substantial physical stress imposed by the aerobic exercise, was used for analysis.

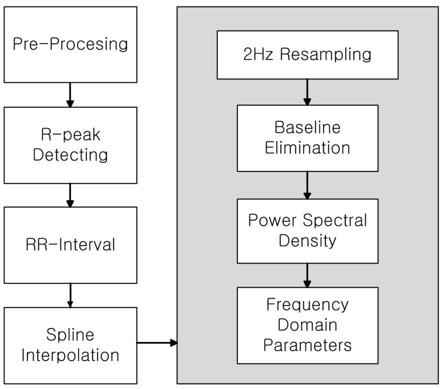

Figure 2. HRV signal processing obtained from ECG raw data

This study developed a program for HRV and TEMPV data analysis using Labview 8.6. The program analyzed ECG's R peak as shown in Fig. 2 to get RR-Interval, which was then spline interpolated. In addition, FFT analysis was made by using "zero padding" to improve frequency solution and rearrange signals with the same interval (0.5s time intervals). With such processes, the test came up with TP, VLF, LF, HF, LF/HF Ratio, which are frequency domain parameters of HRV [3].

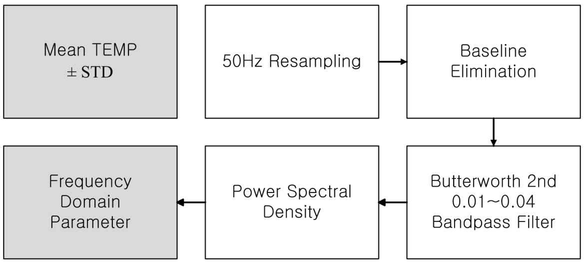

Figure 3. S-TEMPV signal processing obtained from STEMP raw data

The study made STEMP analysis by looking at both 'average value' and 'TEMPV value'. Standard deviation and average value were gained from original STEMP data and 1000 sample signals were down-sampled to 50Hz as in Fig. 3 and processed for frequency analysis.

To make frequency analysis of STEMP signal exhibiting the largest energy at 0.01~0.03Hz, the test removed DC element by deducting a linear element from the original signal. This process presented STEMP's delicate variations and enabled TEMPV frequency analysis conducted in the same manner as HRV frequency analysis [4].

STEMP analyzed was compared with HRV's total power by tracking variations in the average temperature in Fig. 4(a) and peak amplitude (PA) in Fig. 4(c), which is TEMPV's PSD corresponding to Fig. 4(b).

III. Results

The subjects' VO2max is as shown in Table 4 using (1) with IPAQ (International Physical Activity Questionnaire) and BMI using height and weight measured prior to the test.

$$VO2max = 51.733 + (0.001 \times IPAQ) - (0.140 \times age) - (0.549 \times BMI) \quad (1)$$

TABLE IV. Exercise Ability of Subjects

Subject	BMI (cm)	IPAQ (kg)	VO2max (ml/kg/min)
1	20.52	2015	38.98
2	25.73	558	35.66
3	22.09	3636	40.16
4	24.80	1278	34.89
5	23.12	2958	38.49
6	24.39	598	34.84

With the VO2max estimated, the test divided the subjects with strong exercise capacity (1, 3, 5) and those with relatively weaker exercise capacity (2 4, 6) based on 34~42, which is the average VO2max of people in their 20s based on ACSM.

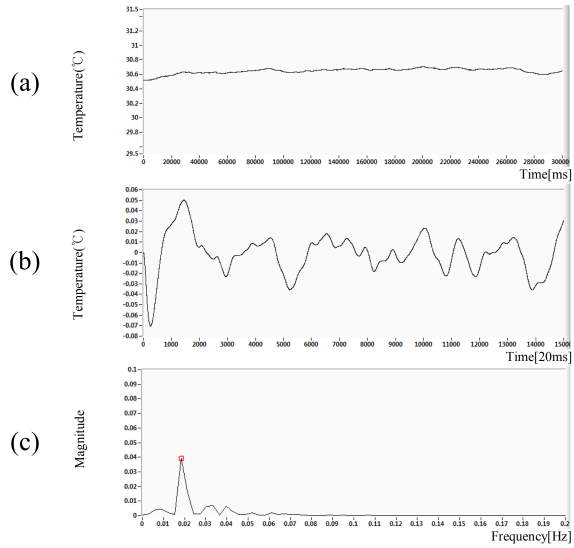

Figure 4. Raw temperature signal (a), bandpass filtered temperature signal (b), spectra of temperature variability and PA (c)

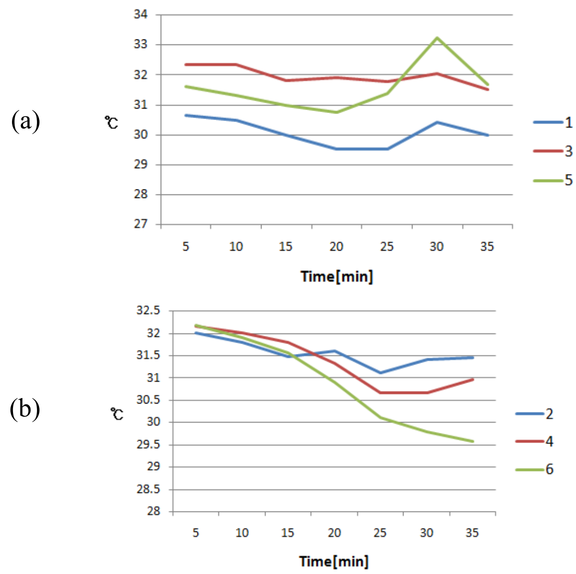

Figure 5. Average skin temperature. Fast recovery group (a), slow recovery group (b)

According to Fig. 5, average STEMP of all six subjects during resting stage was 31.83±0.63℃ on average but declined to 31.28±0.69℃ during exercise. The subject group, however, split into one whose average temperature went up as in Fig. 5(a) and the other whose average temperature went down as in Fig. 5(b). TEMPV also showed the same pattern in which it in Fig. 4(b) either increased or decreased as per exercise capacity of PA, which is the frequency analysis in Fig. 4(c). The subjects were chosen each from 1, 3, 5 with strong exercise capacity and from 2, 4, 6 with slightly weaker exercise capacity, of which the test results are in Table 5. The PA of subject 3 whose VO2max is 40.16 went down alongside HRV under physical stress only to rise during recovery stage. Average STEMP also rose during recovery stage. HRV of subject 2 whose VO2max is 35.66 went down under physical stress but rebounded during recovery stage. The PA continued to go up regardless of physical stress while average temperature continuously tumbled.

TABLE V. CHANGE IN MEAN, PA, AND HRV FROM EACH PERIOD

		Mean(℃)	PA(a.u.)	HRV(a.u.)
Decrease	***Rest***	32.36	0.066	3054
	Exercise	31.77	0.015	627
	Recovery	32.05	0.131	2299
Increase	***Rest***	32.16	0.026	2430
	Exercise	31.80	0.035	302
	Recovery	30.66	0.308	903

IV. DISCUSSION

Body heat produced during exercise grows in proportion to the amount of exercise and the threshold temperature resulting from heat production is around 40□. Since temperature higher than the threshold causes cell modification, which poses a threat to life, the temperature control mechanism enhances skin blood flow to help core body heat to be released out.

This study focused on addressing challenges in measuring core body temperature during exercise by comparing average value of STEMP and S-TEMPV with HRV, which is a barometer of the autonomic nervous system. The test divided six subjects into 'DECREASE' and 'INCREASE' groups depending on PA value change under physical stress. Average STEMP and PA of 'DECREASE' group went down under physical stress due to aerobic exercise. Both, however, increased again during recovery stage when stress was removed, of which the values increased were similar to HRV under physical stress. Such observations lead to conclude that activities and impact of the sympathetic nervous system dwindled while those of parasympathetic nervous system relatively increased bringing homeostasis to the autonomic nervous system when physical stress disappeared.

The PA went up while average temperature continued to decline in 'INCREASE' group. Also, when compared with HRV, the PA continued to increase as opposed to the autonomic nerve system activities, which diminished while reacting to stress. This indicates that 'INCREASE' group with weaker VO2max compared to 'DECREASE' failed to rapidly react to the activities required for the autonomic nerve system to maintain homeostasis in the core body. Future studies will center around improving the accuracy of data generated in this study by comparing HRV parameter with STEMP according to VO2max of 30 subjects and study the interrelation between HRV and S-TEMPV to propose it as the new measurement factor replacing HRV during aerobic exercise.

V. CONCLUSION

This study used S-TEMPV and average STEMP to serve as factors representing HRV's spectrum analysis parameter to assess the autonomic nervous system activities during aerobic exercise when it is difficult to measure body temperature. The test showed similarity between HRV and S-TEMPV by comparing HRV's TP and S-TEMPV under physical stress environment. The work is in agreement with the idea that autonomic nervous system of a person with strong exercise capacity is more capable of controlling homeostasis of the body during recovery stage after exercise.

REFERENCES

[1] H. S. Choi et al., "Effects of Aerobic Exercise on Heart Rate Variability (HRV), " J. Korean Acad. Fam. Med., vol. 26, no. 9, pp. 561-566, 2005

[2] S. M. Kim et al., "Bilateral Skin Temperature Change of the Anterior Thigh Following Unilateral Isokinetic Exercise," KAUTPT, vol. 2, no. 1, pp. 14-20, 1995

[3] K. S. Jung, "Overview of HRV," J. Korean Acad. Fam. Med., vol. 25, no. 11, Suppl., November, pp. 528-532, 2004

[4] Vladimir Shusterman, Ofer Barnea, "Sympathetic Nervous System Activity in Stress and Biofeedback Relaxation," IEEE Engineering in Medicine and Biology Magazine, vol. March/April, pp. 52-57, 2005

[5] S. R. Kim et al., "A Literature Study on Change of Superficial Temperature," J. of Oriental Medical Thermology, pp. 54-60, 2005