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Variation in Physiological Parameters Before and After an In-door Simulated Driving Task: Effect of Exercise Break

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Abstract: **-** The objectives of the study were to monitor variation in physiological parameters before and after a 120-min indoor simulated driving task and to investigate the effect of 15-min exercise break taken at mid-term of driving. Blood pressures, heartbeat, heart rate variability (HRV), and temperature of both palms were measured using a new wrist monitor ANSWatch® and a high-precision thermometer. Distinct trends were found between the two study groups after driving. For the control group without exercise break, systolic pressure, heart rate, and palm temperatures were all lower caused by driving fatigue and poor circulation in lower body. In response, the body activated para-sympathetic nervous system and entered a sleepy state, as evidenced by increased HF and total HRV, and decreased LF/HF. In strong contrast, for the study group with exercise break, systolic pressure was maintained. The body activated both sympathetic and para-sympathetic nervous systems, as indicated by increased LF, HF, and total HRV while LF/HF almost unchanged. The distinct trends were consistent with the written questionnaire taken after driving where the control group participants reported more-sleepy or fatigue symptoms than the study group. It is believed that the traffic accident risk associated with the control group was attenuated in the study group with the mid-term exercise designed specifically to improve lower body circulation. The measurement of physiological parameters in the research had gained great insight into mechanisms of homeostasis and provides foundation in the future work to quantify driving fatigue based upon degree of deviation from the homeostatic states.

Key-Words: **-** Simulated Driving、Driving Fatigue、Physiology Parameters、Heart Rate Variability (HRV)、Homeostasis、ANSWatch

1 Introduction

Induced by mental and body exhaustion, driving fatigue is a common experience during long-hour traveling which remains one of the most probable causes for traffic accidents. In one aspect of driving, drivers have hard time maintaining fresh concentration on the road with repetitious and unexciting scenery. In another aspect of driving, the limited hip and leg spaces constrain the lower body from active movement. The "pumping" action by leg muscle contraction, which forces the venous blood back to the heart during walking or exercise, is largely lost. It is our belief that immobilization of the lower body plays a major role in driving fatigue, as it hinders systemic blood circulation and induces significant hemo-dynamic changes. We further believe that new technologies being developed for the prevention of driving fatigue related accidents should address the problem of blood circulation and homeostasis. Our findings in this series of studies may be applicable to other long-hour sitting activities, such as air traveling, computer or switchboard operations, factory assembly work, and video games, where poor circulation in the lower body is experienced.

It is well known that when local or systemic circulation is obstructed, autonomic nervous system (ANS) in the body will be activated swiftly. Through its sympathetic and parasympathetic branches, ANS helps the cardiovascular system to maintain proper blood supply under these compromised circumstances. If the activation and execution of ANS is effective, deviation from the homeostatic state can be avoided. On the other hand, any significant change in vital physiological parameters from baseline may point to an "exhausting" body which is unable to respond to physiological needs. Symptoms under such states include cold hands and feet, low blood pressures, brain hypoxia, drowsiness, and deep vein thrombosis (DVT).

Along these lines, several authors have studied the effect of long-hour air travelling on DVT. Markus Mittermayer et.al.[13] and Bo Eklof et.al.[2] both pointed out that there were several factors that could induce DVT during air flights, but the most contributing factor was immobilization. They found that blood was accumulated in the lower parts of the body (such as legs and feet) causing tissue thickening that would not go away for a few days after the flight. Fabrice Paganin et. al.[5] and K. J. O'Donovan [9] further demonstrated that proper exercise during air flights, such as leg extension and knee rotation, could lower the risk of DVT. These simple exercises tend to improve calf muscle pump activity (CMPA) and thus improve systemic circulation.

Heart rate variability (HRV) has been used in various studies for the assessment of physiological states. Originated from the sub-conscious cyclic variation in heartbeat period, HRV is commonly analyzed in both time and frequency domains to give rise to parameters that are linked to total ANS activity (HRV or SDNN, TP or total power), sympathetic activity (LF (AU) and LF(NU)), parasympathetic (or vagal) activity (HF(AU) and HF(NU)), and sympatho-vagal balance index (LF/HF). Nis Hjortskov et.al.[14] and Anne Helene Garde et.al.[1] monitored HRV changes in volunteers before and after a computer task during which various degrees of metal stress were introduced. J. Wahlstrom et.al.[8] also introduced time and verbal stresses during a mouse-driven computer task to investigate the physiological and psychological responses based upon heartbeat, blood pressures, and HRV.

In the area of indoor simulated driving tests, Yang Yu Shu et. al.[18] utilized electrocardiography (ECG) to monitor the driver's HRV changes. They discovered four HRV parameters that were significantly changed after driving, namely increased HRV (or SDNN), increased LF(AU), decreased HF(NU), and increased LF/HF. Li Zeng Yong et.al.[12] again based their HRV study on ECG and found three HRV parameters with significant changes after a driving task, including increased LF(NU), decreased HF(NU), and increased LF/HF. They proposed using HRV as a quantitative index for driving fatigue. Zengyong Li et.al.[19,20] studied the effect of acupuncture on driving fatigue. Their findings suggested that driving fatigue induced symptoms could be attenuated by acupuncture.

Up to date, most HRV studies have been using ECG due to its availability in research laboratories. A few studies have based their HRV measurements on finger blood pressure waveforms using an optical sensor (see Paula S. McKinley et.al.[15], Carrasco S et.al.[3] and Giardino ND[7]). The authors reported correlation coefficients of HRV parameters in the range of 0.75 to 0.99 when compared to ECG. In this work, we would like to introduce a new wrist monitor ANSWatch® (Taiwan Scientific Corp., Taipei, Taiwan; Taiwan DOH Approval number 001525) which employs multiple piezo-electrical sensors enclosed in the cuff to directly measure the blood pressure waveforms in the radial artery. According to the company documents submitted to Taiwan Department of Health (Sun DC [16]), the device accuracy in terms of correlation coefficient is in the range of 0.90 to 1.0 using ECG as the control. This portable device requires neither electrodes nor other disposables, and can conduct tests in sitting or lying postures. Each ANSWatch® test takes about 6-minutes and outputs eight patient parameters on the LCD screen (heart rate HR, systolic pressure SYS, diastolic pressure DIA, heart rate variability HRV (or standard deviation of 5-min peak-to-peak intervals SDNN), low frequency (absolute) LF(AU), low frequency (normalized) LF(NU), high frequency (absolute) HF(AU), high frequency (normalized) HF(NU), sympatho-parasympathtic balance index LF/HF, and number of irregular heartbeats). Upon data download to a PC and using the accompanied software (ANSWatch Manager Pro), more HRV parameters can be calculated (such as total power TP, very low frequency (absolute) VLF(AU), and square root of the mean of the sum of the squares of differences between adjacent peak intervals RMMSD, etc.)

In this study, we monitored multiple physiological parameters, including palm temperatures (left and right), heart rate, blood pressures (systolic and diastolic), and heart rate variability (HRV) parameters before and after a 120-min indoor driving task. Volunteers were divided into two groups. One group conducted the driving task continuously while the other groups had a 15-min exercise break taken at mid-term of driving. By comparing the physiological changes between the two groups, the effect of exercise on driving fatigue could be investigated. In addition, a written questionnaire was filled by each participant after the driving task to gauge the subjective feeling of driving fatigue. It is our expectation that the results of this series of studies could provide useful information for the quantitative definition of driving fatigue based upon physiological parameter changes.

2 Method

Indoor simulated driving test (instead of a road driving test) was selected in consideration of cost, safety, and control of variables.

2.1 Subject

A total of 40 male subjects in the age of 22.4±1.9 years old (Table 1; all college students or graduates) were recruited selected to take the driving test. All subjects were currently healthy and without any medical treatments. They were instructed to have sufficient sleep in the previous night and not to eat, drink, or exercise one hour prior to the test.

Table 1 Characteristic of subjects

Item	Average
Age	22.4±1.9 (years-old)
Height	173.3±5.2 (cm)
Weight	71.7±11.1 (kg)
Body Fat Index	22.3±6.2 (%)

2.2 Variables

In the experimental design, gender, age, ambient temperature, and driving duration were controlled. The independent variable was exercise break (with or without). The dependent variables were physiological parameters which include blood pressures (systolic(SYS) and diastolic(DIA)), heart rate(HR), heart rate variability(HRV), total power(TP), sympathetic nerve activity (LF(AU) and LF(NU)), para-sympathetic nerve activity (HF(AU) and HF(NU)), very low frequency (VLF(AU)), sympatho-vagal balance index (LF/HF), RMMSD and temperature of both palms.

2.3 In-Door Simulated Driving

The test room was temperature controlled at 22±2℃. A simulated highway scenery was projected onto a 178 (cm) x 178 (cm) white screen using a computer and a projector (see Fig. 1). The driver's seat was about 3-4 m away from the screen. There were trees on the left and walls on the right side of the four-lane, two-way highway. The driver must operate the wheel to keep the vehicle on the designated lane without hitting trees or walls. A red warning scale appeared on the left side of the windshield glass which would expand in area vertically if the vehicle location deviates further from the designated lane. Noises or laud sounds would go off if the vehicle got too close to or made contact with road trees or walls. The driving task lasted 120 minutes.

Fig. 1 Driving simulator

2.4 Apparatus

Experimental apparatus was comprised of a HP notebook computer, a computer projector, a driving wheel, a timer watch, a body weight and fat balance, a high-precision thermometer (±0.1C), and ANSWatch®. Software included highway scenery simulator, Windows XP, Microsoft Excel, and "ANSWatch Manager Pro" data analyzer.

2.5 Experimental Procedure

40 Volunteers were randomly divided into two groups (A&B). Both groups performed the 120-min driving task in the afternoon during the time of 1:30~4:30 PM. Group A conducted the driving test continuously while Group B had a 15-min exercise break taken at mid-term of driving (60 min). The exercise included feet ground stepping, neck rotation, upper limb and chest stretching, leg extension, and knee rotation. When reported to the test room, each volunteer took a 20-min rest first and then underwent thermometer (both palms) and ANSWatch® tests. The two tests took about 6-7 minutes. Data in ANSWatch® was downloaded to the notebook computer immediately following the test for review and storage (Fig. 25 and 26). The driving task followed which lasted for 120 minutes for Group A and 135 minutes (including 15-min exercise break) for Group B. After driving, each volunteer was tested again for palm temperatures and ANSWatch®. In addition, a written questionnaire consisting of 14 questions related to feeling of fatigue was filled by the volunteer. Similar tests have been used by other authors [19,20,21]. The entire testing program is illustrated in Fig. 2 and Fig. 3. The list of questions is shown in Table 2 while the quantitative scale is shown in Table 3.

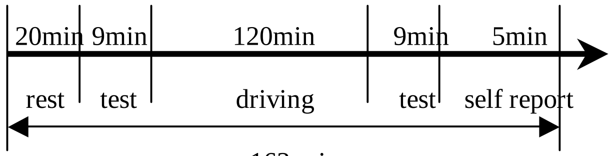


Fig. 2 Procedure of control group B

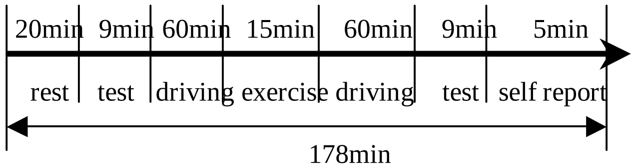


Fig. 3 Procedure of study group B

Table 2 Questionnaire for feeling of driving fatigue

No	Symptom
1	Body tiredness
2	Loss of concentration
3	Desire to lie down
4	Anxiety
5	Lack of Energy
6	Mental response slowdown
7	Headache
8	Shoulder hardening
9	Waist pain
10	Lower body numbness
11	Eye fatigue
12	Feeling of sleepiness
13	Feeling of vomit
14	Hand and foot trembling

Table 3 Quantitative scale (1-7)

Scale	Fatigue Description
1	No such feeling
2	Negligible feeling
3	Some feeling
4	Clear Feeling
5	Strong feeling
6	Very strong feeling
7	Extremely strong feeling

2.6 Physiological Parameter Analysis

During the 6-min test, ANSWatch® (Fig. 4) first uses the oscillatory method to obtain heart rate, systolic pressure, and diastolic pressure. It then conducts a standard 5-min HRV test. The piezo-electrical sensors in the cuff pick up blood pressure waveforms produced by the radial artery, with the aid of an air pouch pressure controlled by an air pump. Peak-to-peak intervals are determined followed by time and frequency domain analyses. The HRV analysis follows closely the 1996 international standard (Task Force of the European Society of Cardiology and North American, 1996)[17], and consists mainly of the following steps:

(1). The original data is fed through a low pass FIR filter at 0 to 14 Hz

(2). Fundamental frequency is determined based upon the first 5-second data.

(3). The primary peak in each cycle is determined

(4). Peak-to-peak intervals are calculated

(5). Time-domain HRV parameters (mean period or heart rate; variance and standard deviation of peak-to-to peak intervals) are calculated. Peak intervals greater than 4*standard deviation are removed and not replaced.

(6). Peak-to-peak intervals are re-sampled to 1024 points with interpolation and Hamming window adjustment.

(7). Fast Fourier Transform (FFT) is performed with Hamming window adjustment.

(8). Integration of power spectral density between 0.0001 and 0.04 Hz for the very low frequency component (VLF), between 0.04 and 0.15 Hz for the low frequency component (LF), and between 0.15 and 0.4 Hz for the high frequency component (HF) respectively are conducted.

(9). Frequency-domain HRV parameters (VLF (AU), LF(AU), HF(AU), LF(NU) (equal to LF/(LF+HF)*100), and HF(NU) (equal to HF/(LF+HF)*100) are calculated).

Fig. 4 ANSWatch® wrist monitor

It is noted above that irregular heartbeats (those with peak intervals greater than 4 standard deviations in the 5-min test data) are excluded from the raw data prior to HRV analysis (as recommended by the 1996 Standard) [17]. The HRV parameters used in the study are listed below with associated physiological meanings and units:

(1). HR：Heart rate (beat/min)

(2). HRV：Total ANS activity index (ms); equal to standard deviation of adjacent peak-to-peak intervals SDNN defined in 1996 standard

(3). TP(AU)：Total power in the frequency domain analysis (frequency range 0.0 ~ 0.4 Hz)(ms^2).TP(AU)=VLF(AU)+LF(AU)+HF(AU) ; TP(AU) = HRV**2

(4). VLF(AU)：Very low frequency (frequency range 0.0001~0.04 Hz) (ms^2); its physiological meaning not defined by 1996 Standard

(5). LF(AU)：Low frequency (frequency range 0.04~0.15 Hz) (ms^2); sympathetic nervous activity index

(6). HF(AU)：High frequency (frequency range 0.15~0.4 Hz) (ms^2); parasympathetic nervous activity index

(7). LF(NU)：LF%, [LF/(TP-VLF)]*100; contribution of sympathetic nervous activity

(8). HF(NU)：HF%, [HF/(TP-VLF)]*100; contribution of parasympathetic nervous activity

(9). LF/HF： Ratio of LF to HF; sympatho-vagal balance index

(10). RMMSD：Square root of the mean of the sum of the squares of differences between adjacent peak intervals (ms); closely related to HRV.

Although the physiological meaning for VLF (AU) is not defined in the 1996 Standard [17], it has been reported and cited by several other authors. We decided to include it in the paper for completeness.

2.7 Statistics

Student's t-pair tests (one-tailed) were used throughout the entire study to determine the significance of parameter changes before and after the driving task (p-value below 0.05 (significant); p-value below 0.01 (very significant)).

3 Result

3.1 Variation in Physiology Parameters Before and After Driving

Tables 4 and 5 show the test results for Group A (without exercise) and Group B (with exercise), respectively.

Table 4 Physiological parameters before and after driving for Group A (without exercise break)

Parameters	Before driving	After driving	t-value	p-value
SYS	117.8 ± 8.1	113.5 ± 7.5 *	1.79	0.044
DIA	73.8 ± 2.2	73.8 ± 2.0	-0.11	0.456
HR	73.4 ± 10.5	68.8 ± 10.8 **	3.52	0.001
TP(AU)	2517.3 ± 2031.9	3223.0 ± 2125.8 *	-2.12	0.023
HRV	46.9 ± 18.1	54.1 ± 17.6 *	-2.49	0.011
LF(AU)	811.6 ± 844.1	801.1 ± 556.4	0.07	0.472
LF(NU)	59.9 ± 14.2	54.1 ± 16.7 *	2.16	0.021
HF(AU)	595.8 ± 635.2	801.1 ± 556.4	-1.30	0.104
HF(NU)	40.0 ± 14.2	45.9 ± 16.7 *	-2.16	0.021
VLF(AU)	1109.8 ± 787.8	1697.6 ± 1270.5 *	-2.53	0.010
LF/HF	1.8 ± 1.0	1.4 ± 0.9 *	1.86	0.039
RMMSD	37.9 ± 16.9	51.2 ± 26.4 **	-2.8	0.005
Left palm	36.7 ± 0.8	35.8 ± 1.7 **	3.57	0.001
Right palm	36.8 ± 0.7	36.1 ± 1.8 **	2.80	0.005

From Table 4, SYS, HR, HRV, TP(AU), HF(NU), LF(NU), VLF(AU), LF/HF, RMMSD, left palm temperature, and right palm temperature exhibited significant or very significant changes after continuous driving task for Group A, while changes in DIA、LF(AU) and HF(AU) did not reach statistical significance.

Table 5 Physiological parameters before and after driving for Group B (with exercise break)

Parameters	Before driving	After driving	t-value	p-value
SYS	117.5 ± 10.5	117.2 ± 10.0	0.10	0.460
DIA	74.9 ± 2.6	75.2 ± 2.5	-0.77	0.225
HR	71.8 ± 10.6	64.9 ± 8.0 **	5.12	0.000
TP(AU)	2683.8 ± 2420.2	3478.4 ± 2326.8	-1.41	0.087
HRV	48.3 ± 19.3	56.4 ± 17.9 *	-1.94	0.033
LF(AU)	494.7 ± 406.5	799.1 ± 607.4 **	-3.65	0.000
LF(NU)	49.6 ± 18.5	51.3 ± 19.3	-0.43	0.336
HF(AU)	613.6 ± 617.6	849.2 ± 791.0	-1.36	0.094
HF(NU)	50.5 ± 18.5	48.7 ± 19.4	0.44	0.332
VLF(AU)	1575.5 ± 1612.7	1830.1 ± 1301.2	-0.67	0.255
LF/HF	1.3 ± 1.0	1.4 ± 1.1	0.61	0.274
RMMSD	49.6 ± 29.3	59.1 ± 20.1	-1.55	0.068
Left palm	36.3 ± 0.9	35.4 ± 0.9 **	2.79	0.005
Right palm	36.4 ± 0.7	35.7 ± 1.0 **	2.56	0.009

From Table 5, HR, HRV, LF(AU), and palm temperatures(left and right) exhibited significant or very significant changes after driving task for Group B (with exercise break), while changes in SYS, DIA, TP(AU), LF(NU), HF(AU), HF(NU), VLF(AU), LF/HF, and RMMSD did not reach statistical significance. Note that in the above tables, parameter values that are with significant changes are marked with *(p<0.05) while those with very significant changes are marked with ** (p<0.01).

3.2 Comparison of Groups A and B for Physiological Parameters

Physiological parameter changes before and after the driving task are plotted in the following figures for Groups A and B (Fig. 5 through 18)

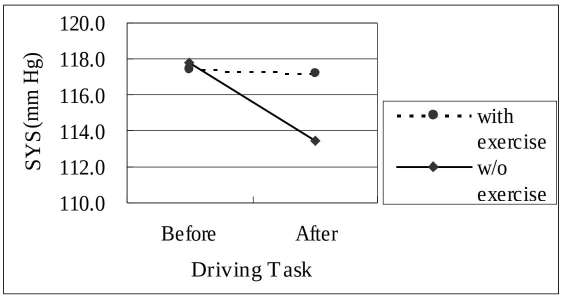


Fig. 5 Trend chart for systolic pressure (SYS)

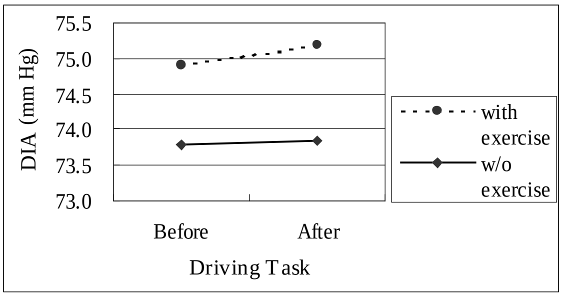


Fig. 6 Trend chart for diastolic pressure (DIA)

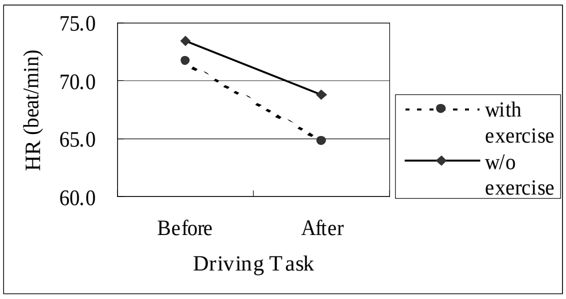


Fig. 7 Trend chart for heart rate (HR)

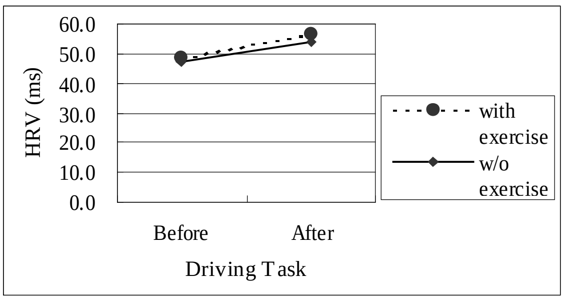


Fig. 8 Trend chart for heart rate variability (HRV)

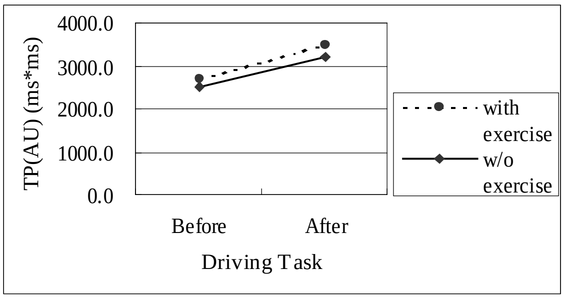


Fig. 9 Trend chart for total power (TP(AU))

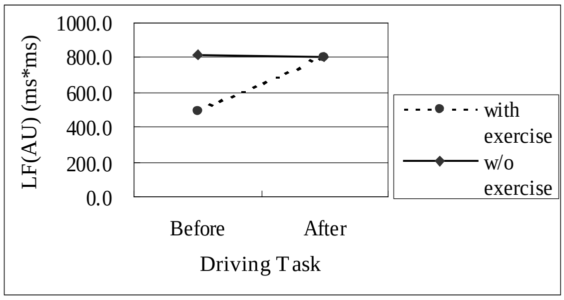


Fig. 10 Trend chart for LF(AU)

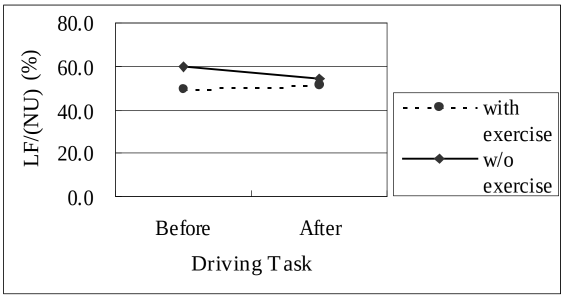


Fig. 11 Trend chart for LF(NU)

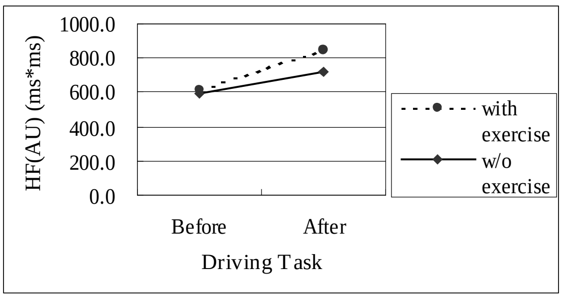


Fig. 12 Trend chart for HF(AU)

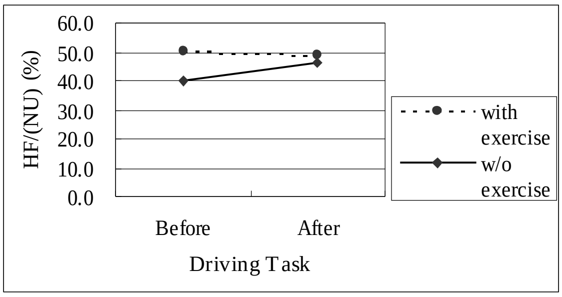


Fig. 13 Trend chart for HF(NU)

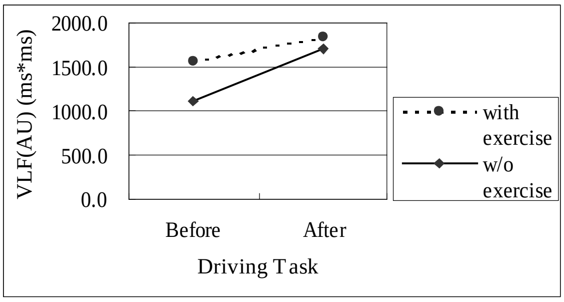


Fig. 14 Trend chart for VLF(AU)

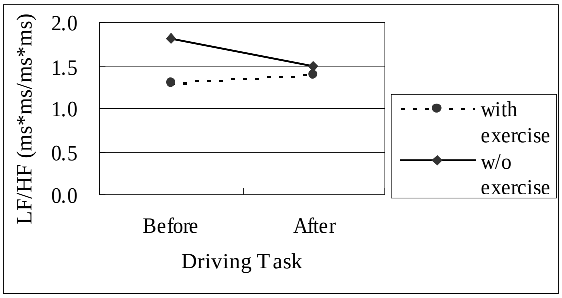


Fig. 15 Trend chart for ratio LF/HF

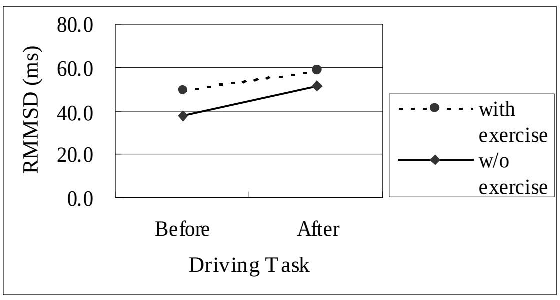


Fig. 16 Trend chart RMMSD

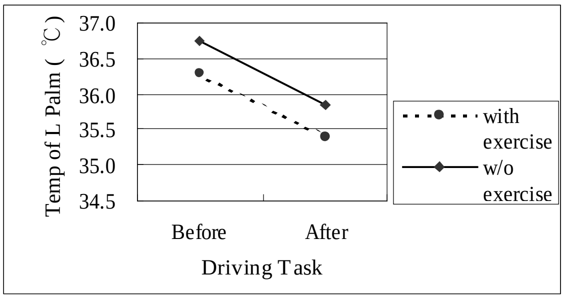


Fig. 17 Trend chart for temperature of left palm

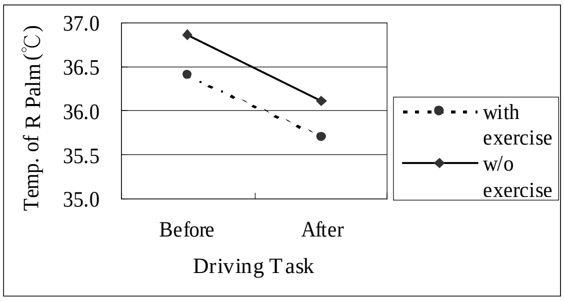


Fig. 18 Trend chart for temperature of right palm

3.3 Questionnaire

Results of written questionnaire taken after the driving task are tabulated in Table 6. Comparative charts for average score of each question and total average score are plotted in Fig. 19 and 20**.**

Table 6 Results of questionnaire on driving fatigue for Groups A (without exercise break) and B (with exercise break)

Item	Average score		t-value	p-value
	W/o exercise	With exercise		
Body tiredness	4.75	4.25	1.066	0.146
Loss of concentration	5.50	4.05	3.379	0.000^{**}
Desire to lie down	5.15	4.05	1.842	0.036^{*}
Anxiety	4.55	3.20	2.629	0.006^{**}
Lack of Energy	4.60	4.00	1.352	0.092
Mental response slowdown	4.55	3.85	1.511	0.069
Headache	2.25	2.50	-0.495	0.311
Shoulder hardening	3.70	3.45	0.419	0.338
Waist pain	2.25	2.45	-0.413	0.340

Lower body numbness	5.00	3.06	4.173	8.4E-05**
Eye fatigue	5.20	4.90	0.613	0.271
Feeling of sleepiness	5.90	4.95	2.011	0.025*
Feeling of vomit	1.55	1.70	-0.380	0.352
Hand and foot trembling	2.15	1.80	0.987	0.164
Total	57.5	48.2	2.285	0.013*

Note that in the above table, question scores that are with significant difference between two groups are marked with*(p<0.05) while those with very significant difference are marked with** (p<0.01).

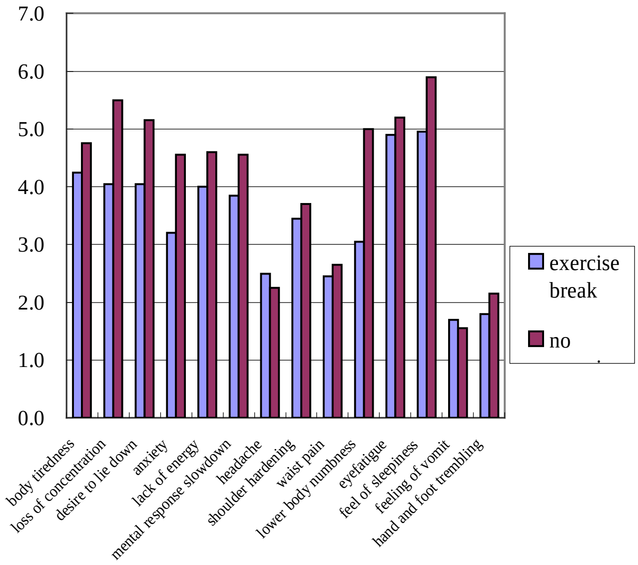


Fig. 19 Average score for each question

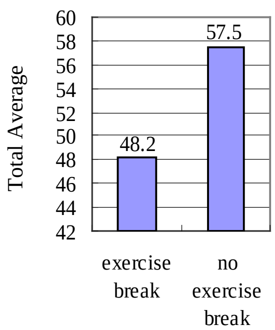


Fig. 20 Total average for questionnaire

4 Discussion

Multiple vital physiological parameters were monitored in the study to evaluate the effect of driving fatigue. Furthermore, attempt to reduce driving fatigue was made by introduction of a 15-min exercise break. Each physiological paramer change is discussed below.

4.1 Blood Pressure (SYS/DIA)

From Tables 4 and 5 and Fig. 5 and 6, a significant reduction in SYS after driving was observed for Group A with 120-min continuous driving. In contrast, SYS was almost unchanged for Group B with the 15-min exercise break. Homeostasis of blood pressure was better maintained in Group B with the assistance of the 15-min exercise which was specifically designed to boost lower body blood circulation. ANS activities involved in the maintenance of blood pressure for the two groups will be discussed later in Section 4.5 and 4.6. Diastolic pressure was little changed for both groups.

4.2 Heart Rate (HR)

From Tables 4 and 5 and Fig. 7, HR reduced significantly in both Group A and B after driving. Zengyong Li [19,21] also reported a reduction in HR after their indoor simulated driving experiments. In general, driving exerts a mental stress and a physical load on the driver, especially under heavy or complex traffic conditions. Compared to actual road driving, however, indoor simulated driving may be less stressful, due mainly to the driver's recognition that the simulation is non-real. In addition, body movement was limited during simulated driving with the hip, legs, and feet almost stationary. As a result, HR was lowered from the restful condition.

4.3 Heart Rate Variability (HRV)

From Tables 4 and 5 and Fig. 8, HRV increased significantly in both Group A and B after driving. Further analysis indicates that the increase in HRV for Group A was contributed mainly from sympathetic activity LF and very low frequency VLF (physiological meaning not defined), while in Group B, HRV increase came mainly from parasympathetic activity HF and very low frequency VLF.

4.4 Total Power [TP (AU)]

From Tables 4 and 5 and Fig. 9, TP(AU) increased significantly in both Group A and B after driving. TP(AU) is the total power in the frequency analysis and mathematically equivalent to HRV^2. The discussion is similar to HRV.

4.5 Sympathetic Nerve Activity [LF (AU) and LF (NU)]

From Tables 4 and 5 and Fig. 10 and 11, LF(AU) was slightly lower (non-significant) and LF(NU) significantly lower after driving for Group A with continuous driving. In contrast, with the exercise break in Group B, LF(AU) increased significantly. Increase in LF(NU) for Group B was non-significant. The results show that the sympathetic nervous activity was reduced in Group A but enhanced in Group B.

4.6 Para-Sympathetic Nerve Activity [HF (AU) and HF (NU)]

From Tables 4 and 5 and Fig. 12 and 13, HF(AU) was slightly higher (non-significant) and HF(NU) significantly higher after driving for Group A with continuous driving. In contrast, with the exercise break in Group B, HF(AU) increased slightly (non-significant) while HF(NU) decreased slightly (non-significant). The results show that the parasympathetic nervous activity was enhanced in Group A but maintained in Group B after driving

4.7 Very Low Frequency [VLF (AU)]

From Tables 4 and 5 and Fig. 14, VLF(AU) increased significantly for Group A but non-significantly for Group B. The physiological meaning of VLF(AU) is not defined in the 1996 Standard [17].

4.8 Sympatho-Vagal Balance Index (LF/HF)

From Tables 4 and 5 and Fig. 15, a significant drop in LF/HF was observed in Group A. In contrast, LF/HF exhibited a slight rise in Group B. The results show that after driving, the balance of ANS activity shifted towards parasympathetic nerve branch for Group A but sympathetic nerve branch for Group B. The expected effect of exercise break to boost cardiovascular system was indeed observed in Group B.

4.10 RMMSD

From Tables 4 and 5 and Fig. 16, RMMSD increased significantly after driving in both groups. The statistical definition of RMMSD is close to that of HRV. Refer to HRV for similar discussions.

4.11 Temperature of Palms

From Tables 4 and 5 and Fig. 17 and 18, both groups showed significant drops in palm temperatures after driving. Further analysis indicates that the drop in Group B with exercise break was smaller.

4.12 Questionnaire

4.12.1 Average Score for Each Question

From Tables 6 and Fig. 19, most average scores of the fatigue questions were higher for Group A without exercise break compared to Group B with exercise break (12 out of 14 questions). Among all the 14 questions, Question 12 (feeling of sleepiness) stood out with the highest average scores (5.90 and 4.95 for Group A and B respectively), suggesting that sleepiness is a major symptom in driving fatigue. The subjective questionnaire results are consistent with physiological parameters results shown in Tables 4 and 5.

4.12.2 Total Average Score

From Tables 6 and Fig. 20, total score of the 14 fatigue questions was 57.5 for Group A without exercise break, significantly higher than 48.2 for Group B with exercise break indicating that Group A volunteers felt more sleepy compared to Group B. Again, the subjective questionnaire results are consistent with physiological parameters results shown in Tables 4 and 5,

4.13 Overall Discussion

As driving fatigue develops, cardio-vascular system is unable to fulfil the basic physiological needs. Hands and feet become cold, heart rate slows, and eventually blood pressures go down. Poor circulation causes muscle pain and numbness. Hypoxia in brain induces drowsiness and loss of concentration. Under these circumstances, our body re-assesses the new physiological needs and activates ANS instantly (seen with HRV increase in the study). If re-assessment finds the body under exhaustion which requires an immediate rest, parasympathetic nerve branch in ANS is called upon (seen with Group A in this study). On the other hand, if re-assessment determines that a boost to cardiovascular system can meet the new physiological needs, sympathetic nerve branch is activated (Group B in this study). The success of ANS action depends on several factors, including mental alertness, heart strength, and peripheral circulation resistance. Immobilisation of the lower body, which increases blood flow resistance significantly, could compromise the sympathetic nerve’s function in boosting systemic circulation. Since the monitoring of physiological parameters was done at the beginning and the ending of driving in the study, it is unclear whether or not the sympathetic nerve branch was activated first in the early face of driving for Group A. Noted that at the end of driving for this group, the parasympathetic activity was enhanced. Under these conditions, if the driver continues to drive, the risk of traffic accidents would be extremely high. For Group B, the sympathetic nerve was enhanced at the end of driving, which helped to maintain systolic pressure and other vital parameters. But even the ANS action in this group is regarded as a partial success since palm temperatures and heart rate are still below baseline.

The results of this preliminary study indicate that driving fatigue can be tracked by vital physiological parameters, including extremity temperatures, heart rate, and blood pressures. Significant deviation of any vital parameter from baseline during or after driving should be viewed as a symptom of fatigue. In disagreement with previous authors [20], we regard HRV increase as a response of ANS to driving (or any body) activity, and not necessarily related to driving fatigue. We further propose that among the HRV parameters recorded, parasympathetic nerve indexes (HF(AU) and HF(NU)) and sympatho-vagal balance index LF/HF (in a reverse relationship to fatigue) are two most promising parameters that could be employed for quantitative ranking of driving fatigue.

5 Conclusion

Overall, driving is a demanding task both mentally and physically. ANS activation may overcome some fatigue symptoms, but recovery is nonetheless incomplete due to immobilization of lower body. Exercise break is proven to be a more effective remedy, especially accompanied by the ANS action.

6 Future Research

All the volunteers involved in the study were young college students with active ANS and healthy cardiovascular system. Yet, significant deviation from homeostasis was observed after 120-min simulated driving. In the future work, we will recruit older and less healthy volunteers to assess body response to worsen driving fatigue. We will evaluate new remedy techniques for the reduction of driving fatigue. A score-based driving fatigue index is to be developed in the future work.

7 Appendix

(1). Data download：fast or full data download can be selected.

Fig. 25 Data download to PC

(2). Data display

a. Multiple parameters can be displayed in the data page window.

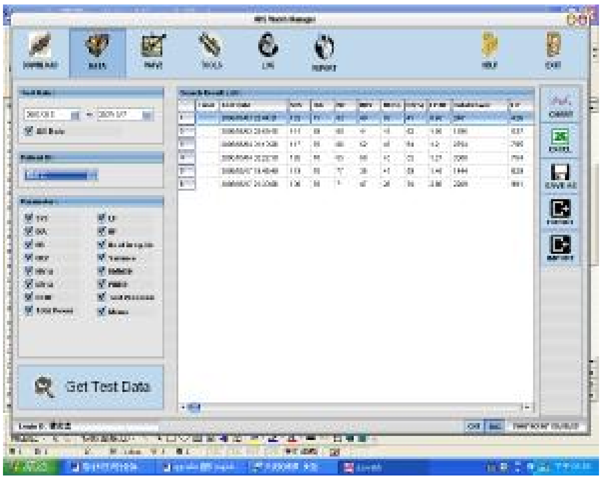
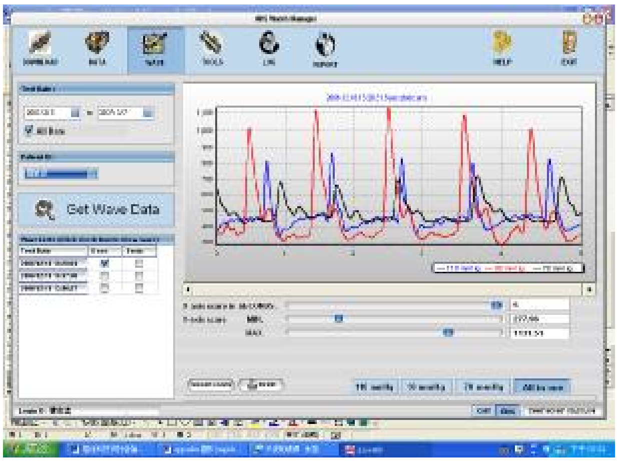


Fig. 26(a) Data display after download

b. 5-sec blood pressure wave measured at three cuff pressures (70,90, 110 mmHg)



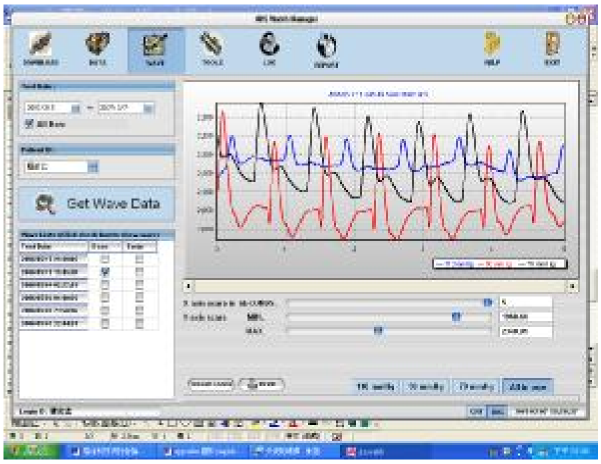
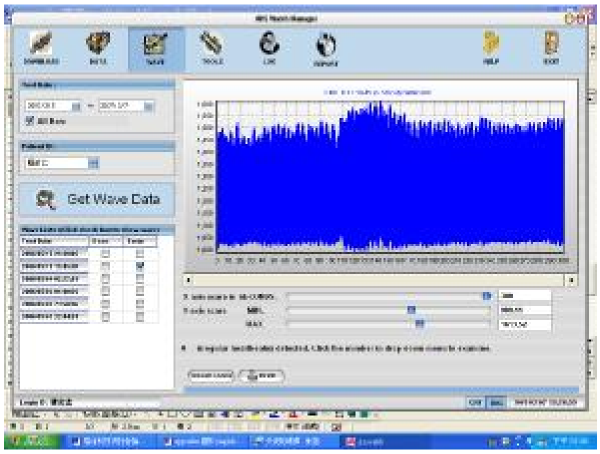


Fig. 26(b) 5-sec blood pressure wave

c. 5-min blood pressure wave



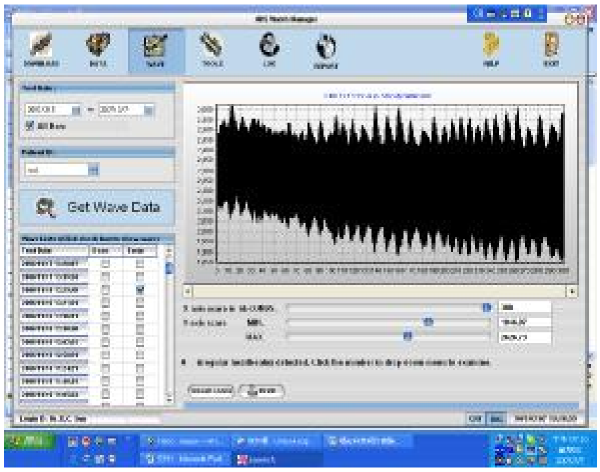


Fig. 26(c) 5-min blood pressure wave (wave patterns are caused by respiration)

d. 5-min blood pressure wave (expanded)

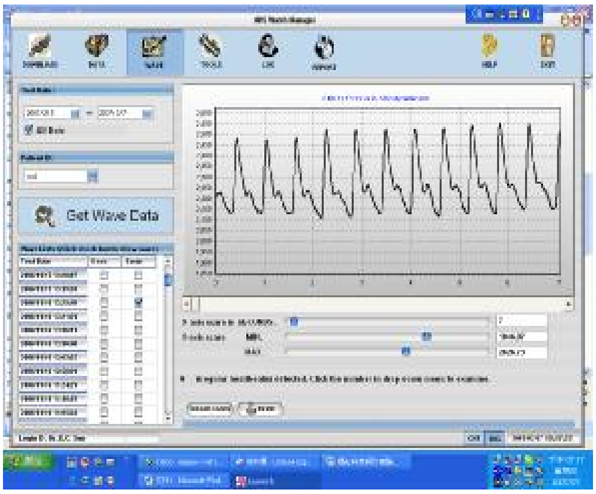


Fig. 26(d) 5-min blood pressure wave (expanded)

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