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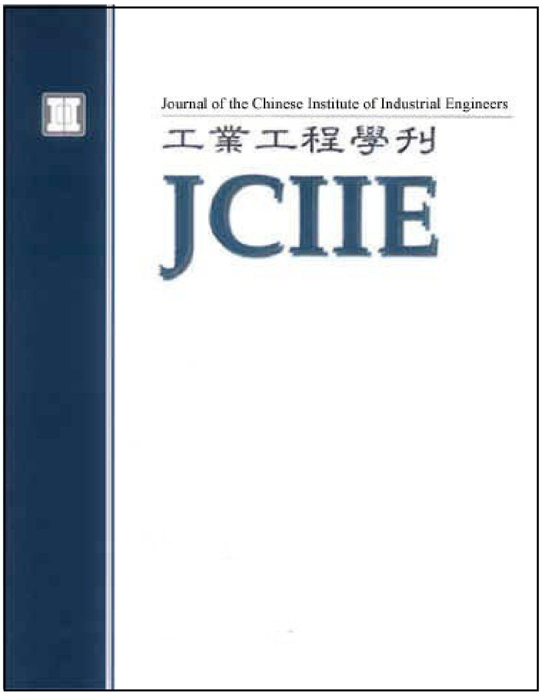

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CHANGES IN PHYSIOLOGICAL PARAMETERS INDUCED BY SIMULATED DRIVING TASKS: MORNING VS. AFTERNOON SESSION

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ABSTRACT

Introduction: Driving fatigue is one of the most common causes for traffic accidents. Immobilization of legs, hip, and waist is thought to play a major role in driving fatigue, as it hinders blood circulation and induce hemodynamic changes. **Objective:** the objective of the study was to monitor changes in physiological parameters before and after indoor simulated driving tasks conducted in the morning as well as afternoon sessions. **Method:** 40 young male subjects were randomly divided into morning (group A) and afternoon (group B) sessions and participated in the 90-min simulated in-door driving task. Before and after the task, BP (blood pressure), HR (heart rate), and HRV (heart rate variability) parameters were measured using a novel wrist monitor ANSWatch® which utilized built-in bio-sensors in the cuff to acquire radial pulse waves directly. Palm temperatures were measured by a high-precision thermometer. A questionnaire ranking driving fatigue was filled by each volunteer before and after the driving task. **Results:** (1) from paired T-tests, both the morning and afternoon driving tasks caused decreases in HR and palm temperatures, and increases in HRV and VLF(AU) (Very Low Frequency(Absolute Unit)); For the morning session, LF(AU) (Low Frequency(Absolute Unit)) and LF(NU)(Low Frequency(Normalized Unit)) increased while HF(NU) (High Frequency(Normalized Unit)) decreased; In contrast, LF(NU) and LF/HF decreased while HF(NU) increased for the afternoon session (all changes $p<0.05$). Systolic pressure was maintained in the morning session but dropped in the afternoon session ($p<0.05$). (2) From One-way and Two-way MANOVA analyses, there was no significant difference between morning and afternoon session for the entire group of physiological parameters measured before or after driving tasks; However, LF(AU), LF(NU), and LF/HF three individual parameters measured before driving were higher in the afternoon session than in the morning session ($p<0.05$). (3) From written questionnaire, all subjects felt some degree of fatigue following the driving task. No statistical difference existed between the two driving sessions in terms of fatigue score baseline or score change due to driving. **Conclusion:** Multiple physiological parameters showed significant changes after simulated driving tasks. Distinct trends were found between the two driving sessions. In the morning session, poor circulation in the lower body (limbs, abdomen, and hip) caused decrease in palm temperatures and heart rate, but blood pressures were maintained due to activation of the sympathetic nervous system as evidenced by increased HRV, LF(AU), and LF(NU). For the afternoon session, palm temperatures, heart rate, and systolic pressure were all lowered. Para-sympathetic nervous system was activated (indicated by increased HF(NU)) prompting the body to enter a sleepy state, which greatly increases accident risks in actual road driving. Monitoring of multiple physiological parameters in the study had gained great insight into mechanisms of homeostasis and provided a foundation in the future work to quantify driving fatigue in terms of degree of deviation from homeostatic states.

Keywords: Driving Fatigue, Heart Rate Variability (HRV), Homeostasis, Autonomic

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Nervous System, Blood Pressure, Simulated Driving, ANSWatch

1. INTRODUCTION

While driving fatigue is still a vaguely defined term physiologically, its effect on traffic accidents is well documented. Numerous statistics and studies have shown that long hour driving resulted in physical tiredness and slowdown in mental judgment. In the report published by Shinar in 1978 [18], a significant portion of highway accidents were attributed to driving fatigue. National Transportation Safety Board in U.S. investigated 286 accidents involving commercial vehicles and discovered that 38% of accidents were caused by the drivers' drowsiness or neglect (Harris and Mackie, 1972). Overall, driving fatigue remains one of the most probable causes for traffic accidents. A better understanding in driving fatigue on the physiological level will lead to new development for effective prevention.

In one aspect of driving, drivers often fail to maintain fresh concentration on the road with repetitious and unexciting scenery. In another aspect of driving, the limited waist, hip and leg spaces constrain the lower body (limbs, abdomen, and hip) from active movement. The "pumping" action by the leg muscle contraction, which forces the venous blood back to the heart (such as 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 hemodynamic changes. This belief is consistent with widely discussed mechanisms in driving fatigue, including hypoxia in brain, blood pressure drop, and below-normal heart rate.

It is well known that when local or systemic circulation is obstructed, ANS(Autonomic Nervous System) in the body is 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, deviations of physiological parameters from the homeostatic states can be avoided or minimized. On the other hand, any significant change in vital physiological parameters from baseline (such as body temperature or blood pressures) may point to an "exhausting" body which is unable to respond to physiological needs.

HRV (Heart rate variability) has been used in various studies for the assessment of physiological states. The subconscious cyclic variation in heart rate period 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 (LF/HF) indexes. Hjortskov et al. [7] and Garde et al. [5] both monitored HRV parameter changes in volunteers before and after a computer task during which various degrees of mental stresses were introduced. Hjortskov et al. [7] indicated that stressors led to changes in HRV (increase in LF(AU), HF(AU), and LF/HF compared to those under resting conditions), and a sustained increase in blood pressures (SYS and DIA). Garde et al. [5] also reported an increase in heart rate, blood pressure, and LF (NU), and a decrease in TP(AU) and HF (NU) in response to a physically demanding reference computer task. Wahlstrom et al. [26] also introduced time and verbal stresses during a mouse - driven computer task to investigate the physiological and psychological changes based upon heart rate, blood pressures (SYS and DIA), and HRV. Increases in both the physiological (HR, BP, LF/HF) and psychological reactions were observed compared to control conditions. These reports suggest that physical and mental stresses may cause the activation of sympathetic nervous system as indicated by increased BP, HR, LF, and LF/HF.

In a similar manner, several authors investigated the effect of simulated flight on physiological parameters [9][11][25]. Their general finding is that the complexity of a pilot's task in operating a flight often caused an increase in HR and BP (SYS and DIA), and a decrease in HRV. Lee [11] clearly showed that when the pilots conducted tasks that required high concentration, such as during take-off and landing, their heart rates increased significantly. Among various tasks performed by pilots (take off, climb and cruise, descent and approach, and landing), HRV was seen lowest during approach as it was the most critical period of piloting.

In the area of indoor simulated driving tests [8][14][15][16][17][27], Yang et al. [27] utilized ECG to monitor the drivers' 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. Yang et al. [27] also reported that as the degree of fatigue increased (indicated by increasing driving hour), SDNN (equivalent to HRV in this study), LF(NU) and LF/HF all increased while HF(NU) decreased progressively. The authors believed that the increase in LF/HF was an indication of increase in degree of driving fatigue, as the balance of ANS shifted towards the sympathetic branch. Li et al. (2003) [16] also based their HRV study on ECG and found three HRV parameters with significant changes after simulated driving, including increased LF (NU), decreased HF (NU), and increased LF/HF. After three hours of continuous driving, the drivers showed an increase in response time, a drop in judgment accuracy, and a lower heart rate. Subjective written questionnaire also showed increased symptoms of driving fatigue. They proposed using HRV as a quantitative index of driving fatigue. Li et al. [14,15,17] further studied the effect of acupuncture on driving fatigue. Their findings suggested that driving fatigue induced physiological changes could be attenuated by acupuncture. Actual road driving involves much higher mental and physical loads than the indoor simulation. Both Fumio et al. [4] and Miloševic et al. [21] observed an increase in BP on taxi drivers on long duty schedules. It is to be noted that the levels of mental and physical workloads, time duration, as well as the degree of body immobilization are all different among the above were cited studies as well as in this research. We thus expected to see unique body responses in the volunteers during the 90-min indoor driving employed in this study.

In this study, we monitored multiple physiological parameters, including palm temperatures (left and right), HR, BP (SYS and DIA), and HRV parameters before and after a 90-min indoor driving task. In addition, a written questionnaire was filled by each participant before and after the driving task to gauge the subjective evaluation of driving fatigue. The study was divided into two sub-groups, one conducted in the morning, and the other in the afternoon, so that body reactions to long-hour driving at different times of the day could be investigated. It is our hope that the results of this first phase in a series of studies could provide useful information for the definition of driving fatigue based upon physiological parameter changes.

2. METHODS

In-door simulated driving (instead of road driving) was selected in consideration of cost, safety, and control of variables.

2.1 Subjects

All volunteers gave their informed consent before the study. To avoid the influences of gender and age on HRV [13][28], a total of 40 male subjects in the age of 23.3±1.9 years old (Table 1; all college students or graduates) were 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. All subjects were confirmed to be in fresh or non-fatigue conditions before driving when reporting to the laboratory.

Table 1. Characteristics of subject

Item	Average
Age	23.3±1.9 (years-old)
Height	169.2±6.2 (cm)
Weight	70.6±9.6 (kg)
Body Fat Index*	22.5±6.1 (%)

* Body fat index measured by a commercial instrument manufactured by TANITA corporation (Model: ULT 2000 / ULT 2001, Tokyo, Japan)

2.2 Variables

In the experimental design, gender, age and ambient temperature (and humidity) were controlled. The independent variables (effects) were driving session (morning or afternoon) and driving task (before or after). The dependent variables were physiological parameters which included blood pressures [systolic (SYS) and diastolic (DIA)], heart rate (HR), heart rate variability (HRV), sympathetic nerve activity indexes [LF(AU) and LF(NU)], parasympathetic nerve activity indexes [HF(AU) and HF(NU)], sympatho-vagal balance index (LF/HF), and temperature of left and right palms.

2.3 In-door simulated driving

The test room was temperature controlled at 22±2℃. A simulate highway scenery was projected onto a 178 (cm) x 178 (cm) white screen using a computer and a projector (Figure 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 which would expand in area vertically if the vehicle location deviated from the designated lane. Laud sounds would go off if the vehicle got too close to or made contact with road trees or walls. The driving task lasted 90 minutes. While the driver's main task was to operate the wheel, he was not required to step the gas or the break peddle (both not equipped). Instead, a constant driving speed (the road view) was provided by the computer. Such a simulation is close to a highway driving where the traffic conditions are more constant as compared to a local in-town driving where the driver must change the speed frequently using gas and break peddles.

Figure 1. Driving simulator

2.4 Apparatus and materials

Experimental apparatus consisted 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, SPSS 12.0, and "ANSWatch Manager Pro" data analyzer.

2.5 Experimental procedures

40 subjects were randomly divided into two groups (A&B). Group A conducted driving tests in the morning (8:30~11:00AM) while Group B in the afternoon (2:00~4:30PM). 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 needed about 7 minutes. Data in ANSWatch® was downloaded to a notebook computer immediately following the test for review and storage. The driving task followed which lasted for 90 minutes. After driving, each volunteer was tested again for palm temperatures and ANSWatch®. In addition, a written questionnaire consisting of 14 questions related to fatigue (similar to those developed by authors in [17]) was filled by the volunteers before and after driving. The entire testing program is illustrated in Figure 2. The list of questions is shown in Table 2, while the quantitative scale for each question is shown in Table 3. A score of 4 or higher is an indication of positive response to the question.

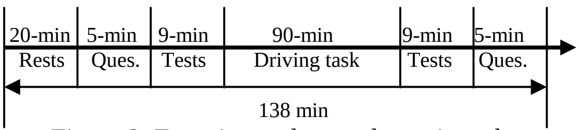

Figure 2. Experimental procedures time chart

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 stiffening
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 parameters analyses

During the 6-min test, ANSWatch® (Figure 3) first used the oscillatory method to obtain heart rate, systolic pressure, and diastolic pressure. It then conducted a standard 5-min HRV test. The piezo-electrical sensors in the cuff picked up blood pressure waveforms produced by the radial artery, with the aid of an air pouch pressure controlled by an air pump and a release valve. Peak-to-peak intervals were determined followed by time and frequency domain analyses. The HRV analysis followed closely the 1996 international standard [24], consisting of the following steps:

(1). The original data was fed through a low pass FIR filter at 0 to 14 Hz.
(2). Fundamental frequency was determined based upon the first 5-second data.
(3). The primary peak in each cycle was determined.
(4). Peak-to-peak intervals were calculated.
(5). Time-domain HRV parameters (mean period or heart rate; variance and standard deviation of peak-to-peak intervals) were calculated. Peak intervals greater than 4*standard deviation were removed and not replaced.
(6). Peak-to-peak intervals were re-sampled to 1024 points with interpolation and Hamming window adjustment.
(7). Fast Fourier Transform (FFT) was performed with Hamming window adjustment.
(8). Integrations 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 were 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]} were calculated.

Figure 3. ANSWatch® wrist monitor

It is noted above that irregular heartbeats (defined as those with peak intervals greater than 4 standard deviations in the 5-min test data, as caused by cardiac arrhythmia or body movement) were excluded from the raw data prior to HRV analysis (as recommended by the 1996 Standard [24]). For clarity, 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). VLF(AU)：Very Low Frequency (Absolute Unit) (frequency range 0.0001~0.04 Hz) (ms^2); its physiological meaning not defined by 1996 Standard
(4). LF(AU)：Low Frequency (Absolute Unit) (frequency range 0.04 ~0.15 Hz) (ms^2); sympathetic (and some parasympathetic) nervous activity index
(5). HF(AU)：High Frequency (Absolute Unit) (frequency range 0.15~0.4 Hz) (ms^2); parasympathetic nervous activity index
(6). LF(NU)(%)：Low Frequency(Normal Unit), [LF/(TP-VLF)]*100; contribution of sympathetic nervous activity
(7). HF(NU)(%)：High Frequency(Normal Unit) [HF/(TP-VLF)]*100; contribution of parasympathetic nervous activity
(8). LF/HF：Ratio of LF(AU) to HF(AU); sympatho-vagal balance index

Although the physiological meaning for VLF (AU) was reported by ANSWatch, it is not defined in the 1996 Standard. The authors decided to report VLF (AU) data to aid discussions.

2.7 Data collection

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 [1][6][20]. They reported data accuracy in terms of correlation coefficient in the range of 0.75 to 0.99 when compared to ECG. In this paper, we are introducing a new wrist monitor ANSWatch® (Taiwan Scientific Corporation, Taipei, Taiwan; Taiwan DOH (Department of Health) 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 and published literature [12][22][23], the device accuracy (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 (normalized) LF (NU), high frequency (normalized) HF(NU), sympatho-parasympathetic balance index LF/HF, and number of irregular heartbeats (cardiac arrhythmia). Upon data download to a PC and using the accompanied software (ANSWatch® Manager Pro), more HRV parameters can be calculated (such as low frequency (absolute) LF (AU), high frequency (absolute) HF (AU), 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.)

2.8 Statistical analyses

Student's T tests (two-tailed) were used throughout the entire study to determine the significance of parameter changes before and after the driving task for respective driving sessions. Furthermore, One-way and Two-way MANOVA (Multivariate analysis of variance) analyses were used to examine any group difference or interactions. The questionnaire results were analyzed using the same methods.

3. RESULTS

3.1 Variation in physiological parameters before and after driving (pair T test analyses)

Table 4 and Table 5 show the test results for the morning session (Group A) and the afternoon session (Group B) respectively.

Table 4. Physiological parameters before and after driving task for the morning session

Parameters	Before driving	After driving	t-value	DF [a]	p-value
SYS	113.8±9.0	113.8±9.2	0.02	19	0.987
DIA	73.4±1.8	73.6±1.9	0.44	19	0.666
HR	70.2±11.3	65.8±8.6	-3.09	19	0.006
HRV	44.5±14.7	58.7±16.4	6.20	19	0.000
LF (AU)	468.4±302.7	716.7±434.5	3.12	19	0.006
LF (NU)	46.3±17.1	54.3±14.5	2.26	19	0.036
HF (AU)	580.0±518.1	591.5±383.4	0.11	19	0.916
HF (NU)	53.7±17.1	45.6±14.5	-2.26	19	0.036
VLF (AU)	1142.4±983.8	2366.2±1584.3	5.62	19	0.000
LF/HF	1.1±0.8	1.3±0.7	1.45	19	0.164
T_{LP}	36.5±0.6	35.4±1.7	-3.01	19	0.007
T_{RP}	36.6±0.7	35.6±1.7	-2.65	19	0.016

[a]: DF (degree of freedom)

From Table 4, HR, HRV, HF(NU), LF(AU) & LF(NU), VLF(AU), left palm temperature (T_{LP}) and right palm temperature (T_{RP}) exhibited significant changes ($p<0.05$) after the driving task conducted in the morning for Group A, while changes in SYS, DIA, HF (AU) or LF/HF did not reach statistical significance.

Table 5. Physiological parameters before and after driving task for the afternoon session

Parameters	Before driving	After driving	t-value	DF [a]	p-value
SYS	118.7±7.7	111.4±5.0	-4.16	19	0.001
DIA	73.9±2.3	73.9±2.0	0.11	19	0.917
HR	71.4±9.2	67.0±9.7	-3.33	19	0.003
HRV	48.7±16.9	56.3±17.7	2.71	19	0.014
LF (AU)	879.8±847.6	817.9±545.1	-0.39	19	0.700
LF (NU)	63.2±14.8	53.5±16.7	-3.21	19	0.005
HF (AU)	510.9±465.7	742.4±565.3	3.02	19	0.007
HF (NU)	36.8±14.8	46.6±16.7	3.21	19	0.005
VLF (AU)	1253.7±823.9	1907.1±1372.8	2.70	19	0.014
LF/HF	2.1±1.2	1.5±1.0	-2.69	19	0.015
T_{LP}	36.7±0.8	35.7±1.8	-3.78	19	0.001
T_{RP}	36.8±0.8	36.0±1.9	-2.87	19	0.010

[a]: DF (degree of freedom)

From Table 5, SYS, HR, HRV, LF(NU), HF(AU), HF(NU), VLF(AU), LF/HF, left palm temperature(T_{LP}) and right palm temperature (T_{RP}) all exhibited significant changes ($p<0.05$) after the driving task conducted in the afternoon for Group B, while changes in DIA and LF(AU) did not reach statistical significance. It is noted that average systolic pressure went down from 118.7 (before driving) to 111.4 mmHg (after driving) with a p-value of 0.001.

3.2 Variation in physiological parameters (Multivariate Analysis of Variance, MANOVA)

3.2.1 One-way MANOVA (morning vs. afternoon)

(1). Before driving

a. Entire group of physiological parameters

This analysis was based upon the entire group of physiological parameters measured before driving in the study (a total of 12, see Table 4 or 5) to examine any statistical difference between the morning and the afternoon session. The results are shown in Table 6.

Table 6. Comparison between sessions for the entire group of physiological parameters before driving

Effect	Test	Value	F	Hypothesis DF [a]	Error DF [a]	p-value
Driving session	Wilks' λ	0.673	1.23	11	28	0.309

[a]: DF (degree of freedom)

From Table 6, there was no significant group difference ($p=0.309$) between the morning and the afternoon session for the 12 physiological parameters taken before driving.

b. Individual physiological parameters (independent T-test)

Individual physiological parameters were examined by independent T-tests for any group difference between the morning and the afternoon session. Results are shown in Table 7.

Table 7. Comparison between sessions for individual physiological parameters before driving

Parameters	Session average		Difference [b] between session	Standard deviation	DF [a]	p-value
	Morning	Afternoon				
SYS	113.80	118.65	4.85	2.65	38	0.075
DIA	73.45	73.90	0.45	0.65	38	0.498
HR	70.20	71.40	1.20	3.27	38	0.716
HRV	44.55	48.70	4.15	5.02	38	0.414
HF (AU)	580.00	510.85	-69.15	155.77	38	0.660
HF (NU)	53.70	36.80	-16.90	5.06	38	0.002
LF (AU)	468.45	879.75	411.30	201.26	38	0.048
LF (NU)	46.30	63.20	16.90	5.06	38	0.002
VLF (AU)	1142.40	1253.70	111.30	286.95	38	0.700
LF/HF	1.11	2.13	1.02	0.32	38	0.003
T_{LP}	36.54	36.71	0.16	0.22	38	0.474
T_{RP}	36.61	36.78	0.17	0.25	38	0.507

[a]: DF (degree of freedom)
[b]: Difference was defined as value (afternoon session) – value (morning session)

From Table 7, LF(AU), LF(NU) and LF/HF were higher while HF(NU) was lower in the afternoon session as compared to those in the morning session ($p<0.05$). In other words, a slight shift towards the sympathetic activity was found in the afternoon group before driving. Other authors have reported HRV differences measured at different hours of the day [2][3]. This difference does not affect the paired T-tests shown in Tables 4 and 5 for the effect of driving, but the authors plan to investigate this effect in the future studies.

(2). After driving

a. Entire group of physiological parameters

This analysis examined any statistical difference between the morning and the afternoon session based upon the entire group of physiological parameters taken after driving. The results (not shown here for brevity) indicated that there was no significant group difference (Wilks' λ value 0.764; $p=0.652$) between the morning and the afternoon session for the 12 physiological parameters taken after driving.

b. Individual physiological parameters (independent T-test)

Independent T-tests were utilized to examine individual physiological parameters for any group difference between the morning and the afternoon session. Results (not shown here) again indicated that no physiological parameter taken after driving showed a statistical difference between the morning and the afternoon session (all p-values>0.05).

(3). Changes in physiological parameters due to driving

a. Entire group of physiological parameters changes

This analysis was based upon the entire group of physiological parameter changes due to driving measured in the study (a total of 12, see Table 4 or 5) to examine any statistical difference between the morning and the afternoon session. The results (not shown here) indicated that no statistical difference was observed between the morning and the afternoon session (Wilks' λ value 0.609, p=0.142).

b. Individual physiological parameter changes

Examination of individual physiological parameter changes due to driving for any group difference between the morning and the afternoon session was conducted by independent T-tests. Results are shown in Table 8.

Table 8. Comparison between sessions for individual physiological parameter changes

Parameters	Average of change [b] due to driving		Difference [c] between session	Standard deviation	DF [a]	p-value
	Morning	Afternoon				
SYS	-0.05	7.30	7.35	3.54	38	0.045
DIA	-0.15	-0.05	0.10	0.58	38	0.865
HR	4.40	4.40	0.00	1.94	38	1.000
HRV	-14.20	-7.60	6.60	3.62	38	0.076
HF (AU)	-11.50	-231.50	-220.00	132.07	38	0.104
HF (NU)	8.05	-9.75	-17.80	4.67	38	0.001
LF (AU)	-248.25	61.85	310.10	176.87	38	0.088
LF (NU)	-8.05	9.75	17.80	4.67	38	0.001
VLF (AU)	-1223.80	-653.35	570.45	325.57	38	0.088
LF/HF	-0.24	0.68	0.91	0.30	38	0.004
T_{LP}	1.09	0.97	-0.12	0.44	38	0.779
T_{RP}	0.92	0.81	-0.11	0.44	38	0.806

[a]: DF (degree of freedom)
[b]: Change was defined as value (after driving) – value (before driving)
[c]: Difference was defined as value (afternoon session) – value (morning session)

From Table 8, changes in SYS, HF(NU), LF(NU), and LF/HF were significantly different between the two driving sessions (p<0.05). Further analysis shows that all four parameter changes are in the opposite trend (increase vs. decrease or vise versa) between the two groups.

3.2.2 Two-way MANOVA (driving session and driving task) on physiological parameters

The following analyses treated the driving session and the driving task as two independent variables and investigated each individual effect as well as interactions between variables on physiological parameters (the dependent variables).

(1). Entire group of physiological parameter changes

Based upon the entire group of physiological parameters, MANOVA results are shown in Table 9.

Table 9. MANOVA of driving session and driving task on entire group of physiological parameters

Effect	Test	Value	F	Hypothesis DF [a]	Error DF [a]	p-value
Driving session	Wilks' λ	0.84	1.13	11	66	0.348
Driving task [b]		0.65	3.15	11	66	0.002
Driving session × Driving task		0.84	1.12	11	66	0.360

[a]: DF (degree of freedom)
[b]: Driving task was defined as value (after driving task) – value (before driving task)

From Table 9, Driving hour of the day (driving session) had no significant effect on the entire group of physiological parameters (p>0.05). In contrast, the driving task had a significantly effect (p<0.05). As expected, no significant interaction was observed between the driving hour and the driving task (p>0.05).

(2). Individual physiological parameter changes before and after driving

Independent T-tests were used to assess the effect of the driving task on each physiological parameter regardless of the driving session. The results are shown in Table 10.

Table 10. Comparison of individual physiological parameters between before- and after-driving

Parameters	Average (both sessions included)		Difference [b] between before- and after-driving	Standard deviation	DF [a]	p-value
	Before driving	After driving				
SYS	116.23	112.60	-3.62	1.77	78	0.044
DIA	73.68	73.78	0.10	0.45	78	0.825
HR	70.80	66.40	-4.40	2.18	78	0.048
HRV	46.63	57.53	10.90	3.69	78	0.004

HF (AU)	545.43	666.93	121.50	109.08	78	0.269
HF (NU)	45.25	46.10	0.85	3.53	78	0.811
LF (AU)	674.10	767.30	93.20	127.28	78	0.466
LF (NU)	54.75	53.90	-0.85	3.53	78	0.811
VLF (AU)	1198.05	2136.63	938.57	274.84	78	0.001
LF/HF	1.62	1.40	-0.22	0.21	78	0.298
T_{LP}	36.62	35.66	-1.02	0.30	78	0.001
T_{RP}	36.69	35.83	-0.86	0.31	78	0.008

[a]: DF (degree of freedom)

[b]: Difference was defined as value (after driving) – value (before driving)

From Table 10, SYS, HR, HRV, VLF(AU), T_{LP}, and T_{RP} all showed significant difference between before- and after-driving (all p-values<0.05). Among them, HRV and VLF(AU) were higher while SYS, HR, T_{LP} and T_{RP} were lower after driving.

3.3 Subjective questionnaire analyses

It was confirmed by verbal communication that all volunteers followed the pre-test instructions (having sufficient sleep in the previous night and no eating, drinking, or exercise one hour prior to the test and maintained fresh and healthy when reporting to the test laboratory). In addition, each volunteer filled the fatigue questionnaire before and after driving. Results of the written questionnaire and statistical analyses are tabulated in Tables 11 through 14.

3.3.1 Pair T test of questionnaire for morning and afternoon session

Paired T-tests were conducted for both the morning and afternoon sessions before and after the driving task. Results are shown in Tables 11 and 12.

(1). Morning session

Table 11. Paired T test of questionnaire before and after driving for morning session

Question items	Average Score		Standard deviation	DF [a]	p-value
	Before driving	After driving			
Body tiredness	2.80	4.75	0.358	19	0.000
Loss of concentration	2.80	4.90	0.315	19	0.000
Desire to lie down	2.70	4.70	0.502	19	0.001
Anxiety	2.15	3.95	0.394	19	0.000
Lack of Energy	2.20	4.15	0.373	19	0.000
Mental response slowdown	2.15	4.05	0.354	19	0.000
Headache	1.15	1.95	0.277	19	0.009
Shoulder stiffening	1.60	3.55	0.425	19	0.000
Waist pain	1.45	2.45	0.251	19	0.001
Lower body numbness	1.30	4.85	0.407	19	0.000
Eye fatigue	2.35	5.35	0.355	19	0.000
Feeling of sleepiness	2.35	5.15	0.367	19	0.000
Feeling of vomit	1.20	1.85	0.334	19	0.067
Hand and foot trembling	1.25	1.95	0.272	19	0.019
Average score per question	1.96	3.82	0.188	19	0.000
Total average score	27.45	53.60	2.638	19	0.000

[a]: DF (degree of freedom)

From Table 11, all fatigue questions except ”Feeling of vomit” showed increased scores after driving for the morning session (p<0.01 or 0.05). In addition, average scores and total scores were all significantly higher following driving (p<0.01). The questionnaire results clearly indicated subjective feeling of driving fatigue expressed by these young volunteers after 90-min continuous driving.

(2). Afternoon session

Table 12. Paired T test of questionnaire before and after driving for afternoon session

Question items	Average Score		Standard deviation	DF [a]	p-value
	Before driving	After driving			
Body tiredness	2.35	4.90	0.366	19	0.000
Loss of concentration	2.45	5.45	0.340	19	0.000
Desire to lie down	2.45	5.40	0.407	19	0.000
Anxiety	2.20	4.55	0.466	19	0.000
Lack of Energy	2.65	4.75	0.306	19	0.000
Mental response slowdown	2.35	4.75	0.302	19	0.000
Headache	1.55	2.45	0.383	19	0.030
Shoulder stiffening	2.40	3.95	0.413	19	0.001
Waist pain	2.30	3.10	0.569	19	0.176
Lower body numbness	1.95	5.05	0.409	19	0.000
Eye fatigue	2.15	5.50	0.350	19	0.000
Feeling of sleepiness	2.35	5.90	0.343	19	0.000
Feeling of vomit	1.35	1.70	0.254	19	0.185
Hand and foot trembling	1.85	2.45	0.319	19	0.076
Average score per question	2.16	4.27	0.228	19	0.000
Total average score	30.35	59.9	3.200	19	0.000

[*]: DF (degree of freedom)

From Table 12, 11 fatigue questions (out of 13 total questions) showed increased scores after driving for the afternoon session (p<0.01 or 0.05). The exceptions were “Waist pain”, “Feeling of vomit, and “Hand and foot trembling”. In addition, average scores and total scores were all significantly higher following driving (p<0.01). Similar to the morning session, volunteers in the afternoon session also clearly felt driving fatigue after 90-min continuous driving.

3.3.2 Independent T test for two sessions before driving

Table 13. Comparison between sessions for fatigue scores before driving

Question items	Average score before driving		Difference [b] between session	DF [a]	p-value
	Morning (Group A)	Afternoon (Group B)			
Body tiredness	2.80	2.35	-0.45	38	0.247
Loss of concentration	2.80	2.45	-0.35	38	0.351
Desire to lie down	2.70	2.45	-0.25	38	0.561
Anxiety	2.15	2.20	0.05	38	0.884
Lack of Energy	2.20	2.65	0.45	38	0.212
Mental response slowdown	2.15	2.35	0.20	38	0.547
Headache	1.15	1.55	0.40	38	0.159
Shoulder stiffening	1.60	2.40	0.80	38	0.033

Waist pain	1.45	2.30	0.85	38	0.021
Lower body numbness	1.30	1.95	0.65	38	0.039
Eye fatigue	2.35	2.15	-0.20	38	0.615
Feeling of sleepiness	2.35	2.35	0.00	38	1.000
Feeling of vomit	1.20	1.35	0.15	38	0.466
Hand and foot trembling	1.25	1.85	0.60	38	0.023
Average score per question	1.96	2.16	0.20	38	0.393
Total average score	27.45	30.35	2.90	38	0.393

[a]: DF (degree of freedom)

[b]: Difference was defined as value (afternoon session) – value (morning session)

From Table 13, average score per question and total average score were similar between the two sessions measured before driving, as examined by independent T-tests. None of the 13 questions showed a p-value below 0.01. Overall, volunteers were not feeling fatigue (all scores below 3.0, the threshold for feeling of fatigue, see definition in Table 3) before driving regardless of driving hour.

3.3.3 Independent T test for driving-induced changes in fatigue scores between session

Table 14. Comparison between sessions for fatigue score changes due to driving

Question items	Average of change [b] due to driving		Difference [c] between session	DF [a]	p-value
	Morning (Group A)	Afternoon (Group B)			
Body tiredness	1.95	2.55	0.60	38	0.249
Loss of concentration	2.10	3.00	0.90	38	0.060
Desire to lie down	2.00	2.95	0.95	38	0.150
Anxiety	1.80	2.35	0.55	38	0.374
Lack of Energy	1.95	2.10	0.15	38	0.758
Mental response slowdown	1.90	2.40	0.50	38	0.290
Headache	0.80	0.90	0.10	38	0.834
Shoulder stiffening	1.95	1.55	-0.40	38	0.504
Waist pain	1.00	0.80	-0.20	38	0.750
Lower body numbness	3.55	3.10	-0.45	38	0.441
Eye fatigue	3.00	3.35	0.35	38	0.487
Feeling of sleepiness	2.80	3.55	0.75	38	0.144
Feeling of vomit	0.65	0.35	-0.30	38	0.480
Hand and foot trembling	0.70	0.60	-0.10	38	0.813
Average score per question	1.86	2.11	0.24	38	0.417
Total average score	26.15	29.55	3.40	38	0.417

[a]: DF (degree of freedom)

[b]: Change was defined as value (after driving) – value (before driving)

[c]: Difference was defined as value (afternoon session) – value (morning session)

Examination for fatigue score changes due to driving by independent T-test showed that there was no statistic difference between the morning and afternoon session (Table 14). None of the 13 fatigue questions showed significant difference in terms of score change between the two driving sessions. Average score changes per question as well as total score changes also showed no significant difference due to driving hour. It is concluded that increase in fatigue score due to driving was not significantly affected by driving hour (morning or afternoon). Although the overall session difference did not reach statistical significance, the data details seem to suggest that the afternoon volunteers felt slightly more tired due to driving. Among the 13 questions, the afternoon volunteers felt more fatigued (based upon the score change) for 9 questions and less fatigued for 4 questions than the morning volunteers. Both average score change and total average score change were higher for the afternoon session. As known by scientists, subjective questionnaire is often not as accurate or reliable as other quantitative means of measurement. More data or refined fatigue questions are needed in this area in the future research.

4. DISCUSSION

Multiple vital physiological parameters were monitored in the study to evaluate the effect of driving task. In general, for driving tasks conducted in the morning (such as Group A in the study), drivers are in a fresh state both physically and mentally, ANS response to the driving task should be swift and satisfactory. On the other hand, the sleepy and tiring body may have difficulty in coping with driving fatigue for driving in the afternoon (such as Group B in the study). Our results tend to agree with the expected effect. Each physiological paramer change is discussed below.

4.1 Blood pressures (SYS and DIA)

From Tables 4 and 5, SYS was almost unchanged for Group A in the morning session after driving. In contrast, a reduction in SYS was observed for Group B tested in the afternoon. Diastolic pressure was little changed for either session. Static driving task accompanied by lower body (waist, hip, abdomen, and legs) immobilization resulted in poor systemic circulation. ANS reacted to the physiological change swiftly but differently in each session. For Group A, homeostasis of blood pressures was maintained through the activation of sympathetic nervous system. For Group B, activity of sympathetic nervous system slowed down while parasympathetic branch activity increased (see discussions on HRV related parameters below). As a result, the body entered a sleepy state and SYS was lowered. Garde et al. [5], Hjorskov et al. [7], and Veltman et al. [25] all observed the active role played by the sympathetic branch in the modulation of blood pressure during work load. An increase in LF was often accompanied by blood pressure rise. From Tables 4 and 5, activation of the sympathetic branch was a body response to maintain blood pressures in the morning session while de-activation of the sympathetic branch along with activation of the parasympathetic branch in the afternoon session prepared the body to enter a restful (or sleepy) state (see more discussions on HRV parameters later).

In contrast, Fumio et al. [4] conducted blood pressure and HRV tests on city taxi drivers and observed increased blood pressure during service. There are two major differences in the experimental setting between their and our study. For taxi drivers, their physical and mental stresses are much higher than those experienced in the indoor simulation. Even though our driving room was designed to duplicate road driving as closely as possible, volunteers might regard the test as a non-real driving event. In our study, volunteers were not allowed to get up or leave the driving seat in the 90-min continuous driving. City taxi drivers, on the other hand, need to get out to open doors or handle luggage from time to time. The extent of lower body immobilization is thus lower for taxi drivers. Driving conditions in our simulation are more similar to those encountered in long-distance highway driving. In cardiology and hemodynamics, pulse pressure is defined as the difference between systolic pressure and diastolic pressure. In this study, since diastolic pressure was little changed after driving (Tables 4 and 5), it follows that any change in systolic pressure is directly related to pulse pressure change. In general, a lower pulse pressure represents a lower cardiac output. Furthermore, decrease in cardiac output is seen when the body demand for energy is low or the body is “exhausted”. Thus, a reduction in pulse pressure (as seen in the afternoon session in this study) might be one of the candidates in terms of physiological parameter that can be employed to quantify driving fatigue.

4.2 Heart rate (HR)

From Tables 4 and 5, HR reduced significantly in both Group A and B after driving. During driving, body movement was limited with the hip, legs, and feet almost stationary. The inactivity in the lower body (limbs and abdomen) also caused poor circulation. In particular, venous return to the heart was slowed down. As a result, HR was lowered from the restful condition. Several previous studies Lal et al. [10], Li et al. [14][17], and Milos̆ evic [21] on long-hour driving also reported a reduction in HR, consistent with our finding. Again, based upon cardiology and hemodynamics, a slower heart rate represents a smaller cardiac output. Decrease in cardiac output may be a sign that the body is “tired”. Thus, a reduction in HR might be one of the candidates in terms of physiological parameter that can be employed to quantify driving fatigue.

4.3 Heart rate variability (HRV)

From Tables 4 and 5, HRV increased significantly in both morning and afternoon sessions after driving. Li at al. [14] and Yang et al. [27] also observed similar trends in their driving studies. Further analysis indicates that the increase in HRV for the morning session (from 44.5ms to 58.7ms) was contributed mainly from the sympathetic activity LF and very low frequency VLF (whose physiological meaning not clear). In contrast, the afternoon session saw HRV increase (from 48.7ms to 56.3ms) coming mainly from the parasympathetic activity HF and very low frequency VLF. Literature reports from Garded et al. [5], Hjorskov et al. [7], Jorna [9] and Veltman et al. [25] often observed a decrease in HRV after subjects conducted operations involving complexity or urgency. On the other hand, HRV was seen increased after a light, routine, or near-restful operation. It is noted that no constraint in body movement was encountered in those studies. Another factor affecting the ANS response is that indoor simulated driving is not as intense as the actual road driving. Also noted is that HRV represents the total activity of ANS in a general sense. Body response to a specific action may take different routes (branches) to achieve the new balance. For instance, to lower the heart rate or blood pressure, one route would be to lower the sympathetic branch activity. Another route is to increase the activity of parasympathetic branch. The first route will decrease HRV while the second will do the opposite. In certain occasions or subjects, both routes may be taken together to achieve the adjustment. Thus, it is important to examine not only the change in HRV but also parameters related to each branch of ANS, as discussed below. Due to the complexity involved, it is a general belief by the authors that HRV alone is not a good candidate in terms of physiological parameter for quantifying driving fatigue.

4.4 Sympathetic nerve activity [LF(AU) and LF(NU)

From Tables 4 and 5, LF (AU) and LF (NU) both increased significantly after driving for Group A conducted in the morning. In contrast, LF (AU) decreased and LF (NU) decreased significantly for Group B in the afternoon session. The results show that the sympathetic nervous activity was enhanced in Group A but reduced in Group B. Our morning session results are consistent with previous studies Jiao et al. [8], Li et al. [14,15,16] and Yang et al. [27] where the driving tasks were also conducted in the morning and increases in LF(AU) and LF(NU) were found. According to our results, subjects in the morning were in a fresher body state so that activation and execution of sympathetic nervous system was more satisfactory compared to the afternoon driving. As a result, homeostasis of systolic pressure was maintained in the morning session. For the afternoon session, driving fatigue (discussed later in Questionnaire results) must have reached a critical level that subjects "turned off" the sympathetic nervous system and lowered the systolic pressure to some extent in order to force the body to rest.

4.5 Parasympathetic nerve activity [HF(AU) and HF(NU)]

From Tables 4 and 5, HF (AU) held almost constant and HF (NU) decreased [due to increased LF (AU)] after driving for the morning session. In contrast, Group B in the afternoon session exhibited increased HF (AU) (non-significant) and HF (NU) (significant). The results show that in a relative sense (in terms of normalized units) the parasympathetic nervous activity was reduced in the morning (Group A) but enhanced in the afternoon (Group B) after driving. Again, our morning finding on HF(NU) decrease is in agreement with previous driving studies reported by Jiao et al. [8], Li et al. [14,15,16] and Yang et al. [27] conducted in the morning. It is noted that for the morning driving when the body was in a fresh state, the parasympathetic nervous branch was in sync (decrease in activity) with the sympathetic nervous branch (increase in activity) to collectively boost cardiac output and maintain homeostasis during driving. In contrast, the exhausting body during the afternoon driving reduced the sympathetic activity (discussed earlier) and enhanced the parasympathetic activity (again in sync) to enter a sleepy mode.

4.6 Very low frequency [VLF(AU)]

From Tables 4 and 5, VLF (AU) increased significantly for both the Group A in the morning session and Group B in the afternoon. The physiological meaning of VLF (AU) is not defined in the 1996 Standard [23].

4.7 Sympatho-vagal balance index (LF/HF)

From Tables 4 and 5, a significant increase in LF/HF was observed in the morning session for Group A attributing to higher sympathetic activity (LF) and almost unchanged parasympathetic activity (HF). In contrast, LF/HF exhibited a decrease in the afternoon session for Group B as a result of unchanged sympathetic activity (LF) and enhanced parasympathetic activity (HF). The results show that after driving, the balance of ANS activities shifted towards the sympathetic branch for the morning session but parasympathetic branch for the afternoon session. The objective of morning ANS activities in the body was to increase cardiac output and maintain homeostasis of vital signs (such as systolic pressure) while ANS activities in the afternoon called for the body to rest. Again, our morning results on increased LF/HF are consistent with previous driving studies published by Jiao et al. [8], Li et al. [14,15,16] and Yang et al. [27] conducted in the morning. It is well known that the parasympathetic tone is dominant when the body is under a restful or sleepy state. A lower LF/HF (or a shift towards the parasympathetic branch from baseline) might be a sign that the body is fatigued. Thus, a reduction in LF/HF might be one of the candidates in terms of physiological parameter that can be employed to quantify driving fatigue.

4.8 Temperature of palm

From Tables 4 and 5, both sessions showed significant drops in palm temperatures after driving. The results clearly show that body temperature, especially one measured at extremity, is a sensitive indicator for blood circulation and homeostasis. The results also show that even with successful activation of sympathetic branch in the morning, poor blood circulation due to lower body immobilization was not fully compensated. Again, a lower body temperature might be an early sign that the body can not cope with poor circulation and it is about to be or already fatigued. Thus, a reduction in body temperature might be one of the candidates in terms of physiological parameter that can be employed to quantify driving fatigue.

4.9 Subjective questionnaire

From Tables 11 through 14, questionnaire results on driving fatigue clearly showed that 90-min continuous driving resulted in multiple symptoms of body and mental fatigue, regardless of driving hour (morning or afternoon). Statistically, there was no difference in terms of fatigue score changes due to driving between the morning and afternoon session. However, from measured physiological parameters, distinct difference was seen between the two driving session in terms of changes in systolic pressure and HRV parameters (such as LF, HF or LF/HF). While more studies are needed to provide a firm interpretation, it is a general belief that the subjective questionnaire is not as a reliable tool as the direct measurement of physiological parameters for assessment of body conditions.

4.10 Overall discussion

When defining fatigue, it is important to discuss the association between body fatigue and boredom (monotony), since one may affect or instigate the other. In our preliminary driving studies, no differentiation was made between body fatigue and boredom. We considered boredom as a special type of fatigue due to the fact that boredom is caused by a reduction of the activation level of the brain [10]. Also, our indoor driving simulation is close to driving conditions on a highway with monotonic scenes and routine vehicle maneuver. Long-hour driving under these conditions will involve both body fatigue as well as boredom, as our physiological data and questionnaire results have shown.

As driving fatigue develops, cardiovascular system is unable to fulfill the basic physiological needs. Hands and feet become cold, heart rate slows [10][14][17][21], 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) [14][27]. If re-assessment finds the body in the state of exhaustion which requires an immediate rest, parasympathetic branch in ANS is called upon (seen with Group B in this study). On the other hand, if re-assessment determines that a boost to cardiovascular system can meet the new physiological needs, sympathetic branch is activated (Group A in this study) [8][14][15][16][27]. The success of ANS action depends on several factors, including mental alertness [5][7][11][25], heart muscle strength, and peripheral circulation resistance. Immobilization of the lower body (limbs, abdomen, and hip), 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 the driving task in the study, it is unclear whether or not the sympathetic branch was activated first in the early face of driving for the afternoon session (Group B). Note 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 A conducted in the morning, the sympathetic nerve was enhanced at the end of driving [8][14][15][16][27], 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 were still below baseline [14][17].

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 some previous authors, 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 measured, parasympathetic nerve indexes [HF (AU) and HF (NU), expected to have a positive correlation with fatigue] and sympatho-vagal balance index LF/HF (expected to have a negative correlation with fatigue) are two most promising candidates that could be employed for quantitative ranking of driving fatigue.

5. CONCLUSION

Driving is a demanding task both mentally and physically. Driving fatigue remains one of the most common causes for traffic accidents. Immobilization of the lower body is thought to play a major role in driving fatigue, as it hinders blood circulation and induce hemodynamic changes. ANS activation may overcome some fatigue symptoms, but recovery is often incomplete due to immobilization. Distinct trends were found between two driving sessions in the study. In the morning session, driving caused decrease in palm temperatures and heart rate, but blood pressures were maintained by activation of the sympathetic nervous system. For the afternoon session, in sharp contrast, palm temperatures, heart rate, and systolic pressure were all lowered. Parasympathetic (rather than sympathetic) nerve was activated prompting the body to enter a sleepy state, which greatly increases driving accident risks. Monitoring of physiological parameters in the study had gained great insight into mechanisms of homeostasis and provided a foundation in the future work to quantify driving fatigue based upon deviation from homeostatic states. For the first time in literature, in the authors' belief, ANS effects was shown clearly to be related to driving fatigue, homeostasis, and traffic accident risks.

6. FUTURE RESEARCH

All the volunteers involved in the study were young college students with active ANS and a healthy cardiovascular system. Yet, significant deviation from homeostasis was observed after 90-min simulated driving. In the future work, we will recruit older and less healthy volunteers to assess body response under worsen driving fatigue conditions. We will conduct driving tests during the evening hours also. Furthermore, remedy techniques for the reduction of driving fatigue (such as exercise break, body massage, …etc.) will be evaluated. A score-based driving fatigue index is to be developed in the future work.

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模擬駕駛任務所引發的生理參數變化：早上 vs.下午時段

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摘要

簡介：駕駛疲勞是造成交通意外事故的一項很常見的原因，下半身包括腿部、臀部及腰部無法移動於駕駛疲勞中扮演一個很重要的角色，此種情況會阻礙血液循環及引發血液動力學的的改變。**目的**：本研究之目的爲探討上午及下午兩時段分別執行室內靜態駕駛模擬，並且監視生理參數的變化。**方法**：40位年輕男性受測者被分成A(上午)、B(下午)兩組來進行90分鐘的室內模擬駕駛任務，駕駛任務前後使用新型腕式生理監視器-心律大師(ANSWatch®)來量測血壓(SYS/DIA)、心搏率(HR)、心率變異(HRV)等生理參數，心律大師(ANSWatch®)是直接採用對稱於手腕處內建生物感應器(bio-sensor)而獲取橈動脈波形，另外藉由高精確度紅外線溫度量測儀來量測手掌溫度，每一位受測者於駕駛任務前後被要求填寫主觀疲勞問卷評價。**結果**：(1).由成對T檢定知：無論上午或下午時段，駕駛任務後皆會造成心搏率(HR)及手掌溫度顯著遞減、HRV及VLF(AU) 顯著遞增；對上午時段而言，駕駛後LF(AU)及LF(NU) 顯著遞增、HF(NU) 顯著遞減；反之，對下午時段而言，駕駛後LF(NU)及LF/HF顯著遞減、HF(NU) 顯著遞增($p<0.05$)。(2).由One-way及Two-way多變量分析(MANOVA)知：整體而言，駕駛任務前或後，上下午兩時段受測者生理參數沒有顯著差異，雖然駕駛任務前LF(AU)、LF(NU)及LF/HF三項參數下午時段高於上午時段($p<0.05$)。(3).由主觀疲勞問卷知：所有受測者於駕駛任務後都明顯感覺疲勞，而駕駛任務前(Score baseline)及駕駛前後變化(Score change)對兩時段都未達顯著的差異。**結論**：不同時段駕駛任務後多項生理參數之變化趨勢有所差異，從上午時段結果知，由於連續駕駛使得下半身血液循環不良，造成手掌溫度及心搏率(HR)遞減，但由於體內自律神經啓動交感，而使得LF(AU)、LF(NU)及HRV明顯遞增，因此收縮壓(SYS)得以維持恆定狀態；但到了下午時段，手掌溫度、心搏率(HR)及收縮壓(SYS)皆明顯遞減，此刻體內啓動副交感(HF(NU)明顯遞增)而促使身體進入昏睡狀態，此狀況在實際的道路駕駛中會增加意外的風險，本研究藉由多重生理參數的監控可了解身體維持恆定的程度，並在未來將偏離恆定狀態的程度定量爲駕駛疲勞或昏睡指標之一。

關鍵詞：駕駛疲勞，心率變異，恆定，自律神經系統，血壓，模擬駕駛，ANSWatch
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