

Physiological Status Assessment of Locomotive Engineer During Train Operation

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Abstract – In this study, physiological status of locomotive engineers were measured through EEG, ECG, EDA, PPG and respiration signals from 6 subjects to evaluate their arousal status during train operating. Existence of tunnels and mechanical vibration of train using 3-axes acceleration sensors were recorded simultaneously and were correlated with operator's physiological status. As the result of the analyzed subjects' physiological signals, mean SCR was increased in the section where more body movement is required. The RR interval was decreased before and after train stop due to the higher level of mental tension. The intensity of beta wave of EEG was found to be higher before and after train stop and tunnel section due to the increased mental arousal and tension. Therefore, it is expected that the outcomes of the physiological signals explored in this study can be utilized as the quantitative assessment methods for the arousal status to be used for sleepiness prevention system for vehicles operators which can greatly contribute to public transportation system safety.

Keywords: Arousal status, Emotion status, Locomotive engineer, Physiological signal, Sleepiness prevention system

1. Introduction

Statistics in 2005 shows that carelessness caused more than 60% of vehicle related accidents in Korea. According to Japan statistics in 1998, 89% of car crash accidents were related to the mistakes of the drivers [1]. Particularly, for the last 10 years, 90% of 740 reported accident cases in Korean railroad worker were caused by their carelessness [2]. There has been active research for riding quality for passengers and car driver's sleepiness and arousal [1, 2]. However, there has been less attention to mental or physical status of locomotive engineer and it is also limited to the simulated environment [3].

Comparing the condition of train operation with car driving, the decrease of arousal is more often observed from the train operation than passenger car driving due to the simplicity of visual stimuli. Also, the sealed operating space causes the sleepiness phenomenon due to the lack of oxygen concentration and increased carbon dioxide in the air. Specially, the shortage of the oxygen induces earlier exhaustion of driver and affects brain function in consequence dwindle the attention, memory and making decision [4]. The decline of arousal causes the judgment

decline. Therefore, the risk of human error increases. Recently, human error has brought a great attention in the field of Human Engineering and Safety Engineering. Human errors mean the mistakes of the man who operates something. There are misconception, illusion, assumption carelessness, etc. In the case of train, minor error can be developed to a catastrophic accident. Therefore, various countermeasures have been considered to reduce the human error in the advanced countries [5].

Examples of physiological signals which reflect the arousal status are electrodermal activity (EDA) and skin temperature. Compared to the rest time, heart rate variability (HRV) and the beta component of electro-encephalogram (EEG) increases under stressed state when mental work-load is high [6, 9-12]. EDA is to measure sweating condition. It generally increases under tension or arousal status and it approaches to near 0 values during sleeping which the arousal level declines absolutely. Also, it reflects the body reaction against external stimuli while its value increases or decreases depending on the body movement [2, 8]. The state of excitement or relaxation can be speculated from the depth and interval of breathing pattern. Vasoconstriction from photoplethysmogram (PPG), also reveals the activity of autonomic nervous system instead of ECG. HRV can reflect tension and stress. The signals which reflect mental work-load are EEG and electrocardiogram (ECG).

In this study, we measured physiological signal from 6 locomotive engineers to evaluate their arousal status during train operation. While measuring signals of the central

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nervous system (4Ch EEG) and autonomic nervous system (ECG, EDA, PPG and respiration), the 3-axes acceleration were measured simultaneously to correlate the vibration of train to measured physiological signal. Also, existence of tunnels was recorded by ON/OFF switch when train passed through tunnel while train operation. As we analyzed and evaluated the changes of engineer’s physiological signal during train operation, the attempt has been made to clearly define the physiological signal which sensitively responds against the change of environment. Furthermore, it is expected that the quantified physiological status will be very useful for establishing safety operation system like alarm system for sleep prevention.

2. Methods

The experiment had been done in the engine room of Nuriro-ho with the collaboration of Korean National Railroad during September to October in 2011 in real operation environment. The physiological signals were acquired from the same engineer during round trip, one in the morning and the other trip in the afternoon. The six healthy subjects (avr. 43.5 yrs) who have no chronic, internal and psychiatric disease participated in this study.

2.1 Experimental protocol

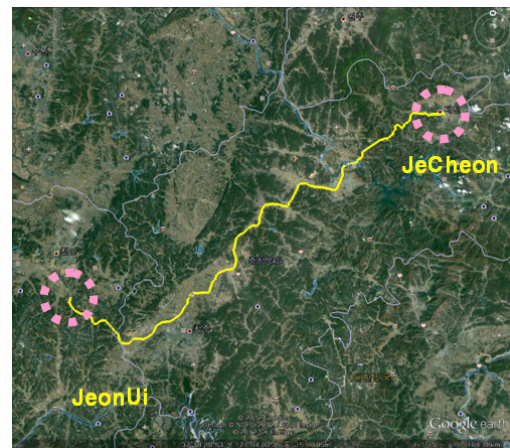
The questionnaire survey had been done two times before and after signal measurement. The basic information (age, height, weight) and general health condition (sleeping hours, checking deep sleep, drinking alcohol and smoking, blood pressure, chronic disease, etc.) were collected prior to the experiment. To compare the body conditions before and after experiment, the levels of fatigue (visual, general), concentration (difficulty concentrating, sleepiness) and uncomfortableness of wearing sensor (back pain, stiffness, spasticity, etc.) were estimated in 10 points scale. Reference signal was measured 3 times (before starting up-line and down-line and after arrival down-line) for 10

Table 1. Experiment protocol

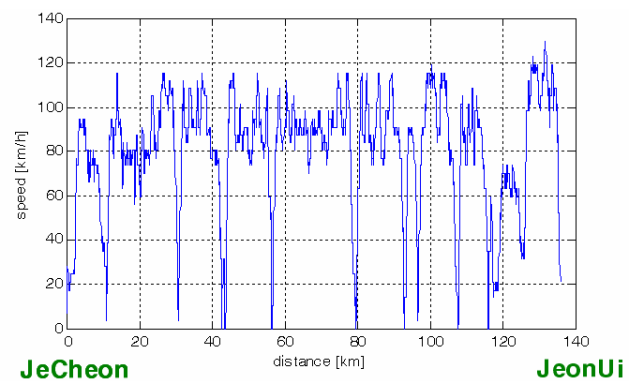
Time	details of experiment	memo
08:00	- Arriving JeCheon, - Setting up experiment	
08:30	- Measuring reference signals	- 10 minutes
09:00	- Leaving JeCheon station	- measuring signals - questionnaire
~		
10:46	- Arriving JeonUi station	
10:55	- clear up equipment - Arriving CheonAn	
	- Take a rest	
18:00	- measuring reference signal	- 10 minutes (except EEG)
19:11	- Leaving CheonAn station - Setting up experiment	
19:23	- JeonUi station	- measuring signals - questionnaire
~		
21:05	- Arriving JeCheon station	
	- Measuring reference signals	- 10 minutes

minutes. And the signals, train movement and tunnel existence had been recorded for each 1 hour and 40 minutes in up and down operating section (Table 1).

The reference data as the arousal status was measured for 10 minutes in stable state from the engineer before and after operating train and the body condition was checked through questionnaire. Fig. 1 shows the train operation route and the rate of train movement graph. The signals were measured for 1 hour and 40 minutes of operating train during the round trip between JeCheon station and JeonUi station of ChungBuk line (Nuriro-ho). The measurement had been done in the following section and schedule,



(a) movement route map



(b) rate of train movement graph (distance : 132.5 km, moving time : 1hr 45min, average speed : 73.47 km/h, maximum speed : 128.18km/h)

Fig. 1. The train operation route map and the rate of train movement graph for up line (from JeCheon station to JeonUi station in the morning)

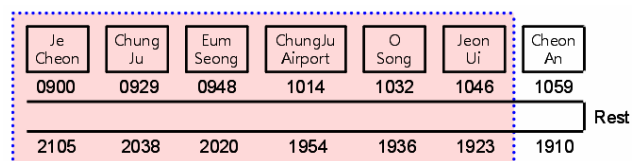


Fig. 2. The section of measuring signals (blue dotted line)

starting from Jecheon station to JeonUi station in the morning, starting JeonUi station to Jecheon station in the afternoon. (yellow line on the route map in Fig. 1 (a) or blue dotted line section in Fig. 2)

2.2 Data acquisition

For this experiment, uninterruptible power supply (UPS) was set for neutral section and 3-axes acceleration sensor was set for checking of train movement according to heading direction. The red switch beside the acceleration sensor was in ON/OFF state to check the existence of the tunnels (Fig. 3). After setting sampling frequency 1 kHz, the physiological signals, 3axes accelerator and tunnel existence were measured simultaneously by MP150 (BIOPAC Inc., USA) and AcqKnowledge ver.4.1 (BIOPAC Inc., USA).

EDA and PPG sensor were attached on the left hand to allow right hand holding the lever for train operation. The belt-type respiration sensor was attached on the midpoint between waist and chest. ECG sensor was attached on the chest with Lead II electrode configuration. EEG signal was checked from 4 sensors (Fp1, Fp2, F7 and F8) in cap type electrodes (Fig. 4).

Fig. 5 shows the measured signals for 20 seconds. Total 12 channels were measured simultaneously.

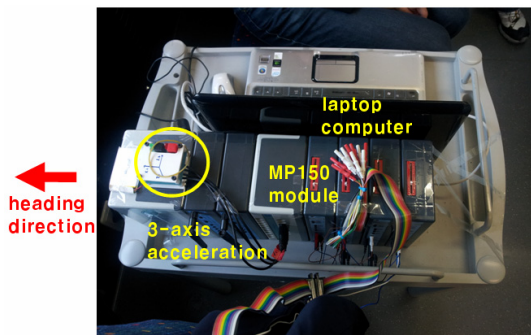


Fig. 3. Equipment for measuring signals

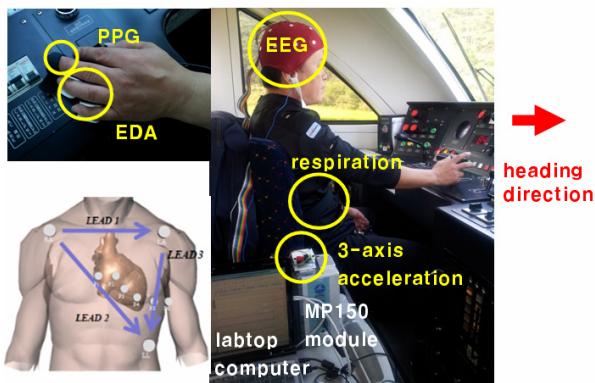


Fig. 4. An engineer who is operating train with sensor modules and the regions which are attached sensors for measuring signals.

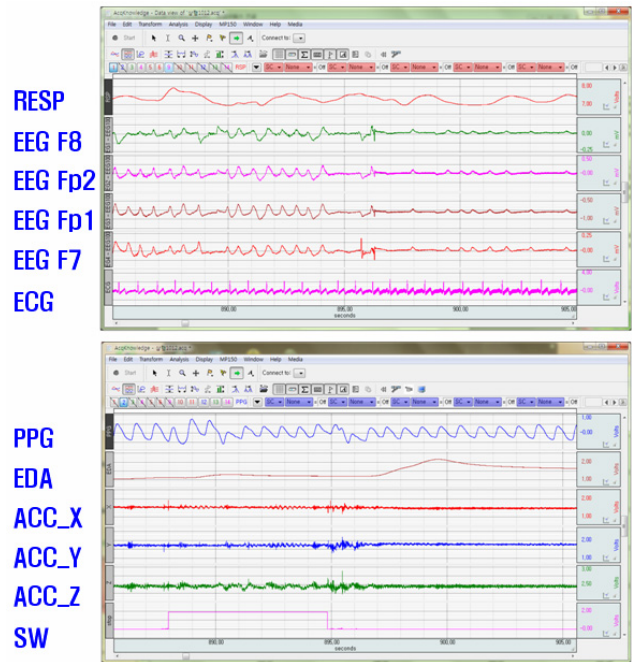


Fig. 5. Measured signals with MP150 module and Acq Knowledge ver. 4.1 during 20 sec. (RESP : respiration, ACC : acceleration, SW : ON/OFF switch)

2.3 Data analyzing

In this study, total 6 engineers participated in the experiment for measuring physiological signal while they were operating train. However, data from only 4 subjects' were collected and excluded 2 inappropriate cases. With analyzing ECG, EDA and EEG among the physiological signals, the engineer's arousal status was evaluated [8, 11-15].

3-axes accelerator data (a_x, a_y, a_z) were transformed into signal vector magnitude(SVM) [17] at each of 0.5 second. SVM is presented as

$$SVM = \sqrt{a_x^2 + a_y^2 + a_z^2} \quad (1)$$

EEG was found as a percentage at the band of frequency in the 30 seconds analyzing section. The analysis section of the autonomic nervous system signal was done with 4 minutes data, the parameters were extracted with shifting at each of 1 minute (Fig. 6) (MATLAB 2010a, The MathWorks, Inc., USA).

2.3.1 EEG Parameters

EEG is the electrical signal of the cerebral cortex activity. Though it contains high level of noise, it is the essential signal to interpret the basic function of brain. EEG shows a vibrating wave form with complicated pattern. Therefore, instead of visual inspection of EEG wave forms, power

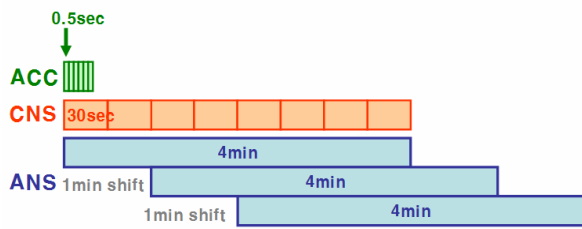


Fig. 6. Analysis section of each measured signals (ACC : acceleration, CNS : central nervous system, ANS : autonomic nervous system)

spectrum analysis was applied which assorted EEG with frequency. Early study analyzed EEG with low alpha, middle alpha and high alpha which were more subdivided by frequency range. However, generally EEG is assorted with delta wave (0.5~4Hz), theta wave (4~8Hz), beta wave (13~30Hz) and gamma wave (30~50Hz) by frequency range [14, 18].

The delta wave is clearly appeared in newborn babies, deep sleeping and coma. So, the delta wave was excluded in this study because its frequency range almost coincides with the noise from blinking and body movement. The theta wave is related with memory, creativity, concentration and ataraxia, etc. The alpha wave appears in comfortable and stable state such as relaxation, also its amplitude increases more in the comfortable state. The alpha wave restrained in a mentally excited state. The beta wave mostly appears in forehead. It is the component which appears in self-conscious activity (while speaking or staying awake) and increases at anxiety state, tension and complicated calculation. The gamma wave is related with advanced recognition information processing as like inference, judgment, etc.

In this study, frequency component ratio was found in F7 or F8 which had relatively small noise. The number of blink was extracted from Fp1 or Fp2.

2.3.2 HRV Parameters

Autonomic nervous system has a roll to keep the internal balance against the internal and external environment change. It directly influence in keeping the homeostasis and the life. Generally, there are sympathetic and parasympathetic nervous systems in the same organ. As they have antagonism, the balance of body can be maintained. Especially the cardiovascular system among the organs ruled by autonomic nervous system is very important and complicated. HRV is a method to judge the existence of disease with observing the periodic change rate of heart beat[8]-[10]. The change of RRI (RR intervals) which is influenced with the emotion, body temperature, position, illumination, autonomic dysfunction, cardiovascular disease, neuropathy, stress and aging, etc., is continuously changed. The ergonomist have attempted to identify the state of related disease through observing the

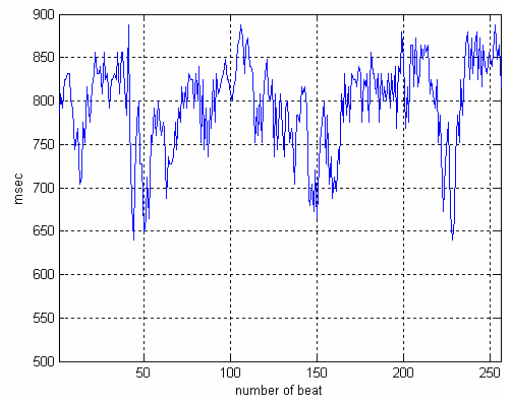


Fig. 7. RRI tachogram (mean RRI=791ms)

Table 2. HRV parameters extracted from engineers during train operation.

Time domain	Statistical parameters	mean RRI[ms], mean BPM[1/min], SDNN[ms], RMSSD[ms], NN50[count], pNN50[%]
	Geometric parameters	SD1, SD2, CSI, CVI
Frequency domain	Spectral analysis	normalized LF(0.04-0.15Hz), normalized HF (0.15-0.4Hz), LF/HF ratio

changes of RRI. So, the standard of HRV measuring method, physiological analysis and clinical use were established in 1996 by the European Society of Cardiology and the North American Society of Pacing and Electrophysiology [8].

Fig. 7 shows tachogram which is the temporal change of RRI series detected from ECG signal. The changing range of RRI is wide in normal case to cope with the external environment stimuli. On the contrary, it is very narrow in the case of autonomic imbalance or cardiovascular abnormality.

Table 2 shows HRV parameters which are extracted from subjects in this study [8, 11]. The parameter which reflects HRV is divided into time domain and frequency domain.

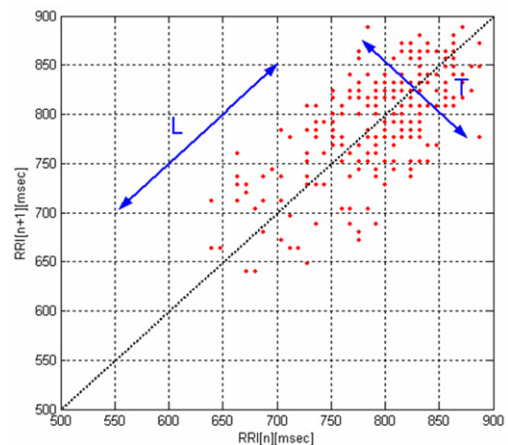


Fig. 8. Lorentz plot (normal subject)

In time domain, mean RRI, standard deviation and the gap which is more than 50msec with adjacent RRI were recorded. Lorenz plot (or Poincare plot) [11, 19], which RRI[n] is indicated in horizontal axis and RRI[n+1] is indicated in vertical axis. It provides with both sympathetic and parasympathetic indices. L represents the length of the longitudinal axis and T is that of the transverse axis in Lorentz plot. SD1 and SD2 are calculated to four times the standard deviation of the distribution along each axis. SD1 reflects long period component and SD2 shows short period component. SD1/SD2 means the index of sympathetic nervous system activity, CSI and $\log_{10}(SD1 \times SD2)$ means the index of parasympathetic nervous system activity, CVI. Each of these is geometric parameter which reflects sympathetic or parasympathetic nervous system activity. In frequency domain, the particular cycle of wave through spectral analysis was analyzed.

LF and HF component are 0.04~0.15 and 0.15-0.4Hz frequency range in power spectrum. It is believed that LF shows quantitatively sympathetic nervous system activities or it reflects both of sympathetic and parasympathetic nervous system activities[16]. HF component reflects parasympathetic nervous system activities. HF/LF means normalized ratio of the LF and HF component. It also shows parasympathetic nervous system balance which reflects the sympathetic nervous system.

FFT and AR power spectral estimation have been widely used for evaluating the activities of autonomic nervous system from ECG. But the RRI extracted from ECG was not evenly sampled data. So, the spectral analysis such as

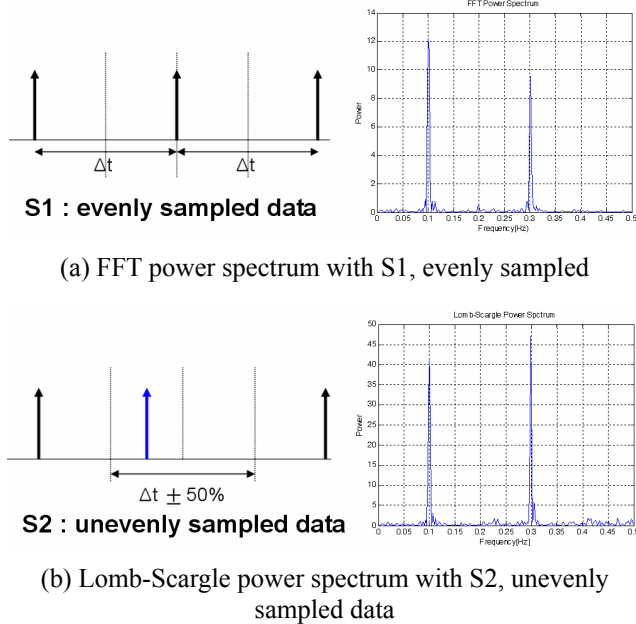


Fig. 9. (a) The result of FFT power spectrum after evenly resampled data; (b) The result of Lomb-Scargle power spectrum after unevenly resampled data. The data is the sum of random noise and two sine waves which have different cycle.

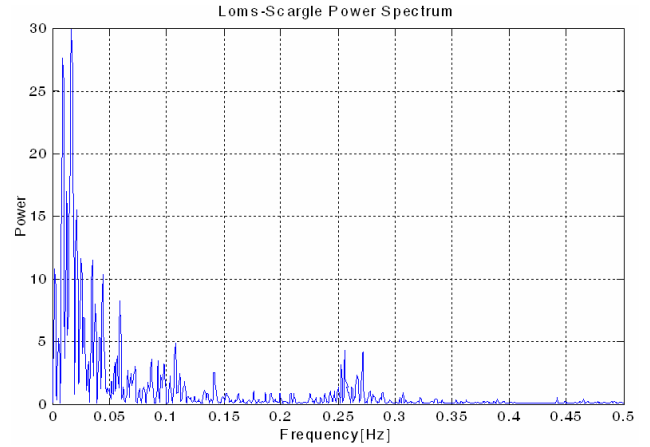


Fig. 10. The Lomb-Scargle Power Spectrum with RRI which is unequally spaced.

interpolation and resampling had been applied after preprocessing. However, in this process, it could be happened that the component of low frequency increased and the component of high frequency decreased. In this study, the spectrum can be directly calculated from RRI by the Lomb-Scargle method [20, 21] without preprocessing.

Fig. 9 shows FFT power spectrum with evenly sampled data and Lomb-Scargle power spectrum with unevenly sampled data which add random noise and two different cycle sine waves. At the point of 0.1Hz and 0.3Hz in FFT and Lomb-Scargle power spectrum, peak appears coincidentally. Fig. 10 shows Lomb-Scargle power spectrum with RRI.

Suppose that there are N data points $[(t_i, y_i), i = 1, 2, \dots, N]$. Lomb-Scargle normalized periodogram $P_N(\omega)$ is defined by

$$P_N(\omega) = \frac{1}{2\sigma_y^2} \left\{ \frac{\left[\sum_i y \cos \omega(t^i - \tau) \right]^2}{\sum_i \cos^2 \omega(t^i - \tau)} + \frac{\left[\sum_i y \sin \omega(t^i - \tau) \right]^2}{\sum_i \sin^2 \omega(t^i - \tau)} \right\} \quad (2)$$

Here mean \bar{y} , variance σ_y^2 and τ are defined by the relation

$$\bar{y} = \frac{1}{N} \sum_{i=1}^N y_i, \quad \sigma_y^2 = \frac{1}{N-1} \sum_{i=1}^N (y_i - \bar{y})^2 \quad (y_i = \frac{y_i - \bar{y}}{\bar{y}}) \quad (3)$$

$$\tau = \frac{1}{2\omega} \arctan \left(\frac{\sum_i \sin 2\omega t_i}{\sum_i \cos 2\omega t_i} \right) \quad (4)$$

2.3.3 EDA Parameters

EDA is to measure increasing skin conductivity while perspiring, and it is used for the useful index to evaluate

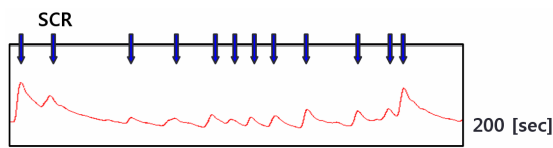


Fig. 11. The EDA with SCR occurrence

psychological work-load, stress and arousal. The EDA signal increases or decreases according to the degree of movement. The arousal level can be measured with it. When work-load increases, also EDA increases because the activity of sweat glands is getting vigorous.

With analyzing the average level, peak size, number of peak and the reaching time to peak in certain section, we can find the frequency of load occurrence and the size of work-load (Fig. 11). In this study, we extracted the average level of EDA (mean EDA), the number of SCR (skin conductance response) appearance (NSCR), average SCR level (mean SCR) and SCR rising time up to maximal peak (rTime) as parameters after 100Hz down sampling.

3. Results

Fig. 12 shows the vibration condition of train operation, tunnel existence, engineer's EEG parameter change and the

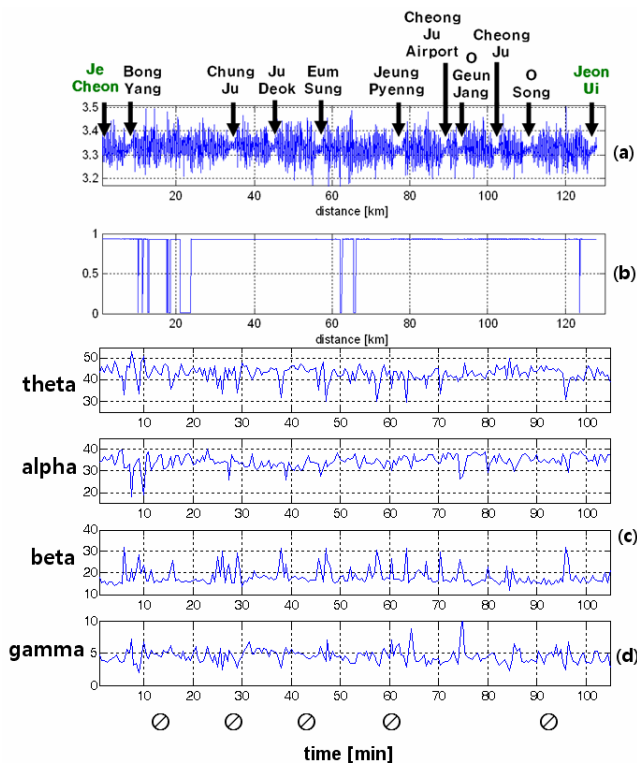


Fig. 12. The changes of engineer's EEG parameters in time sequence during the train operation : (a) SVM of 3-axes acceleration data, (b) tunnel existence data, (c) EEG parameters, (d) \circ marker, neutral section.

time fluctuation of neutral section information. First Fig shows the vector sum of 3-axes accelerator in the data of up train section (JeCheon to JeonUi station). It can be known that the vibration of train is getting down in the station section. Fig. 12 (b) shows the existence of tunnels with ON/OFF switch. When train was in the tunnel, OFF switch was turned on. The beta wave in the components of EEG frequency is rapidly increasing when train start from train stop and tunnel section. It is the most important factor to reflect the effect of environment change during train operation.

As the result of physiological signal analysis, beta wave among several frequency components of EEG rapidly increased at the starting point of stop station. The increasing tendency of beta wave component over vigorous tension or brain activity means that arousal also increases because of focusing on control handle for train operation (speed control) at the starting point of stop station. As the sudden luminance change of environment happens as coming out from the tunnel, it has an effect to the arousal status. The results are reflected in EEG. The number of blinking was extracted from Fp1 or Fp2, and there was no effect of operation condition and environment change. This means that the train operation is monotonous work with no big stimuli, and there was no visual fatigue in a short time. There was no increasing of the engineer's tiredness after operation in the questionnaire results of before and after experiment.

Fig. 13 shows engineer's EDA parameter on operating train. There was no specific response against environment

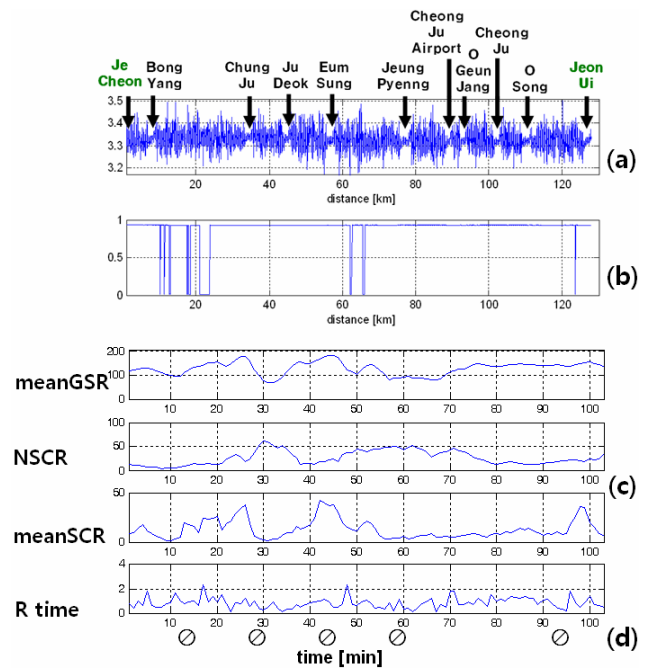


Fig. 13. The change of engineer's EDA parameters in time sequence during the train operation : (a) SVM of 3-axes acceleration data, (b) tunnel existence data, (c) EDA parameters, (d) \circ marker, neutral section

changes (vibration condition, entry and starting of stop section) There are correlation between neutral section and size of SCR.

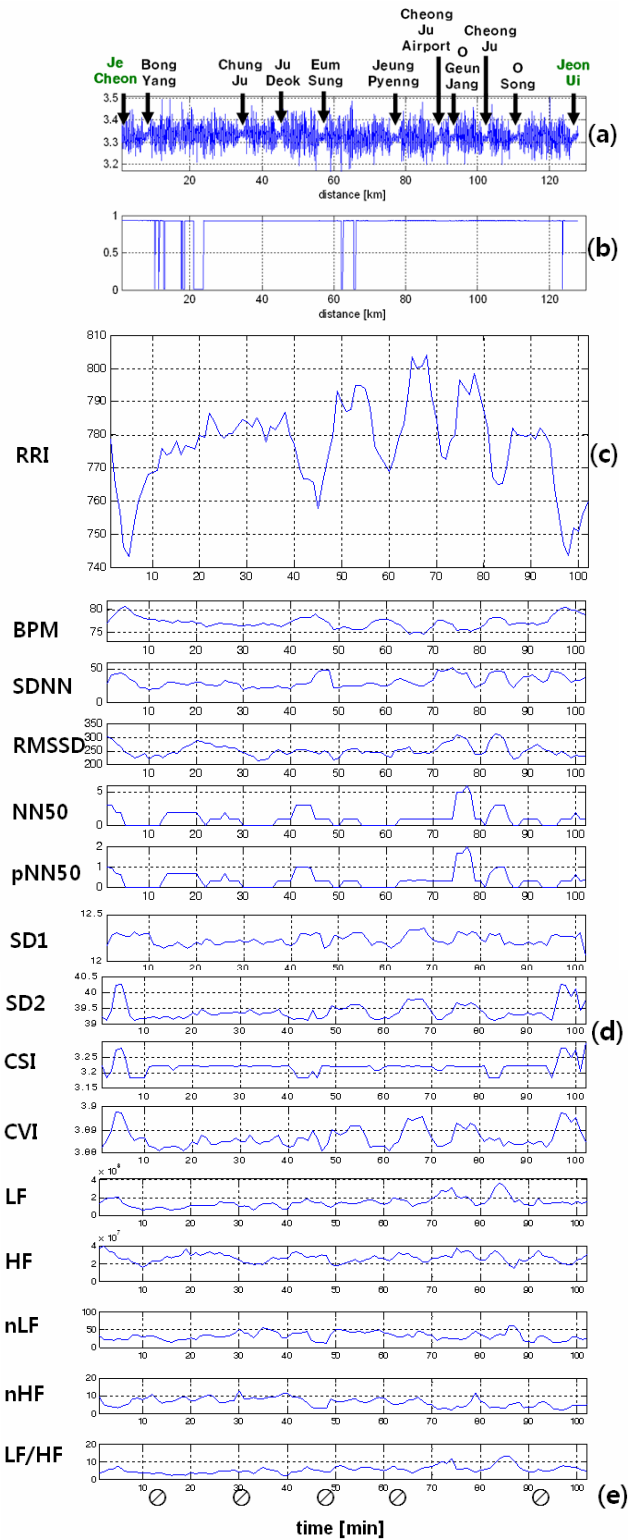


Fig. 14. The changes of engineer's HRV parameters in time sequence during the train operation : (a) SVM of 3-axes acceleration data, (b) tunnel existence data, (3) HRV parameters, (d) ⊗ marker, neutral section

Among the several parameters of EDA, there was similar tendency in the average EDA level and the size of SCR. Especially, SCR had strong response to the body movement. In the neutral section, i.e. the section which needed more button control (the engineer must control specific button in neutral section), SCR had strong increasing tendency. Though there were some report which the occurrence frequency of SCR is related with fright and arousal frequency [7], we couldn't find the correlation with arousal frequency.

The temporal change of HRV parameter was observed with extracting RR interval from ECG. RR interval had increasing tendency all over the operating time (Fig. 14). This means that heart beat is getting slow because the tension was getting reduced as time passes. However, RR interval was rapidly shortened in the stop station. Its reason is that the stop work needs strong tension to reduce speed gradually for stopping exact location while train enters in stop station. HRV affected by the directly-opposed action of autonomic nervous system (i.e. sympathetic or parasympathetic nervous system). As number of heart beat increased in the state of psychological work-load, stress and tension, RRI reduced.

In the correlation coefficient between RR interval and the rest of HRV parameters (Table 3), higher than 0.6 absolute values were shown at the rest except SD2, CSI, CVI, normalized LF and LF/HF ratio in up train and at the rest except normalized LF in down train. Also there is relation($r=0.684$) between RRI and NSCR in down train. EDA signal reflects much more activities of ANS because of little information through eyes at night time. It means that there are a lot of visual stimuli in day time. (SPSS ver.12, SPSS Inc., USA)

There were many cases of using simulator to avoid the risk of experiment in car and especially in train. Though it is useful for offering same condition with no risk, there might be the difference in the result since it is not real situation. Test equipment setting had been done before operation in order to avoid engineer's inconvenience for train operation. Even through we couldn't insist definite results using the data of only 4 locomotive engineers, but we got the positive result in spite of operation condition

Table 3. Correlation coefficient between RRI and the rest of parameters in ECG and EDA (n=4)

HRV	BPM	SDNN	RMSSD	NN50	pNN50
up line	-0.998**	0.646**	0.773**	0.747**	0.765**
down line	-0.999**	0.843**	0.905**	0.841**	0.856**
HRV	SD1	SD2	CSI	CVI	
up line	0.622*	0.469**	0.237**	0.578**	
down line	0.838**	0.771**	-0.894**	0.867**	
HRV	LF	HF	nLF	nHF	LFHF ratio
up line	0.607**	0.789**	0.05	0.538**	-0.467**
down line	0.800**	0.929**	0.186**	0.701**	-0.627**
EDA	mean EDA	NSCR	mean SCR	rTime	
up line	-0.223**	-0.249**	0.056	0.102*	
down line	0.172**	-0.683**	0.287**	0.024	

(** : $p < 0.01$, * : $p < 0.05$, nLF : normalized LF, nHF : normalized HF)

change. If we increase number of subjects, we expect more objective results.

As the result of the analyzed subjects' physiological signal, the parameters of EDA, ECG and EEG show the high correlation with the arousal and tension. It was qualitatively verified that SCR, EDA parameters in this experiment had relations with the increase of the body movement. The tendency of increasing rTime in tunnel section was due to the changes of arousal status by visual environment changes.

In this experiment, EDA and EEG showed correlation with the arousal level which was due to the visual stimuli by tunnel luminance change. The ECG reflected the tension caused by entering and starting from station. Generally, when the sympathetic nervous system of autonomic nervous system was activated, arousal status was shown with tension.

4. Discussion

In this study, the physiological signals of the central nervous system and autonomic nervous system were measured and analyzed to evaluate the arousal and tension condition of locomotive engineers while they were operating train. Also the information of train operating condition, the tunnels existence, the changes of train vibration and illumination intensity appearance were recorded at the same time.

This experiment is to consider time gap in the measured signals because the information of neutral section, tunnel existence were input by manual. This could be compensated by recording the luminance information with using illuminometer and to attach additional acceleration sensor for observing engineer's movement in neutral section. It is also necessary to develop and use non-restricted and non-aware system for measuring physiological signals in ordinary situation.

In the case of measuring car driver's psychological and physiological status, the driver's arousal status increased with speed increase. But during the train operation with high speed, the decrease of attention was easily observed because of the monotony of visual stimuli, simple driving course and easy operation[3]. It is necessary to develop characterized safety train operation system because of those differences.

Therefore, if this analyzed result is applied to the sleepiness prevention caution system as the quantitative assessment of arousal, it will be useful for the public transportation safety.

Acknowledgements

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