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Estimate of Knowledge and Experience Level by Autonomic Nerve Activity During Task Execution, and Follow Up Effect of Education

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Abstract: Simulated experiments of a nuclear power plant emergency operation were conducted with three groups of subjects, separated by knowledge and experience level in plant operation: Level 1 (beginners), Level 2 (intermediate class) and Level 3 (experts). Autonomic nervous systems activity (ANS) was measured during the simulation. The level 2 and 3 groups showed high sympathetic nervous system activity (SNS), and very low parasympathetic nervous system activity (PSNS) during the simulation. In contrast, the Level 1 group showed a high PSNS and a low SNS, indicating that operator lack of knowledge and experience in plant operation can be detected by measuring ANS during operation. Furthermore, after educating the Level 1 group and repeating the simulation, measured ANS values changed, becoming similar to those of the Level 2 and Level 3 subjects.

Key Words: nuclear power plant, emergency operation, knowledge level, autonomic nervous systems activity, effect of education

1. Introduction

Task execution accompanied by certain necessary judgments is pervasive throughout modern society. Examples include personal computer operation at home, private vehicle operation, airline operation of large aircraft, and operation of a factory or plant. Successful task execution demands knowledge and experience about the task, as well as the ability to utilize that knowledge and experience. Therefore, a variety of educational and training exercises are performed, and a final qualification examination by paper test and/or a skills test is given. However, at present there is no acceptable method of checking whether a person actually possesses sufficient knowledge and experience for task execution. Hence, an incorrect positive judgment of a person through paper examination and/or skills test may ultimately lead to an accident.

Shirouzu et al.1), measured the autonomic nervous system activity of a high school student and several university students taking school examinations, and found that it is possible to distinguish between attending an examination with sufficient knowledge, answering smoothly and getting high score, and attending without sufficient knowledge and receiving only a low score, by the behavior of autonomic nervous system

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activity. For the former, the subject can concentrate on the examination, allowing sympathetic nervous system activity to increase and parasympathetic nervous system activity to decrease. For the latter case, however the subject is unable to do anything to make his mental state similar to that found at rest, or while asleep. Para-sympathetic nervous systems activity increases and sympathetic nervous systems activity decreases. Using these findings, it may be possible to distinguish whether a subject has sufficient knowledge and experience for current task execution by contemporaneous measurement of his autonomic nervous system activity.

In safety critical military facilities, oil and chemical plants, and nuclear power plants (NPPs), human error due to inappropriate operator performance can be critical since it may lead serious problems[2)]. The bottom line for reducing human error is to give operators sufficient knowledge and experience to perform their duties. The aim of this study is to ascertain whether we can determine the level of knowledge and experience of a human operator by measuring the operator's autonomic nervous systems activity during the operation.

Simulated experiments of a nuclear power plant emergency operation were conducted with three groups of subjects, separated by knowledge and experience level in plant operation: Level 1 (beginners), Level 2 (intermediate class) and Level 3 (experts)[2)]. Autonomic nervous systems activity (ANS) was measured during the simulation[2)].

The level 2 and 3 groups showed high sympathetic nervous system activity (SNS), and very low parasympathetic nervous system activity (PSNS) during the simulation. In contrast, the Level 1 group showed a high PSNS and a low SNS, indicating that operator lack of knowledge and experience in plant operation can be detected by measuring ANS during operation. Further, after educating the Level 1 group and repeating the simulation, measured ANS values changed, becoming similar to those of the Level 2 and Level 3 subjects.

2. Experiments

2-1 Subjects

Experiments were performed using nineteen graduate students majoring in nuclear engineering at Korea Advanced Institute of Science and Technology (KAIST) in the Republic of Korea and Khalifa University of Science, Technology and Research (KUSTAR) in the United Arab Emirates[2)]. The subjects comprised 10 males and 9 females from 21 to 34 years of age. The subjects were divided into three groups, Level 1 (beginners, 11 subjects) ; Level 2 (intermediate class, 5 subjects) ; and Level 3 (experts, 3 subjects) based on their knowledge of plant operations[2)].

2-2 Simulation of Nuclear Power Plant Emergency Operation[2)]

The nuclear power plant simulation experiments were designed to mimic the main control room in a nuclear power plant using a compact nuclear simulator. The test subjects were asked to follow the tasks described in the emergency operating procedures manual.

Before starting the experiments, the subjects were trained for two hours to acclimatize them to operating the plant simulator and to emergency operation procedures (EOPs) for the given accident. After training, each subject was asked to follow the EOPs to mitigate the accident acting as a reactor operator (RO) in

Table 1 List of Subjects

No	Affiliation	Age	Sex	Knowledge Level
1	KAIST	27	F	3
2	KAIST	24	F	1
3	KAIST	34	M	2
4	KAIST	25	F	3
5	KAIST	29	M	3
6	KAIST	21	M	1
7	KAIST	25	M	1
8	KAIST	27	M	1
9	KAIST	28	F	2
10	KAIST	33	M	2
11	KAIST	29	M	2
12	KAIST	28	M	1
13	KAIST	23	M	1
14	KUSTAR	24	F	1
15	KUSTAR	26	F	1
16	KUSTAR	25	F	1
17	KUSTAR	26	F	1
18	KUSTAR	27	F	1
19	KUSTAR	32	M	2

charge of the primary loop control in the nuclear plant. In conducting the experiment, instructors took on roles of other operators, including a supervisory reactor operator, an electrical operator, and a turbine operator. The time required for each unit task and the timing of errors were each recorded.

A steam generator tube rupture (SGTR) scenario was selected as the nuclear simulator malfunction. On the primary side of the plant the event unfolds like a small break, loss of coolant accident until the primary pressure drops down to the level of the secondary pressure.

After rupture, the flow in the break is controlled by small pressure differences between the primary and the secondary sides. In the broken stream generator the secondary water level rises, slowly filling the secondary side. The operator is expected to isolate the broken steam generator and reduce the primary injection. In this situation, the operator should follow a set of predefined procedures defined in the EOPs. The operator is not allowed to make an independent decision.

2-3 Measurement of Autonomic Nervous System Activity

Contraction of the heart takes place because electrical excitation generated by the sinus node spreads to the whole cardiac muscle from the outside of the heart. ECG measurements detect the electrical excitation of the heart as a voltage between two electrodes attached on the surface of the human body. Just before cardiac muscle contraction, when electrical excitation spreads across the entire cardiac muscle, the voltage level of ECG reaches a maximum. This peak is called the R wave.

Normally, the timing of the electrical excitation of the sinus node happens regularly at the same interval, like a metronome. However, fluctuations in the timing of electric excitation may occur due to the influence of the sympathetic nervous system and the vagus (para-sympathetic) nervous system, which govern the heart. Activity of the sympathetic and parasympathetic nerves can therefore be determined by detecting and analyzing fluctuations in electrical excitation timing.

During the simulation experiments, ECG signals were measured using a small, lightweight ECG data logger (M-BIT) for all subjects[3,4]. Electrode placement for ECG measurements made using M-BIT involves a monitoring lead, which is similar to a II lead. A body ground is unnecessary due to improvements in electronic circuit design. M-BIT is small and lightweight, allowing it to adhere to a subject's thorax using two electrodes. A good quality ECG signal can be acquired by attaching MBIT near the position of a subject's heart.

Details of the M-BIT ECG data logger are publicly available[3]. The M-BIT includes an ECG measuring circuit, an accelerometer, a temperature sensor, 32 M-bytes of memory, a USB connection plug, snap fasteners for electrode, and a coin battery. M-BIT allows for 24 hour measurement, data storage to memory, and USB communication in standalone configurations, all packed into a compact size measuring 40 × 39 × 8 mm with a weight of 14 g. The ECG sampling frequency is 128 Hz.

We measured time locations of the R wave on the ECG signal based on a robust real time QRS detection algorithm currently in broad use worldwide[3]. In this algorithm, ECG signals undergo band pass filtering using a frequency band of 5 to 11 Hz, where most components of QRS peaks exit, and are then differentiated. Absolute values are determined and averaged over an 80 millisecond window, resulting in conversion to hill like waveforms. The R wave is located at points where the waveform exceeds a certain defined threshold level.

According to earlier study, it has been assumed that the T wave always becomes shorter hill than the QRS complex and can be removed[3]. However, young subjects from kindergarteners to people in their early 20's frequently show ECG waves with a large T wave, and detection of the R wave is sometimes difficult. To obtain an exact time location for the R peak even when T wave is very large, we improved the QRS peak detection algorithm.

Normal analysis may be implemented by performing frequency analysis of R-R interval time series data that comprise the amount of time between successive R waves, and then calculate high frequency (HF, 0.15Hz-0.40Hz) and low frequency (LF, 0.04Hz-0.15Hz) components as the area below the spectrum of these frequency bands. Para-sympathetic and sympathetic nervous system activity can then be taken as HF and LF/HF, respectively.

Inferior quality ECG signal areas due to body movement or deterioration of contact between the skin surface and electrode, or the superimposition of power line alternating-current noise, however, may generate a fake RR interval and affect the results of the RR interval frequency analysis. We have been classifying and removing false RR intervals by considering the distribution behavior of the RR intervals[3,4]. Furthermore, we perform synchronous inspections of RR intervals and ECG signals for suspicious time regions, and reject all analyze results for regions where unreliable RR intervals may exist.

The origin of high frequency components of RR interval variability is respiratory sinus arrhythmia (RSA). Since changes to the RR interval are caused by the mechanism whereby the activity of the para-sympathetic nervous system is intercepted during inspiration, and only works during expiration, the frequency of the RR interval is a respiratory frequency. Many of the early stage studies of RSA also utilize synchronous respiratory measurement[5]. Novak et al.[6,7] demonstrated that the time frequency MAPs of RR intervals and respiration measured synchronously are remarkably similar.

Since RR intervals form an unequal interval time series, to the data must be converted to an equal interval time series for frequency analysis. How to convert the data determines the upper limit frequency used for frequency analysis. Jasson et al.[8] resampled RR interval time series using a re-sampling frequency of 2 Hz, and performed time frequency analysis up to a level of 1 Hz. They calculated instantaneous central frequencies[9] of high frequency bands, low frequency bands, and the entire frequency region, and indicated that the instantaneous central frequency of high frequency bands corresponds to respiration frequency. On the other hand, Bailón et al.[10] proposed that a re-sampling frequency of 5Hz and frequency analysis up through the frequency of the average heart rate is necessary when considering respiration.

We based our analysis on Bailon et al.[10] Since the half frequency of a heart rate of 180 bpm (assumed as the maximum daily heart rate of common people) is 1.5Hz (upper limit for analysis), and therefore used a re-sampling frequency of 4 Hz. We set analysis time unit to 1 minute, and for each minute we performed a time frequency analysis of RR intervals using the SPWV (Smoothed Pseudo Wigner-Ville) method, obtaining time frequency MAPs. Details have been reported previously[3,4]. In time frequency analysis, it is impossible to have simultaneous large time and frequency resolution. In our previous studies, we tuned our analysis to provide a large time resolution. However, to obtain better respiration frequency, we modified our analysis software to provide the largest available frequency resolution.

Extending the method of Jasson et al[8], we calculated an instantaneous central frequency (CFR) from 0.15 Hz (lower limit of high frequency band) to the half frequency of the average heart rate for 1 minute. We defined respiration frequency as a 10 second average of these CFRs.

As an index of autonomic nervous systems activity, we calculated LF, HF as the sum of the absolute values of the time frequency map of corresponding frequency bands along the frequency axis and their average over the 1 minute, and we set HF and LF/HF as indexes of para-sympathetic and sympathetic nervous systems activity representing this one minute, together with average heart rate[3,4].

3. Results and Discussion

Although changes in average heart rate, respiration frequency, and PSNS and SNS activities were observed during the course of the experiments, no significant change in heart rate or respiration was observed. Hence, we focused on the behavior of PSNS and SNS activities.

Fig. 1 shows examples of ANS activity changes of Level 1 and 3 subjects during the course of simulation experiments. We propose using the ANS activity map shown in Fig.1 when making ANS activity behavior comparisons. The horizontal axis shows PSNS activity, while the vertical axis shows SNS activity here. Dark lines correspond to Level 3 subject, and light gray lines correspond to Level 1 subject. The ANS activity of Level 3 subject resides in a very small PSNS activity area and is distributed along the vertical axis to relatively high SNS activity area, i.e. tense zone. On the contrary, that of Level 1 subject resides in a very small PSNS area and is distribute along the horizontal axis to a high PSNS activity area, i.e. relaxed zone. Thus, ANS activity distribution differs significantly between the Level 1 and Level 3 subject, and may be represented using average values when comparing the ANS activity of all nineteen subjects, as shown in **Fig. 2.**

In Fig. 2, white and black circles denote the ANS activity of female and male Level 1 subjects, respectively. The Level 1 subjects from Fig.1 reside in the relaxed zone at a PSNS activity of about 1065 msec^2 and an SNS activity of about 1.4. Most ANS activity of the Level 1 subjects is located the relaxed zone. Due to their lack of knowledge of plant operations, the Level 1 subjects were not able to conceptualize what should be done, and were not able to concentrate on their task. These situations may make their ANS activity similar to that of people in resting or relaxed states.

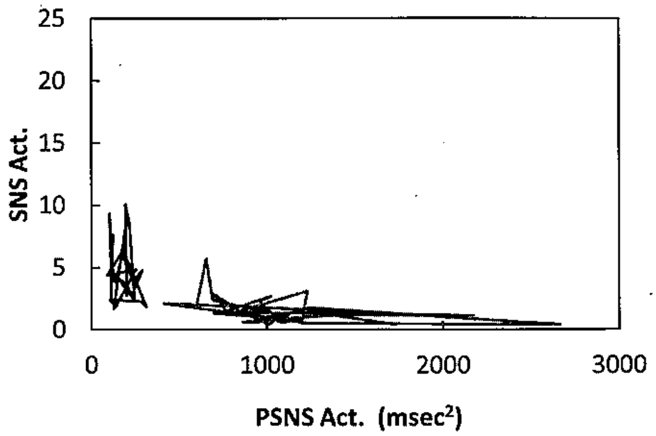

Fig. 1 Examples of ANS activity of Level 1 (light gray line) and Level 3 (dark line) subjects during simulation experiment expressed as an ANS activity map. Horizontal and vertical axes show PSNS and SNS activity, respectively.

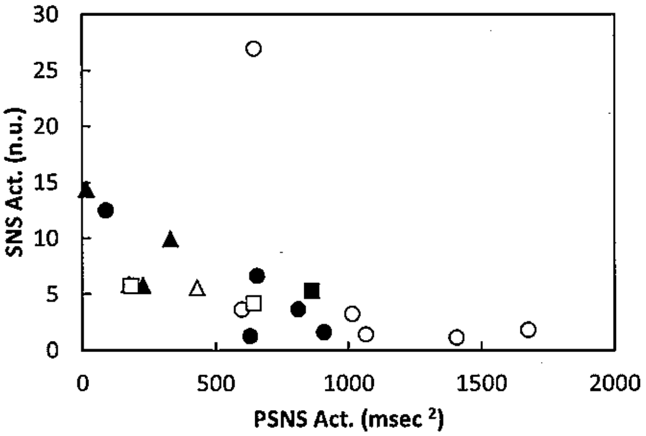

Fig. 2 Averaged ANS activities of all nineteen subjects expressed as an ANS activity map. Horizontal and vertical axes show PSNS and SNS activity, respectively. Circles denote Level 1 subjects, triangles denote Level 2 subjects, squares denote Level 3 subjects, white data points denote female subjects, and black data points denote male subjects.

White and black triangles in Fig. 2 denote ANS activity of female and male Level 2 subjects, respectively. All four data points are located in a tensed area, and three of the four differ remarkably from those of the Level 1 subjects. With sufficient knowledge, the Level 2 subjects can concentrate on the given task, make suitable judgments, and perform operations. Their PSNS activity decreased, and their SNS activity increased.

White and black squares in Fig. 2 denote ANS activity of female and male Level 3 subjects, respectively. Although the Level 3 seen in the subject included in Fig.1 lies in the tensed zone, with a PSNS activity of about 182 msec^2 and an SNS activity of 5.8, data for the other two subjects falls in a rather large PSNS activity area. These two points suggest the possibility of a reduction in concentration caused by repetitive operation, and may be one cause of human error.

Since the small total number of Level 2 and 3 subjects, however, makes it difficult to draw clear conclusions, especially regarding possible effects of repetition. The education of Level 1 subjects up to that of the Level 2 or 3 subjects requires great time and effort, both from the subjects themselves and from teaching stuff. Furthermore, education and experiments require a simulator and three trained staff, placing limits on the number of Level 2 and Level 3 subjects able to be tested.

To support the findings showing position differences in the ANS activity map between Level 2 and Level 1 subjects, we tried to demonstrate the effect of education. We selected five Level 1 subjects, including the Level 1 subjects of Fig.1 having positions in Fig. 2 as follows: A (1065, 1.4), B (656, 6.7), C (909, 1.6), D (810, 3.7), and E (631, 1.3). Initially sufficient education relating to the current simulation scenario was provided in the mother language of the respective subjects, who were then allowed to perform simulations.

ANS activity changes observed due to the effect of education of the subjects are shown in **Fig. 3**. The scale of the horizontal axis is the same as that of Fig. 2, while the vertical axis is expanded three times compared to Fig. 2. Subject A, is represented by a square; Subject B is represented by a circle; Subject C is represented by a triangle; and Subject D is represented by a diamond. Data for only four subjects is available here because measurements of subject E failed. Each subject performed the simulation three times: an initial trial (Fig.2), after education first time, and after education a second time. The arrows show the direction of time order. Fig. 3 shows that the locations of all four subject's ANS activity during the first simulation after education moved toward the more tensed region in the ANS activity map.

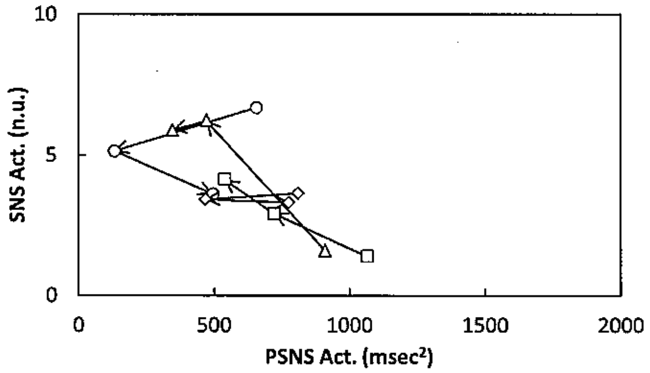

Fig. 3 Observed ANS activity changes due to the effect of education of Level 1 subjects. The scale of the horizontal axis is the same as that of Fig. 2, while the scale of the vertical axis is expanded three times compared to Fig. 2. The square denotes subject A, the circle denotes subject B, the triangle denotes subject C, and the Diamond denotes subject D. Each subject performed the simulation three times, an initial trial (Fig. 2), after education a first time, and after education a second time. The arrows show changes in individual subject data point over time. Simulations after education a second time were performed the same day as the prior simulation for subjects B and D, but during the next day for subjects A and C.

For the second simulation, the subjects were asked whether they would prefer to perform it the same day as the first simulation, or the following day. Subjects A and C selected the following day, while B and D selected the same day. As shown in Fig.3, the locations of ANS activity during the second simulation of subjects A and C further moved toward the more tensed region. In contrast, those of subject B and D moved back toward the more relaxed area, although the distances moved were small.

The former results may suggest two simulations performed once a day works subjects positively in increasing of experience and knowledge. In the latter case, two simulations performed twice on the same day may cause a negative effect due to fatigue, tiredness, boredom regarding the second simulation, thus cancelling out a portion of the education effect.

The sample size of our subjects was small, and to clarify the points observed requires further study. Nevertheless, we may conclude that an increase of knowledge for plant operations moves the location of subject's ANS activity during simulation toward the more tensed region.

4. Summary

The level 2 and 3 groups showed high sympathetic nervous system activity (SNS), and very low parasympathetic nervous system activity (PSNS) during the simulation. In contrast, the Level 1 group showed a high PSNS and a low SNS, indicating that operator lack of knowledge and experience in plant operation can be detected by measuring ANS during operation. Furthermore, we ascertained that the increase of plant operation knowledge moves the location of subject ANS activity during simulation toward the more tensed region.

References

1) Shirouzu S, Katayama S and Shirouzu A: 24 Hours Autonomic Nervous Activity of a High School Student Taking

School Examination: Human Development for All 2: 65–67, 2012.

2) Kim A R, Jang I, Al Harbi M A S, et. al.: The Effect of Human Operators' Condition and Knowledge to Human Errors in Plant Emergency Operation. Submitted to Reliability Engineering & System Safety (RESS-S-12-00468)

3) Shirouzu S, Katayama S and Masaki T: 24 hours Monitoring of Activities of Autonomic Nerves of Four and Five Years Old Children: Human Development for All 1: 32–41, 2011.

4) Shirouzu S, Katayama S and Shirouzu A: One Week's continuous monitoring test of activities of autonomic nervous: Human Development for All 1: 197–202, 2011.

5) Shirouzu S: High Frequency Components of RR Interval Variability and Respiratory Sinus Arrhythmia: Human Development for All 2: 54–60, 2012.

6) Novak P, Novak V, de Champlain J et. al.: Influence of respiration on heart rate and blood pressure fluctuations: J Appl Physiol. 74: 617–626, 1993.

7) Novak P, Novak V. Time/frequency mapping of the heart rate, blood pressure and respiratory signals: Med Biol Eng Comput. 31: 103–110, 1993.

8) Jasson S, Medigue C, Maison P et. al.: Instant Power Spectrum Analysis of Heart Rate Variability During Orthostatic Tilt Using a Time-/Frequency-Domain Method Circulation 96: 3521–3526, 1997.

9) Boashash B: Estimating and interpreting the instantaneous frequency of a signal, I: fundamentals. Proc IEEE.; 80: 520–538, 1992.

10) Bailón R, Laguna P, Mainardi L et. al.: Analysis of Heart Rate Variability Using Time-Varying Frequency Bands Based on Respiratory Frequency. Proc. 29th Ann. IEEE EMBS Int. Conf., Lyon, France 6674–6677, 2007.