An evaluation of mental workload for effective navigation

Murai, Koji

Hayashi, Yuji

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Koji Murai[1] and Yuji Hayashi[1]

[1] Kobe University, 5-1-1 Fukaeminami, Higashinada, Kobe, Hyogo 658-0022 Japan
E-mail: {murai, hayashi}@maritime.kobe-u.ac.jp, Fax: +81-78-431-6242 or 6245

Abstract
Purpose- This paper proposes that the nasal temperature is an effective index to evaluate the mental workload of a navigator for effective navigation.
Design/methodology/approach- The evaluation comes from the actual on-board experiment, not simulation. The subject is real bridge teammates; captain, duty officer, and quarter master. The mental workload is evaluated for a lot of navigational situations.
Findings- The nasal temperature responds when the navigator makes a decision regarding ship-handling and collision avoidance, and shows well the whole trend of his decision-making. Then the nasal temperature takes effect to evaluate the bridge team work among captain, duty officer and quarter master.
Research limitations/implications- Future research is to make cross-indices with the nasal temperature and the heart rate variability (R-R interval) complementary to each other where the nasal temperature registers the trend and the R-R interval registers the quick response of the mental workload.
Practical implications- The paper describes the effective index which is useful to evaluate bridge teammates' mental workload for effective navigation.
Originality/value- Navigator's skill has been evaluated according to behavior (performance) and a questionnaire as a quantitative evaluation; moreover, the mental workload tries to do it using nasal temperature and heart rate variability.

Keywords: Ship navigator, Mental workload, Nasal temperature, Heart rate variability, Skill
Paper type: Research paper

1. Introduction

The evaluation of a human skill and *Kansei* (individual and common sense) (see Murai and Inokuchi, 2004, see Inokuchi *et al*, 1994) depends on the subjective evaluation of a professional who is a pilot and a captain in a sea navigation field. The human skill has been evaluated according to behavior (performance) and a questionnaire as a quantitative evaluation; moreover, the mental workload tries to do it (see Kobayashi and Senda, 1998). We think old methods with human performance or available area under the vessel's performance requires, but a physiological index

which evaluates the mental workload can catch a response of decision making of a navigator and how to keep the good strain while they achieve the safe navigation. Of course, the physiological index is a quantitative evaluation for the human skill combined with the mental workload. Moreover, we can apply to catch the change of the mental workload for bridge teammates (captain, duty officer, quarter master) (see Murai *et al*, 2004(IEICE)).

We selected two indices which are the heart rate variability (R-R interval) (see Murai *et al*, 2004(ITSE), see Murai *et al*, 2002(IEEJ)) and the nasal temperature (see Murai *et al*, 1996). These indices got a good response and required only a slight experimental load for the data measurement from the pre-experiment (see Murai *et al*, 2002(IEEJ)). The R-R interval is available to show the response to ship-handling decision making in a real situation; however, we need to produce satisfactory results using the nasal temperature, because our results to date have only been tested when the subject navigator was the using the ship bridge simulator. Although a sophisticated device, a bridge simulator does not mimic real navigation 100 percent.

This paper presents a characteristic of the mental workload of the navigator using the nasal temperature when entering/leaving port and during a general navigation at daytime and nighttime, and the quarter master's for order from the captain or duty officer. We propose a cross evaluation with two indices if the nasal temperature is effective like the R-R interval. We look forward to determining the quality of the judgment of the ship-handling skills with the mental workload if the evaluation method is successful.

We take the R-R interval data for comparing with the nasal temperature. The R-R interval is a heart rate at a moment. The R-R interval means the time interval from a peak point R wave to next peak point and is one of the waves which consist of P, QRS and T of an electrocardiogram (ECG) (Figure 1). The evaluation using the frequency components, Low Frequency (LF) and High Frequency (HF), of the R-R interval is used. The LF, 0.04 to 0.15 Hz, reflects the sympathetic nervous system and the parasympathetic nervous system, the HF, 0.15 to 0.40 Hz, reflects parasympathetic nervous system (see Malik, 1996, see Sayers, 1973, see Ohtsuka, 1994). The SNS, (SNS = LF / HF) is available to evaluate the sympathetic nervous system and parasympathetic nervous system simultaneously (see Kobayashi and Senda, 1998). We have shown the effect of SNS value.
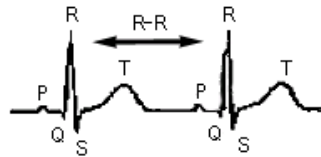

Fig.1. R-R interval.

2. Ship's bridge teamwork and watch conditions

The bridge teamwork is considered one of the resources of Bridge Team Management (see Swift, 1993), which refers to the management of the human resource available to the navigator, who is the quartermaster, engine room watch, look out or other team member, and their teamwork accomplishes the goal of safe and efficient navigation. The advantage of teamwork is the potential interaction with individual abilities and the effect is a multiplication of skills for the work; however, we never forget that teamwork doesn't always demonstrate the desired effects. In other words, if one step is mistaken a bit, the effects decrease dramatically.

The watch conditions depends on geographical and weather conditions, and these conditions are divided into four sections depending on fog, heavy traffic, entering a channel, harbor or restricted area, heavy weather and fire, flooding, or other emergency. Each watch condition is as follows (see Bowditch, 1995).

1) Watch Condition 1:
All clear conditions on maneuverability, weather, traffic and systems. A deck officer and a quartermaster can handle the bridge watch, and sometimes a deck officer does it.

2) Watch Condition 2:
Somewhat restricted visibility, constrained geography and congested traffic. A deck officer and a quartermaster can handle the bridge watch.

3) Watch Condition 3:
Serious poor visibility, close quarters – in bay and approach channels, and heavy traffic. A captain, a deck officer and a quartermaster can handle the bridge watch.

4) Watch Condition 4:
On Berthing and anchoring, a captain, a deck officer, a quartermaster and pilot at special ports in the bridge can handle the bridge watch. A chief officer and bosun are at the bow station, and a second officer and deckhand are at the stern station.

We selected the watch conditions 1 and 4 for general navigation at daytime/nighttime and upon entering/leaving a port for the experimental situations. For the general navigation at daytime/nighttime, operators pay attention to the sharpness of the lookout. On leaving and entering port, operators pay attention to the control of the ship's course as it approaches a berth. They must control the rudder, the engine motion and the thruster at the same time. Furthermore, they must give orders to the bow and stern stations as wind and current often affects the ship's control. Also, a ship's rudder effect is worse at low speed. We can say that the operator needs to multitask in the short time. Of course, the all conditions do with teamwork between the operator and his assistant. We will evaluate the changes in the mental workload.

3. Experiment

3.1 Outline

We carried out the experiment in 12 kinds of navigational situations: three leaving port (1. Fukae, 3. Nagasaki, 5. Takamatu), three entering port (1. Fukae, 3. Nagasaki, 5. Takamatu), two navigations at nighttime (2. off Tosa), two navigations at daytime (3. off Nagasaki), anchoring and weighing anchor (4. Obe). Figure 2 shows the experimental sea area, on the west side of Japan.

The subjects are the captain when entering/leaving port, anchoring/weighing anchor and the chief officer when conducting general navigation at nighttime/daytime.

The experimental ship is the Training Ship Fukae-maru of our school (Figure 3). Her length is 49.95 meters, width is 10.00 meters, draft is 3.20 meters, tonnage is 449.0 tons.

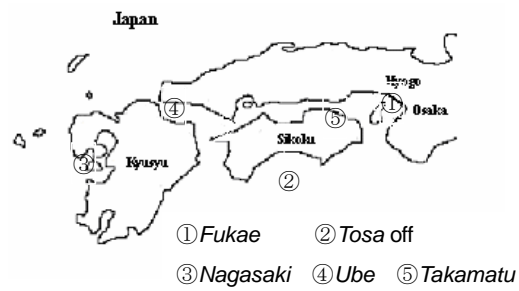①*Fukae*   ②*Tosa* off
③*Nagasaki*   ④*Ube*   ⑤*Takamatu*

Fig.2. The experimental sea area at west side of Japan

Fig.3. Training ship of Kobe University, Graduate school of Maritime Sciences, *Fukae-maru*.

Fig.4. The experimental sinstrument; Thermography (Left Fig.), Heart rate monitor (Right Fig.).

A tester measures the facial temperature including the nasal temperature with a thermography. Moreover, he records the experimental situation, the subject's behavior, conversation and the R-R interval by video camera, observation with work-sampling every second (see Murai and Hayashi, 2004), IC recorder, and heart rate monitor, respectively. The R-R interval data is the reference data to confirm the characteristic of the nasal temperature. We show the thermography device and the heart rate monitor in Figure 4.

3.1 Measurement of Facial Temperature

A tester measures the facial temperature at intervals of from thirty seconds to two minutes. To do the measurement, we have the subject stand in front of the ship's compass which is exactly one meter from where the thermography device is set. Figure 5 shows the outline of the facial temperature measurement in the experiment. The position isn't influenced by the wind from the air conditioner. Table 1 shows the specification of the thermography.

Fig.5. Outline of the experiment of the facial temperature measurement on the bridge.

TABLE 1. SPECIFICATION OF THE THERMOGRAPHY DEVISE.

Range [centigrade]	0.0 - 70.4
Accuracy [centigrade]	0.1
Resolution [line]	320
Scanning line [line]	120
Distance [meter]	20 - inf.
View [degree]	H:20.0 * V:15.0

4. Analysis

We calculate the "Nasal-Forehead temperature (N-F temperature)" in order to evaluate the mental workload of the navigator. The N-F temperature is the difference between the nasal temperature and the forehead temperature which are mean values of the data in one square centimeter (Equation (1)).

N-F temperature = Mean (Nasal temperature) – Mean (Forehead temperature)   (1)

The part of the calculation areas were decided with the frame of the pair of spectacles as in Figure 6. We needed to identify the measurement position in some way, and proposed to utilize the frame of a pair of spectacles.

The size of the thermal image changes because the navigator walks around on the bridge to do careful lookout, and is never fixed the cockpit like an airline or car driver. It is difficult for us to fix accurately the distance between the navigator (subject) and thermography device so we corrected for this variable by using the frame of spectacles worn by the subject.

Fig. 6. The parts of the calculation areas to evaluate the N-F temperature utilizing the frame of a pair of spectacle.

Figure 7 shows the example of the facial temperature image by the thermography devise. Regarding the facial temperature, the red color shows a higher temperature than the blue color. We gathered the numerical data from the thermal image. The data consists of two files of the thermo data and the picture. In Figure 7, we can pick up the thermo data easily with the thermography devise.
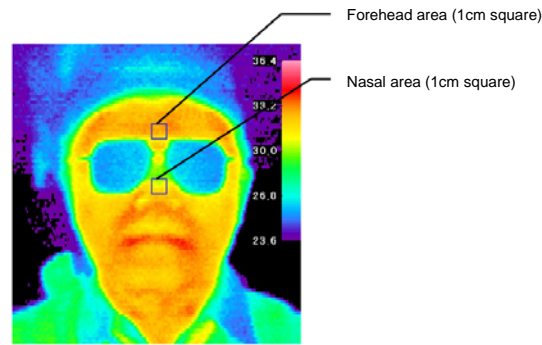

Fig. 7. Example of thermal image.

We calculated the mean, maximum and minimum value of the nasal and forehead measurement part. Figure 8 shows the three values of the nasal temperature while entering a port.
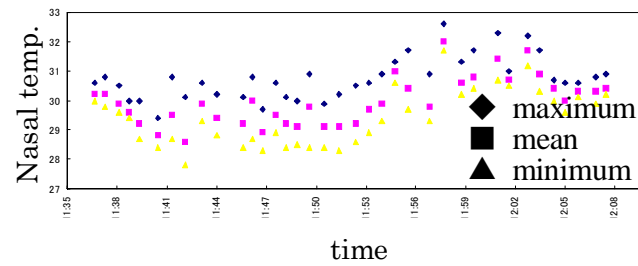
Fig. 8. Three nasal temperatures; maximum, mean, minimum values (Captain, when entering a port)

In Figure 8, 'diamond (blue)', 'square (pink)', and 'triangle (yellow)' represent the maximum, mean, and minimum values respectively. The tendency of the three values is similar. But, maximum and minimum values vary a little among the three values. The forehead temperature also has the same tendency. We selected the mean value as

the index.

The relationship between the N-F temperature and the mental workload is:

Case 1) N-F temperature < 0 : bad emotion (strain).
Case 2) N-F temperature $= 0$: normal emotion.
Case 3) N-F temperature > 0 : good emotion (no strain).

We can evaluate the mental workload of the navigator with three cases utilizing the N-F temperature.

The nasal temperature decreases while they strain. Meanwhile, the forehead temperature doesn't change for various mental workload conditions (see Sakamoto *et al*, 2006, see Iwata, 1988). Therefore, the N-F temperature is better to evaluate the mental workload on the ship's bridge where it is difficult to control the temperature. We need a base value not influenced by the movement of the subject or space conditions so selected the N-F temperature.

5 Results

We show typical results of the N-F temperature at entering a port and general navigations when daytime/nighttime.

5.1 Entering a port (watch condition 4)

We show the results of the N-F temperature while the subject navigates while entering port (Figure 9). Figure 9 shows the results of SNS values at the same time, and 'A' to 'G' in the Figure represents the events. Two flat lines, dots and a curved line are the N-F temperature equal to zero, means of SNS value, N-F temperature, and SNS value, respectively.
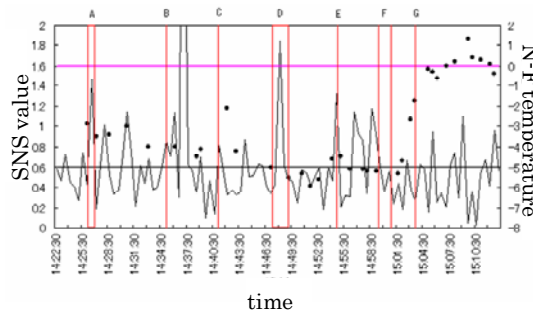

Fig. 9. The N-F temperature (entering port).

In Figure 9, the N-F temperature decreases as the ship approaches the port before the subject is relieved of navigational watch. He gets navigational information and

makes decisions for safe navigation. Then, after being relieved of navigational watch (event B), the N-F temperature increases control of the engine motion becomes easier, which we call "S/B Engine" (event C). He sends the line to the wharf (event F) and then finishes moving the ship into the port, which we call "F/W Engine". His N-F temperature increases dramatically.

  Events in Figure 9 are below;
  A: talks with duty officer while he uses the personal computer.
  B: relieves the navigational watch.
  C: stands-by Engine.
  D: turns the heading 6 to 8 degrees to account for the current at the entrance of the port.
  E: begins to use the thruster and the engine.
  F: sends the line to the wharf.
  G: finishes with Engine.

5.2 General navigation (watch condition 1)

We show the results of the N-F temperature while the subject navigates under general navigation at nighttime/daytime (Figures 10 and 11). 'A' and 'B' with a circle in Figures 10 and 11 are events. The flat line, dotted and curved lines are the N-F temperature equal to zero, the N-F temperature, and heart rate.
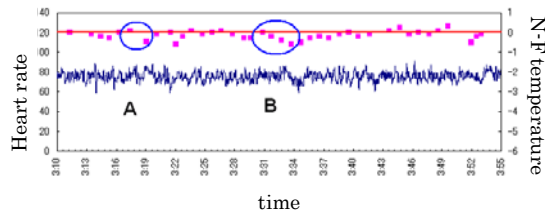

Fig. 10. The N-F temperature (general navigation at night).
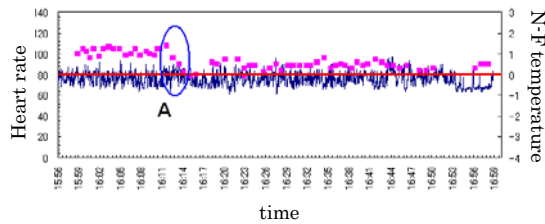

Fig. 11. The N-F temperature (general navigation at daytime).

  In Figures 10 and 11, the N-F temperature decreases at the point of decision making when judging collision avoidance for the target ship. Then, even night

navigation, the N-F temperature doesn't change while under usual navigation. The N-F temperature is around zero values except for events 'A' and 'B'. This tendency shows well that the navigator makes a good effort for safe navigation.

Events in Figures 10 and 11 are below;
[Figure 10]
A: identify the targets ship' information.
B: find the target ship and avoid the target.
[Figure 11]
A: find other ships and fishing boats.

5.3 Bridge teammate's mental workload (Quartermaster)
We show the results of the N-F temperature for the quartermaster while the captain navigates while entering port (Figure 12). Figure 12 shows the results of heart rate values at the same time, and 'A', 'B' in the Figure represents the events. The flat line, dots and a curved line are the N-F temperature equal to zero, heart rate value, and N-F temperature respectively.
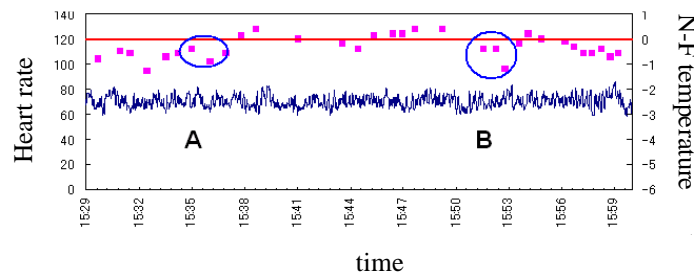

Fig. 12. The N-F temperature (Quartermaster, entering port).

Events in Figure 12 are below;
A: stands-by Engine and uses the engine a bit.
B: uses the thruster and the engine.

In Figures 12, the N-F temperature decreases at the point of captain's decision making when he gives the quartermaster orders for using the engine and the thruster. This tendency shows that we can catch the points of the bridge teammates' cooperation from the individual response.

From the results, the N-F temperature (nasal temperature) is valuable in determining the response to changes in mental workload; moreover, we can get more accurate response if the data sampling speed becomes higher. Meanwhile, we can apply the relation to the SNS value as the cross index.

6 Conclusions

We challenged ourselves to evaluate the mental workload of the navigator in an actual navigational situation. The index used was the nasal temperature. In this paper, we used the difference between the forehead temperature and the nasal temperature, because the ship's bridge space where the navigator walks is usually wide and the room temperature changes. Our index is influenced by the temperature. We used the forehead temperature for the base value to evaluate the nasal temperature.

As a result, we can confirm the effect of the nasal temperature as follows:

1. The nasal temperature decreases when the navigator begins his mental workload, i.e. decision making for ship-handling; judgment for collision avoidance.

2. The nasal temperature shows well the broad trend of the mental workload in compared with the heart rate variability.

3. The navigator maintains a strong mental workload (strain) to be able to take measures suited to the occasion.

In future research, we will make cross-indices with the nasal temperature and the heart rate variability (R-R interval) complementary to each other where the nasal temperature registers the trend and the R-R interval registers the quick response of the mental workload. Regarding the measurement method of the nasal temperature, we need to record the nasal and forehead parts automatically.

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