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Evaluation of Ship Navigator's Mental Workload for Ship Handling Based on Physiological Indices

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***Abstract*— Mental workload is useful to evaluate performance of ship bridge teammates: a captain, a duty officer, a helmsman, and a pilot. The physiological indices, heart rate variability and nasal temperature, are good indices of the mental workload found in ship handling; however, it is best if we get response and evaluation results quickly on the spot. A recent study shows salivary amylase activity is reflected by the sympathetic nervous system. This paper proposes that salivary amylase activity shows a ship navigator's mental workload during ship handling.**

***Keywords*—Navigator, mental workload, stress, saliva, nasal temperature, heart rate**

I. INTRODUCTION

Physiological index, heart rate variability (R-R interval) and nasal temperature, are sufficient to evaluate the mental workload (stress) of a ship navigator [1]-[3]. During the evaluation period, it is crucial to get the results in a short time and on the spot, without requiring special sensors for the subject. In a recent study, researchers showed salivary amylase measurement reveals sympathetic nervous system activity. The research evaluated a motor vehicle driver's stress and developed a compact measuring instrument [4].

In this paper, we attempt to evaluate the mental workload using nasal temperature, heart rate variability and salivary amylase activity simultaneously. The experiment is carried out using a real ship, because we have already done the experiment using the simulator with which we easily to control some conditions- subjects, time, temperature, humidity, scenarios, etc., and confirmed the effect [5]. Our work was to evaluate the three factors using a real ship. The ship handling situation is a ship entering and leaving a port. The navigator has to make a lot of ship handling decisions as he moves the ship into a port. We show that salivary amylase activity, nasal temperature and heart rate variability are good indices for effective navigation.

II. SHIP BRIDGE TEAM

The ship bridge team consists of a captain, a duty officer, a helmsman, and sometime includes a ship's pilot. Team members depend on the geographical and weather conditions. The 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 [6].

1) Watch Condition 1:
All clear conditions for maneuverability, weather, traffic and systems. A deck officer and a helmsman 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 helmsman 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 helmsman 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 on 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 select Watch Condition 4 upon entering and leaving a port for the experimental situation during daytime. On leaving and entering port, a captain pays attention to the control of the ship's course as it approaches a berth. He must control the rudder, the engine motion and the thruster at the same time. Furthermore, he 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 he needs to multitask in the short time.

III. EXPERIMENT

A. Outline

The experiment is carried out on the Training Ship of Kobe University, Graduate School of Maritime Sciences, *Fukae-Maru* (Figure 1). Her length is 49.95 meters, width is 10.00 meters, draft is 3.20 meters, tonnage is 449.00 tons. The subject is the Captain of Training Ship (male, 52 years old). Based on the pre-experiments using heart rate variability and nasal temperature, entering a port is a common navigational situation; we have selected the "Entering a port" and "Leaving a port" for two ports: *Fukae* and *Miyazaki* port (Figure 2).

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Figure 1. Training Ship *Fuka-maru*, Kobe University, Graduate School of Maritime Sciences.

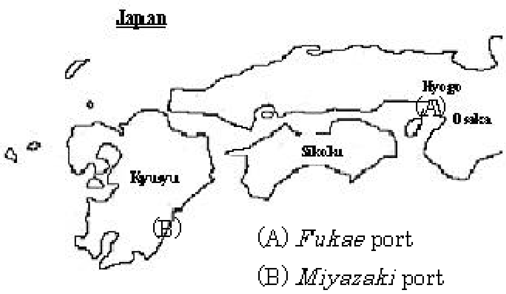

Figure 2. Experiment position in west side of Japan.

A tester measures the Salivary Amylase Activity (SAA value) [kIU/L], the facial temperature including the nasal temperature and the heart rate variability (R-R interval) at the same time using a SAA monitor, a thermography and a heart rate monitor. Moreover, we record the ship's performance (course, speed, rudder angle, etc.), the subject's behavior, and conversation (subject's performance) using a video camera. We also analyze his performance with work-sampling every second [7], [8].

B. Measearment of Salivary Amylase Activity Value

A tester measures SAA value using the SAA monitor which consists of a measurement part and a marker (Figure 3). The saliva is gathered with the marker (Figure 3(b)); the subject puts it under his tongue for thirty seconds; the amylase is extracted by the measurement part (Figure 3(a)) for thirty seconds.

(a) measurement part (b) marker

Figure 3. SAA value measuring instrument.

We measure the SAA value for one minute. The clean saliva comes from under the tongue because a salivary gland is located there. The captain can drink some water during the experiment to aid in getting enough saliva for the measuring instrument; however, he never needed any water during all the experiments.

C. Measurement of R-R Interval

A tester measures the heart rate variability (R-R interval) with a tolerance of one millisecond. In the majority of the R-R intervals, the accuracy is one millisecond as well; 95 percent confidence interval is better than plus/minus 3 milliseconds. The heart rate monitor consists of a chest belt and a wrist watch (Figure 4).

Figure 4. The heart rate monitor which consists of a chest belt and a wrist watch.

The chest belt with sensor measures the R-R intervals. It sends the data to the wrist watch which has a memory. The memory of the wrist watch can keep 30,000 bits of data. We take the R-R interval data from the heart rate variability.

The R-R interval means the time interval from a peak point 'R' wave to the next peak point. The 'R' is one of the waves which consist of P, QRS and T of an electrocardiogram (Figure 5). The 'R' wave is easier to pick up than other waves because the amplitude is clear. We use the heart rate to evaluate the mental workload.

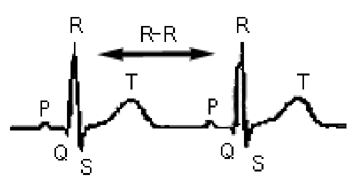

Figure 5. Outline of the R-R interval.

D. Measurement of Facial Temperature

A tester measures the facial temperature at intervals of one second. 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 [9]. The position isn't influenced by the wind from the air conditioner in the bridge house. Table 1 shows the specification of the thermography.

TABLE I
SPECIFICATION OF THE THEMOGRAPHY DEVISE

Range [centigrade]	0.0 - 70.4
Accuracy [centigrade]	0.1
Resolution [line]	320

Scanning line [line]	240
Distance [meter]	20 - inf.
View [degree]	H:20.0 * V:15.0

IV. EVALUATION

A. SAA value

We evaluate the mental workload using a reference value. The reference value is the mean value of three to five SAA values after the experiment. Research on motor vehicle drivers uses the mean value before the experiment [3]; however, a captain plans to guide the ship to the birth or to the open sea for entering/leaving a port before the experiment. In other words, he gets the mental workload for the ship handling before the experiment. We show the relationship between the reference value and the mental workload in equations (1) and (2).

If "Reference SAA value" < SAA value,
then "strain" results (1)

If "Reference SAA value" > SAA value,
then "no strain" results (2)

B. R-R Interval

We measure heart rate variability (R-R interval), and R-R interval shows the heart rate on the spot. The heart rate is small for a long time R-R interval and large for a short time. For example, the R-R interval 1,000 [ms] means 60 heartbeats per minute. We show the relationship between the R-R interval and the mental workload in equations (3) and (4).

If "R-R interval decreases",
then "strain" results (3)

If "R-R interval value increases",
then "no strain" results (4)

C. Nasal Temperature

We calculate the "Nasal-Forehead temperature (N-F temperature)" in order to evaluate the mental workload. 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 (5)).

N-F temperature = Mean (Nasal temperature)
– Mean (Forehead temperature) (5)

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

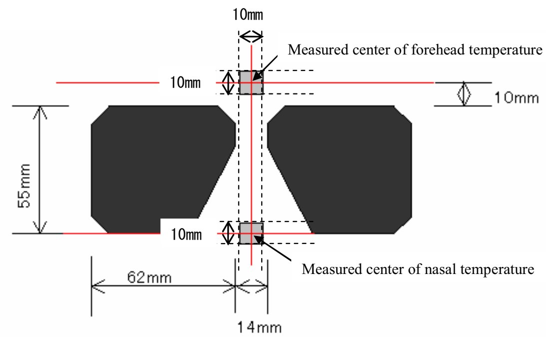

Figure 6. The parts of the calculation areas to evaluate the N-F temperature utilizing the frame of a pair of spectacles.

We show the relationship between the N-F temperature and the mental workload in equations (6) to (8).

If "N-F temperature" < 0,
then "strain" results (6)

If "N-F temperature" = 0,
then "normal" results (7)

If "N-F temperature" > 0,
then "no strain" results (8)

The nasal temperature decreases during stress or strain. Meanwhile, the forehead temperature doesn't change for various mental workload conditions [10], [11]. 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.

V. RESULTS

We show the typical result of the SAA value, R-R interval and N-F temperature for *Miyazaki* leaving a port (Figures 7 and 8). SAA value is every two minutes.

In the Figure 7, the blue line and the pink line are the R-R interval and the N-F temperature respectively, and 'A' to 'D' represents the events.

Events in Figures 7 and 8 are below;

A) Lets go all shore lines; leaves a birth at 3 minutes.
B) Fishing boat appears from the stern side at 10 minutes.
C) Pass the breakwater, port side at 16 minutes.
D) Pass the breakwater, starboard side at 20 minutes.

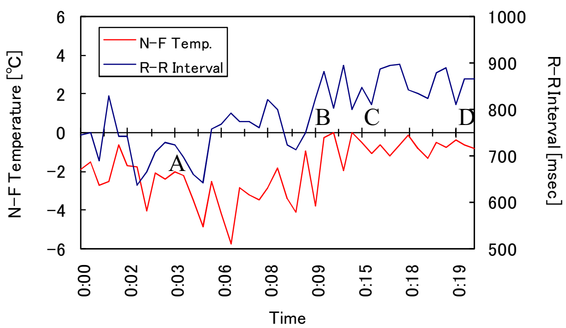

Figure 7. The results of the N-F temperature and the heart rate while leaving a port (*Miyazaki* port).

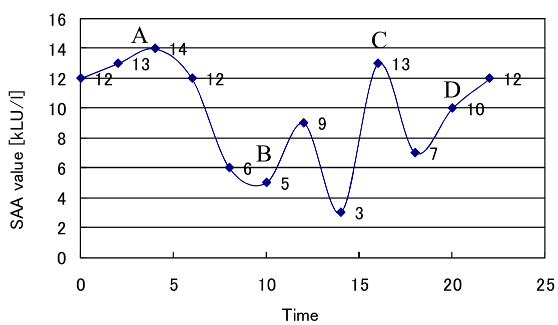

Figure 8. The results of the SAA values every two minutes while leaving a port (*Miyazaki* port).

In Figures 7 and 8, the small values of N-F temperatures are taken from 29 seconds to 3 minutes including events 'A' when the captain begins to leave the port (event A). The SAA value also takes large values of more than 12 [kIU/l]. In event B, the captain's mental workload is stable- small SAA value, large N-F temperature and R-R interval, because the fishing boat does not create an avoidance situation. However, the captain's mental workload increases when the ship passes the narrow passage at the breakwater (event C). The SAA value is taken at 13 [kIU/l] and the N-F temperature and the heart rate decrease.

From the results, the SAA values show well the mental workload when the navigator needs to make a lot of decisions for safe navigation. This trend is similar to R-R interval and nasal temperature.

VI. CONCLUSIONS

We attempted to evaluate the mental workload of the navigator using the SAA value, nasal temperature and the R-R interval simultaneously on a real ship. In this paper, we used the difference between the forehead temperature and the nasal temperature as the N-F temperature, because our index should be available on a real ship where the subject walks in the bridge space. 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 SAA value, the nasal temperature (N-F temperature) and the R-R interval as follows:

1. The SAA value increases, and the N-F temperature and the R-R interval decrease when the navigator begins his mental workload for safe navigation: decision making for ship handling.

2. The SAA value evaluates the mental workload of the ship navigator quickly on the spot in one to two minutes.

3. The SAA value, the nasal temperature and the R-R interval are better indices as they are complementary to each other. These indices double/triple check each other, and show more accurate evaluation.

We confirmed that the SAA value, the nasal temperature and the R-R interval are better cross-indices for evaluating the mental workload of the ship navigator.

In future research; 1) we will evaluate the response time for the differences among individuals; 2) we will design student's training evaluation systems with which we can evaluate results in real time; and 3) we need more data to get more accurate results.

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