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Evaluation of Marine Simulator Training Based on Heart Rate Variability

Sam TEEL, Jim SANDERS, Daniel S.PARROTT, Larry WADE, Timothy GERVAIS, Katherine ROVINSKI and Laurie C.STONE
Marine Transportation/Arts and Sciences
Maine Maritime Academy
Castine, Maine, USA
{steel, jim.sanders, dparrott, lwade}@mma.edu

Koji MURAI and Yuji HAYASHI
Maritime Sciences
Kobe University
Kobe, Japan
{murai, hayashi}@maritime.kobe-u.ac.jp

Abstract- **Mental workload is useful for evaluating performance of a ship's navigator: a captain, a duty officer, and a pilot. The heart rate variability (R-R interval), the nasal temperature and the salivary amylase predict well based on pre-experiments; however, most of the research tests a professional's skill. The evaluation does not test a cadet's skill yet. In this paper, we evaluate a cadet's R-R interval as he guides a ship from a narrow channel to open sea, and consider simulator training effects. The experiment is carried out using a ship bridge simulator, not a real ship. We show the R-R interval is a good index for the evaluation of marine simulator training.**

***Keywords*—Simulator, training, R-R interval, mental workload, skill**

I. INTRODUCTION

The LF/HF value which comes from a frequency component of heart rate variability (R-R interval) can indicate the mental workload for a ship navigator (navigator) [1]. We have confirmed the efficiency and have tried it on bridge teammates: a captain, a duty officer and a helmsman [2], [3]. Moreover, the nasal temperature and salivary amylase activity is a good index for the navigator from pre-experiments [4]-[7]. However, all previous research is based on a professional's skill, error and *Kansei* [8]; the evaluation has not been tested on a cadet yet. Instructors for ship handling can utilize these physiological indices for evaluation of the training.

In this paper, we attempt to evaluate the mental workload of a cadet undergoing simulator training using heart rate variability. The experiment is carried out using a bridge simulator, because the experimental environment in the simulator room makes it easy to control some conditions- such as the subjects, time, temperature, humidity, scenarios, etc. In other words, a subject is not influenced by external factors; a tester can carry out the same experiment on all subjects. The scenario is a narrow channel in New York. The cadet has to make a lot of ship handling decisions as he moves the ship through the channel. We show that R-R interval is a good index for the evaluation of simulator training.

II. SHIP BRIDGE SIMULATOR

We use the Maine Maritime Academy (MMA) "Captain Granville I. Smith Simulator" to achieve our goal to measure the R-R interval of subjects guiding a ship through a narrow channel. Kongsberg Norcontrol IT, Norway, manufactured the simulator.

The simulator consists of three ship systems, a briefing/debriefing system and an instructor system. A visual system in the simulator produces a seascape of 240 degrees in a horizontal view and 25 degrees in a vertical view. Enough specs exist to mimic a real ship's movements when produced by the simulator. The navigational instruments: Radar (Radio Detection and Ranging) with ARPA (Automatic Radar Plotting Aids), AIS (Automatic Identification system), ECDIS (Electric Chart Display Indication System), VHF, rudder stand, engine console, etc. found on a real ship are also found on the simulator.

Figure 1. The simulator at Maine Maritime Academy (Captain Granville I. Smith Bridge Simulation Room).

III. EXPERIMENT

A. Outline

An evaluation of the mental workload for the cadets was carried out on the simulator at MMA. The index was the R-R interval of heart rate variability. The scenario was a narrow channel in New York Harbor, where the ship was a chemical tanker with 37,000 Gross Tonnage, 176.80 meters length, 31.03 meters breadth, and 11.90 meters (even keel) draft.

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The subjects were ten 4th year cadets (Subjects A to J) of the Marine Transportation Operations Department at MMA. The bridge team members included a Mate, Assistant Mate, and Helmsman. The cadets changed these positions when the scenario was repeated (Table 1). Seven cadets served as Mate. The experiment was carried out at the same time, from 16:00 to 18:00, and on the same days of the week: Monday and Wednesday. The subject usually served in two positions during the experiment.

TABLE I
SUBJECT AND POSITION OF THE BRIDGE TEAM

No.	Time	Mate	Assistant Mate	Helmsman
#1-1	1600-1700	Sub. D	Sub. F	Sub. E
#1-2	1700-1800	Sub. F	Sub. E	Sub. D
#2-1	1600-1700	Sub. A	Sub. J	Sub. B
#2-2	1700-1800	Sub. B	Sub. A	Sub. J
#3-1	1600-1700	Sub. E	Sub. D	Sub. F
#3-2	1700-1800	Sub. D	Sub. F	Sub. E
#4	1600-1700	Sub. A	---	Sub. B
#5-1	1600-1700	Sub. H	Sub. B	Sub. I
#5-2	1700-1800	Sub. I	Sub. H	Sub. B

A tester measured the R-R interval of the bridge team member using a heart rate monitor. We recorded the track passed and the ship's performance (course, speed, rudder angle, etc.) using the simulator system and the subject's behavior, conversation (subject's performance) using a video camera. We also analyzed his performance with work-sampling every second [9], [10].

B. Simulation ExperimentPhilosophy and Description

A tester explains the simulation philosophy before the experiment in a ten-minute briefing. The subject has enough preparation time to understand the scenario before the experiment begins. He is made aware of the simulation training philosophy and experiment description as shown below.

<u>MMA ship simulation training program:</u>

The undergraduate students at Maine Maritime Academy take a series of ship simulation-based courses during their matriculation. The courses start at an introductory level and progress to a capstone course as the student approaches graduation.

As first year students, they are trained and assessed on their ability to act as a ship's helmsman and lookout. During the second year the students learn and practice skills ranging from chart navigation, operation of the ship's collision avoidance radar (ARPA), depth sounders, electronic chart display information systems (ECDIS), and the global positioning system (GPS). During the third and fourth year, the students further experience and are assessed in upper level maritime operations proficiencies. The college is dedicated to experiential training and the ship simulator system is a technology which supports the college's philosophy of educating and assessing in a hands-on learning environment.

A notable example of experiential education occurs in the student's senior year. It is a simulation-based capstone course required of all students who are seeking certification as an Officer in Charge of a Navigational Watch (OICNW) under the mandate of the International Maritime Organization's standards of training, certification, and Watchkeeping [11]. The course seeks to have the students demonstrate the cumulative mariner skills previously learned while affording an opportunity to further hone their competency at leadership, command, and team management in a challenging yet controlled environment. The students are also assessed during this time to ensure that they meet the specific outcome requirements of the course.

The student participants in the heart rate variability experiment at MMA are all upper level students and were within one year of degree completion and examination for their certification as a merchant marine officer. All students are enrolled in the capstone course and have had a minimum of 6 months of time at sea while serving as an apprentice on commercial merchant marine vessels and the college's 500 foot training vessel.

<u>Experiment Description:</u>

New York Harbor is selected as the port for the experiment scenario. The simulation software supports a detailed database of the harbor that includes all visual, radar imagery, and hydrodynamic aspects of the port which are accurately modeled and simulated. The area of operation needed to provide sufficient challenge for the experiment subjects. The port of New York has numerous inlets and difficult channels, with the associated bends and turns, constrained depths, and challenging channel junctions making it a perfect area of operation. The lower end of the East River where it joins the flow of the Hudson River off lower Manhattan is selected as the ideal operation area. The channel is narrow and would require two major course adjustments which must be executed nearly flawlessly in order to avoid grounding the vessel. In addition to the navigation and ship maneuvering aspects of the scenario the experiment participants would be tasked with ship to ship radio communications, tracking, predicting and avoiding collisions with nearby vessels, and managing the bridge team.

The following scenario description is provided to the students. The description is read aloud to the students and they are encouraged to ask questions of clarification. The navigation charts of the area are pre-drawn and mark with appropriate course lines, margins of safety, and "No-Go" areas following normal conventions of chart preparation that the students are familiar with. Wheel over points are carefully marked on the chart as per normal shipboard practice. Wheel over points are predetermined locations along the intended track line at which the ship's officer will execute a turn. The term wheel over literally means the point at which the ship's steering wheel is turned in order to begin a maneuver.

Scenario:

Your vessel is the M/V Stolt Confidence, call sign KOJI. You are located just above the Brooklyn Bridge in the East River. You are headed southwesterly and are positioned in the center of the channel. It is 0600 on a summer morning. You are down bound /outbound in a loaded condition. The task is to complete a transit out of the East River, turning to starboard off lower Manhattan then to enter the Hudson River and to continue an outboard transit, bound for sea.

Your LOA is 560 feet, beam is 102 feet, and you are drawing a deep draft of 39 feet, fore and aft. Your height of eye is 82 feet; the air draft 120 feet, there is no concern with bridge clearance. The deviation card is posted on the bridge. Deviation is minimal on all headings. Variation is 13 W. A magnetic compass is mounted overhead and a course board is available. There is no gyro compass error.

The charts have been prepared with appropriate track lines, margins of safety and "No-Go" areas and suggested wheel over points.

As you begin the scenario, the ship's speed is approximately five knots. Previous successful attempts of this transit have been made in the 4 -8 knot speed range.

The Simulation staff will set up all bridge equipment and provide instructions as needed.

Weather notes:

- *Wind is 335 at 10 knots; visibility is fair with patchy fog predicted throughout the morning. A high tide occurs at 0615 with slack water in the vicinity of your area of operation. You may anticipate minimal current influence.*

Maneuvering notes:

- *The vessel is equipped with a Becker Rudder and steers well at all speeds. The M/V Stolt Confidence is a directionally stable vessel. Provided you are on or near track, the first turn may be executed with a turn radius of 0.2 nm by using an approximate 15 degrees per minutes turn rate. The second turn may be made with a turn radius of 0.3 nm using an approximate 10 degrees per minute rate of turn.*

Operational notes:

- *You will encounter moderate traffic and should communicate by VHF radio as needed. All vessels in NY Harbor will monitor 13 and 16 VHF radio.*

- *You will not be required to communicate with New York VTS during the exercise.*

- *You are expected to make a Security Call on channel 13 / 16 as you merge into the Hudson River.*

- *There are two charts required; the charts are annotated with a change chart line.*

- *A rough log should be maintained to a degree sufficient to recreate your passage*

Experiment notes:

- *Please be assured that you are not being put in a situation that is outside the limits of possible success. The exercise has been thoroughly tested and vetted. With attention to detail and appropriate use of the equipment you have every reason to expect a successful transit. The exercise has been developed to assess your stress levels during the experiment. The course changes, traffic situation and radio communications are specifically designed to provide a period of cognitive challenge followed a period of cognitive rest. The Exercise is designed to provide you with sufficient but not overwhelming challenges and activity throughout the 35 +/- minutes it takes to complete the experiment.*

IV. MEASUREMENT OF R-R INTERVAL

A tester measures the R-R interval of heart rate variability with a tolerance of one millisecond. In the majority of the R-R intervals, the accuracy is one millisecond as well, and the 95 percent confidence interval is better than plus/minus 3 milliseconds. The heart rate monitor, POLAR RS800, consists of a chest belt with two sensors and a wrist watch (Figure 2). The chest belt with sensor measures the R-R intervals. It sends the data to the wrist watch which has a memory capable of holding 30,000 bits of data.

Figure 2. The heart rate monitor which consists of a chest belt and a wrist watch.

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 consists of P, QRS and T of an electrocardiogram (Figure 3). The 'R' wave is easier to pick up than other waves because the amplitude is clear.

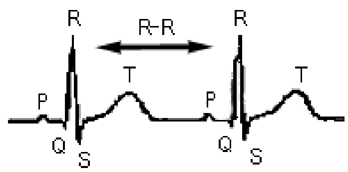

Figure 3. Outline of the R-R interval.

The R-R interval fluctuates because the frequency component characteristics depend on the sympathetic and parasympathetic nervous systems. We can evaluate the mental workload by using the frequency component. Figure 4 shows an example of the measured R-R data for a cadet (subject E) while he served as mate and helmsman. We know the R-R data fluctuates with various characteristics.

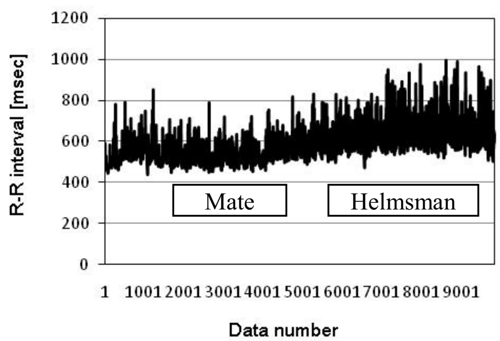

Figure 4. Measured R-R interval during the experiment #3-1 amd #3-2 in Table 1 (subject E).

V. EVALUATION

We calculated "LF/HF value" every thirty seconds by the Maximum Entropy Method (MEM) in order to evaluate the mental workload of the cadet based on the R-R interval. The thirty seconds produced by comparison between the LF/HF values and the specialists' subjective evaluation [12].

On the 'LF', Low Frequency (LF) and High Frequency (HF) are the frequency components of the R-R interval. The 'LF' value is from 0.04 to 0.15 Hz which reflects the sympathetic and the parasympathetic nervous systems. The 'HF' value is from 0.15 to 0.40 Hz which reflects the parasympathetic nervous system [13], [14]. The 'LF/HF' value allows evaluation of the sympathetic and parasympathetic nervous systems simultaneously. We show the relationship between the LF/HF value and the mental workload in equations (1) and (2). In the two equations (1) and (2), a subject reveals stress or "strain" when the LF/HF value decreases.

[Relationship between LF/HF and Mental workload]

If the "LH/HF value increases",
then "strain" results (1)

If the "LF/HF value decreases",
then "no strain" results (2)

VI. RESULTS

We show two types of the LF/HF value result when passing a narrow channel in New York Harbor: subject B (#2-1, #2-2 in Table 1) and subject D (#3-1, #3-2 in Table 1) in Figures 5 and 6. Subject B served as helmsman and mate, and subject D served as assistant mate and mate. The red color line in the Figures is the mean value, and 'A' to 'E' represents the events. The LF/HF value is calculated every thirty seconds by MEM.

[Type 1]

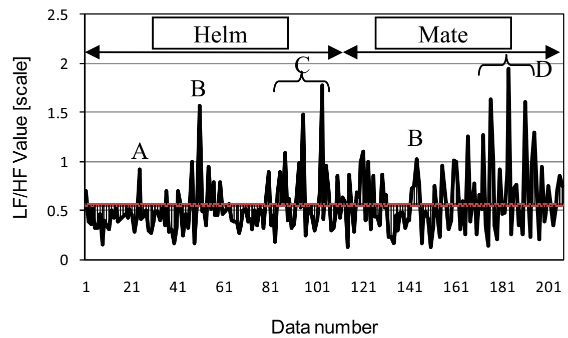

Figure 5. The results of the LF/HF value while passing a narrow channel every thirty seconds (subject B).

[Type 2]

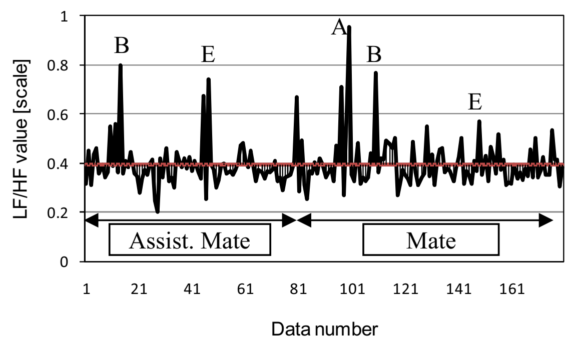

Figure 6. The results of the LF/HF value while passing through a narrow channel every thirty seconds (subject D).

Events in Figures 5 and 6 are below;

A) Subject prepares to begin the navigation in simulator bridge room with bridge team members who receive a briefing from a marine transportation professor.
B) Just before beginning the scenario, team members check radio communication.
C) Mate makes a radio call to a target ship and gets steering orders. The subject then turns the ship to the left and avoids the target ship.
D) Subject makes a radio call to the target ship and gives a lot of steering orders to helmsman. The subject then turns the ship to the left and avoids the target ship.

E) Subject checks target ship, makes radio call, and avoids it.

In Figures 5 and 6, the remarkable response of the LF/HF values appears when 1) the subject checks and plans his navigation before beginning his navigation (event A), 2) the subject begins to navigate (event B), 3) the subject makes a decision to avoid target and keep a course for safe navigation (event D, E), and the subject pays attention to his work (event C). The values of the LF/HF show well when cadets make decisions for safe navigation well.

From the Figures, two types of mental workload characteristics appeared for the cadets' simulation training. Figure 5 is Type 1: "un-Stable (fluctuating) Type", and Figure 6 is Type 2: "Stable (clear) Type". Type 2 is better because it is similar to the expected professional style.

Figure 7 is the reference result of a professional (captain). His mental workload appears clearly when he needs to make a decision. The event meaning is the same as Figures 5 and 6.

[Reference Result]

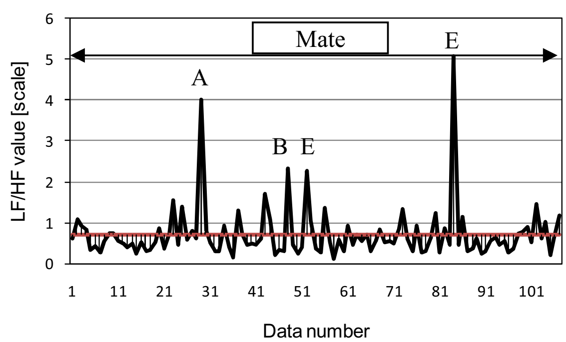

Figure 7. The results of the LF/HF value while passing through a narrow channel every thirty seconds (Captain).

VII. Discussion

Generations of deck officers have successfully embarked upon careers without the benefit of bridge simulator training. Yet there is reason to believe that simulator training offers advantages over earlier methods of career preparation. Simulator training cannot impart all the skills required of a competent watch keeper. It will not, for instance, necessarily make a poor navigator into a good one. However, simulator training can highlight human performance in ways that other types of training do not, particularly with regard to stress. A superb navigator in a relatively static situation may discover he or she has poor skills when it comes to a dynamic traffic situation involving frequent radio calls. Conversely, an average navigator may be exceptionally well suited to piecing together a complex traffic situation and making timely decisions. The ideal mariner combines both, but when dealing with human beings we are invariably faced with a spectrum of abilities.

One area where we see improved performance through bridge simulator training is the manner by which passage planning appears to reduce stress on the officer in charge. Students who have not been instructed in passage planning, and do not apply the techniques, frequently do poorly in simulator exercises. They cannot keep up with developments, they quickly become overwhelmed, and may ultimately lose control of the situation. As cadets gain exposure to passage planning techniques, and incorporate them into their preparations, they are able to develop a more accurate mental model of the simulated world around them. Situational awareness rises, and students often appear calmer and more able to handle the unexpected. Importantly, cadets are often well aware of this transformation in themselves, and thereby adopt the concept of passage planning as part of their personal route to success.

Admittedly, a mariner with extensive experience may be able to perform successfully with very little situation-specific preparation. But cadets who do not have the benefit of long experience quickly learn that passage planning is one of the best ways they can compensate for their lack of experience and lower their stress levels.

VIII. Conclusions

We attempted to evaluate the mental workload of the cadet using a well-known index, LF/HF value, in simulation training. As a result, we can confirm the effect of the LF/HF value as follows:

1. The LF/HF value increases when the cadet begins his mental workload for safe navigation: making decisions for ship-handling like a professional.

2. The LF/HF value shows the level of the cadet's mental workload well.

3. The LF/HF value is a good index for the evaluation of simulation training.

In future research; 1) we will compare the response relationship between cadets and professionals when attempting safe navigation; 2) we will try to determine how to reduce the cadet's mental workload; and 3) we will use a real ship to conduct experiments.

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