Mental Workload of Ship's Navigator
– A Few Comments on Heart Rate Variability during Navigational Watch Keeping –

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Abstract. A navigator efforts to handle the ship for safe navigation by judging navigational information on own ship's condition, targets and current-wind effect, and he/she has the responsibility of human lives and economical values under the judgment. The navigator keeps a mental workload during the navigational watch keeping.
Therefore, we need the development of a support system to reduce the mental workload with human-system cooperation based on navigator's *KANSEI*, and we must research on an index to asessment of a mental workload for the first step. The purpose of this paper is to find characteristics of navigator's mental workload with heart rate variability (R-R interval). The experiment carry out for six kinds of sea area in Japan, and the subject is chief officer of a training ship in Kobe University of Mercantile Marine.

1 Introduction

A navigator gets navigational information from own ship's condition and her navigational environment through five senses, and he/she keeps to handle the ship for safe navigation to recognize and analysis it.

For modern navigation, a navigator is supported by the navigational instrument, and he/she has obtained the convenience and human ability promotion from human-systems cooperation. Now, we mainly request the system draws the ability of a navigator. In short, it put navigator's *KANSEI* to practical use, and its system guide naturally him/her to safe navigation. Here, human *KANSEI* is an individual sense, and its ability is not always achieved by the experience. In this paper, we define *KANSEI* is a sense including perception, recognition and awareness under conscious and unconscious level. Also, it is said that there are public's, artist's and professional's *KANSEI* in the type[1–3].

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The first step of our study is to find a proper index of system assessment. So, we propose the evaluation of navigator's mental workload with R-R interval, which used to evaluate a mental workload of air pilots and car drivers in transport system. Here, we think that the physiological response that is himself/herself inner response is most important index for navigational system's assessment to support safe navigation, because the ship handling is done by the navigator.

Our experiments carry out for the navigator in six kinds of sea area in Japan. The subject is chief officer of the training ship of Kobe University of Mercantile Marine (KUMM).

The results show that his mental workload is different for the ship handling of each sea area. To be concrete, his mental workload increases while the judgment of the ship handling is required in congestion sea area with fisher boats and there is the effect of the wind, and the other his mental workload decrease in the open sea. We know our index has the possibility for the evaluation of navigator's mental workload and human-systems cooperation.

2 Measurement of R-R Interval

We measure subject's R-R interval in six kinds of sea area in Japan to find characteristics of navigator's mental workload during navigational watch keeping. We describe our experiment and outline of R-R interval.

2.1 Experiment

We measured R-R interval in *Kii Suido* (①), *Hyuga Nada* (②), *Akasi Kaikyo* (③), *Tosa Wan* offing (④), *Turusima Suido* to *Kurusima Kaikyo* (⑤) and *Sumoto Ko* offing (⑥). Each sea area is shown in Figure 1. This figure shows west part of Japan from *Kyusyu* to *Osaka*. About each sea area name, *Suido* means channel, *Kaikyo* means strait, *Wan* means bay, *Ko* means harbor and *Nada* means open sea[4].

The R-R measurement duration of each sea area is 0400 hrs to 0800 hrs (four hours watch keeping) in *Tosa Wan* offing, 1600 hrs to 2000 hrs (four hours watch keeping) in *Kii Suido* and *Hyuga Nada*, 0400 hrs to 0600 hrs (two hours watch keeping) in *Turusima Suido* to *Kurusima Kaikyo*, 1600 hrs to 1800 hrs (two hours watch keeping) in *Akasi Kaikyo* and 0800 hrs to 1000 hrs (two hours watch keeping) in *Sumoto Ko* offing. The total experimental time is eighteen hours of six navigational watches. R-R interval is measured with millisecond accuracy in the range of 200 to 4,090 milliseconds. Also, our heart rate monitor is holder type, and place three electrodes on the skin.

About the training ship, her length is 49.95 meters, the breadth is 10.00 meters, and gross tonnage is 449.00 ton.

The subject is chief officer of the training ship Fukae-Maru in KUMM. He has twenty-nine years experience on board, the man of forty-seven years old.

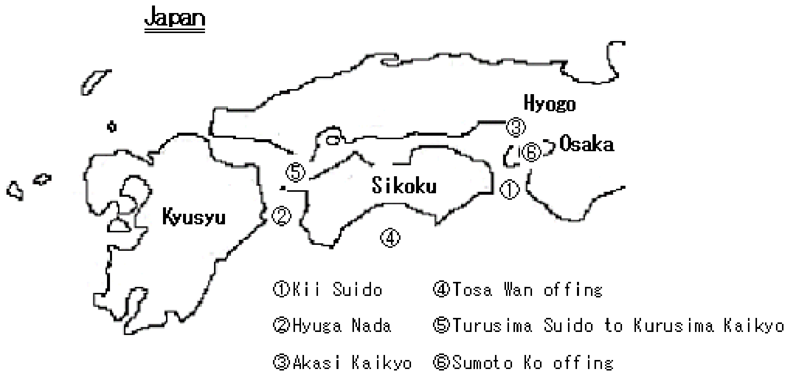

Fig. 1. Experimental area

2.2 R-R Interval

A heartbeat consists of P, Q, R, S and T wave. We show an electrocardiogram (ECG) in Figure 2. From the figure, R-R interval is the peak point R to next peak. Its interval is always variability for a body and a physiological conditions, and the characteristic will be the different for navigational conditions. Also, we select R-R interval from five waves (P, Q, R, S and T) because the R amplitude is most remarkable, and we can easily detect the peak point.

3 How to Analysis of R-R Data

We analyze measured data on time and frequency domain, and we calculate mean, standard deviation, the ratio of mean to standard deviation, *LF*, *HF* and *SNS* value. Also, we consider its data by dividing between the morning watch (0400 hrs to 0800 hrs) and the evening watch keeping (1600 hrs to 2000 hrs), because people has the rhythm of a day. Area number ① to ③ is the morning navigational watch, and ④ to ⑥ is the evening navigational watch keeping.

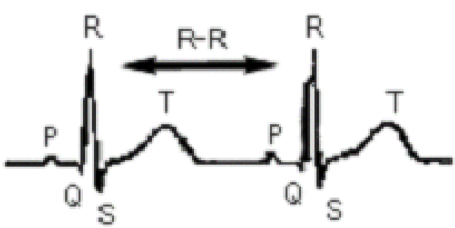

Fig. 2. R-R interval

3.1 On Time Domain

We convert measured R-R interval into heart rate (*HR* [bpm]) with following equation (1) and calculate mean (μ), standard deviation (*SD*) and the ratio (ρ) of mean to standard deviation with *HR*[5].

$$HR = \frac{1}{\frac{x_i}{1000}} \times 60 \tag{1}$$

Here, x_i is values of R-R interval at measurement number i.

3.2 On Frequency Domain

We analyze R-R interval by utilizing the frequency component (*LF* and *HF*) will show an activity of the sympathetic nervous system and the parasympathetic nervous system, and we calculate Low Frequency (*LF*), High Frequency (*HF*) and Sympathetic Nervous System (*SNS*) value[6,7] with Fast Fourier Transform (FFT) and Maximum Entropy Method (MEM) after interporated with cubic spline. Here, *LF* is the frequency component of 0.04 to 0.15 Hz, *HF* is the frequency component of 0.15 to 0.40 Hz[8], and *SNS* calculate by following equation (2). Also, we use FFT for the analysis at every sea area and MEM at every event of each sea area.

$$SNS = \frac{LF}{HF} \tag{2}$$

SNS value is effectively index, which can evaluate for the sympathetic nervous system and the parasympathetic nervous system activity at the same time. It is considered that the navigator keeps the mental workload when its values increase.

4 Results

We show results of the mental workload calculated for each sea area and events of *Akasi Kaikyo* with the values (μ, *SD*, ρ, *LF*, *HF* and *SNS*), and we check the relationship between the mental workload and wind velocity. Also, we attach "A" and "P" of A.M., P.M. to number of sea area ① to ⑥.

4.1 Mental Workload for Each Sea Area

We show the mental workload for six kinds of sea area with mean, standard deviation and *SNS* values in Figure 3. In the figure, a bar shows *SNS*, a dot shows mean and vertical line shows *SD*.

From the result, mean of *HR* increase for *Sumoto Ko* (⑥), *Kii Suido* (①), *Akasi Kaikyo* (③) and *Tsurusima Suido* to *Kurusima Kaikyo* (⑤), he needed to judge the avoidance of fisher boats and the engine control in these area, and *SD* and mean are the same tendency. *SNS* value increase for *Sumoto Ko* (⑥),

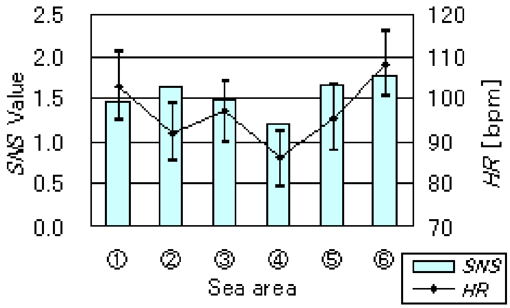

Fig. 3. Mental workload for six kinds of sea area

Turusima Suido to *Kurushima Kaikyo* (⑤) and *Hyuga Nada* (②). On the other hand, these values decrease for *Tosa Wan*, which is open sea (the Pacific Ocean).

There is the difference of the characteristics between *HR* and the frequency components of R-R interval (*SNS* value), and the value of frequency component is better from subjective evaluation, because the frequency component has shown well the relationship between his behaviour of the ship handling and its values. This difference shows it is difficult to distinguish the body and the mental activity with *HR*.

We know characteristics of navigator's mental workload are different for each sea area in Japan, and in other words, we may be able to evaluate navigator's mental workload of various situations on board. However, we do not know characteristics for events of the ship handling in each sea area because of averaging results in Figure 3. Therefore, we must check the relation to events.

4.2 Mental Workload for Events during Navagational Watch Keeping

As a result, we show *SNS*, *LF* and *HF* values during navigational watch keeping of *Akasi Kaikyo* (çB) in Figure 4. In the figure, each frequency spectrum is a ratio to total spectrum, and number (I) to (IV) show main events of subject's behavior obtained from our observation. In this paper, *SNS* value calculate every thirty seconds with MEM.

From the figure, *SNS* value and its fluctuation increase at the entrance of the passenger route (I), the judgment of ship handling (II) and chart work (III). Moreover, it increases while there is the effect of the wind (IV).

This result shows that *SNS* values increase while a navigator needs to judge the ship handling and to feel mental workload emotionally, and a navigator gives attention to not only avoidance of targets but also wind-current effects. The characteristics of navigator's mental workload with *SNS* had shown by the level, the response time and the reaction time.

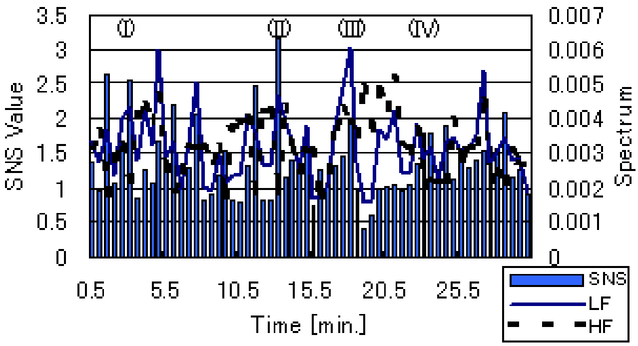

Fig. 4. Mental workload for events (*Akasi Kaikyo*)

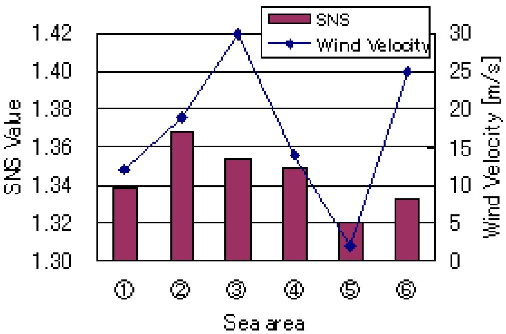

Fig. 5. Relationship between mental workload and wind velocity

4.3 Relationship between Mental Workload and Wind Velocity

A navigator is careful about not only targets but also wind and tidal current from our results. We show relationship between mental workload and wind velocity in Figure 5 with SNS values. Here, the value of wind velocity is mean of each sea area.

From the figure, subject's mental workload tends to decrease in proportion to the wind velocity. A navigator sensitively shows the reaction on the effect of wind velocity. From this result, *SNS* value shows navigator's mental workload well.

5 Conclusions

We proposed the index with R-R interval for evaluating the navigator's mental workload, and carried out the experiment for professional in six kinds of sea area.

From the results, R-R interval was effective in finding the defference of the mental workload for each navigatinal conditions.

Our future works is as follows.

1. to carry out the experiment for other professional.
2. to analyze frequency components of R-R interval in detail.

References

[1] S.Inokuchi, K.Inoda, S.Tanabe and T.Nakamura: *KANSEI* Information Processing, Ohmsha Ltd. (1994) 1–12, 103–130
[2] J.Gyoba and Y.Hakoda: Psychology of Intellect and *KANSEI*, Fukumura Ltd. (2000) 65–75
[3] S.Tsuji: Science of *KANSEI* Saiensu-Sha Ltd. (1997) 1291–1295
[4] Japan Institute of Navigation: Basic Navigation Glossary, Kaibun-Do Ltd. (1993)
[5] K.Murai, Y.Hayashi and S.Inokuchi: A Basic Study on the Body and Physiological Response to Visual Simulation of Ship Rolling, Trans. IEE of Japan, Vol.122-C, No.12 (2002) 2172–2179
[6] H.Kobayashi and S.Senda: A Study on the Measurement of Human Mental Workload in Ship Handling Using SNS Value, The Journal of Japan Institute of Navigation, Vol.98 (1998) 247–255
[7] K.Murai, Y.Hayashi and N.Wakabayashi: Analysis of Heart Rate Variability of Navigator at in/from Ports by Wavelet Transform, Proc. of 2001 IEEE Pacific Rim Conference on Communications, Computers and Signal Processing, vol.2 (2001) 681–685
[8] K.Ohtsuka: Clinical Assessment of Heart Rate Variability, Respiration and Circulation, Vol.42, No.2 (1994) 125–132