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Mental Workload of the VTS Operators by Utilising Heart Rate

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ABSTRACT: This study clarifies the mental workload of VTS Operator; by understanding their characteristics during carrying out their task, with a physiological index. The objective is to determine VTS Operators' mind stress that might trigger any human error based on their mental workload during their watches. For this purpose, Heart Rate Monitor (HRM) is utilized as physiological index. The VTS Operators fitted the HRM and all of them have experience as a Master Mariner. During the all experiments, their heart rates and behaviours were recorded on the Event Record Form based on the time scale. After getting the heart rate variability, it is matched with the events, and then Operators' behaviour is understood as the mental workload due to such kinds of events. Furthermore, these workloads include the Operators' mind stress and their decisions under these circumstances. This study provides the fundamental information for understanding the VTS Operators' characteristics.

1 INTRODUCTION

This study is one of authors' systematic studies for understanding the behaviours of seafarers. And, the investigation of heart rates is found a suitable physiological index for evaluating mental tasks.

1.1 *Heart Rates and Heart Rate Variability (HRV)*

A healthy person's heart will pump between 60 and 140 times per one minute, depending on whether the individual is under exertion or at rest. Beating of the heart is caused by rhythmic contraction of the atria and ventricles under the control of Autonomic Nervous System, ANS, (Malik 1996). ANS has two components; Sympathetic Nervous System (SNS) and Parasympathetic Nervous System (PNS).

Heart rate is a term used to describe the frequency of the cardiac cycle. It is calculated as the number of contractions (heart beats) of the heart in one minute and expressed as "beats per minute (bpm)".

Heart Rate Variability (HRV) is the variation in times between successive heartbeats (i.e. R-R intervals that is a term from the peak of R wave to the next peak in microseconds). R-R interval always fluctuates to reflect the physical and the mental conditions. The frequency components of R-R interval reflect Low Frequency, LF, (0.04 - 0.15 Hz) and High Frequency, HF, (0.15 - 0.40 Hz). This index is able to evaluate both SNS and PNS activity at the same time. The LF provides a quantitative index of the sympathetic and parasympathetic activities controlling the heart rate, while HF provides an index of the parasympathetic tone (Ishibashi & Yasukouchi 1999).

The relationship between R-R interval and heart rates (bpm) is when the interval time of R peaks increases conversely heart beats decrease in minute. It means that the fast heart pulsates, the smallest R-R intervals. HRV analysis is based on measuring variability in heart rate; specifically, variability in intervals between R-R. Power spectral analysis (obtaining HF and LF) on HRV is useful to assess the mental workload (Sloan et al. 1995).

HF relates to parasympathetic activity (such as controlled respiration, cold stimulation of the face, and rotational stimuli), and LF relates to both parasympathetic and sympathetic activities such as tilt, standing, mental stress, and moderate exercise (Malik 1996). Some studies suggest that LF is a quantitative marker of sympathetic modulations; other studies view LF as reflecting both sympathetic activity and parasympathetic activity. Consequently, the ratio of LF/HF is considered to reflect the sympathetic modulations. That's why this ratio can be considered to the SNS index for evaluating mental workload as defined by Kobayashi & Senda (1998).

Before carrying out experimental studies, authors carried out pre-study for recording heart rates of VTS Operators (VTS-Os) while sitting operation desk (console table) when they are doing nothing and when they arrange display of the operating system before taking the watch. These two conditions compared and the results can be summarized as; two samples (resting and arranging display at the console table) compared with ANOVA analysis in heart beats and also R-R intervals. The analysis results show that two samples data are different (F statistics is significant at the confidential level, $p < 0.05$). The physical actions of operator are at the minimum level due to always sitting. It can be assumed that this difference mainly occurs for the effort of performing task as mental behaviours. This information is useful for considering the results that would be mainly affected by the fluctuation of heart rates caused by sympathetic activities as mental workload (until the respirations doesn't influence for the contra verse situation such as instantaneous emotion).

The relation between HR and HRV is found from the pre-study as; recording R-R intervals and predicted R-R intervals (that estimated by heart beats, using by average values of R-R for every beat times) are the same pattern, (the correlation is 0.99 significantly ($p < 0.01$)). And also, two samples belong to same population (F (0.0005), p: $0.98 > 0.05$).

There is very few study related to HR in the maritime field, and they mainly consider to the navigators' heart rate variability during on board and in the simulator experiments. These studies (Kum et all. 2004, Kobayashi & Senda 1998, Murai et all. 2004a and Murai et all. 2004b) obviously show that there were remarkable effects for the navigators' heart rates during the task performing. On the other hand, there is not found such kind of study for the VTS-Os. That's why heart rate variability has enthusiastically been employed in physiological assessment of respective working environmental factors during the executing task process of VTS-Os in this paper.

1.2 *Mental Workload – MWL*

Workload is defined as the physical and/or mental requirements associated with a task or combination of tasks (Gudipati & Pennathur, unpubl.). Workload refers to the operators have limited capacity that actually required to perform a particular task; it is the interaction between the operator and assigned task (Gopher & Donchin 1986).

Workload is classified as Physical Workload (PWL) and Mental Workload (MWL). PWL is the measurable portion of physical resources expended when performing a given task (Gudipati & Pennathur, unpubl.). MWL is defined as the level of processing capacity while performing the task or the difference between the capacity to affect the usable real performance and human-information processing system (Eggemeier & Wilson 1991). The common idea for the MWL is directly proportional with the difference between existing sources and required sources by the task.

Under these explanations, we can consider three kinds of loading for performing a task. Firstly, the operator capacity is over to the required performance. This situation tends to the operator bored and then also tends to make mistakes. Secondly, the capacity is equal to the required performance that is the best fitting of the employment not only for human resources but also for the efficient performance of the task. Finally, when the operator capacity is not enough to perform a task due to overlapping task items; this situation tends to the operator has stress. And, if the last situation ordinarily continues, occupational stress will occur automatically and it makes the operator has not satisfied his/her job. That's why; the acceptable workload can be determined as the level of workload not to impede the operator to manage the system safely and effectively (Jung & Jung 2001).

The concept of mental workload has become an important issue for all kinds of industry after 1960's. The main reason of that is the computer and it becomes indispensable component of the life. Therefore, there is a rapid increase for the publishing of papers related to the MWL. On the other hand, the quantity of research related to MWL in maritime field is so restricted. Authors hope that this study could take an interest to consider not only shore side staff in maritime sector but also for personnel on board and in shipping companies. It is assumed that the factors to cause MWL and its affects can be analyzed by the common measures (such as NASA TLX, SWAT and so on) for more understanding of maritime human factors. Because when we investigate the studies in the maritime field, regretfully saying that there is not any study found related to measurement to MWL in these common measures such as utilized in the air and land navigation field, just a few studies consider to MWL of navigators by only using the heart rate variability as mentioned by section 1.1. Authors also submitted a questionnaire to the VTS-Os for determining the MWL factors and applied NASA-TLX for measure their MWL as the forward stage of this study.

In this study, the mental task of VTS-O is defined as shown in Figure 1. VTS-O obtains cognitive information from the VTS System and performs the task under his skill based on the regulations. That's why the "mental workload" is the difference between human information process and the operator's capacity which affects to the actual performances that can be expended by operator (for covering the required performance). Under this excessive mental workload, operators may exhibit delayed information processing, or even not respond at all to incoming information, because the amount of information surpasses their capacity to process it (Ryu & Myung 2005).

It is mentioned in all studies (the common sense) of the air and land navigation (except of maritime navigation due to not found any related study) that the factors to cause MWL is not clarified. On the other hand, some studies show that nature of work, training and age (Duru et al. 2005), physical conditions of working environment (Leplat 1993), the structure of task such as task aim, performing in the most proper way and operator's task perception (Hart & Staveland 1988) have affect on MWL. According to ISO 10075:1991 (*Ergonomic principles related to mental workload*), the fundamental factors of MWL are; task, work equipment, physical work environment and social work environment.

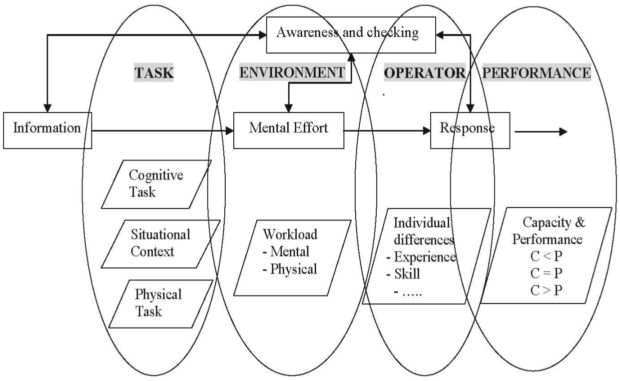

Fig. 1. Mental task of VTS-O

2 EXPERIMENTAL STUDY

Turkish Straits VTS (TSVTS) consists of Istanbul VTS and Çanakkale VTS by covering area of the Istanbul Strait, the Marmara Sea and Çanakkale Strait (total length of the area is 164 nm). This experimental study is carried out at the Istanbul VTS Center. Istanbul VTS has 4 sectors; (North to South) Sector Türkeli is the north entrance of the Istanbul Strait (between the northern limit of the Istanbul VTS and the line joining Fil-Çali Point), Sector Kavak covers the area between the line of Fil-Çali Point and the Fatih Sultan Mehmet Bridge, Sector Kandilli's southern limit is the line of Haydarpasa Breakwater and Sector Kadiköy is the southern limit of the Istanbul VTS.

TSVTS is operated in 24 hours; there are two watching system as day shift and night shift. The shifts have 2 hours watches. There are; two VTS-Os (while one of them operates the system the other is standby), one Assistant Supervisor and one VTS Supervisor, VTS-S, (who is an appropriately qualified VTS-O carrying out supervisory duties on behalf of the VTS Authority) in every watch. Additionally, some of the VTS-S (who engaged for daily administrative works other than interaction with the vessels), Data Input Operator (who engaged to input the vessels sailing plans to the system) and other staffs are involved day shifts.

The number of VTS-Os is 48 (including VTS-S) at the Istanbul VTS and 30 operators at the Çanakkale VTS. All of the Turkish VTS-Os has sea experience (their average sea experience is 13.6 years) as a Ship Master (5.5 years is the average level of their experience as actual Ship Master). Their average age is 33 years and all of them have Bachelor's degree from a maritime faculty.

2.1 *The Profile of VTS-Os*

There are 48 persons employed for the Vessel Traffic Services at the Istanbul VTS Center, 32 of them are actually engaged for operating the system to communicate with the ships [two operators for every sectors at the each (A, B, C and D) shift].

Eight of 32 VTS-Os have fitted HRM under different conditions for experimental studies. There are not any specific criteria to choose these VTS-Os, they were chosen randomly. But authors mainly want to investigate different environmental situation in the VTS. That's why; four of experimental study was particularly carried out simultaneously for the four sectors. It was quite difficult to carry such kind of experiment during the actual task execution not only for the authors but also for the VTS Authority for giving any permission. In this concept, during the permission time to carry out these experiments, authors made as much as experiments for understanding of the harmonized environments. And, finally 8 VTS-Os were analysed from total of 32 VTS-Os by the ratio of 25%.

Table 1 shows the profile of these operators. VTS-Os have 6.8 years experience as Ship Master and 2.5 years as VTS-O (in average). Majority of operators doesn't smoke and they are healthy. Their average weight is 91.5 kg, average height is 178.3 cm and average age is 41 years.

Table 1. Profile of VTS-Os

		VTS-O_1	VTS-O_2	VTS-O_3	VTS-O_4	VTS-O_5	VTS-O_6	VTS-O_7	VTS-O_8	Average
Competency		Ship Master – Unlimited, VTS Operator (Certificate)								
Educational Level		BSc at Istanbul Technical University Maritime Faculty Deck Dept.								
Experience as (years)	Master	2	6	8	0	11	10	6	11	6.8
	Chief Officer	5	2.75	6	6	1	5	4	4	4.2
	Officer	3	2.75	2	3	4	5	4	3	3.3
	Total Sea Exp.	10	11.5	25	9	16	20	14	18	15.4
	VTS-O	2	0.75	5	3	0.5	5	2	2	2.5
Age		37	39	47	36	37	52	39	42	41.1
Weight		84	80	103	95	97	92	76	105	91.5
Height		172	180	185	175	186	179	179	170	178.3
Smoking		No	No	Yes	No	Yes	Yes	No	No	No

2.2 *Conditions of Experimental Study*

The experimental studies are carried out in different conditions such as; the flow of traffic direction, watch keeping times, weather conditions and sectors in VTS area. Authors carried out totally 8 experimental studies at the Istanbul VTS Center as shown in Table 2. Four of them are carried out simultaneously for determining the interactions among the Operators by covering all sectors in the VTS area. The others are carried out randomly.

Normally, the traffic situation in the Istanbul Strait is two ways traffic based on the Traffic Separation Schemes. But at that time, the flow of traffic was just one way due to the operation that carried at the southern entrance of the Strait for underground railway system. That's why during our experimental study, the traffic in the Strait was just one way, it is important to indicate this information due to considering workload of VTS-Os'. Their workload level was under the normal case because the capacity of the system was not routine. As the mentioned by VTS-Os, they don't feel that it is really as difficulty as comparing the normal traffic situation in the Strait, so it is observed that they are in quiet behaviours (especially VTS-O in the middle sectors for just observing to passage of one way traffic). One of the experiment was carried out when the traffic direction was changed due to estimating the VTS-O's MWL in more congested traffic cases, and also authors mainly focused the south/north entrance of the Strait depends on the traffic direction. The environmental conditions in the Strait are fine.

Table 2. Outline of the experimental studies

Date	Time	Sector	VTS Op.	Traffic Direction
22.11.2006	13:50-16:00	Kadıköy	VTS-O_1	North to South (Southbound)
	13:58-15:42	Kandilli	VTS-O_2	
	13:35-15:56	Kavak	VTS-O_3	
	13:24-15:30	Turkeli	VTS-O_4	
23.11.2006	14:41-15:43	Turkeli	VTS-O_5	
24.11.2006	18:55-20:16		VTS-O_6	
25.11.2006	00:00-00:59	Kadıköy	VTS-O_7*	South to North (Northbound)
	00:56-01:57		VTS-O_8	

* Traffic direction was change to South to North.

2.3 *Recording Data*

The Heart Rate Monitor (HRM) which is equipment that consists of a wrist watch, a chest belt (strap) and software produced by POLAR Co. Ltd. is utilised in this study. The type of this model is S 810i which can measure not only heart beats (bpm based on time sequence as 5 sec., 15 sec. and so on) but also R-R intervals.

Before executing the experimental studies, authors needed to prepare equipments (such as HRM, voice data recorders and camera) and documents (such as Information Data Sheet for recording ships' data (e.g. ship's name, type, length, cargo, pilot on board or not and so on) that interrelated to VTS-Os' communication and Event Record Form for recording their all behaviours and actions as shown in Figure 2) for reliable keeping records.

EVENT RECORD FORM (VTS Operator)

Name : .... **Date:** .../........../......
Nationality :
Present Position : ☐ VTS-O; Sector: ☐ Türkeli ☐ Kavak ☐ Kandilli ☐ Kadıköy
Competency : ....
Educational Level : ....
Experience as : ☐ Master.....years ☐ C. Officer...........years ☐ Officer......years
☐ VTS-O ....years ☐ Other ....years
Any Sea Experiences: ....years / .... months (Total)
Age/Weight/Height : ......yrs / ....kg / ......cm **Start/Finish Time:** ..../..........
Additional information : *(heart problem, smoking and so on)*

TIME			Event	Whom-Ship-Pilot	Remarks-Position
Hour	Min.	Sec.			

Environmental Information:

(1) Weather Condition : ☐ Rain ☐ Fog ☐ Cloudy ☐ ....
1) Wind Force :
2) Wind Direction :
3) Temperature :
4) Barometer :

(2) Sea Condition : ☐ Rough ☐ Calm ☐ ....
1) Temperature :
2) Wave Height :
3) Wave Direction :
4) Swell Height :

(3) Current :

Fig. 2. Event Record Form for VTS-Os

2.4 *Analysing Data and MWL Assessment*

In the analysis, the software (Polar Precision Performance SW Version 4.03.044) is used for getting the characteristics of heart rate and frequency components. And for the further analysis, the statistical analysis techniques (to determine the significances of differences and similarities), power spectrum analysis and Maximum Entropy Method (obtaining LF, HF and the ratio of LF/HF) are also investigated.

Heart beats (recorded as bpm for every 5 sec.) of VTS-Os are the raw data, then R-R intervals are predicted from heart beats by using the average value of R-R intervals for every bpm (Figure 3 shows the R-R intervals of VTS-O_7). Later, the components of R-R intervals (LF and HF) are calculated, and then LF/HF ratio is obtained.

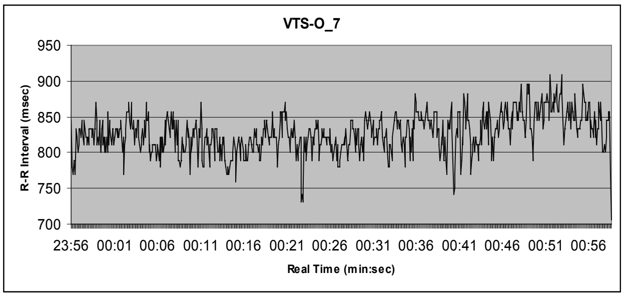

Fig. 3. R-R intervals of VTS-O_7

When authors checked the direct relation (by the regression analysis) among heart beats, R-R interval and LF/HF ratio, it is found that the coefficient of correlation is 0.68 ($p < 0.01$).

The mental workload assessment is performed as follows (Fig. 4);

- Individual assessment for every VTS-O; firstly to consider on fluctuation of heart beats and then the ratio of LF/HF.
  - To consider the rise and declines in the heart rates and to check the events for this fluctuation simultaneously and also to check the ships' specifications in these events.
  - To consider the remarkable events and their effects on the heart rate.
  - To consider the remarkable vessels and their effects on the heart rate.
- General assessment (including individual and mutual assessment) for getting common and sharing behaviours; to consider the sharing behaviour for VTS-Os in the different sectors based on the events and/or the ships' specifications.
- Assessment based on the sectors; to consider the any relation between MWL of VTS-O and the sector that he operates, e.g. there is not strong effect for MWL of VTS-O who operates the middle sectors due to traffic direction was one-way and mainly they focused to observe the passage and just communicated for position reports and so on.
- Finally, the assessment made for any difference because of the different watch times, environment, weather and sea condition that may affects to MWL of VTS-O.

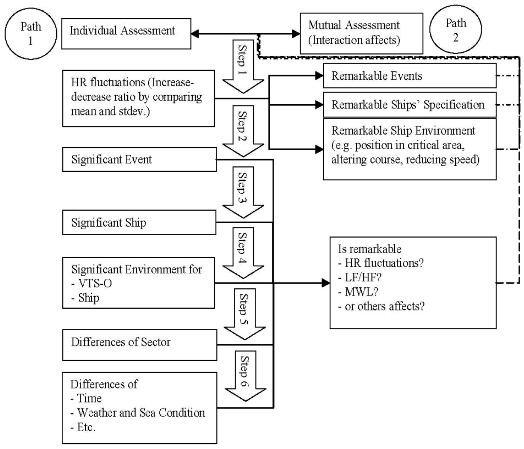

Fig. 4. Procedure for mental workload assessment

3 RESULTS AND CONSIDERATION

As indicated by the summary of VTS-Os' heart rates in Table 3, the average heart rate is 79 bpm (standard deviation is 5 bpm) is slightly high, because of they are ready to have any task, and every time they keep their attention.

Table 3. Summary of VTS-Os' heart rates

Data	Unit	VTS-O_1	VTS-O_2	VTS-O_3	VTS-O_4	VTS-O_5	VTS-O_6	VTS-O_7	VTS-O_8
Duration	h:m:s	02:11:55	01:44:45	02:12:10	02:07:05	01:00:50	01:18:15	01:02:35	01:00:45
Number of Heart Beats	beats	10,824	8281	11,505	8520	5421	5326	4574	5353
Minimum Heart Rate	bpm	66	66	72	54	80	57	66	73
Average Heart Rate		82	79	87	67	89	68	73	88
Maximum Heart Rate		111	99	121	99	110	81	85	104
Standard Deviation		7.1	5.9	6.9	6	3.7	3.5	2.5	4.8

When comparing the means of heart beats for four sectors during the simultaneous experimental study, it is determined that VTS-Os have different behaviour significantly ($p < 0.01$) as shown in Figure 5.

General assessment made for getting the interaction affects and sharing behaviours of VTS-Os. The remarkable points are as follows:

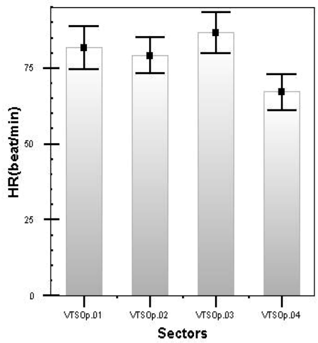

Fig. 5. Changes in HR at the 4 sectors

- At the beginning of watches their MWL was highest (2-3 minutes of the watches), and they mainly arranged the display of monitors, observing the existing traffic during this time. And also, it is obtained that when they made observing the traffic, their MWL was higher and continuous during any time of the watch.
- It is determined that 90 bpm of heart beat is the baseline for remarkable MWL. When heart beats are over 90 bpm, the increase in the MWL is obtained.
- There is not found any statistical relation between physical condition of VTS-Os and fluctuations of heart rates. As an example; the result of Chi-Square test between smokers and non-smokers of VTS-Os shows there is not any difference between these two groups based on their heart rate and heart rate variability ($p > 0.05$). Indirectly saying that the smoking situation of VTS-Os doesn't affect to their MWL.
- The ships over 150 mt. affected to increase MWL. Also, tankers, gas carriers and the ships carry dangerous material slightly affected to increase MWL. In generally, ship's length and type had close relations, but some cases when the ship's length was less than 100 mt., mental workloads were affected by ship's type.
- The ships which took pilot increase their MWL. Ship's size and taking a pilot had also close relation, but similar case was found as above.
- When the other operator asked questions to not any affect on MWL, but when the operator asked questions to the others his MWL was increased.
- When VTS-Os spoke the individual items with the other operators/persons, their MWL increased temporary (comparing the situations related to operation) and calmed down again.
- When they gave "advice" and "instruction" to the ships, MWL increased but that was not the highest workload (the sample of such kinds of case were not enough, it occurred 3 times during the time of all experimental studies).
- There is not strong effect for MWL of VTS-Os who operate the middle sectors due to traffic direction was one-way and mainly they focused to observe the passage and mainly communicated for position reports and so on.
- Cut down of electric power or some system technical problems did not affect their MWL.
- There are not found any remarkable effect due to the difference of environment, during the experimental studies weather and sea conditions, current were fine. And visibility is clear in the Strait.
- The difference of MWL for VTS-Os depends on the sectors which they operate, traffic density (especially changing the traffic direction mainly affects to increase the traffic volume and as a result of this, the communication is increased until the stable navigation is performed for covering the ships would enter the Strait).

The figures of VTS-Os' heart rates clearly show that there is a rapid decline of heart fluctuations when the beginning of mental workload, and it instantaneous increases during the task execution then slightly keeps the condition (depends on the performing time), and finally repeats the rapid decline.

4 CONCLUSIONS

The specifications of ships such as length, speed and draft (when they are in high values that mean to reach the limitations of the passing area (e.g. some limitations are applied for the ships with a length over all of 150 m. or upwards in the Istanbul Strait) and the traffic volume have an effect on the mental workload of VTS-Os. On the other hand, one of the remarkable points is the vessel that took pilot affect to VTS-Os' mental workload.

The factors to cause MWL of VTS-Os can be summarised as follows; ships' specifications, the area where ship is sailing (sailing area), traffic density, either ship takes a pilot or not, communication skills of Ship Master, and work fatigue, tiredness.

In conclusion, this study provides the fundamental information for understanding the VTS Operators' characteristics. Our future work is to analyse more situations in the different VTS areas (e.g. the Japanese VTS-Os (especially who don't have any maritime background)); not only utilised by HR as physiological assessment but also utilised by subjective assessment measures such as NASA-TLX, SWAT, etc. for clarifying the relation of these two assessment techniques.

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