VTS Operators' Eye Movements

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Abstract

This study clarifies the characteristics of Vessel Traffic Services (VTS) Operators' eye movements during their regular tasks. Experimental studies are carried out at the Istanbul Strait VTS Head Center in TURKEY for the general aim of the authors as maximising integrated human reliability on board during the passage of congested waterways.

The safe passing through the Istanbul Strait is a critical issue not only for VTS Operators (VTS-Os) but also for Ship Masters, ship owners, major oil companies and so on for saving lives, keeping clean seas and also economic aspects.

The objective of this study is to define eye movements of VTS-Os who have a long-term experience as a Ship Master. For this purpose, Eye Mark Recorder (EMR) is utilized as physiological index to evaluate fixation points, fixation durations and changes in viewpoints of VTS-Os. Three experimental studies are carried out in different conditions of watch keeping times and sectors in the VTS area.

VTS-Os' eye movements were recorded by the EMR-8 that provided by Istanbul Technical University Maritime Faculty. In the analysing part, the visual field is categorized to determine the fixation points of VTS-Os and to understand of what is the mainly information and its significance for their decision-making. Then, the data was analysed by using "Frame by Frame" method. The results are also compared among the VTS Sectors.

The visual field of the operator consists of two computer screens, two monitors for displaying of cameras in the Istanbul Strait and cameras' control unit, VHF communication unit and paper work area. Computer screens of the VTS System can spread from one display to other and VTS-Os generally used the function of picture in picture on the display.

There are some sharing behaviours for the VTS-Os' fixation durations and some differences based on their individual characteristics. Generally, their eye movements have

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similar pattern for operating VTS System and for the information. However, the order of information changed among the fixation points, and the fixation durations changed based on the operating display as individual choosing. On the other hand, moving of viewpoints was over 60 deg/sec, so saccade of eye movements has significant ratio, because of quick eye movements through the categories.

Keywords: Human Element; VTS Operator; eye movements; fixation duration; viewpoints

1. Introduction

The most important source of getting information through the environment of human is the eyes. Almost 70% of the all information is got by the eyes. When considering the information inputting from external world, its quantity is too high for human being, so human selects the necessary information by using the five senses. As the result of that, the source of getting information and the style of using information are valuable for the mariners, especially to consider the supporting systems to the vessels for the safe passing of a narrow waterway; the main supporting tool is their information to provide to the ships. Vessel Traffic Services (VTS) and such kind of services are the main supporting systems as a shore side partner for the ships. In here, the investigating item is; how the VTS obtains this information, what is the way of VTS Operators (VTS-Os) to get, assess and use such various data, and so on? In this paper, authors aim to indicate VTS-Os' behaviours based on their eye movements through the answering such kind of questions for minimizing human error considering to ergonomic design during their task execution. While doing this, it is crucial to keep in mind that VTS-Os who involved in experimental studies have experience as a Ship Master and now they are not onboard but they are involved to bridge as a supporting part of the Captain/Pilot.

There are a few researches related to eye movements of mariners, but there is not any study to search of VTS-Os' eye movements before.

1.1. Turkish Straits Vessel Traffic Services (TSVTS)

Istanbul Strait is one of the difficult to manoeuvre narrow waterways in having of densest traffic. The average numbers passing through the Istanbul Strait is 48,456 yearly, 4,038 for monthly and 133 for daily. Additionally, the number of maritime accidents (daily average is 22.5 ships had accident) is in the high level (Kum et all. 2006). On the other hand, it is obvious the effect of the VTS that constructed in 2003 for the safe passage of ships from Black Sea to Aegean Sea by covering territorial waters of Turkey.

VTS covers the area of the Marmara Sea, Istanbul and Çanakkale Strait is called as the Turkish Straits VTS (TSVTS). The total length of this area is 164 nm. TSVTS is oper-

ated in 24 hours; there are two watching system as day shift and night shift. The shifts have two hours watches. There are; two VTS-Os (while one of them operates to 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 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. The 32 of VTS-Os at the Istanbul VTS have engaged actually for the system operation (who sit on console table and make communication with ships). All of the Turkish VTS-Os has sea experience (13.6 years in average) as a Ship Master (5.5 years in average). Their average age is 33 years and all of them have Bachelor's degree from a maritime faculty.

The experimental studies are carried out at the Istanbul VTS Center. Istanbul VTS has four sectors as shown in Fig. 1.

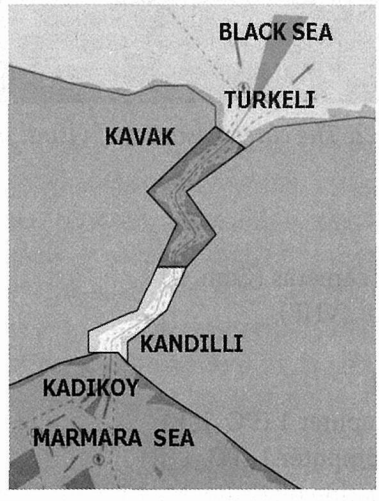


Figure 1. Istanbul VTS sectors

2. Experimental Study

2.1. Experimental Conditions

The eye mark recorder is a head mounted equipment, NAC EMR-8, for detecting subjects' eye movement and recording the fixation points with images superimposed on VTR (Video Tape Recorder) every 1/60 second. The EMR-8 is provided by Istanbul Technical University Maritime Faculty (ITUMF).

It is important to divide the categories to visual field for analysing by "Frame by Frame" method. That's why the whole area of VTS-O's visual field is divided mainly twelve categories as shown in Fig. 2. The visual field of VTS-Os consists of,

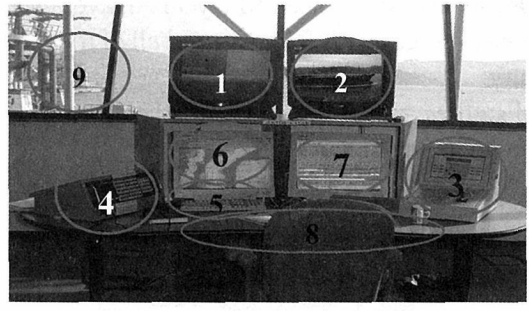


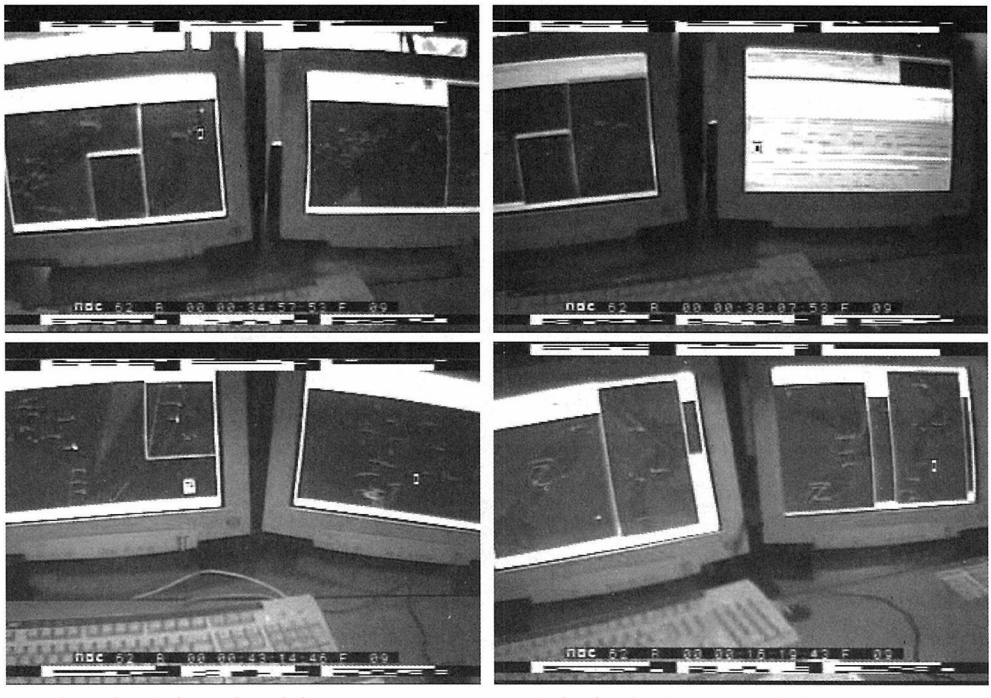
Figure 2. The categorisation of visual field

1. Camera 1 (Cam_1)
2. Camera 2 (Cam_2)
3. Control unit for the cameras (Cam_C)
4. Communication unit (VHF)
5. Keyboard
6. Computer 1 (PC_1)
   a. Left screen of computer 1 (PC_1_L)
   b. Right screen of computer 1 (PC_1_R)
   c. Menu and information on computer 1 (PC_1_M&I)
7. Computer 2 (PC_2)
   a. Left screen of computer 2 (PC_2_L)
   b. Right screen of computer 2 (PC_2_R)
   c. Menu and information on computer 2 (PC_2_M&I)
   d. Page of Ship Movement Information (SMI)
8. Paper works, PW, (notes, logbook etc.)
9. Other spaces (OS); it consists of fixations to environment either than other categories such as looking around, windows etc.

10. Others; means that eye blinks, saccade of eye movements and the shifting period of eye movements from one category to the others.
11. Other operators (OO); when VTS-O looks the near operator on his sides, it is categorised as other operators.
12. Supervisor (VTS-S); when operator communicates and looks the supervisor about one issue it is evaluated that he looks to supervisor.

Almost all operation mainly performed on the computers and their screens can spread from one display to other, also VTS-Os used the function of picture in picture on the display. That's why the screen of computers is divided categories for getting detail information about VTS-Os' eye movements. The photos in Fig.3 show that how VTS-Os use the display function and illustrate the situation of recording eye movements (the small white square indicates the fixation point at that time). Fig. 3 also shows the individual choosing of VTS-Os to operate the VTS system.

During the time of experiments, the flow of traffic in the Istanbul Strait was just one way, North to South (southbound), due to the operation that carried at the southern entrance of the Strait for underground railway system. Moreover, the environmental conditions in the Strait were fine; weather was partly cloudy, average wind force was 8



The order of photos from left upper part is; computer's display forVTS-O_1 and when he looked to Ship Movement Information page, the display of computers for VTS-O_2 and VTS-O_3.

Figure 3. Samples of the recording data and display of computers (PC_1 & PC_2)

knots and northerly, calm sea and normal level of current flow, and visibility was clear in 3 km.

For keeping the fresh knowledge of experiments, authors also fill "Event Record Form for Eye Mark Recorder" included profile information of operators, remarkable events and other useful information based on the time scale.

There are some restrictions to carry out such kind of experiments as;

- To provide a suitable instrument for recording eye movements (it is quite expensive),
- To take administrative permission,
- To be accepted by VTS-O as to be a subject,
- Time limitation for recording (after 20-30 minutes later the subjects do not feel convenient due to infrared light for tracking eye movements, it makes the paint) and analysing (the number of data is so high just for one minute),
- Restrictions for the analysing data (number of raw data, methodology and so on),
- Some environmental restrictions

2.2. Profile of Subjects (VTS-Os)

Totally, authors had three experimental studies at the Istanbul VTS Center. The characteristic of VTS-Os who involved in experiments is shown in Fig. 4. All of them have onboard experience as a Ships Master (5 years in average) and their total average sea experience is 12.7 years. Their average age is 37 years old and they have not any eye problem.

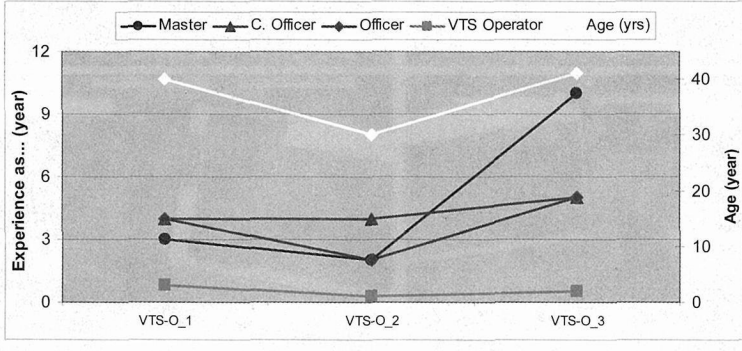


Figure 4. The profile of VTS-Os

2.2. Analysing Method (Frame by Frame)

Frame by Frame method is used to analyse the results of eye movements. The qualitative and quantitative assessments are made based on the result of Frame by Frame method. This method is most suitable, because it doesn't include head motions comparing to the software of eye tracking methodologies.

The raw data of EMR includes 18,000 data (every cell corresponds to one frame) for 5 minutes recording. The steps for the Frame by Frame method are summarised as follows;

1. Watching VTR for getting the general idea of eye movements,
2. Preparing the Microsoft Excel sheets for every subject; in this part when the time is indicated by row, columns indicate the categories that divided by researcher. In addition, the time series continue as indicated by VTR image for every frame. In Fig. 3, time indicated at the lower part as hour, minute, seconds and frame number. The relations between frame and second is "1 second = 60 fields = 30 frames". In Excel sheet, one cell corresponds to one frame and so the cell indicates 33 milliseconds.
3. Filling the category's cell; the researcher starts to watch VTR for playing frame by frame between the time interval of analysing part (starting frame and ending frame on VTR). While this watching, the point of eye tracking by "white square" is followed and its position is marked depend on the categories. In here, it is a good way to put "1" to each cell on the point of eye tracking with different colours of cell that corresponds to different categories.
4. Counting the cells, determining fixation points and durations; when putting the number "1" for viewpoints of VTS-Os, at the end it is counted how many cell or "1" putted in each category. This is the total frames and time for fixation duration. Later similar calculation made for determining the fixation points.

In this study, the fixation duration means that the subject looks at the same area more than 133 milliseconds (four frames). The fixation points mean that how many times subject looks at the categories (successive fixation to the category). And, the place of viewpoints means what the subject have looked at and not related to the duration. In this study authors don't consider the place of viewpoints because eye movements are so fast and they just focus their task, it means that the meaningless image and fixation on empty spaces are almost minimum level, and when they look at one area there should be some meaning for the operation and their decisions during the communication with ships.

The sampling data were chosen randomly as shown in Fig. 5. The first five minutes were neglected due to calibration and arrangements of EMR, subject needed the time to be used to instrument and feel free to return his ordinary task.

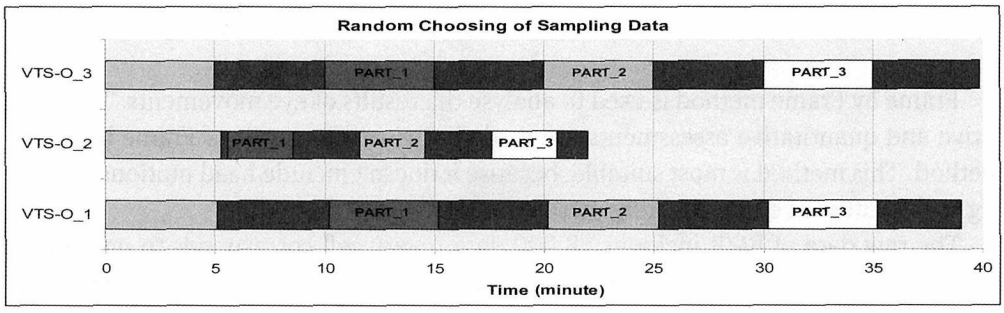


Figure 5. Random choosing of sampling data

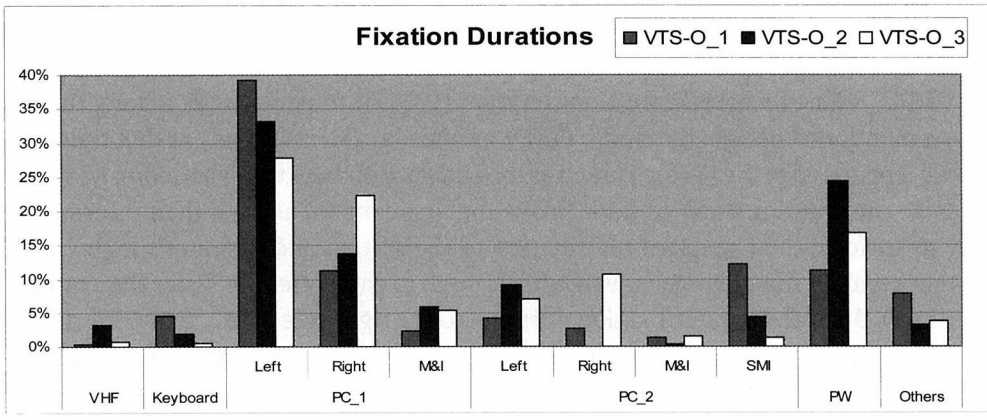
3. Results and Considerations

3.1. Fixation Durations

During the first experiment (VTS-O_1) there were many times cutting off electricity. Normally, the generator supplies the power for the whole VTS system with just a little bit delays. The main parts of the VTS system (operators' console table) are supplied by UPSs until the generator steps in. VTS-Os immediately recognise to cut off electric power and automatically they give some reactions, especially if the generator steps in lately, because during that time they can just follow the screens and the lighting system of the operation room and/or VTS Centre don't work (except emergency lightings and exists). This knowledge is important because the EMR-8's electric supply gets from main source (city electricity) and eye-tracking window cannot be obtained. However, its camera is working so it can be obtained the area where VTS-O_1 fixates on. In the analysing part, the area of fixation points is decided based on the eye-tracking window according to Frame by Frame method. On the other hand, it can be estimated where the eye-tracking window should be, but authors don't do this, and these areas (when the eye-tracking window cannot be observed) are put as "Others" category for VTS-O_1. Then, the fixation duration to "Others" category comes higher than normal for this operator. When authors estimate the area of eye-tracking window based on the camera images, it is determined that the general behaviour of VTS-O_1 is the similar. Moreover, comparing to the other VTS-Os, the results have similarity and the same tendency for the general characteristics of operators (it means that all the below explanation is the same whether electricity cuts off or not). The difference of analysing with cutting off electricity is the ratio of fixation durations to PC_2_M&I increased and "Others" decreased for VTS-O_1.

The significance of the results of Frame by Frame method tested by ANOVA Two-Factor analysis. According to ANOVA analysis, there is no significant difference among the behaviours of VTS-Os based on the fixation durations to the categories as shown in Fig. 6. It is determined that the fixation durations to the categories are significantly different

from each other. VTS-Os have the highest fixation durations to the left side of computer 1 (33.5% to PC_1_L), and the lowest fixation durations to the categories are cameras and camera control unit, supervisor, other operators and other spaces.



F value of VTS-Os is 0.005, $p > 0.05$; F value of the categories is 14.6, $p < 0.01$
Figure 6. Fixation durations to the categories among the operators

Table 1 shows the VTS-Os' choosing display items of computers. VTS-O_1 mainly divided the display of PC_1 in two parts, but he is also to add one small display as shown in Fig. 3. Because sometimes he needed to look the higher scale on PC_1 and sometimes he opened this small display and later closed again. This necessity can be explained as; the sector operated by VTS-O_1 (Sector Kandilli) covers the critical area of the Strait (from Vaniköy to Kanlıca) and the devil currents flows in this sector at the point of Kandilli. VTS-O_1 has the highest fixation duration to SMI by 75.6% in the total fixation durations.

Table 1. *The area displayed on the computer screens by VTS-Os*

	Computer 1		Computer 2	
	Left side	**Right side**	**Left side**	**Right side**
VTS-O_1 (Sector Kandilli)	Southern part of the sector (Haydarpasa to Bogazici Bridge)	Northern part of the sector (Bogazici Bridge to FSM Bridge)	It covers the southern anchorage area in the Sector Kadıköy	Southern part of the Sector Kavak (FSM Bridge to Selvi-Tarabya Point)
VTS-O_2 (Sector Türkeli)	The area (Rumeli Light to northern limit of the sector by covering the anchorage area) covers to 2/3 of the screen	It is small part of the screen and covers the approaching area to the Light (North entrance of the Strait)	The display of computer isn't divided. It is the largest viewpoint of the sector.	

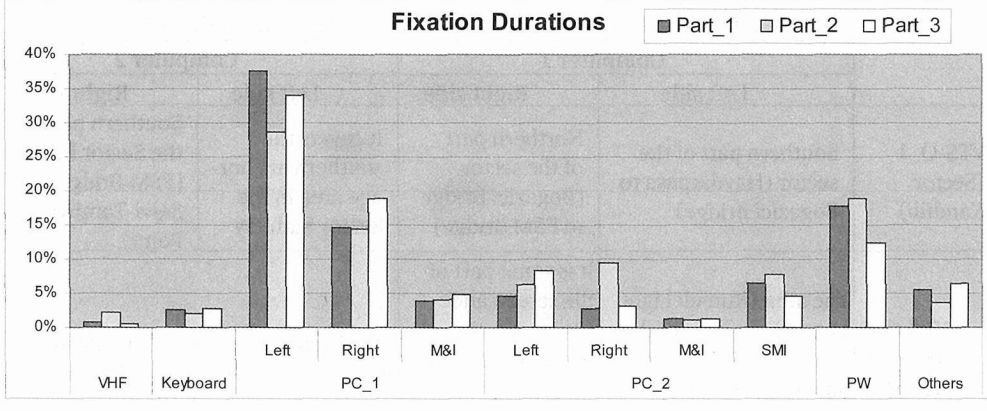
	Computer 1		Computer 2	
	Left side	Right side	Left side	Right side
VTS-O_3 (Sector Kavak)	North of the sector (Garipçe-Fil Point to Beykoz)	South of the sector (Beykoz to Kanlıca, FSM Bridge)	South of the Sector Turkeli Turkeli (Rumeli Light to Garipçe)	South of the sector (Beykoz to Kanlıca, FSM Bridge)

VTS-O_2 has the highest fixation duration (24.3%) to paper work among the others. As mentioned before, the traffic flow was one way (southbound) at that time, and VTS-O_2 operated to the Sector Türkeli as the entrance of the Strait. Therefore, he should organize the entering order of ships, make the first contact, and get their information, later to perform their updated information to the system and operator's logbook. As another result of that, his eye movements through to categories are faster than others'.

VTS-O_3 has the highest fixation duration to the right side of PC_ 2 by 79% among the operators. There is no significant difference among the parts based on the fixation durations to the categories as shown in Fig. 7. In addition, the fixation durations to the categories are significantly different from each other among the parts.

According to the average values of fixation durations as shown in Fig. 8, the order of VTS-Os fixations are; PC_1 (53.8%), PC_2 (19.0%), paper works (16.4%), others (5.2%) and keyboard (2.5%), and the other categories are equal to 1% or less than 1%. Fixation durations to the left side of the computers are higher than right side. This result is the similar for computer users as a common behaviour that the eye movements start to search from left part of the screen (Fukuda & Bubb 2003, Özçelik et all. 2006).

Fixation duration to PC_1 for the all operator is 74% among the computers, and it is 53.8% among the other categories. Moreover, the ratio between PC_2 and PC_1 is 0.35. It means that VTS-Os use one of the computers (PC_1) for understanding the general situation in the sector, and they divide the display in two screens. In addition, all opera-



F value of parts is 0.004, $p > 0.05$; F value of the categories is 53.08, $p < 0.01$

Figure 7. Fixation durations to the categories among the parts

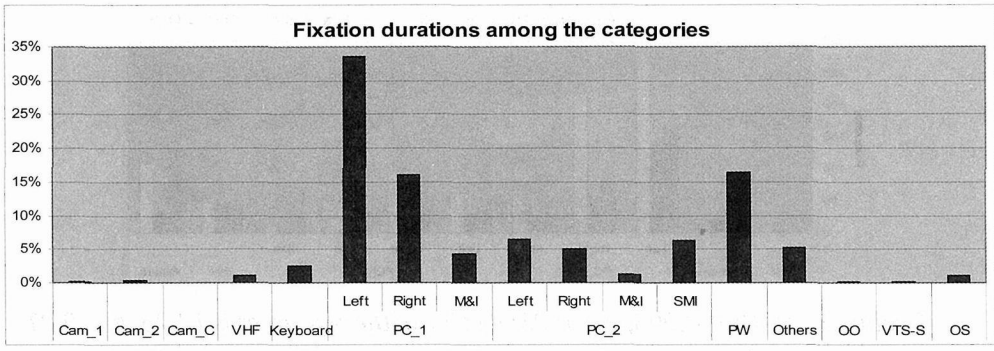
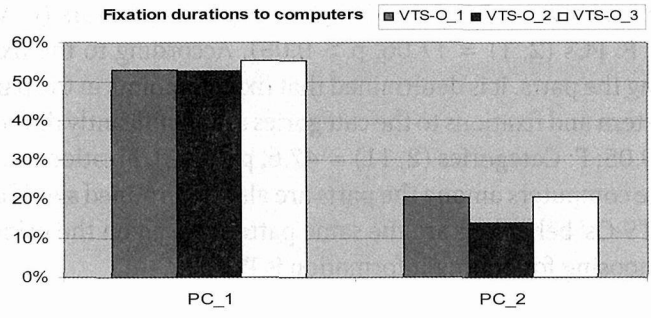


Figure 8. The percentages of the average fixation durations to the categories



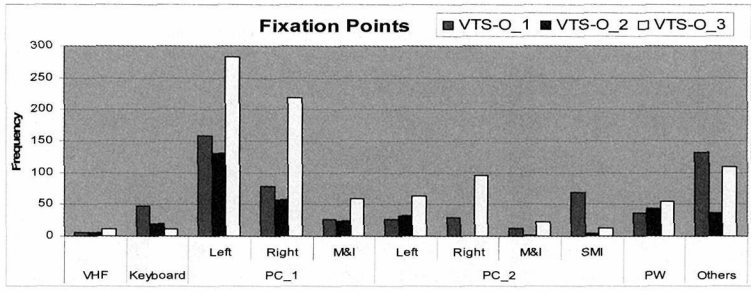
F value of VTS-Os is 2.1, $p > 0.05$; F value of computers is 342.3, $p < 0.01$
Figure 9. The percentage of fixation durations to computers among the operators

tors use the function of picture in picture. VTS-O_3 has the fast and most eye movements, then VTS-O_1 and VTS-O_2. All operators open the page of Ship Movement Information on PC_2. Fig. 9 shows that there is significantly difference between PC_1 and PC_2 and the fixation durations to the computers are significantly similar.

3.2. Fixation Points

VTS-Os' most fixation point is to PC_1 as shown in Fig. 10, and PC_1_Left has the most fixation points for all operator. The operators' behaviour on the fixation point is significantly similar and their fixation points to the categories significantly have different meaning.

VTS-O_1 and VTS-O_2 are the only operators to have fixation durations to the cameras; and VTS-O_3 has the only fixation durations to "Other Operator", and "Supervisor". VTS-O_3 has the highest fixation points to computers among the operators and parts. His ratio of fixation points to the PC_1 is 54.1% in the total fixation points to PC_1 among the operators, and that is 52.8% for PC_2.



F value of VTS-Os is 0.003, $p > 0.05$; F value of the categories is 12.76, $p < 0.01$
Figure 10. The frequency of fixation points to the categories among the operators

VTS-Os' fixation points to the computers are determined as insignificant and there isn't any difference between PC_1 and PC_2 among the operators (F: VTS-Os (2, 1) = 0.28, $p > 0.05$; F: PCs (2, 1) = 17.06, $p > 0.05$). According to the fixation points to categories among the parts, it is determined that fixation points in the parts significantly are the same pattern and fixations to the categories are significantly different (F: Parts (2, 11) = 0.01, $p>0.05$; F: Categories (2, 11) = 47.6, $p<0.01$). Fixation durations and fixation points to the computers among the parts are also determined significantly different. It means that VTS-Os' behaviour are the same pattern based on the using of computers, and their first choosing for getting information is PC_1.

4. CONCLUSION

Authors have another experiments at the Istanbul VTS Center simultaneously with this study, the assessment of mental workload of VTS-Os by utilising Heart Rate Monitor and questionnaire for determining the factors to cause mental workload and the level of VTS-Os' mental workload based on the NASA Task Load Index. When matching the result of VTS-Os' heart rate variability and eye movements it is determined that the ship specifications and position effect the VTS-Os' behaviours while executing task, especially the ships with long length in the critical area and sharp turning points. On the other hand, it is quite difficult to tracking eye position of the operators on the computer screen to understand what kinds of information looked, because of frequency difference between the recording camera of EMR and computers. When the authors make relatively comparison among the VTS-Os based on their fixation durations and fixation points for the main fixations in the visual field; the computers, paper work and others (because of the saccades among the categories) have the highest fixations. Table 2 shows this relative comparison and percentages of the fixation durations (horizontal texts of table) and fixation points (vertical texts of table) to the mainly areas where VTS-Os fixate on the visual field.

FREQUENCY (%)		TIME DURATION (%)											
		VTS-O_1				VTS-O_2				VTS-O_3			
		Among the categories		Among the operators		Among the categories		Among the operators		Among the categories		Among the operators	
	Keyboard	HFP (7.3)	MFD (4.67)	Highest fixation point (61.0)	Highest fixation duration (73.40)	MFP (5.3)	LFD (1.95)	Middle fixation point (24.7)	Middle fixation duration (18.23)	LFP (1.1)	LFD (0.55)	Lowest fixation point (14.3)	Lowest fixation duration (8.37)
	SMI	VHFP (10.6)	VHFD (12.13)	Highest fixation point (80.0)	Highest fixation duration (75.59)	LFP (1.1)	MFD (4.45)	Lowest fixation point (4.7)	Middle fixation duration; SMI (16.43) PW (34.44)	LFP (1.3)	MFD (6.29)	Middle fixation point (15.3)	Lowest fixation duration (7.98)
	Paper Work	MFP (5.7)	VHFD (11.29)	Lowest fixation point (27.6)	Lowest fixation duration (26.97)	VHFP (12.0)	VHFD (24.32)	Middle fixation point (32.1)		MFP (5.6)	VHFD (16.85)	Highest fixation point (40.3)	Highest fixation duration (38.59)
	Others	VHFP (20.5)	HFD (7.77)	Highest fixation point (47.5)	Highest fixation duration (58.57)	VHFP (10.1)	MFD (3.20)		Lowest fixation duration; Others (14.29) PC_1 (22.81) PC_2 (16.97)	VHFP (11.4)	MFD (3.76)	Middle fixation point (39.6)	Middle fixation duration (27.14)
	PC_1	VHFP (40.8)	VHFD (52.88)	Middle fixation point; PC_1 (25.4) PC_2 (37.1)	Similar with VTS-O_3; PC_1 (38.53) PC_2 (42.18)	VHFP (59.4)	VHFD (52.81)	Lowest fixation point; PC_1 (20.5) PC_2 (10.0)		VHFP (57.9)	VHFD (55.32)	Highest fixation point; PC_1 (54.1) PC_2 (52.8)	Similar with VTS-O_1; PC_1 (38.65) PC_2 (40.85)
	PC_2	VHFP (21.3)	VHFD (20.47)			VHFP (10.4)	VHFD (13.89)			VHFP (20.2)	VHFD (20.68)		

Table 2. *Summary of VTS-Os' fixation durations and fixation points*

LFD: Low Fixation Duration
MFD: Medium Fixation Duration
HFD: High Fixation Duration
VHFD: Very High Fixation Duration
LFP: Low Fixation Point
MFP: Medium Fixation Point
HFP: High Fixation Point
VHFP: Very High Fixation Point

The main parts of the VTS consist of computer-based design. That's why when the operator used to use computer, it makes to fast operation on the computer and keyboard. It also effects to decrease VTS-Os' mental workload.

Finally, the affect of ergonomic design of the operator console table cannot be rejected to VTS-Os' behaviours. The fixation durations to the cameras are the lowest for all operators. If they want to look cameras, they should up their head. Moreover, the fixation points through the vertical line from one category to other are slightly less than horizontally. It clarifies that the vertical movements of eye movements are not chosen by the operators. On the other hand, the fixation durations to the left side of computers are higher than right side. The first choosing to display data is the left sides and it is convenient for the operators to shift eyes left to right on the horizontal line.

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