MONITORING SEAFARERS' COGNITIVE PERFORMANCE UNDER STRESSOR FACTORS DURING A VOYAGE BY AUTOMATED NEUROPSYCHOLOGICAL ASSESSMENT METRICS

[1]UMUT TAC, [2]LEYLA TAVACIOGLU, [3]PELIN BOLAT, [4]OSMAN KAAN KORA, [5]FIRAT BOLAT

[1, 2, 3] Istanbul Technical University Maritime Faculty, Turkey
[4] Marmara University, Department of Psychiatry, Turkey
[5] Turkish Republic Ministry of Transport, Maritime Affairs and Communications Tuzla Port Authority, Romania

ABSTRACT

Cognitive science is a multidisciplinary science area that identifies the mental processes by checkout the actions of mind and intelligence through understanding the dynamics of interactions between them. In this study, based on the definition of cognitive science, the effect of cognition of the seafarers during the operational processes are evaluated under certain stressor factors such as fatigue-sleepiness, noise and thermal strain. Research was conducted on the bridge and engine room during the voyage of a short route container vessel. Test results showed that, (a) the cognitive tests performance and the reaction response times decline through fatigue and sleepiness during the watchkeeping period (b) increasing temperature and noise causes to decline the reaction time and the cognitive performance.

Keywords: *Seafarer, cognitive performance, stressor factor*

1. INTRODUCTION

The acceleration of marine traffic due to the globalization forces the maritime regulatory agencies and policy making institutions to systemize maritime safety and security. These systemizings are generally based on the maritime accidents or incidents which had negative impacts on environment or/and which were resulted with loss of lifes such as accidents of Torrey Canyon, Exxon Valdez and Titanic. When the investigation reports of maritime accidents of recent years are analyzed, it is seen that defects in human factor for operational tasks during maritime transportation process has been rising as one of the main causes of marine accidents. Accordingly International Maritime Organization (2004) adopted a resolution about focusing on the human related activities and need of high standards during ship operational tasks. IMO also has taken a decision which implies that IMO would give priority to the subjects related with human factors in its work plan [52]. So here it is important to define what the human factor is from the perspective of safety issues.

The relation between safety and human factor is definitely relied on a known fact that states humans -as operational members of a system- can make errors (Wiegmann and Shappell, 1999; 2001). However, the important question is what the risk level of these errors. Answers for this question can be given by evaluating the criticality of the errors, which is a function of the variables in the performed operational task. These variables can be the conditions, task intensity and psychological/ physical state of the individuals that constitute "human factor" theme. Concepts of "Human Factor" can refer to the area of psychology that deals with ergonomics, workplace safety, human error, product design, human capability and human-computer interactions. On the other hand, from a managerial perspective, human factor concept has arisen as a multidisciplinary area that deals with the human capability and limitations during the period of information acquiring and processing. Consequently the aim of the researches on human factor is to produce safe, comfortable, and effective human performance within an operational tasks that include the equipment, systems, software, facilities, procedures, environments, training, staffing, and personnel management [33].

In this context, based on the definition of human factor, human factor-based error can root in the loss of information and capabilities during the information processing cycle of an operational task, which can refer to giving a response to environment after acquiring and transforming data to information. Thus, performing a given task or solving an operational problem is a function of capacity of information processing which can also be defined as cognitive ability [41]. Cognitive ability is associated with four main capacities [71];

- o Capacity of learning
- o Capacity of acquiring knowledge
- o Capacity of adaptation to unfamiliar conditions
- o Capacity of configuration of knowledge for future events

Apparently, environmental, psychological and physiological variations that occur during execution of these four main abilities will affect the cognitive process of the individual who is performing the task. From the perspective of maritime transportation process, the reasons for these variations that are experienced by seafarers are generally outcomes of the stress on them. Stress can be defined as the consequence of the stressor factors which can easily arise in during a sea voyage due to the reason that ships are complex and closed systems. Accordingly for maritime safety researches, human factors related safety issues turn into human based error subjects and human based error subjects can shift to cognition gaps in a stressful environment.

When the transportation literature is analyzed, it is seen that the studies for cognition-stress have been done for road and air transportation processes. For example, Hutckin and Klausen (1996) studied on the cognition in a cockpit by focusing on the activies between the captain pilots and airplane crew and they stated that the cognitive processes had been shared during information exchange, cooperation and coordination. Cassiabue et al. (2004) analysed the cognitive behaviors with COSIMO, a cognitive simulator, during an accident management operation of a system operator. Anstey et al. (2005) also found that there were important impacts of cognitive, sensitive and physical functions for developing the safest drive behavior for road transportation.

The studies for maritime transportation have been generally focused on only the stressor factors that form the basis of stress on individuals and in environment. Fatigue has commonly arisen as a main topic of human based errors studies in maritime transportation literature [4]. In most of these studies, it is obviously seen that fatigue has only been approached with its definition that can be called as the tip of iceberg. The mechanism of the fatigue on human error as a stressor factor has not been studied. There are also few studies that tried modeling the cognitive processes in maritime transportation. For example Embrey and et al. (2006) developed cognitive based work load model, CLIMATE, to evaluate the maritime accidents from the perspective of cognitive processes. Horizon Project (2012) is also one of key studies for cognition-safety in maritime transportation. This project has been conducted to analyse the cognitive processes of seafarers under fatigue in a simulator environment.

It should be emphasized that studies on seafarers have been generally experienced with the experiments that have done in simulator environment. Few studies have analyzed the cognitive performance of the seafarers in the real dynamic work space. It is a known fact that experimental stressors are the factors that are temporary, have low intensity and have generally no long term impacts on the individuals while real stressors are the factors that are intensive, have long term impacts and continual. Anxiety, fright, mental stress and alertness are thought of assumptions in simulator environment. Accordingly a connection problem arises between the simulator and real world for the experimental operational processes. For example Woods and Patterson (2001) observed that continual increase in the demand for cognitive processes could only be seen in the real world, not in the laboratory environments.

In the forementioned circumstances, the aim of this study to monitor the seafarers' cognitive performance under various stressor factors such as noise, thermal stress and fatigue. For this purpose, Automated Neuropsychological Assessment Metrics (ANAM) was applied to seafarers during a voyage under stressor factors. ANAM is a library of sensitive, scientifically-proven computer-based tests designed to detect speed and accuracy of attention, memory, and thinking ability. There are various studies done with ANAM4™ for complex situations [2].

In this context, this paper is consisted of five parts. After introduction, in the second part, theories and maritime transportation regulations that motivate us for this research are given. Thirdly methodology is explained. In the fourth part, results are introduced. Lastly a brief conclusion is presented.

2. MOTIVATION

2.1 Regulations on Stressor Factors in Marine Transportation

Each ship personnel should complete a series of required training in order to work on board. With regard to the STCW 95 Convention of IMO and to the ship crew agreement the conditions are determined, regarding on which ships, the crew could be positioned and how they could increase their qualification, and which trainings they should have been completed. In addition, the certificates required for various ship types and duties are determined along with the trainings for obtaining these certificates. With respect to the instructions compatible with the international agreements (IMO and ILO agreements), the EU and the member states determine the conditions about the training and employment of ship crew and enact these conditions in their national legislation system. Each ship has a Minimum Safe Manning certificate about the manning of ships with the crew. The number and quality of ship crew are determined in these certificates [75]. Some duties on board require 24 hours continuity. Therefore, shift working is administered for duties that require this kind of continuity.

Chapter VIII of the STCW explains the shift working standards. When the convention is examined with regard to work and rest hours; it is seen in Section AVIII Article 1 that the management is asked to consider the fatigue of the shipman could pose danger for ship security and safe operation. Again, according to AVIII Article 1, the shifter officer or crew should be provided a 10 hours rest for a 24 hours period, and 77 hours of rest for a 7 days period. The daily rest period may be divided into two parts, but one of them should be at least 6 hours and the period between resting hours should not exceed 14 hours. This regulation could be violated in cases of emergency. However, the muster, fire fighting and lifeboat drills required by international and national regulations and orders should not disrupt rest hours and should not trigger fatigue [86].

According to the Seafarers' Hours of Work and the Manning of Ships Convention 1996, established in the 84th conference by International Labour Organization, ILO in Genoa on 8 October 1996, the term 'work hours' states the period a shipman is required to work for the ship. The term 'rest hours' state the period excluding the work hours; however, this term does not cover the short breaks.

According to the provisions of Section II, Article 5 Paragraph 1 of this convention, work and rest hours should be as below:

(a) Maximum work hours;
- i. should not exceed 14 hours in a 24 hours period,
- ii. should not exceed 72 hours in a 7 days period.

(b) Minimum rest hours;
- i. should not be less than 10 hours in a 24 hours period,
- ii. should not be less than 72 hours in a 7 days period.

According to Article 2 Paragraph 5, rest hours can be divided into two, maximum, and one of these should not be less than 6 hours. The interval between successive periods should not exceed 14 hours [12].

According to ILO C180 Article 7, the shipmaster may put seafarers to work to ensure the immediate safety of the people on board, the ship and the cargo or to help to other ships or people at risk. However, the shipmaster should be certain that the seafarers get adequate rest period after the emergency [12].

In national legislation, according to Chapter 5 Section 1 Article 1 of the Seafarer Regulation on taking shifts, maritime liners conduct the regulations about shift taking on board, in a way that they would not decrease the performance of seafarers due to fatigue and in line with the following principles below,

Seafarers who take shifts on board;

i. rest at least 10 hours a day.

ii. Their rest period could be divided into two, maximum. In this condition, one of the rest periods could not be less than 6 hours.

iii. The 10 hours per day rest period may be restricted to a time, not less than 6 hours, in cases of emergency and relay drills. However, the shortened rest hours could not be repeated more than twice in consecutive days, and the rest period could not be less than 70 hours per week (Seafarer Regulation, 2002).

As required by Labour Law no 1475, and Article 22 of the Occupational Health and Safety bylaw, noise levels should not exceed 80 dB in places where heavy and dangerous duties are performed, in order not to cause industrial accidents and not to cause the employers to lose their hearing. The noise level can be 95 dB maximum in places which require noisy labour conditions such as ships. Article 20 of the same bylaw, the temperature levels in the indoor workplaces should be between 15°C and 30°C.

2.2 Cognitive Dimension of Stressor Factors in Maritime Transportation

2.2.1 Fatigue

When the effects of fatigue and restlessness on cognitive processes are investigated, it is seen, from the studies on fatigue and performance, that fatigue is inclined to reduce performance. However, it is unclear if these effects originate from stress or directly from fatigue. This study accepts fatigue as a stressor factor, considering the literature on stress and performance.

Before interpreting the studies on the effects of fatigue, it is appropriate to focus on the concept of fatigue. Most probably, the simplest definition was made by NASA (1996) in a way that fatigue covers the feelings of weariness, sleepiness and exhaustion. Job and Dalziel (2001) defined fatigue as inadequacy of cellular capacity and systemic energy in maintaining the normal levels of activity and/or processes using normal resources, in cases where the muscles, internal organs or the central nervous system of an organism lack adequate levels of rest for an activity and/or mental process.

Gawron et al. (2001) developed a general perspective for fatigue studies and proposed two types of definition for fatigue. The first type of fatigue is the physical fatigue; it is environmental in nature and is the decrease in capacity of performing physical labor using physical effort. The second type is mental fatigue defined as the decrease in the performance in, manipulation of and access to the data stored in the memory, in tasks that require awareness. Hancock and Desmond (2001), too, defined two types of fatigue; however, they categorized fatigue as active fatigue and passive fatigue and related passive fatigue with attention. Active fatigue, on the other hand, results from the continuous prolonged interactions with the system.

Matthews and Desmond (2002) observed that fatigue is generally related to concepts based on energy (effort, power, activation, etc.) [84]. Matthews and Desmond pointed out to two hypotheses. In the first hypothesis, fatigue is accepted as the direct consumption of power or indirect redirection of power towards coping strategies. Thus, labor capacity decreases with regard to the decrease in power. With reference to this view, tasks that are more complex are also more sensitive to the effects of fatigue; because these kinds of tasks require more power. However, the second hypothesis argues that fatigue should be related to the effort expended. Some resources define fatigue as a condition of under stimulation, the inability to actively deploy the power or to provide the effort required for obtaining and maintaining a powerful performance. This second condition reflects inadequacy in activation rather than inadequacy of power. Consequently, the combination of these two hypotheses is used as the best expression in defining the effects of fatigue [84].

The controversy and disagreement in defining fatigue caused difficulties in measuring fatigue. In many examples, fatigue is expressed as present or not present; however, it should be considered as a continuous variable. Haslam and Abraham (1987) studied fatigue using continuous tasks which last 90 hours. According to the findings of Haslam and Abraham, while the psychological status and mental skills detoriate, physical form is relatively noneffective. Mental indicators show that attention and complex cognitive performance is more sensitive in simple and learned tasks. Job and Dalziel (2001) argued that this issue aggravates assessing fatigue and developing measures. These findings are compatible with the view that well learned and procedurized tasks are more resilient to the effects of stress.

Buck-Gengler and Healy (2001) investigated a data entry (writing) task and found that response time decreased with the increase in mastery in the task, and correct writing decreased as the fatigue stepped in. Matthews et al. conducted an exhaustive study on driving time and fatigue [70]. Behavior tests for drivers under fatigue induced stress revealed deficiencies such as lane changes and maintaining lateral positioning [8; 9]. Matthews and Desmond (2002) designed an experiment under simulated driving conditions to evaluate the objective and performance based measures for fatigue. During driving, drivers were subjected to high workload pedestrian detecting tasks to induce fatigue. This procedure was continued for 24 minutes by reducing two-way requests (The subjects continued to drive but pedestrian detecting task was stopped). Lateral detection and steering wheel changes were included in the objective measures of performance. Subjective measures were evaluated using the task-induced fatigue scale, Dundee Questionnaire (emotion and motivation) and NASA-TLX (workload) [84].

The results of this study showed that the motivation required for achieving the task decreased with the continuation of the fatigue induced conditions. Following fatigue, direction errors increased, steering wheel control and perceptional sensitivity decreased.

2.2.2 Thermal Stress (Hot and Cold)

Under thermal stress, losses are experienced in many cognitive processes and it is seen that these losses are directly related to the intensity of the stressors. Losses in cognitive functions occur more in cold environments than in hot environments. Literature reviews on this topic evaluated the psychomotor and perceptual motor tasks, but could not evaluate complex cognitive processes. In this respect, the path followed by the losses is tried to be connected with psychomotor skills. However, mixed results were obtained in studies conducted for high order cognitive tasks.

When considered biologically or neurologically, thermal stress causes a detoriation in the thermal order of the individual. On the other hand, thermal difficulty induced distress causes interruption in the information processing required by the task. Focusing on the personal conditions and distraction from the task to be completed can be given as an example to this situation. In studies on thermal stressors, evaluations on how the stressors affect performance were conducted on various cognitive processes. First studies were conducted on attention requiring processes, and tasks which psychomotor and perceptual motor skills [56; 91]. Grether (1973) accepted attention behaviors and response time as basis, and found that temperature did not influence performance up to some certain point and decreased performance after that point. Giebstrect et al. (1993) revealed that there was not any performance loss in low order cognitive processes under cold environment conditions; and there were some difficulties in processes which required high order cognitive processes. Ellis et al. (1985) showed that exposure to cold weather caused errors in selection-reaction time tasks. Driskel et al. (1992) found that hot environments did not influence performance speed, but decreased performance accuracy; and cold environments decreased performance speed and accuracy at the same time. Pilcher et al. (2002) conducted mathematical analyses on how exposure to high and low temperatures influenced performance and found that high and low temperatures negatively affected the performances related to the tasks. Seppänen et al. (2006) found a correlation between temperature and performance. In their studies they revealed that a 2% decrease in performance occurred at each 1 degree increase in the temperature between 25 and 32°C, and there was not any change in performance between 21 and 25 °C. Seppänen investigated the effect of temperature in the workplace on performance and found that the performance was at its maximum level at 22°C. They also found that 91.1% of the maximum performance was obtained at 30°C. Myers et al. (2009) studied on the effect of cold on post-transit run performance of marine high-speed craft passengers and they stated that a three-hour exposure to a cold environment came out with a large post-transit degradation in physical performance about 40%.

2.2.3 Noise

With the industrial development, noise has become a factor that threatens the psychological and physiological health of individuals. Along with the negative effects of noise on hearing, there are some physiological problems such as muscle tension, narrowing of blood vessels, decrease in heart volume, dilation in pupils; and neurological problems such as fear, anxiety, slowing in mental skills, restlessness [63].

As required by Labour Law no 1475, and Article 22 of the Occupational Health and Safety bylaw, noise levels should not exceed 80 dB in places where heavy and dangerous duties are performed, in order not to cause industrial accidents and not to cause the employers to lose their hearing. The noise level can be 95 dB maximum in places that require noisy labour conditions such as ships. At such conditions, individuals should use protective gear such as earplugs or noise cancelling headsets. In the measurements conducted during our research, the average noise level in the engine room was found 108 dB.

Table 1: Some Peak Levels of Industrial Noise in dB(A) (Koçak, G., 2008)

Noise Source	**Noise Level, dB(A)**
Gunshot, motor test mechanism	130
Pneumatic hammer	120
Electric chainsaw, pneumatic riveting machine, electric cutter	115-120
Milling machine, boiler room, weaving loom, punching machine	105-115
Electric engine	100-105
Jet engine	120

The limits for noise level and working hours defined by OSHA (Occupational Safety and Health Organization) are as below:

Table 2: Working hours limits for various noise levels (Koçak, G., 2008)

Intensity of Noise	**Time (hours)**
90	8
92	6
95	4
97	3
100	2
102	1.5
105	1
110	0.5

Generally, exposure to sound causes decrease in performance. Despite the results are variant; it is found in most studies that discontinuous noise is more destructive than continuous noise. However, it is quite difficult to obtain precise results on which decibel level reduces performance, because the findings of the studies in this area show a great variance. As the structure of the task changes, the effects change too. For instance, psychomotor tasks are influenced from noise less than cognitive tasks. Naturally, it is possible for these findings are related to flexibility (resilience) or covert knowledge and skills.

Studies on the effects of noise generally investigate the relationship of noise with performance and they were conducted in many areas including tasks based on awareness and attention [84]. For example, Errett et al. (2006) studied on the noise of HVAC systems in the office environment to understand the effects of noise on the productivity and annoyance. They stated that prolonged effects of noise were seen on the productivity and annoyance of the workers. Ljunberg (2007) also investigated the effects of high level noise and vibration on cognitive tasks. The study found that high stress levels were achieved when there was only noise or there were noise and vibration together. Although noise caused a highly stressed environment, in this study it was argued that noise did not have any direct effect on performance.

The noise in the engine room may negatively influence the performances of the seafarers especially in the process of perceiving information and processing it. More specifically, activities such as communicating by talking and identifying signals may be obstructed by the suppression feature of noise. This situation not only influences the activities of perceiving and applying information negatively, but also it influences the way the task is carried out.

3. METHODOLOGY

This study focuses on the factors that influence the cognitive processes and the results of the change in cognition in maritime transportation using the Cognitive Information Processing Theory, Transactional Stress Theory by Lazarus and Cognitive Continuum Theory by Hammond. In our study, the processors that could influence cognition during maritime transportation were hypothesized and the methods of measurement were planned according to these three theories. Before taking the measurement, ethical permissions were taken from Marmara University Etic Commission. The measurements were conducted on a 1022 TEU container ship which sailed clouse-course (İstanbul – Gebze – Gemlik – İzmir – Mersin – Kıbrıs) and which harboured frequently. The execution of all test lasted 7 days, from İstanbul to Mersin.

3.1 Theories

3.1.1 Information Processing Theory

Information Processing Theory (IPT) gives us an opportunity to measure the cognitive processes with our perceptions. It focuses on two main parts, which are shown in Figure 1.

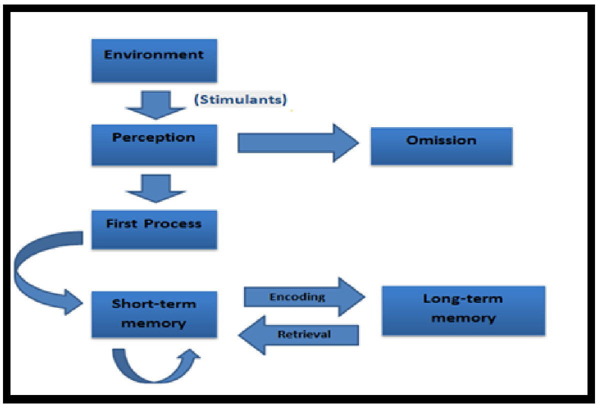

Figure 1: Information Processing Theory (Tac, U., 2012)

The first part is formed by three structures. These are [32 ; 26] :

- Sensory memory gets information related with the senses just long enough for the information to be processed further (mere seconds).
- Short term memory acts as a temporary working memory that gets information for a limited time and holds a limited amount of information.
- Long term memory is the permanent store center of information, capable of retaining an unlimited amount and variety of information.

Second part includes the cognitive processes which are used as a way of transporting the knowledge from sensory memory to short term memory, from short term memory to long term memory. These cognitive processes are [26]:

- attention;
- rehearsal;
- chunking;

- encoding; and
- retrieval.

In this study, based on IPT theory, ANAM is used to measure these cognitive processes of seafarers. The results of the ANAM can give possibility of evaluation of seafarers' cognitive performance during a voyage.

3.1.2 Transactional Stress Theory

Transactional Stress Theory (TST) states that stress is a result of a transaction between a person and his or her environment [66]. It also emphasized that stress contains cognitive, affective and coping factors. According to TST, three appraisals can cause a transaction that is resulted with stress. These appraisals are [66;68]

- Primary Appraisal is a judgment about what the person perceives a situation holds in store for him or her. The individual may determine that the situation represents (a) a potential for harm or loss (threat) or that (b) actual harm has already occurred (harm) or (c) the situation has potential for some type of gain or benefit (challenge).
- Secondary Appraisal is the process of determining what coping options or behaviors are available to deal with a threat and how effective they might be.
- Reappraisal Appraisal is the process of continually evaluating, changing, or relabeling earlier primary or secondary appraisals as the situation evolves.

3.1.3 Continuum Cognitive Theory

In Continuum Cognitive Theory (CCT), stress is resulted due to the breakdowns in continuity, harmony or balance of cognition and environment [44]. Hammond (2000) pointed that all the living beings tend to establish a stable relationship with their surroundings. According to CCT, corruption of this stable relationship results with stress. In this context, CCT defines the area between stress and cognition. This area is constructed over three main proposals (Hammond, 2000) which have arisen as a base for this study. These proposals are:

i. Environmental events and cognitive events have equal role on the determination of the behaviors
ii. Stressor factors should always analyzed with cognitive activities
iii. Breakdowns in balance and harmony of individual with its surroundings defines the current cognitive state of the individual

3.2 Hypothesis

The hypothesis developed for the study is presented below and illustrated in the Figure 2.

i. Antecedents
   - Fatigue and restlessness influence cognition in maritime transportation negatively.
   - Noise influences cognition in maritime tr ansportation negatively.
   - Thermal environment other than normal conditions (27°C) maritime transportation negatively.

ii. Consequent

In maritime transportation, cognition under stressor factors (fatigue-restlessness, high or low temperatures, noise) influences the cognitive performance negatively.

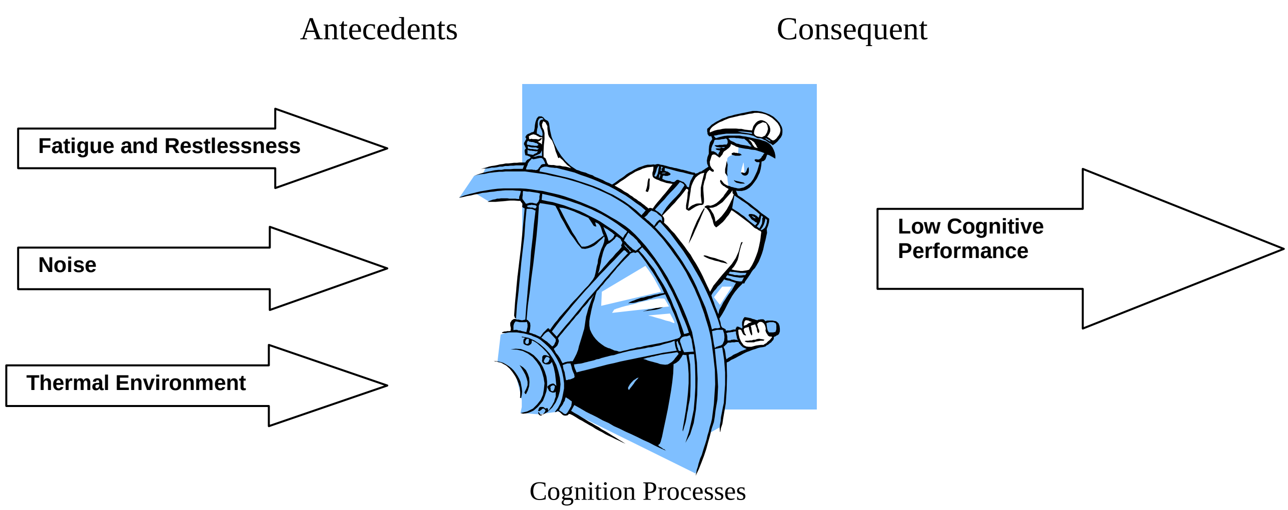

Figure 2: Hypothesis of the study

3.3 Data Collection: Automated Neuropsychological Assessment Metrics (ANAM4™)

The measurements were conducted at the navigating bridge and in the engine room of a ship. Data were collected from seafarers in these areas under stressor factors and without stressor factors, using scientific methods (computer based cognitive tests). These data which would encompass various real-time situations during navigation enabled the researchers to analyze the effects of cognition on operational processes. In order to investigate the effects of fatigue on cognitive performance, measurements were taken at the beginning, in the middle and at the end of the shifts of deck officers and their trainees. The investigation of effects of noise and temperature on cognitive performance, on the other hand, was conducted on marine mechanical engineers and their trainees, during operational processes around the main engine and in the engine control room.

The physical and mental statuses of the seafarers were tracked during navigation. The levels that these physical and mental statuses turn into stress factors were evaluated and a threshold values were defined. Cognitive tests appropriate for the operational processes on the ship were selected for applying the threshold values on seafarers, with reference to the cognitive studies on military personnel by Wayne C. Harris (2003)

The equipments used in data collection were Automated Neuropsychological Assessment Metrics (ANAM4™), Noise Measurement Device, Thermometer.

In order to evaluate the cognitive performances of the individual, the last version of the Automated Neuropsychological Assessment Metrics, ANAM4™, used by the USA Defense Department in 1970 for the first time. ANAM4™ is a test library used to conduct computer based evaluations for cognitive processes such as attention, reaction speed, memory, mathematical skills, executive functions and decision making. ANAM4™ applications are widely used in the literature, especially in military and clinical applications.

ANAM4™ enables the researchers to collect data for evaluating the cognitive status changes and the cognitive performance of an individual in a given time frame. ANAM4™ comprises of 22 performance assessment tests, which are very sensitive with regard to cognition. Researchers build a battery of tests, from the 22 different tests, considering the cognitive status they want evaluate, and the environmental conditions.

ANAM4™ test library investigates the cognitive changes using the parameters below:

- Attention
- Concentration
- Reaction Time
- Memory
- Processing Speed
- Decision Making
- Executive Function
- Mathematical Ability

Along with the 22 cognitive tests, ANAM4™ includes forms such as the symptom assessment test and the emotional status assessment form. These forms are used, before the cognitive tests, to assess the instantaneous emotional statuses and the obstacles that would influence cognitive performance.

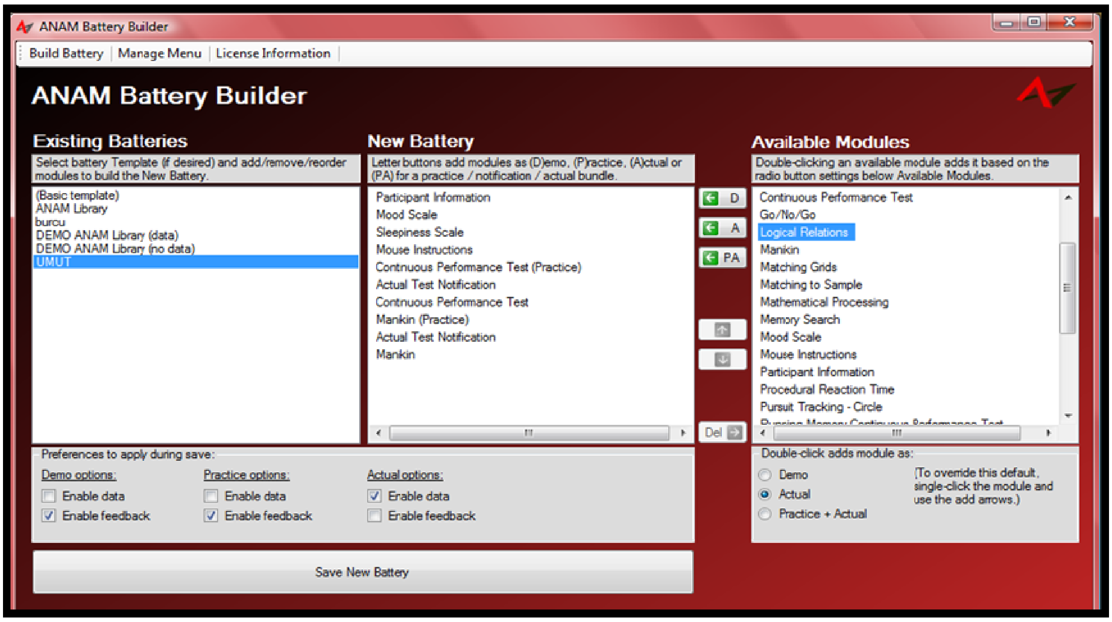

Figure 3: Battery building (ANAM4™ User Guide, 2012)

The 22 different cognitive tests which are used to build a battery in ANAM4™ are presented in Table 3.

Table 3: cognitive tests (ANAM4™ User Guide,2012)

ANAM Tests

2-Choice Reaction Time
Code Substitution - Learning, Immediate or Delayed
Demographics/History Module
Effort Measure
Go/No-Go
Logical Relations - Symbolic
Manikin
Matching Grids
Matching to Sample
Math Processing
Memory Search
Procedural Reaction Time
Pursuit Tracking
Running Memory CPT
Simple Reaction Time
Sleep Scale
Spatial Processing -Sequential and Simultaneous
Standard Continuous Performance Task
Stroop
Symptoms Scale
Switching
Tapping
Tower Puzzle

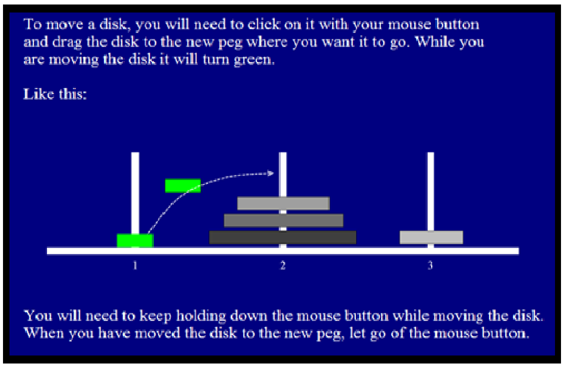

Figure 4: 'Tower puzzle' test (ANAM4™ User Guide,2012)

In our study, ANAM4™ test battery comprising of 5 different tests were built to be conducted on seafarers, considering the requirements of the operational processes and the situations encountered in sea environment. The tests selected for the battery are as below.

- Simple Reaction Time
- Mathematical Processing
- Matching Grids
- Logical Relations
- Running Memory- Continuous Performance Task

3.3.1 'Simple reaction time' Test

'Simple reaction time' test results are used to evaluate attention (reaction time and awareness) and visiomotor (visual and motor) response time.

The test presents the user a series of (*) symbols on a screen, and aims at measuring the reaction time. The user completes the test by giving the most rapid reaction possible when the stimulus appears on the screen.

Figure 5: 'Simple reaction time' test

3.3.2 'Mathematical processing' Test

This test results are used to evaluate the basic computer skills, concentration and running memory of the individuals.

During the test, equations comprising of 3 one-digit numbers and two operations (such as 5-2+3) appear on the screen. The used completes the test by deciding, in the shortest time possible, whether the result of the equation is greater than 5 or not.

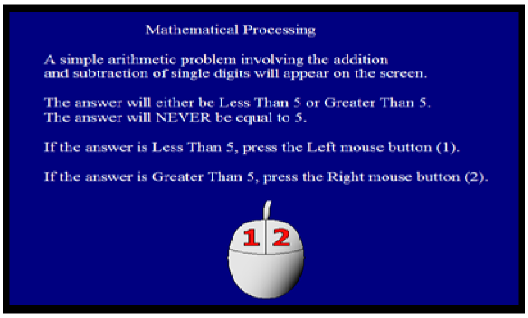

Figure 6 : 'Mathematical processing' test

3.3.3 'Matching grids' Test

'Matching grids' test results are used to evaluate the visio-spatial (visual and spatial) thinking skills of the individuals.

This test aims at taking responses from the user on the condition that the two figures, comprising of small squares on a grid, appearing on the screens are exactly the same, when one of the figures is rotated 90 degrees. The grids to be compared are presented in the screen side by side and at equal sizes. The user completes the test by responding whether the grids are the same or not.

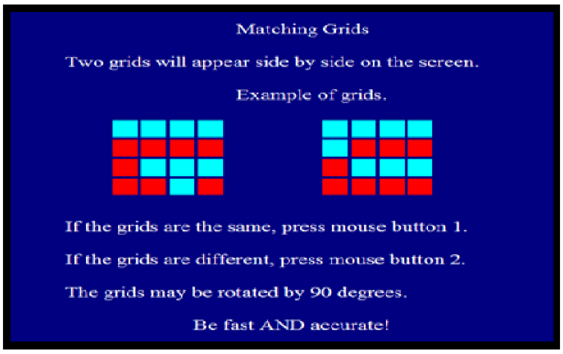

Figure 7: 'Matching grids' test.

3.3.4 'Logical relation' test

The results of this test are used to evaluate the perception and reasoning of the individuals.

During the test, expressions (such as “& comes after #”) appear on the screen. Differently from other tests, in this test, the software itself answers the question. The user gives responses, in the possible time shortest and as soon as the response of the software appears on the screen, whether the software has given the right answer or not.

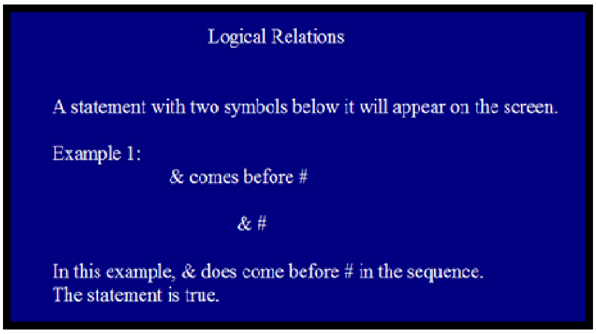

Figure 8: ‘Logical relations’ test.

3.3.5 *‘Running memory- continuous performance task’ test*

The results of this test are used to evaluate attention, concentration and memory skills of the individuals.

During ‘Running Memory- Continuous Performance Task’ test numbers appear on the screen one after another. The user completes the test by responding, in the shortest time possible, whether the previous number is the same as the one on the screen.

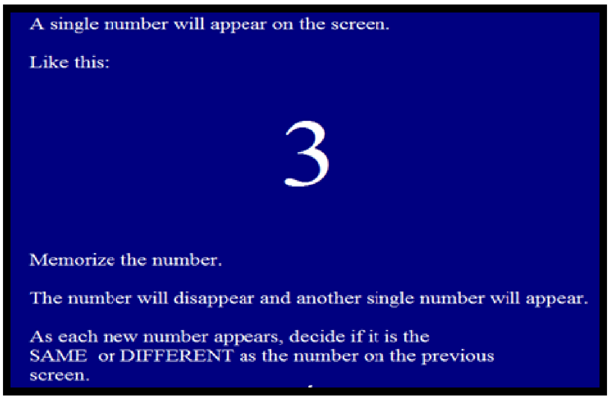

Figure 9: ‘Running memory- continuous performance task’ test.

4 RESULTS

4.1 *Effects of Fatigue and Restlessness on Cognitive Processes and Performance*

In order to evaluate the effects of fatigue and restlessness on cognitive performance and operational processes, a ANAM4™ battery comprising of 5 different tests was built, considering the operational processes encountered in navigation shifts and making use of the cognitive study conducted by Wayne C. Harris (2003) on military personnel. The battery was applied to 6 seafarers; the shipmaster, three deck officers and two deck trainees. The battery comprising of 5 different tests was applied to the volunteers at the beginning, in the middle and at the end of their 4 hours shift; their reaction times and test performances were analysed comparatively.

4.1.1 *‘Simple Reaction Time’ Test Results*

The results of the ‘Simple reaction time’ test, which was administered to evaluate the attention (reaction time and awareness) and visiomotor (visual and motor) response time of the seafarers, are presented below.

Table 4: ‘Simple reaction time’ test results

	Average Correct Response Time (msec)	Number of Correct Responses / 40
1st measurement	26257	38
2nd measurement	25761	38
3rd measurement	33203	35

When the correct response time and the number of correct responses are evaluated according to the results of the test, a statistically significant difference could not be found between the beginning of the shift and the middle of the shift. The measurements at the end of the shift revealed that the reaction times and test performances of the seafarers significantly detoriated compared to the first two measurements. Thus, the possibility of human induced errors to occur would increase in operational tasks which require the attention and rapid decisions of the officers, towards the end of the shift.

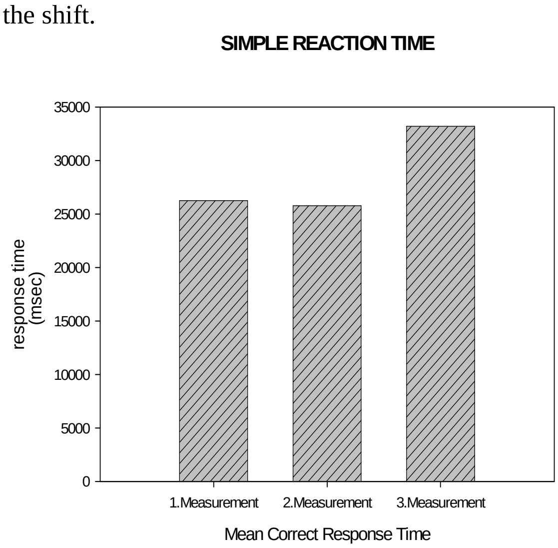

Figure 10: Average Correct Response Time (SRT)

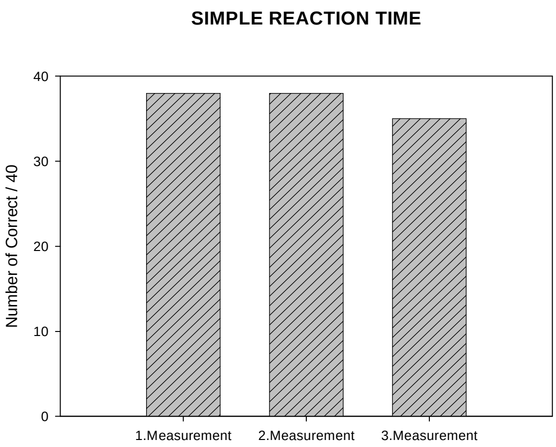

Figure 11: Average Number of Correct Response (SRT)

4.1.2 *'Mathematical Processing' Test Results*

The results of the 'Mathematical processing' test, which was conducted to evaluate the computer skills, concentration and running memory of the seafarers, are presented below:

Table 5: 'Mathematical processing' test results

	Average Correct Response Time (msec)	Number of Correct Responses / 20
1st measurement	135896	19
2nd measurement	140332	20
3rd measurement	174916	17

Among all the tests that were conducted to evaluate the effect of fatigue and restlessness on cognitive function, the 'Mathematical processing' test was the test in which the cognitive performance at the end of the shift presented the most significant decrease compared to the beginning of the shift. In this respect, fatigue and restlessness would cause a negative effect on the activities of using electronic navigation equipment, concentration and memory performances of seafarers, as such that it would pose a risk in operational processes.

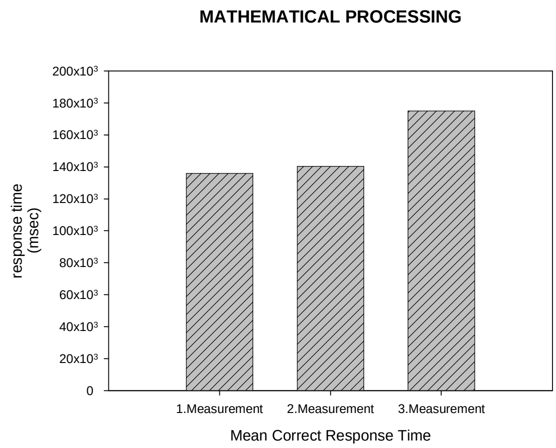

Figure 12: Average Correct Response Time (MP)

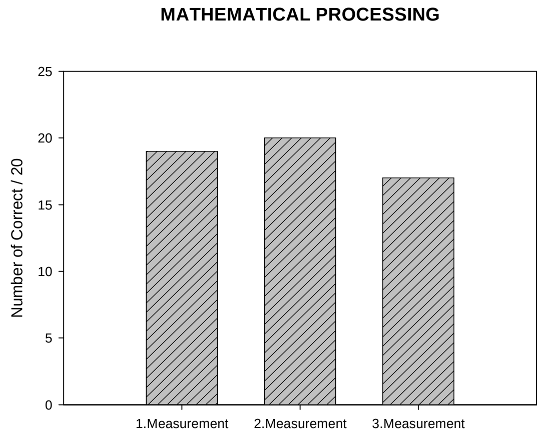

Figure 13: Average Number of Correct Response (MP)

4.1.3 *'Matching Grids' Test Results*

The results of the 'Matching Grids' test, which was conducted to evaluate the visiospatial skills of seafarer, are presented below. The results revealed a statistically significant slowing in the reaction times and a significant decrease in the test performances of the seafarer in the third measurement compared to the first and the second measurements.

Table 6**:** 'Matching grids' test results

	Average Correct Response Time (msec)	Number of Correct Responses / 20
1st measurement	147865	19
2nd measurement	151332	19
3rd measurement	166225	18

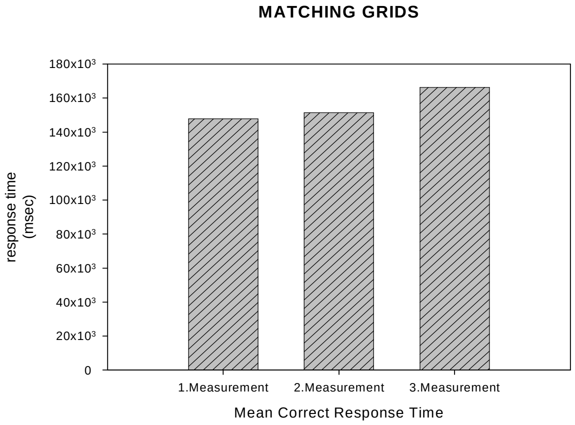

Figure 14: Average Correct Response Time (MG)

As it can be seen in Figure 14, 'Matching grids' test was the most influenced one among all test conducted to evaluate the effects of fatigue and restlessness on cognitive performance, with regard to reaction time and test performance. In this respect, the visiospatial thinking of seafarers was found to be the most rapidly decreasing cognitive function due to fatigue.

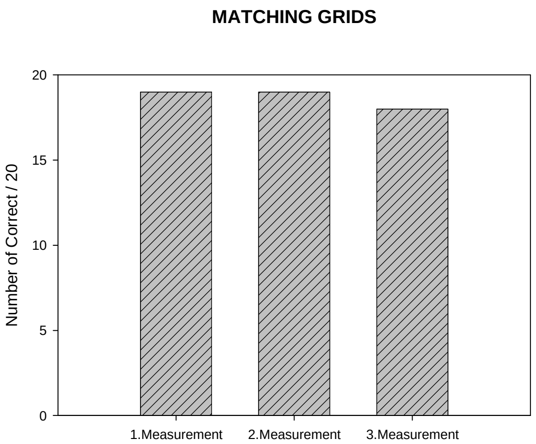

Figure 15: Average Number of Correct Response (MG)

4.1.4 *'Logical Relations' Test Results*

The results of the 'Logical relations' test, which was conducted to evaluate the perception and reasoning skills of seafarers, are presented below.

Table 7: 'Logical relations' test results

	Average Correct Response Time (msec)	Number of Correct Responses / 24
1st measurement	230338	20
2nd measurement	205275	18
3rd measurement	206183	18

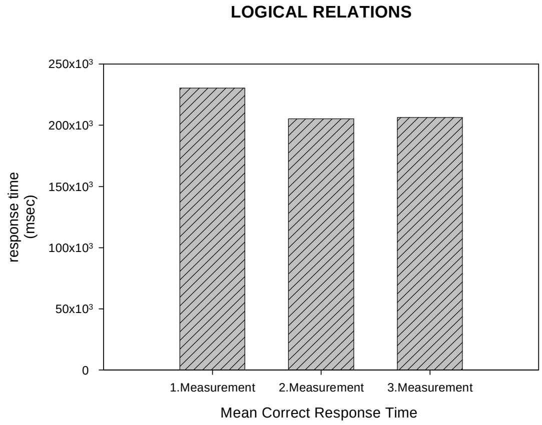

Figure 16: Average Correct Response Time (LR)

As it is seen in Figure 16, the least performance changes during shift are seen in perception and reasoning skills. According to the test results, less decrease was found in both reaction times and test performances, when compared to other test results.

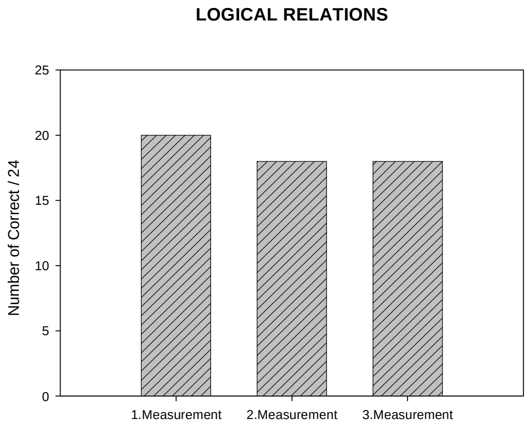

Figure 17: Average Number of Correct Response (LR)

4.1.5 *'Running memory- Continuous Performance Task' Test Results*

The results of the 'Running memory- continuous performance task', which was conducted to evaluate the attention, concentration and memory skills of seafarers, are presented below.

Table 8: 'Running memory- continuous performance task' test results

	Average Correct Response Time (msec)	Number of Correct Responses / 80
1st measurement	51480	71
2nd measurement	53126	69
3rd measurement	57691	62

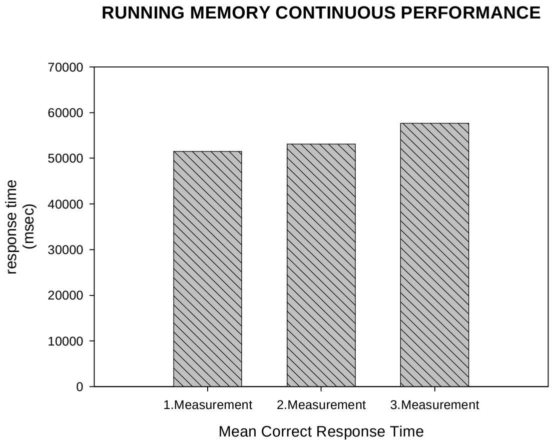

Figure 18: Average Correct Response Time (RM)

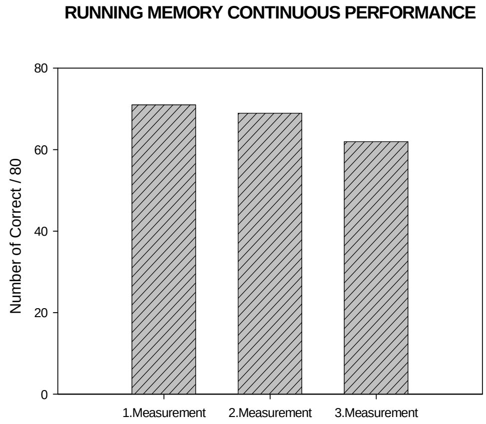

Figure 19: Average Correct Response Time (RM)

4.1.6 Comparative Analysis of the Tests

The comparative analysis of the 5 different ANAM4™ tests which were used to evaluate the effects of fatigue and restlessness on cognitive performance and operational processes, are presented below.

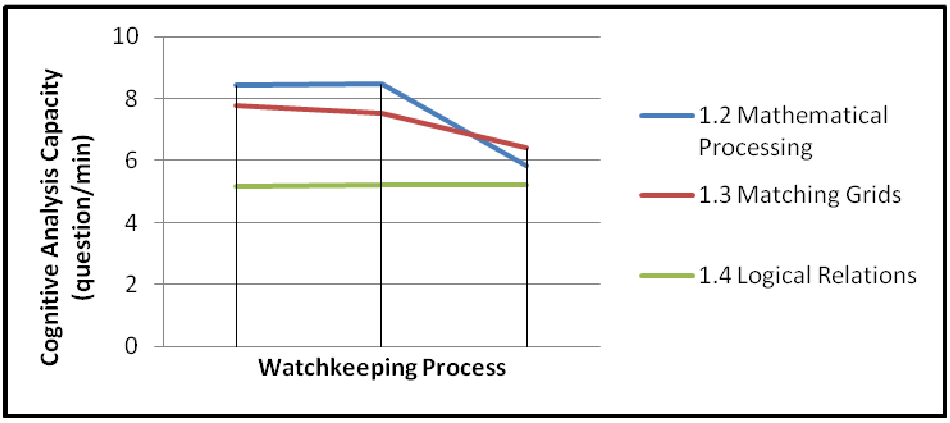

Figure 20: Cognitive Analysis Capacity (MP-MG-LR)

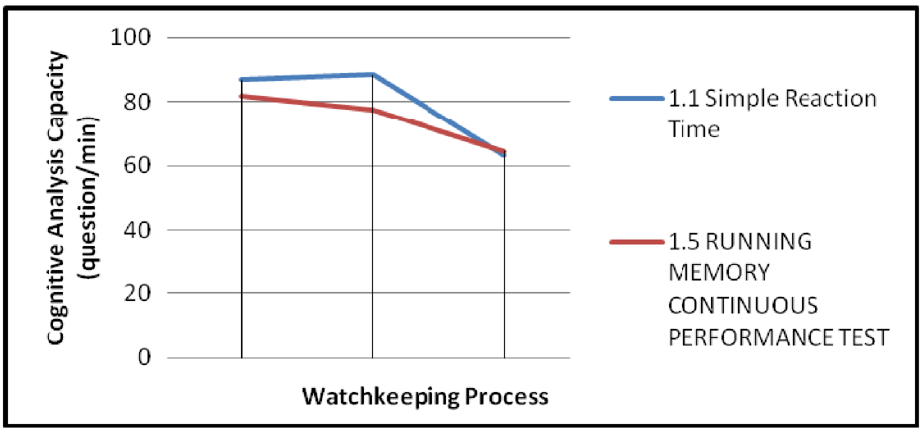

Figure 21: Cognitive Analysis Capacity (SRT-RM)

According to the results of the test, which were conducted to evaluate the effects of fatigue on cognitive performance, the highest influence on cognitive performances of the seafarers is observed in running memory, basic computer skills and attention; the least influenced parameter, on the other hand, is visiospatial thinking.

4.2 Monitoring the Thermal Stress on Cognitive Performance during a Voyage

In order to evaluate the effects of thermal stress on cognitive performance and operational processes, ANAM4™ battery comprising of three different tests was built. The battery was applied to six seafarers, a chief engineer, three engineer officers and two engine cadets, under two different thermal conditions, 40 C° and 27 C° (normal conditions). The reaction times and test performances were analysed comparatively.

4.2.1 Mathematical Processing Test Results

The results of mathematical processing help us to evaluate the concentration capability and working memory of the seafarers. Reaction times and the number of correct answers are given in Table 9, Figure 21 and Figure 23.

Table 9: 'Mathematical processing' test results

	Mean Correct Response Time (msec)	**Number of Correct / 20**
1st Measurement (27°C)	145364	18
2nd Measurement (40°C)	151261	18

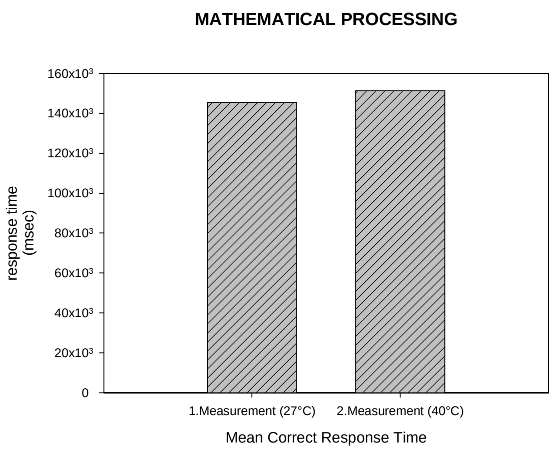

Figure 22: Average Correct Response Time (MP)

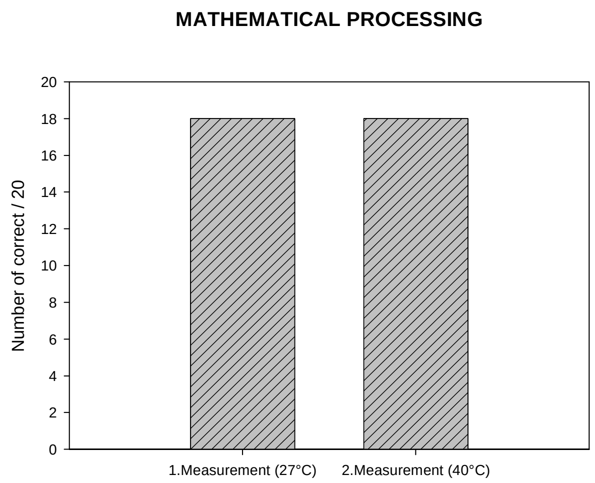

Figure 23: Average Number of Correct Response (MP)

Based on the results, it ıs monitored that thermal stress has no significant effect on the concentration and work memory capabilities of the seafarers.

4.2.2 'Running memory- Continuous Performance task' Test Results

Running memory test is used for evaluating the cognitive processesof attention and memory of the seafarers. The values of reaction time and correct answers to the running memory tests for different temperature levels are given in Table 10, Figure 24 and Figure 25.

According to the test results, it is seen that cognitive processes has decreased under the thermal stressor factors.

Table 10: 'Running memory- continuous performance task' test results

	Mean Correct Response Time (msec)	Number of Correct / 80
1st Measurement (27°C)	54692	73
2nd Measurement (40°C)	54124	70

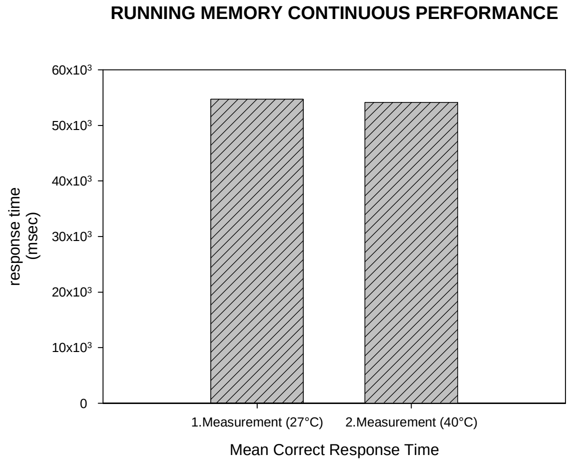

Figure 24: Average Correct Response Time (RM)

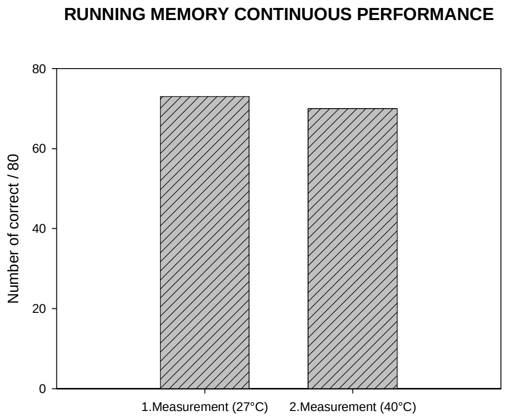

Figure 25: Average Number of Correct Response (RM)

4.2.3 Logical Relations Test Results

Logical relations test was used to understand the perceptional and reasoning capabilities. The results of this test is given with Table 11, Figure 26 and Figure 27.

Table 11: 'Logical relations' test results

	Mean Correct Response Time (msec)	Number of Correct / 24
1st Measurement (27°C)	210964	21
2nd Measurement (40°C)	226989	21

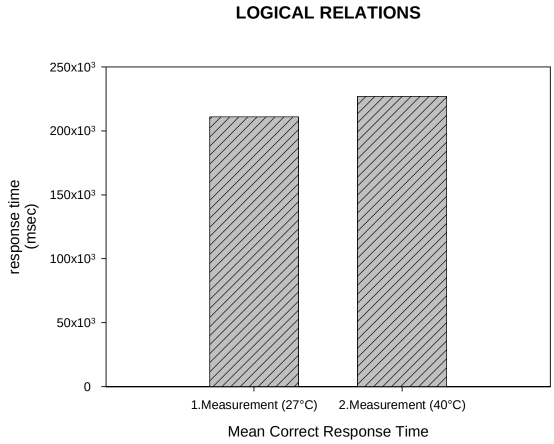

Figure 26: Average Correct Response Time (LR)

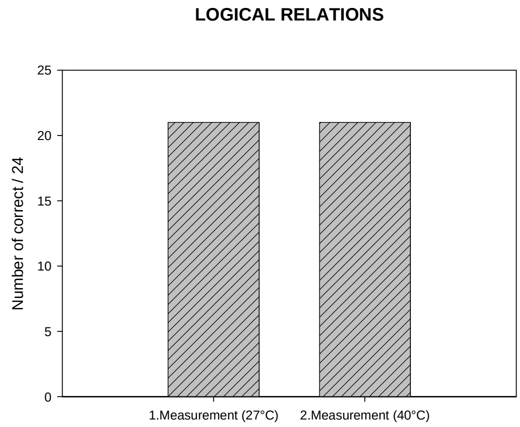

Figure 27: Average Number of Correct Response (LR)

4.2.4 Comparative Analysis of the Tests

The comparative analysis of the results of ANAM battery that was conducting for monitoring the thermal stress effects on the cognitive processes of the seafarers on a voyage are given in Figure 28.

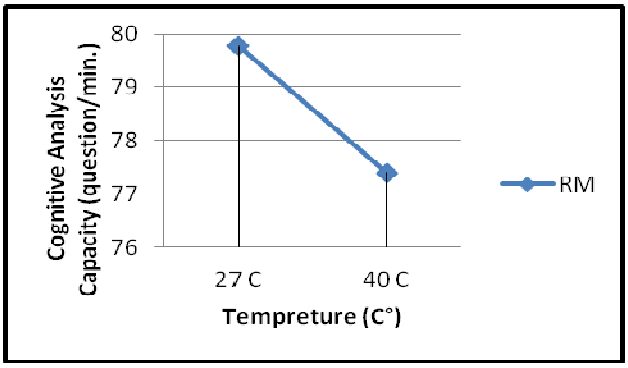

Figure 28: Cognitive Analysis Capacity (RM).

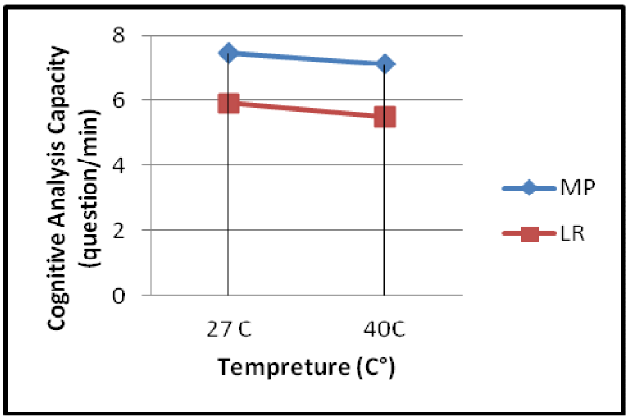

Figure 29: Cognitive Analysis Capacity (MP-LR).

It is monitored that cognitive processing capacity has been decreasing when the environment was 40 C° instead of 27 C°.

4.3 Monitoring the Noise on Cognitive Performance during a Voyage

Three different ANAM battery tests were applied to a chief engineer, three engineer officers and two engine cadets under 60dB and 108 dB sound levels. Then the results of tests were analysed comparatively.

4.3.1 'Mathematical Processing' Test Results

Mathematical Processing test was experienced for monitoring the working memory, concentration and information technology capabilities of seafarers under noise as a stressor factor. The results are given in Table 12, Figure 30 and Figure 31.

Table 12: 'Mathematical processing' test results

	Mean Correct Response Time msec)	Number of Correct / 20
1st Measurement (60dB)	145364	18
2nd Measurement (108dB)	210317	14

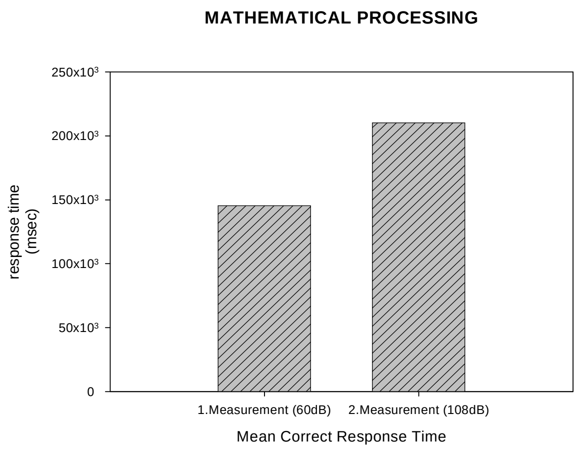

Figure 30: Average Correct Response Time (MP)

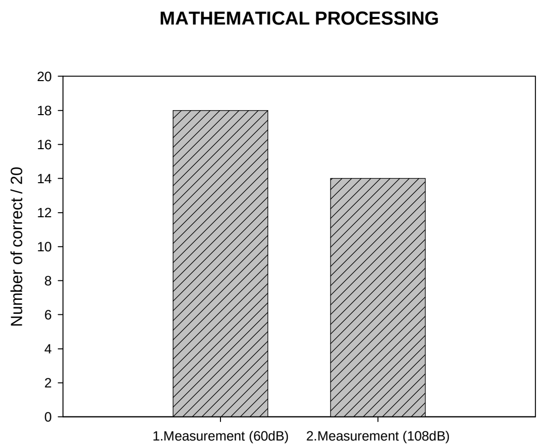

Figure 31: Average Number of Correct Response (MP)

4.3.2 'Running memory- Continuous Performance Task' Test Results

Running memory test was used to monitor the attention, concentration and memory capabilities under two different leves of noise. The results are given in Table 13, Figure 32 and Figure 33.

Table 13: 'Running memory- continuous performance task' test results

	Mean Correct Response Time (msec)	Number of Correct / 80
1st Measurement (60dB)	54692	73
2nd Measurement (108dB)	66591	61

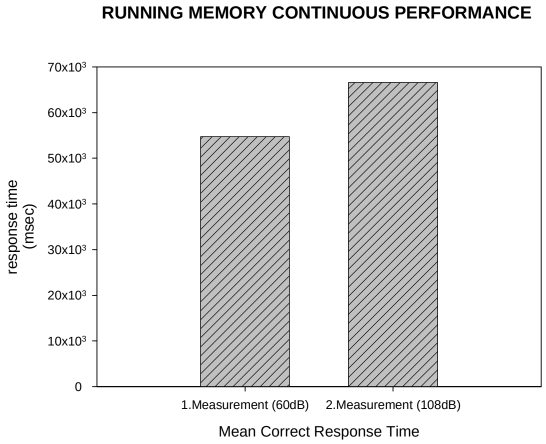

Figure 32: Average Correct Response Time (RM)

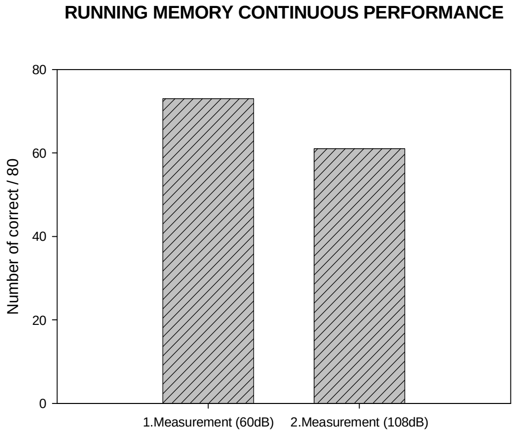

Figure 33: Average Number of Correct Response (RM)

4.3.3 'Logical Relations' Test Results

This test was applied to understand the perceptional and reasoning capabilities of the seafarers under noise as a stressor factor. The results are given in Table 14, Figure 34 and Figure 35.

Table 14: 'Logical relations' test results

	Mean Correct Response Time (msec)	Number of Correct / 24
1st Measurement (60dB)	210964	21
2nd Measurement (108dB)	265251	18

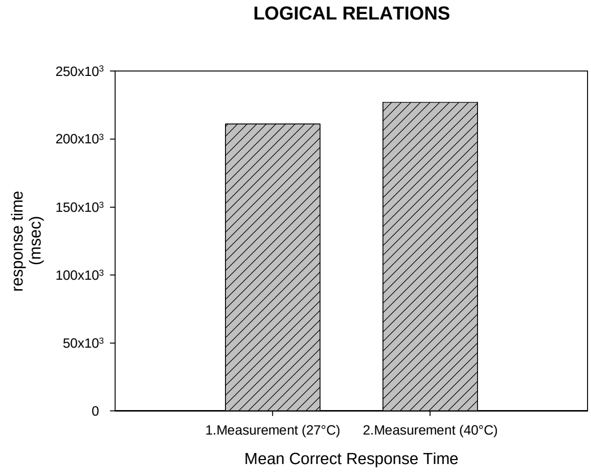

Figure 34: Average Correct Response Time (RM)

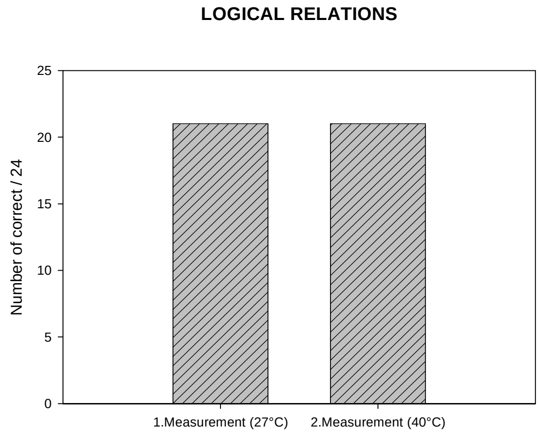

Figure 35: Average Number of Correct Response (LR)

4.3.4 Comparative Analysis of the Results

The comparative analyses of the three different tests for two different levels of noise are given with Figure 36 and Figure 37.

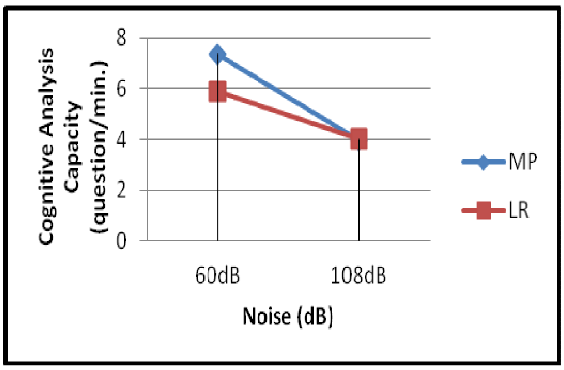

Figure 36: Cognitive Analysis Capacity (MP-LR)

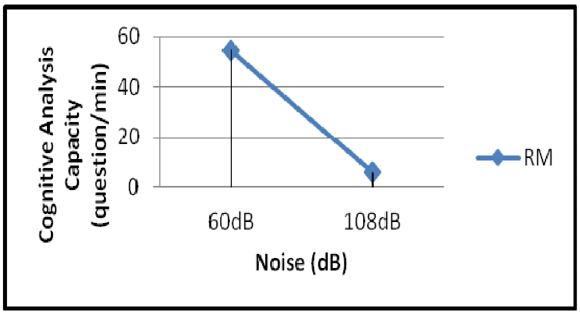

Figure 37: Cognitive Analysis Capacity (RM)

5. CONCLUSIONS

In this study, it is aimed to monitor the seafarers' cognitive performances under stressor factors on a voyage by using ANAM and the cognitive theories in the literature. Three stressor factors are used as driving factors. These are fatigue, thermal stress and noise. As fatigue inherently occurs for the seafarers in a voyage, we did not force anything to create fatigue as a stressor factor. However we changed the temperature and noise levels to be able to measure the responses of the seafarers in different mediums. Actually one of the aims of this study is to be able to conduct the measurements for seafarers in a real environment, not a simulator. For this purpose, using ANAM test batteries is not may be the same issue with a real environment, but this study is being one of the initial studies on the purpose of catching the real environment variables.

The results show that (a) the cognitive tests performance and the reaction response times decline through fatigue and sleepiness during the watchkeeping period (b) increasing temperature and noise causes to decline the reaction time and the cognitive performance. It is obviously seen that noise as a stressor factor has much more effects then the two other stressor factors on the cognitive processes. The monitored facts are consisted with the initial three hypothesis of this study.

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