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Assessing fatigue in the maritime domain

An analysis of the effects of fatigue in human performance in a simulation environment

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Contents

List of Figures

List of Tables

Synopsis

Technology is advancing rapidly. As a result, the automation of procedures in the maritime sector is continuously gaining ground. Nevertheless, the debate regarding the human factor and its contribution to a ship's individual systems, is more topical than ever.

Human factor could be defined as the scientific study of the interaction between the human and the elements of a system. The research concerning human factor aims not only in the optimization of the system's design, but also in the operators' adequate training and education regarding his/her interaction with the system. Therefore, the objective of research is to design a system where human errors are predominantly averted and any potential errors that are not averted are incapable of causing complete system failure.

Every day approximately 2 ships are lost at sea. Human factors constitute a predominant cause for such accidents. During the last 40 years, a series of technological advancements have contributed immensely to the improvement of the ships' dependability, not only in structural aspects (e.g., middle section strength, protection against corrosion etc.) but in technical aspects as well (e.g., main engine horsepower increase, use of navigational aids etc.). At the same time, IMO has mandated the seafarers' training and competencies, by implementing the ISM Code and the STCW Convention. The goal the above, is to cultivate a safety culture among the seafarers, aiming to minimize human errors as much as possible. However, total safety in the maritime domain is impossible to attain.

Fatigue has been identified to be a human factor with an immense impact on human performance. General fatigue could be defined as the accumulation of a day's stressful factors. Such factors may be physical fatigue, mental fatigue, the time of the day that an operation is being conducted as well as the quantity and quality of sleep.

Admittedly, the maritime profession constitutes an industry with a high level of risk, that in order to function properly requires the human presence 24 hours a day, 7 days a week. With a purpose to ameliorate this predicament, IMO, via the STCW Convention, has stipulated resting hours for the seafarers, in an effort to maximize the human performance. On the other hand, due to the frequent occurrence of demanding operations, the crew fails to abide by the predetermined resting hours and as a result, fatigue is manifested.

The scope of this thesis is to study the impact of fatigue on a crew that is subjected to an emergency incident. In order to reproduce the emergency environment, a ship simulator was utilized. The emergency incidents studied were a ship evacuation and a ship fire.

The implemented methodology was based on the use of questionnaires, interviews before and after training, actiwatches, sleep diaries and performance evaluation scales. Special emphasis was given on the analysis of sleep quantity and quality of the participants, as well as the identification of fatigue symptoms during the course of the training. Complementary goals of this study entail establishing a standardized sampling procedure so that it can be utilized in future research activities and the identification of additional skills and competencies that seafarers are required to possess to adequately manage and minimize fatigue.

In chapter 1, the role of the human factor in the maritime domain is pointed out. Specifically, an analysis is conducted on the influence of human factors regarding the ship design, as well as the legislative bodies. Fatigue is identified as a major human factor, that hasn't been effectively addressed up until today.

In chapter 2, fatigue is further analysed. In particular, major maritime accidents that occurred due to fatigue are catalogued, fatigue causes and symptoms are reviewed and measurement methods together with ways of managing fatigue are indicated. In addition, an extensive literature review concerning studies on fatigue is conducted, in order to ensure that credible results will be produced. Finally, the regulatory framework respecting the prevention and the management of fatigue was briefly mentioned.

In chapter 3, the method that was followed is presented, including the thesis' goals, methodological details, the measurement equipment, and the procedure that was implemented in order to collect and analyse the data.

In chapter 4, background information about the participants, as well as the results of the study are entailed. The results include the various measurements that were gathered, such as questionnaires, heart beats, sleep diaries and fatigue symptoms.

In chapter 5, having analysed the collected data, the conclusions and the recommendations are provided.

Finally, in Appendix A and B, analytical tables and charts regarding the measured variables are included.

Περίληψη

Η τεχνολογία αναπτύσσεται συνεχώς και με γοργούς ρυθμούς. Ως αποτέλεσμα, η αυξανόμενη αυτοματοποίηση των διαδικασιών στον τομέα της ναυτιλίας κερδίζει ολοένα και περισσότερο έδαφος. Παρόλα αυτά, η κουβέντα για τον ανθρώπινο παράγοντα και την συμβολή του στην ασφάλεια των επιμέρους συστημάτων ενός πλοίου, είναι πιο επίκαιρη από ποτέ.

Ως ανθρώπινος παράγοντας ορίζεται η επιστημονική μελέτη της συναναστροφής των ανθρώπων με τα στοιχεία ενός συστήματος. Η μελέτη του ανθρώπινου παράγοντα στοχεύει όχι μόνο στη βελτιστοποίηση του σχεδιασμού του συστήματος, αλλά και στην επαρκή επιμόρφωση και εκπαίδευση του ανθρώπου πάνω στην αλληλεπιδράση του με το σύστημα. Συνεπώς, επιδιώκεται η σχεδίαση ενός συστήματος, στο οποίο αφενός θα αποτρέπονται τα ανθρώπινα λάθη και αφετέρου, πιθανά ανθρώπινα λάθη που προκύπτουν να μην δύνανται να οδηγούν στην αστοχία του.

Σε καθημερινή βάση, χάνονται περίπου 2 πλοία στη θάλασσα. Στην πλειοψηφία των περιπτώσεων, ο ανθρώπινος παράγοντας συγκαταλέγεται υψηλά στα αίτια αυτών των απωλειών. Στην πάροδο των τελευταίων 40 ετών, μια σειρά από τεχνολογικές εξελίξεις έχουν συντελέσει τα μέγιστα στην αύξηση της αξιοπιστίας των πλοίων, τόσο σε κατασκευαστικά κομμάτια (π.χ. αντοχή της μέσης τομής, προστασία έναντι διάβρωσης κλπ.), όσο και σε τεχνικά κομμάτια (π.χ. αύξηση ιπποδύναμης κύριας μηχανής, χρήση βοηθητικών συστημάτων ναυσιπλοΐας). Παράλληλα, ο IMO έκανε υποχρεωτική την επαρκή εκπαίδευση και κατάρτιση των πληρωμάτων των πλοίων, θεσπίζοντας τον κώδικα ISM και την συνθήκη STCW. Απώτερος σκοπός όλων των παραπάνω είναι η καλλιέργεια μιας κουλτούρας ασφαλείας στα πληρώματα των πλοίων, ώστε να μειωθούν τα ανθρώπινα λάθη όσο το δυνατόν περισσότερο. Ωστόσο, η απόλυτη ασφάλεια στην ναυτιλία είναι αδύνατον να επιτευχθεί.

Ένας από τους σημαντικότερους ανθρώπινους παράγοντες που επηρεάζει την ανθρώπινη απόδοση, είναι η κόπωση. Ως γενική κόπωση στην ναυτιλία, ορίζεται η συσσώρευση όλων των στρεσογόνων παραγόντων της ημέρας. Τέτοιοι παράγοντες μπορεί να είναι η σωματική κούραση, η νοητική κόπωση, η ώρα της ημέρας κατά την οποία πραγματοποιείται μία εργασία, καθώς και η ποσότητα

και ποιότητα του ύπνου.

Ομολογουμένως, η ναυτιλία αποτελεί μια βιομηχανία υψηλού ρίσκου, η οποία για την φυσιολογική λειτουργία της, απαιτεί ανθρώπινη παρουσία 24 ώρες την ημέρα, 7 ημέρες την εβδομάδα. Στην προσπάθειά του να διευθετήσει την εν λόγω ανάγκη, ο IMO, μέσω της STCW, προδιαγράφει ώρες ξεκούρασης (resting hours) για τα μέλη του εκάστοτε πληρώματος με σκοπό την μεγιστοποίηση της ανθρώπινης απόδοσης. Βέβαια, ανάλογα τις απαιτήσεις της εκάστοτε διαδικασίας που υλοποιείται πάνω σε ένα πλοίο, πολλές φορές είναι αδύνατον να τηρηθούν οι προδιαγεγραμμένες ώρες ξεκούρασης, με αποτέλεσμα η κόπωση να κάνει την εμφάνισή της.

Σκοπός αυτής της διπλωματικής εργασίας είναι η μελέτη της επίδρασης της κόπωσης σε πλήρωμα το οποίο βιώνει κάποιο έκτακτο περιστατικό. Για την αναπαράσταση των συνθηκών, έγινε χρήση εκπαιδευτικού προσομοιωτή πλοίου. Τα έκτακτα περιστατικά τα οποία μελετήθηκαν ήταν η εκκένωση πλοίου και η πυρκαγιά πλοίου.

Η μεθοδολογία που ακολουθήθηκε βασίστηκε στην χρήση ερωτηματολογίων, διενέργεια συνεντεύξεων πριν και μετά την εκπαίδευση, ακτιγράφους καρπού, ημερολόγια ύπνου και κλίμακες αξιολόγησης απόδοσης. Ιδιαίτερη έμφαση δόθηκε στην διερεύνηση της ποσότητας και ποιότητας του ύπνου των συμμετεχόντων, καθώς και στην αναγνώριση των συμπτωμάτων της κόπωσης κατά την διάρκεια της εκπαίδευσης. Συμπληρωματικοί στόχοι της μελέτης, αποτελούν η προτυποποίηση της δειγματοληπτικής διαδικασίας με σκοπό να μπορεί να χρησιμοποιηθεί σε άλλες μεταγενέστερες μελέτες, καθώς και η αναγνώριση τυχόν επιπρόσθετων ικανοτήτων και δεξιοτήτων που χρειάζεται να διαθέτουν τα πληρώματα των πλοίων, προκειμένου να διαχειρίζονται και να αντιμετωπίζουν αποδοτικότερα την κόπωση.

Στο κεφάλαιο 1, γίνεται αναφορά στον ρόλο του ανθρώπινου παράγοντα στην ναυτιλία. Συγκεκριμένα, αναλύεται πώς ο ανθρώπινος παράγοντας έχει επιδράσει τον σχεδιασμό των πλοίων καθώς και το νομοθετικό πλαίσιο της ναυτιλίας και τέλος, αναγνωρίζεται η κόπωση ως ένας από τους σημαντικότερους ανθρώπινους παράγοντες, που δεν έχει αντιμετωπιστεί επαρκώς αποτελεσματικά μέχρι σήμερα.

Στο κεφάλαιο 2, πραγματοποιείται ανάλυση της κόπωσης. Συγκεκριμένα, γίνεται μνεία σε σοβαρά ατυχήματα τα οποία σημειώθηκαν λόγω κόπωσης, αναλύονται τα αίτια και τα συμπτώματά της και αναφέρονται τρόποι μέτρησης και αντιμετώπισής της. Επίσης, γίνεται μια εκτενής βιβλιογραφική ανασκόπηση σε υφιστάμενες μελέτες σχετικές με την κόπωση, με σκοπό την ενίσχυση και θωράκιση της ακολουθούμενης μεθοδολογίας, ώστε να παραχθούν αξιόπιστα αποτελέσματα. Τέλος, γίνεται μια αναφορά στο ισχύον νομοθετικό πλαίσιο το οποίο σχετίζεται με την πρόληψη και την αντιμετώπιση της κόπωσης .

Στο κεφάλαιο 3, παρέχεται μια αναλυτική επισκόπηση της μεθοδολογίας που ακολουθήθηκε συγκαταλέγοντας τους στόχους της μελέτης, την μέθοδο, τα μέσα μετρήσεων που επιλάχθηκαν καθώς και τη διαδικασία που εφαρμόστηκε για τη συλλογή και ανάλυση των αποτελεσμάτων.

Στο κεφάλαιο 4, αποτυπώνονται σχετικές πληροφορίες για το σύνολο των συμμετεχόντων και τα αποτελέσματα της μελέτης αναφορικά με τα μεγέθη που μετρήθηκαν όπως τα ερωτηματολόγια, οι καρδιακοί παλμοί, τα ημερολόγια ύπνου και τα συμπτώματα κόπωσης.

Στο κεφάλαιο 5, συμπεριλαμβάνονται τα συμπεράσματα τα οποία προέκυψαν μετά από ανάλυση των δεδομένων καθώς και οι αντίστοιχες προτάσεις που βασίζονται στα ευρήματα αυτής της μελέτης.

Τέλος, στα Παραρτήματα A και B, εμπεριέχονται αναλυτικοί πίνακες αποτελεσμάτων και διαγράμματα ορισμένων μετρούμενων μεγεθών.

Chapter 1

Human Factor

Even though industrial technology is rapidly evolving and the majority of the procedures have become predominantly automated, the implications of direct human interaction are still present. This interaction, often proves to be a source of major accidental events. As a result, when designing technical systems, it is of utmost importance to also consider the human factors involved, so as to ensure an adequate level of safety. There is a plethora of human factors' definitions throughout various publications. According to International Ergonomics Association, human factors is equivalent to ergonomics [13]:

> *Ergonomics (or human factors) is the scientific discipline concerned with the understanding of the interactions among humans and other elements of a system, and the profession that applies theory, principles, data and methods to design in order to optimize human well-being and overall system performance.*

The terminology ergonomics is commonly used in Europe as an alternative for human factors, which is broadly applied in the United State's literature. Its origin is from the Greek words ergon (work) and nomos (nature's law). In order to avoid ambiguity between the two terms, the International Maritime Organization (IMO) suggests the use of the words Human Element. However, no matter the way it is referred to, the Human Element is an indispensable contributor to the design approach of a system. Consequently, it is preferable to adapt the various tasks, the environment as well as the equipment, to the user's needs and characteristics and not vice versa. This would result in a more efficient and safe human performance, which in turn, will lead to a system with increased reliability. According to Vincente [55]: "If the human factor is taken into account, a tight fit between person and design can be achieved and the technology is more likely to fulfill its intended purpose."

1.1 Human Factor in Maritime Safety

Every day approximately two ships are lost paying millions of US dollars in claims and radically affecting the lives of hundreds of people [24]. Human behavior is the source of practically all such loss. It is also however the reason why the loss is not greater.

Over the last 40 years, the shipping industry has improved the ship structure and the reliability of the operating systems, in its efforts to minimize casualties and enhance efficiency and productivity. Improvements are noticeable in hull design, stability systems, propulsion systems and navigational equipment. As a result, as long as people are involved in marine operations, the potential of human error, becomes a prevalent threat. As shown in Figure 1.1, human error contributes to [16]: 84-88% of tanker accidents, 79% of towing vessel groundings, 89-96% of collisions,75% of allisions and 75% of fires and explosions.

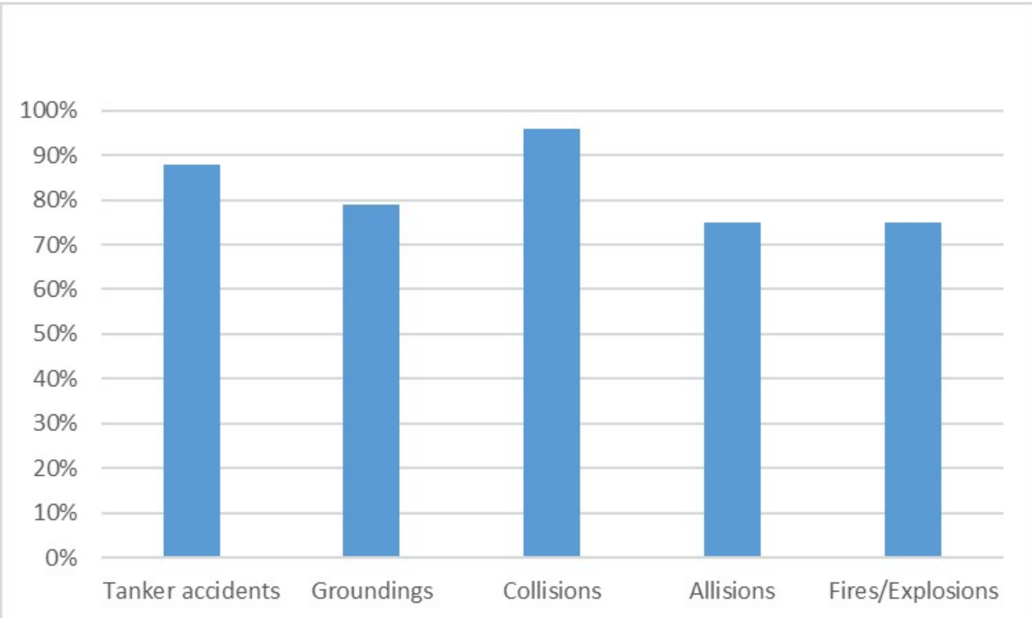

Figure 1.1: Incidents owing to Human Factor

The IMO mandated the training and education of crew members by developing the International Safety Management Code (ISM), which targets to the amelioration of human interference, in the context of an enhanced and more safe maritime transport framework [34].

Absolute safety over ships' operations is unlikely to be achieved. The contribution of human factors over maritime accidents cannot be easily detected.

On the one hand, we find that an accident involves the interaction of individuals, equipment and environment, as well as unforeseen factors. On the other hand, human factors comprise operative human errors derived from personnel's own qualifications or from their physical, mental and personal conditions and situational errors, derived from work environment design, management problems or human-machine interface among others [16].

It must be noted that risk cannot be eliminated completely from maritime activities and that errors are an integral part of human experience. Elements such as appropriate management policies, effective training, experience and qualifications needed, are capable of limiting the occurrence of human errors.

The operations of a ship are determined by regulations, instructions and guidelines which the crew is required to be aware of and follow. The written instructions potentially establish a culture of safety and initially ensure that certain skills are in place. For investing in a good long-term safety culture, it is also necessary for the management ashore and on-board to reassure, encourage and inspire the essential attitudes to complete the safety objectives.

One can conclude that the most prevalent factor for marine accidents is the human element. Therefore, taking measures that consolidate the absence of human errors, will drastically reduce the risk related to marine operations. According to European Maritime Safety Agency (EMSA), it is estimated that 65.8% of marine accidents occurred during the period 2011-2018, were attributed to human actions' category as shown in Figure 1.2.

From all of the above, the marine casualty rate is still high, because the maritime system, is still a human system. The human element however, affects the reliability of automated systems bilaterally. This effect may either be negative (e.g., human working error) or positive (e.g., controlling system breakdowns or system problems). Human performance is determined by the human being's execution of actions taken to accomplish a task.

1.2 Fatigue as an Important Human Factor

In a sense, we all know what fatigue is, and what it means to be fatigued. However, a distinction that we do not generally think about (but is accepted by most researchers), is between muscular and general fatigue. Muscular fatigue comes from heavy physical work and is localized in over-stressed muscles. Of most concern to us in maritime human factors, is general fatigue. General fatigue can be viewed as an accumulation of all of the stresses of the day. These include the duration and intensity of physical and mental work, the time of day that the work is performed and the amount of sleep that an operator has received. These factors need to be balanced by recuperation

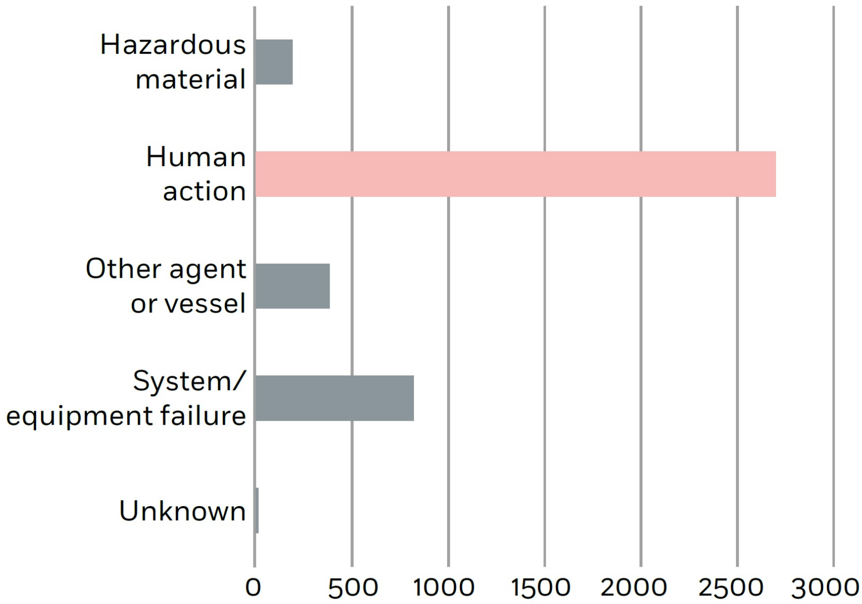

Figure 1.2: Distribution of accident events for 2011 - 2018

[23].

Shipping is a high-risk industry that requires monitoring with human interaction around the clock, 7 days a week. The machinery on the ship, is designed for continuous operation without the need for regular human interference. The same principle however, doesn't apply to the human operator. According to Rosekind et al. [44], human fatigue is acknowledged to be a significant safety concern in high-risk industries. Even though the necessity for rest between working shifts of seafarers have been mandated by the IMO and the convention on Standards of Training, Certification and Watchkeeping (STCW), many times certain tasks on-board require extensive hours to accomplish, without intermediate breaks. In 1999, the U.S. National Transportation Safety Board [31], reported that the occupation of seafarers, was second in the list with the highest number of continuous working time, behind rail workers .

After research, Hethrighton et. al. [54] concluded that fatigue may result in disastrous outcomes in terms of health and human performance. The feeling of fatigue as a state of tiredness, individually leads to heavy eyelids, head-nodding, grogginess, difficulty concentrating, low energy but also has a negative impact on the communication skills, the decision-making ability etc.. As analyzed in the following chapters, several studies have outlined fatigue as the primary factor for mariners under-performance.

It is evident that the contribution of fatigue to casualties due to human errors is significant and cannot be eliminated. Therefore, efforts can be made to reduce, prevent and mitigate errors by ensuring that people have appropriate non-technical skills. Studying the state of sleep and how it is regulated, techniques for optimizing shift working and sleep regulation, will prove beneficial for coping with fatigue.

Chapter 2

Fatigue

The word "fatigue" is used to describe a variety of disorders and sufferings in many fields. There is no universally accepted technical definition of fatigue. It is widely used to describe a state of feeling tired, weak or sleepy, that results in a reduced ability to perform ordinary tasks. Fatigue affects everyone differently and can be categorized as:

- Physical Fatigue (similar to muscle weakness)
- Mental Fatigue (is occasionally expressed by wakefulness or lack of attention)

Fatigue In Medical Terms

In medical physiology, fatigue is the inability to perform reasonable and necessary physical or mental activity. When the metabolic reserves of the body are exhausted and the waste products increased (e.g., after prolonged exertion), the body finds it difficult to continue its function and activity. The accumulation of lactic acid in muscle tissue and the depletion of glycogen (i.e., stored glucose) results in muscle fatigue. The contractile properties of muscle are reduced and continued exertion is impossible, unless the muscle is allowed to rest. In the normal body, a period of rest permits redistribution of nutritive elements to the muscles and tissues and elimination of accumulated waste products, hence the body is then ready to resume activity. There are some persons to whom fatigue is a chronic state, that does not necessarily result from activity or exertion. In some instances, this abnormal fatigue may be associated with systemic disorders such as anemia, a deficiency of protein or oxygen in the blood, addiction to drugs, increased or decreased function of the endocrine glands or kidney disease, in which there is a large accumulation of waste products. If excessive fatigue occurs over a prolonged period, exhaustion (marked by loss of vital and nervous power) may result.

In most individuals with chronic fatigue however, the condition seems to be associated with manic-depressive disorder where further thorough medical and psychiatric examination may be required [5].

Fatigue can additionally be divided into two types: acute and chronic fatigue. The first one does not affect the subject/person after a period of rest. However, if acute fatigue is present for as a long-term condition without recovery, chronic fatigue makes its appearance. The compensation mechanism is not as effective in reducing chronic fatigue as in reducing acute fatigue. A wide variety of noticeable symptoms are observed, which include:

> Increased anxiety, decreased short-term memory, slowed reaction time, decreased work efficiency, reduced motivational drive, decreased vigilance, increased variability in work performance, increased errors of omission which increase in commission when time pressure is added to the task and increased lapse with increasing fatigue in both number and duration [8].

2.1 Maritime Disasters

Fatigue has been recognized by many investigating agencies worldwide (e.g., the Transportation Safety Board of Canada, the National Transportation Safety Board of the United States etc.) as a contributor to a significant number of transportation occurrences. However, it was difficult to justify the suspicion of fatigue as a contributor or cause of industrial accidents. This happened because of the missing links between the unsafe acts and decisions that led to the incidents and the fatigued state of the people involved. There was lack of scientifically data on how fatigue is capable of affecting not only moods and feelings, but both individual and team performance as well [52].

There have been numerous casualties in which seafarer fatigue has been noted as a key casual factor. Regarding the grounding of the tanker ship Exxon Valdez in 1989, the NTSB pointed out that the watchkeeper had slept only 5-6 hours the last 24 hours prior to accident.

In March 1997, the feeder containership Cita ran aground off the English Channel, after the mate fell asleep and the ship sailed ungoverned for two and a half hours. The investigation stated that the sole lookout was short of sleep due to the fact that crew was comprised of only two watchkeepers, that were following the two-shift system (i.e., 6-h on and 6-h off).

The grounding of the general cargo ship Jambo in 2003 near Scotland, occurred after the chief officer's sleep deprivation that resulted in him falling asleep and neglecting an intended change of course.

Moreover, when the bulk carrier Pasha Bulker grounded in June 2007, the master's deposition revealed that he was suffering from fatigue and anxiety at a high level.

An incident including human loss related to fatigue, is the death of a Filipino able seaman (AB) in a fall on-board the Danish-flagged general cargo ship Thor Gitta in May 2009. Investigators who used FAID assessment software found that the seafarer's 6-on/6-off work pattern was at a score of *111* on the morning before the accident – a level considered to be within the very high range [9].

The Australian Transport Safety Bureau investigation found that the grounding of the bulk carrier Shen Neng 1 in April 2010 occurred because the chief mate's operation performance was at a low level. He did not change the ship's course according to the designated passage plan. Investigations revealed that his rest consisted of 2.5 hours of sleep in the 38.5 hours prior to the casualty.

Lastly, in March 2012, Netherlands' registered cargo vessel Spring Bok, collided with the Maltese-registered liquefied petroleum gas (LPG) tanker, Gas Arctic, while the vessels were proceeding in the south-west lane of the Dover Strait Traffic Separation Scheme. The Marine Accident Investigation Branch (MAIB), identified that Spring Bok's officer of the watch (OOW), was fatigued and failed to adequately detect the other vessel prior the collision. Although each vessel had detected and identified one another by both radar and Automatic Identification System (AIS), neither OOW made a full appraisal of the risk of collision, nor took the actions required by the International Regulations for Preventing Collision at Sea (COLREGs, as amended) to prevent the accident. The investigation report showed that the crew of the Dutch vessel had not slept from 0700 the previous morning till then and that the main cause of the collision was fatigue [20].

2.2 Understanding Fatigue

New Zealand's advisory guide on managing fatigue in maritime industry illustrates the mechanism of fatigue, as shown in Figure 2.1. The feeling of fatigue shows up when the balance between the physical and mental effort involved in waking activities and the recovery of body and mind after that effort, is unsteady [38].

The sleep quality can be ensured through the sleep cycle preservation. The internal structure of sleep is described by a five-stage cycle (Figure 2.2). The duration of a full circle is approximately 90 to 120 minutes. There are two discrete types of sleep: the non-rapid eye movement sleep (non-REM sleep) and the rapid eye movement sleep (REM sleep).

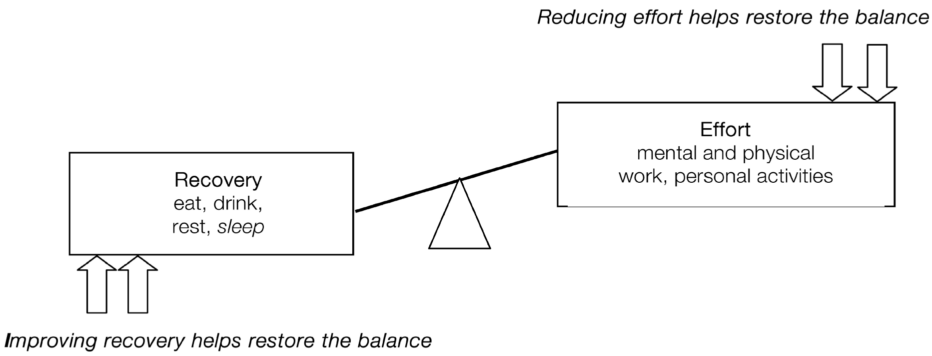

Figure 2.1: The mechanism of fatigue

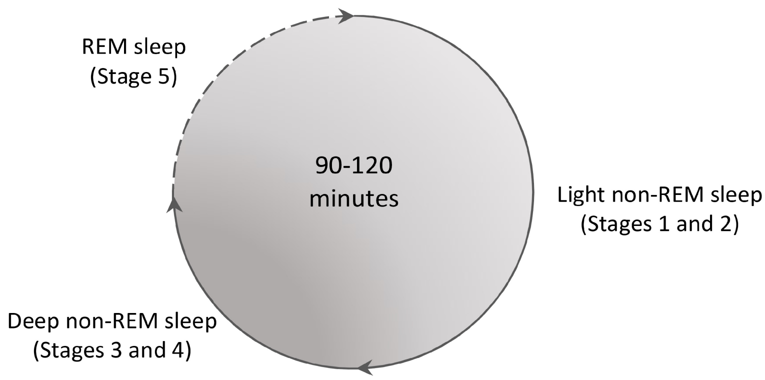

Figure 2.2: The non-REM/REM sleep cycle

The initial four stages are parts of the non-REM sleep, where brain activity is gradually slowing down. The first stage concerns the transition between wakefulness and light sleep, while stage 2 accounts for almost half the total sleep. During the next two stages deep sleep occurs, in which physical and mental recovery is attained. Briefly, stage 4 is related to the slowest brain activity and the deepest sleep. It is mentioned that the deeper the sleep stage, the harder it is to wake someone up and it takes a longer time to become fully alert. At the same time, disturbances to sleep (i.e., a loud noise), draw someone back to a lighter sleep stage, interrupting the essential recuperative effect of the deep sleep stage. Stage 5 corresponds to REM sleep, where brain activity is similar to waking and active dreaming is unfolding. The muscle and spinal reflexes are now maximally suppressed to prevent people from moving and acting out their dreams. REM sleep is critical for mental stability, memory and learning. Deprivation of this type of sleep is responsible for irritability, poor judgment and hallucinations [24].

A sufficient amount of sleep consists of 4 or 5 full non-REM/REM sleep cycles and stages 3-5 recuperate from sleep debt. Additionally, sleep that is fragmented by multiple awakenings, breaks up the non-REM/REM cycles and is less revitalizing than continuous sleep [38].

Keeping natural sleep patterns according to body clock is needed in order to enhance the sleep quality. Inevitably, humans -as most living species- have an internal pacemaker; the biological clock that drives their circadian rhythms. Circadian rhythms are physical, mental and behavioral changes that roughly follow 24-hour cycle, responding primarily to light and darkness in an organism's environment [2]. It is obvious that circadian body clock modifies the brain and body functions in agreement with day/night cycle.

Sleepiness is typically most dominant during the early hours of the morning (i.e., around 3:00-5:00 am) and increased during mid-afternoon (around 3:00-5:00 pm) due to the body clock. On the contrary, body clock causes high level of alertness in the late morning and early evening.

The body clock is sensitive to specific time cues of daily routine, relevant to light/dark, work/rest periods and interaction with other people. The absence of these time cues can slow down the body clock. In other words, the biological day is prolonged further than 24 hours. The regular pattern of activities and sleep, let the body clock keep up with the 24-hour day/night cycle. Meanwhile, unusual working schedules and rotating shifts, send conflicting messages to the body clock. The below excerpt taken directly from New Zealand's advisory guide on fatigue, presents examples of conflicting messages to the body clock [38]:

> *For example, when people go onto night work, the day/night cycle does not change, and neither do the other people in their lives who are active during the day. So, while their work pattern is requiring them to be active at night, the other cues in the environment are telling the body clock that they should be asleep at night.*
>
> *Because of conflicting time cues, the body clock does not adapt fully to shiftwork. On days off, most people also change back to sleeping at night and being active during the day, which helps bring the body clock back to its preferred pattern.*
>
> *Unusual work times also mean that people may be trying to sleep when factors such as noise and light are more likely to disturb them and when there are other demands on their time, like family responsibilities or leisure activities. These external factors can also reduce both the amount and the quality of sleep they are able to get, in addition to the effects of trying to sleep*

at a less optimal time within the body clock cycle.

Focusing on sleep quality, it is necessary to mention another important element; *stress*. For the purposes of this study, stress is defined, in terms of the interaction between a person and his/her work environment, as: *the physiological response to prolonged situations where people are asked to act beyond their available resources.* Initially, stress can play the role of an arousal by stimulating the production of adrenalin. On the other hand though, stress may cause many undesirable physical and behavioral signs/symptoms and the exaggerated production of adrenalin can lead to fight-or-flight response.

One of the first signs of chronic stress, is difficulty in sleeping; an initial factor for the sleep debt occurrence. If the lack of sleep is not restored because of stress-induced insomnia, it will lead to a predicament that raises stress. This becomes a vicious cycle, in which stress contributes to sleep loss and in turn, sleep loss increases the stress level (Figure 2.3). Therefore, inadequate and insufficient sleep, affects every aspect of an individual's functioning, resulting in a radical decline of performance levels.

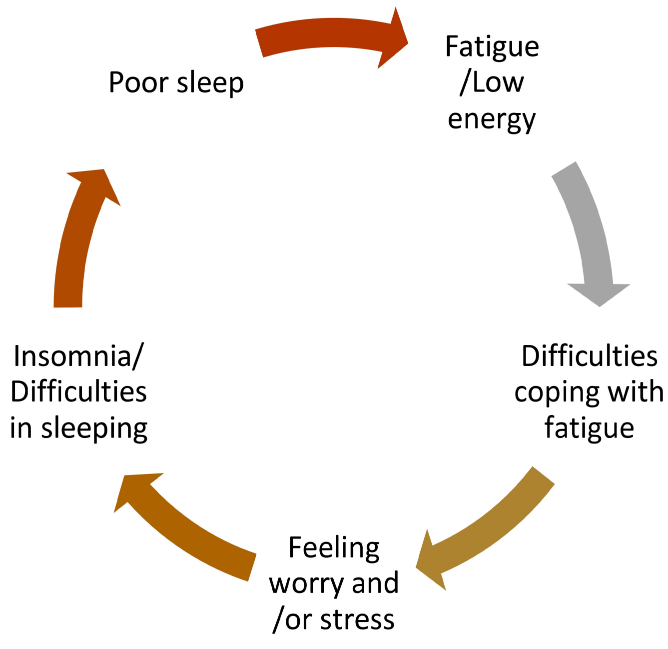

Figure 2.3: A vicious cycle: lack of sleep and stress

2.2.1 Fatigue On Board

A seafarer usually spends three to six months working far away from home, on a "captive" environment. The moving vessel lurks unpredictable environmental factors during the sailing period and occasionally the seafarer is exposed to extreme weather conditions (rough seas and storms). While serving on board regarding the shift schedule, the distinction between work and relaxation is not generally pronounced.

It is an ordinary condition in ships, that most of the time the crew overworks beyond the standard number of hours specified by the International Labour Organization (ILO), but it is a fact that the actual number of hours are greater than the number of hours recorded or documented, in order to avoid ILO and other international regulations. Under these circumstances, the most common causes of fatigue known to seafarers are lack of sleep, poor quality of rest, stress and excessive workload [28]. The Centers for Disease Control and Prevention (CDC) have claimed that the extended hours of wakefulness can impair an individual's performance similarly to drinking alcohol:

- Being awake for at least 18 hours is equal to having a Blood Alcohol Content (BAC) of 0.05%

- Being awake for at least 24 hours is equal to having a BAC of 0.10% [1]

It is clear that working 24-hour shift patterns on a moving vessel poses a number of obstacles to gaining sufficient restorative sleep. The crew has to cope with excessive hours of work, sleep when the body feels naturally awake and face disturbances from both others mariners and vessel activity. It is unavoidable to disrupt the natural rhythms on a regular basis due to shift work and may be compounded by more and more pronounced jet lag type effects as ships get increasingly faster [12].

Stress can arise from various factors, including personal relationships, work demands and management style. There are several ship design characteristics that can interfere with the level of stress and fatigue. Ship design features regarding automation and equipment reliability, affect work load, some have influence on the crew's ability to sleep and others affect the level of physical stress on the crew. Some examples of these features are the following: inspection and maintenance, age of vessel and physical comfort in work spaces, location of quarters, ship motion and physical comfort of accommodation spaces.

2.2.2 Fatigue Causes

From all of the above, fatigue is associated with poor quality sleep, negative environmental factors, high job demands and high stress.

[1] In the U.S., it is illegal to drive with a BAC of 0.08% or above.

The numerous causes of fatigue can be categorized in various ways and one cause may belong to multiple categories. The developed guidance of IMO that address the issue of fatigue, presents the potential causes thoroughly. According to these guidelines, the range of causes is ensured in extent, by separating them into the following general factors [6]:

- Crew-specific Factors
- Management Factors (ashore and aboard ship)
- Ship-specific Factors
- Environmental Factors

The crew-specific factors in particular, refer to features which describe the way humans act. These features derive from the lifestyle, the personal habits and the individual attributes. They consist of the sleep pattern, the biological clock, the psychological and emotional background (including stress), the nutrition habits, work obligations and the physical condition are part of the contributors, as shown in Figure 2.4, and affect human performance.

The category of management factors, as its name implies, contains details related to management policy and operational procedures. The annual review of marine casualties by EMSA [1], identified that ship related procedures, regarding operational practices, is the main safety recommendation coding area (48%), followed by human factors (17%) (Figure 2.5). Operational practices and policies capable of causing stress and influence on-board fatigue mentioned by IMO, are the following [6]:

a. Organizational Factors

    - Staffing policies and Retention
    - Role of riders and shore personnel
    - Paperwork requirements
    - Economics
    - Schedules-shift, Overtime, Breaks
    - Company culture and Management style
    - Rules and Regulations
    - Resources
    - Upkeep of vessel
    - Training and Selection of crew

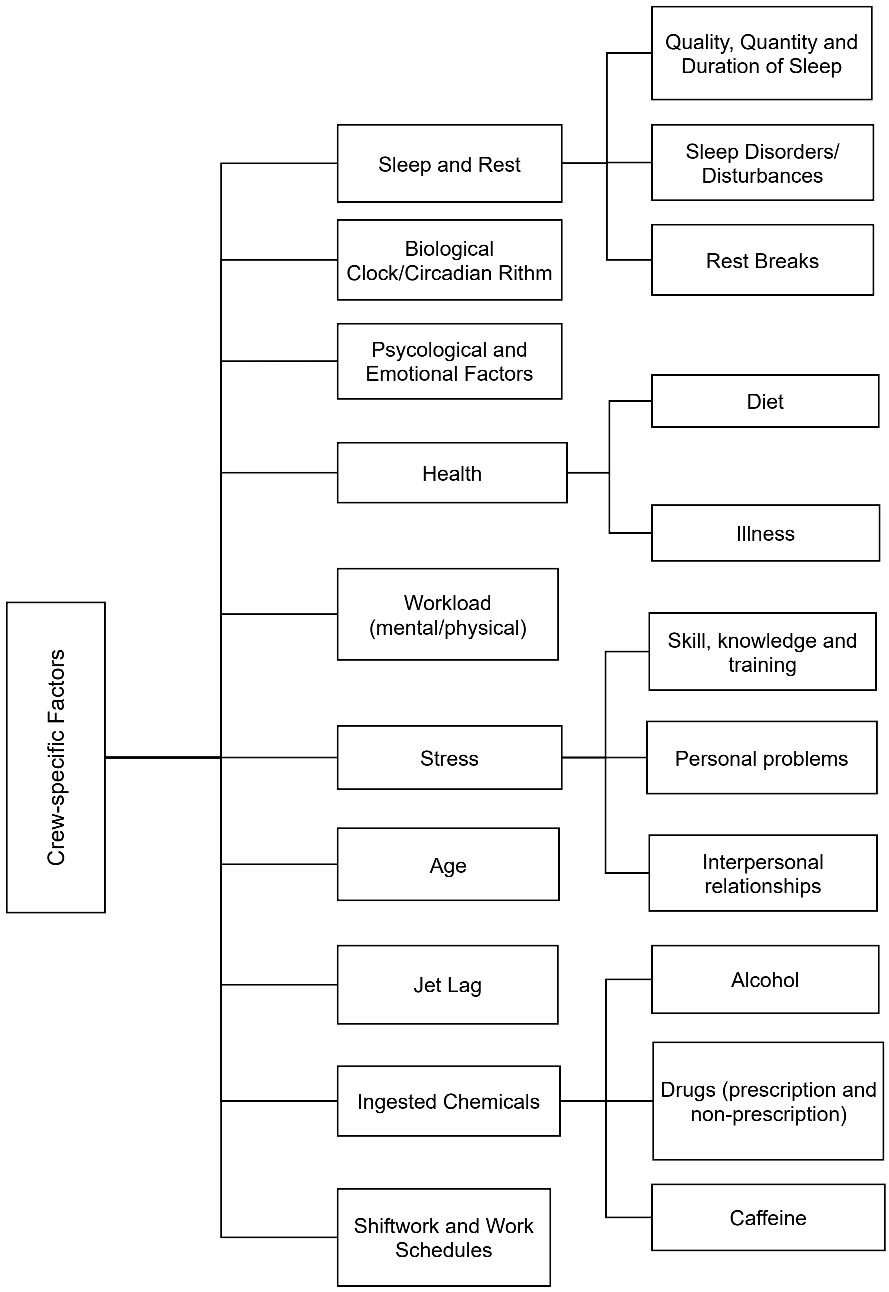

Figure 2.4: Crew-specific factors recommended by IMO guidelines

b. Voyage and Scheduling Factors

- Frequency of port calls
- Time between ports

- Routing
- Weather and Sea condition on route
- Traffic density on route
- Nature of duties/workload while in port

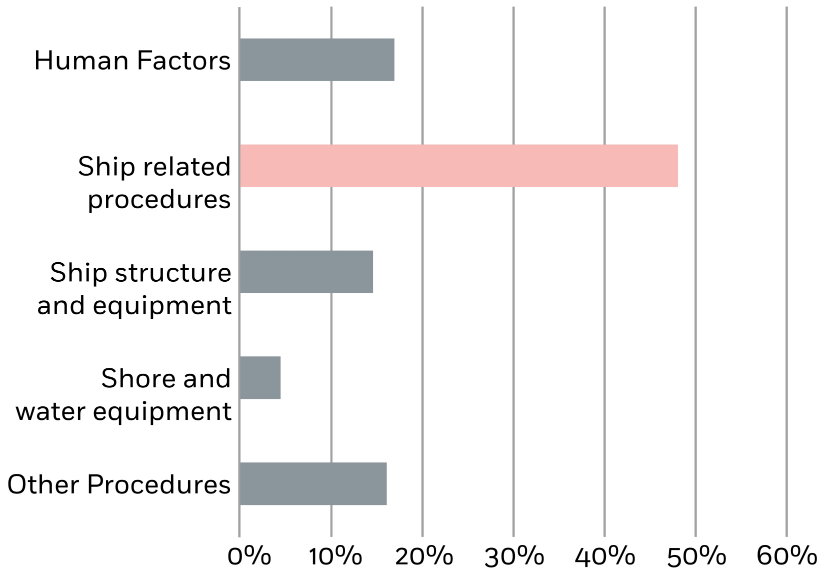

Figure 2.5: Distribution of safety recommendations issued per focus area for 2011-2018

The third type of factors may affect crew endurance indirectly. Although many of the factors are incorporated within the ship design and have an undeniably positive effect on seafarer's fatigue, there are still features that have an impact on workload (i.e., automation, equipment reliability etc.), the crew's ability to sleep and the level of physical stress on the crew (i.e., noise, vibration, accommodation spaces etc.). The following list details ship-specific factors [6]:

- Ship design
- Level of Automation
- Level of Redundancy
- Equipment reliability
- Inspection and Maintenance

- Age of vessel
- Physical comfort in work spaces
- Location of quarters
- Ship motion
- Physical comfort of accommodation spaces

The last category of factors can be divided into two groups, the environmental contributors related externally and internally to the ship (Figure 2.6). The ambient environment of the crew within the ship consists of noise, vibration, temperature etc. On the other hand, port condition, weather and vessel traffic, can be considered as external factors. The IMO guidelines aptly state that [6]:

> *Exposure to excess levels of environmental factors, e.g. temperature, humidity, excessive noise levels, can cause or affect fatigue. Long-term exposure may even cause harm to a person's health. Furthermore, considering that environmental factors may produce physical discomfort, they can also cause or contribute to the disruption of sleep.*

2.2.3 Fatigue Effects

Fatigue can be experienced with a variety of symptoms that range in severity from mild to serious. The signs of fatigue might be difficult to detect, owing to the fact that fatigue itself has an immense influence on a person's cognitive ability. However, IMO listed the behavioral changes due to fatigue and divided them into three groups (Figure 2.7), in an attempt to provide a guide for seafarers [6]. In that manner, the crew would be cautious with its effects and afterwards capable to identify them. The detection of reduced alertness and inefficient performance is beneficial for the mitigation of fatigue.

2.3 Measuring Fatigue

Measuring fatigue is a complex process in any workplace. In an operational context, it is required to select a limited number of both subjective and objective measures of fatigue (e.g., Figure 2.8) due to practical constraints. There are four kinds of measures that are typically used in measuring fatigue: physiological, behavioural, subjective self-report and performance measures [41].

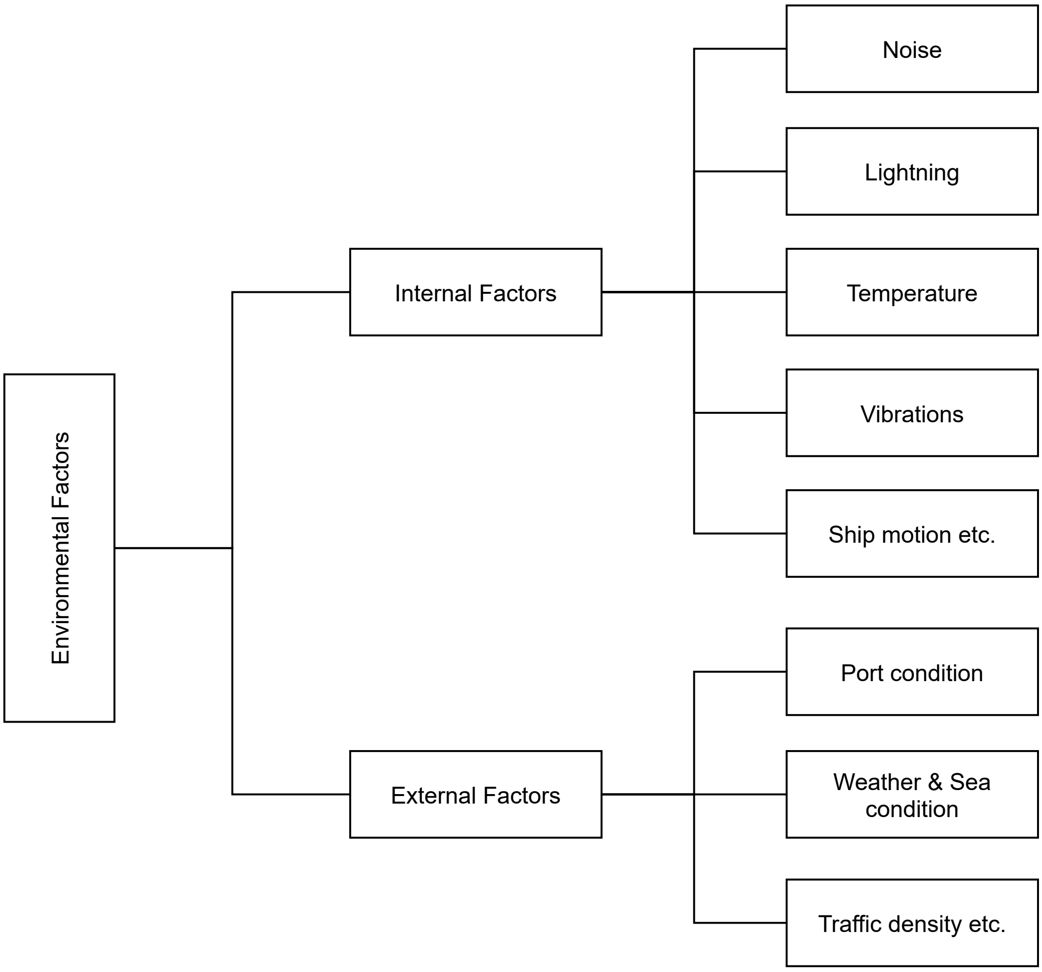

Figure 2.6: Environmental factors recommended by IMO guidelines

Physiological Measures

The term "physiological measurement" concerning fatigue, refers to services that predominantly focus on assessing the function of major organ systems (i.e., body responses), providing information on the extent of fatigue or sleepiness.

Physiological measures that have been used to determine fatigue and sleep include the Electroencephalograph (EEG) and the Multiple Sleep Latency Test (MSLT). EEG is used in clinical circumstances to determine changes in brain activity and MSLT assesses daytime sleepiness by evaluating the subject's likelihood of falling asleep in a controlled environment during the day.

Another common technique that has been widely used to study fatigue

Physical effects	Emotional effects	Mental effects
• Inability to stay awake • Difficulty with hand-eye coordination skills • Speech difficulties • Heaviness in the arms and legs • Decreased ability to exert force while lifting, pushing or pulling • Increased frequency of dropping objects like tools or parts • Non-specific physical discomfort • Headaches • Dizziness • Heart palpitations/irregular beats • Rapid breathing • Appetite issues • Insomnia • Sudden sweating • Leg pains/cramps • Digestion problems	• Increased willingness to take risks • Increased tolerance and antisocial behaviour • Needless worry • Reduced motivation to work well/boredom • Increased mood changes (e.g. irritability, tiredness, depression)	• Poor judgement of estimating elements like distance, time, speed etc. • Inaccurate interpretation of a situation • Difficulty in responding to normal, abnormal or emergency situations • Reduced attention span • Difficulty concentrating and thinking clearly • Decreased ability to pay attention

Figure 2.7: How fatigue may possibly affect mind, emotions and body according to the IMO guidelines

in transportation, has been eye movement recording. Several studies have researched the effectiveness of eye movement, (smooth pursuit, and saccadic) as indicators of sleepiness and fatigue. One study used five subjects to complete the MSLT and the Maintenance of Wakefulness Test (MWT). Results showed that saccadic movement was significantly correlated with increased sleepiness [54].

Another test that was performed using standard hand-held equipment in order to indicate the presence of fatigue, was the Psychomotor Vigilance Test (PVT), developed by David F. Dinges. PVT is a sustained-attention, reaction-timed test that measures the speed at which subjects respond to a visual stimulus. The reaction time, the number of lapses and the mean reaction time are all recorded and stored on the device used.

An alternative method of detecting the presence of fatigue by measuring

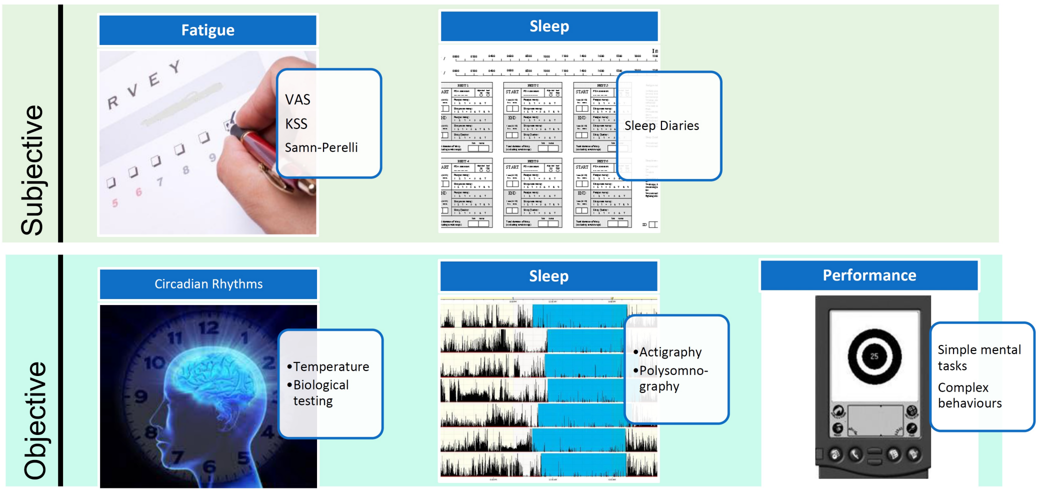

Figure 2.8: Measuring fatigue in operations

alertness, is PERCLOS (Percentage of Eye Closure). This measure attempts to detect the percentage of eye-lid closure as a measure of real time fatigue. This procedure is achieved by utilizing a video camera that is directed towards the subject's eye. As time progresses, the individual's eyelid closure, rate of blinking, and degree of closure is photographed [54]. However , Martin Golz's Lab, figured out that PERCLOS' results were inferior in fatigue detection compared to other measures including EEG [53].

Behavioural Measures

Another type of measure is behavioral and is based on the observation of behaviors in a subject, recorded by researchers.

The most common behavioral measures are the actigraphs/actimeters. These devices can evaluate the sleep duration by monitoring the frequency of body movement (e.g., wrist movements). In the last few years, actigraphs have developed several others features such as heart rate, oxygen level, an established algorithm to evaluate stress level, sleep health and fatigue data [22]. Scientific results have shown a direct connection between actigraph tests and that of the EEG. A recent study of NASA astronauts, found that on a minute-by-minute basis, there was a good correlation between sleep stage and actigraphic movement counts, with a higher level of counts per minute recorded in epochs with lighter sleep stages. Results showed that actigraphs perform properly in space, providing very important data regarding the astronaut's sleeping patterns [54].

Self-report Measures

Self-report measures are a method based on gathering oral or written accounts from the subjects themselves. Instruments of this method are questionnaires or interviews.

A large variety of self-report scales have been developed aiming to measure the nature, severity and impact of fatigue. It is necessary to select a scale that suits the needs of the research, because the information derived, depends on the questions being asked. According to Dittner et al., data collected "will be based on the scale developer's own conceptualization of fatigue and will in turn be answered by the respondent based on his or her own interpretation. This means that different scales may be measuring fundamentally different aspects of the fatigue experience or even potentially distinct constructs" [19].

The Stanford Sleepiness Scale (SSS) is a commonly used measure for subjective sleepiness. It consists of seven-point scales of equal intervals varying from 1 ("Feeling active and vital; alert; wide awake") to 7 ("almost in reverie; sleep onset soon, lost in struggle to remain awake"). A medical research mentioned that SSS is sensitive to deficits in alertness following partial sleep deprivation. However, it generally does not predict individual performance efficiency and therefore cannot act as a substitute for performance measures in studies involving chronic sleep loss [25].

Another simple and quick questionnaire is Visual Analogue Scale for Fatigue (VAS-F). It was designed to estimate the energy levels of patients in the general medical population. The VAS-F is composed of visual analogue scales organized into energy and fatigue dimensions. The psychometric properties are good, although as concurrent validity was established using the SSS, it has been suggested that the VAS-F scale is unable to distinguish between fatigue and sleepiness. It is sometimes called the LFS (Lee Fatigue Scale).

Both the Profile of Mood States (POMS) and Karolinska Sleepiness Scale (KSS) are preferred methods in order to assess fatigue by many researchers in the maritime field. POMS provide a useful brief index of fatigue in the context of broader health outcome. Certain mood states are listed and subjects highlight the most representative of their current state. Even though it is not recommended to be used in isolation without validation, POMS Fatigue sub-scale has been used independently in many studies [25]. The structure of KSS is similar to SSS and measures the subjective level of sleepiness at a particular time during the day. The subject is asked to respond which level describes better the psycho-physical state experienced in the last 10 minutes. Although, the scale is simple and widely used, it is sensitive to fluctuations.

Moreover, several studies' protocols included the diaries, especially when the sleeping pattern was part of the research. Participants were asked to keep logs, as detailed as possible, of their activities regarding work and sleep. These diaries were then analyzed to provide the sleep-wake cycle of the participants and to develop a baseline survey for further studies.

Dittner et al., published a guide for the assessment of fatigue, which describes the scales and their properties and provides illustrations of their use in published studies. The purpose is to describe the range of instruments available and provide guidance on choosing the most appropriate measure for each specific research. The following tables (Table 2.1 and Table 2.2) were taken directly from Dittner et al. [19] and present briefly additional self report measures:

Table 2.1: Unidimensional fatigue scales, characteristics and properties

Scale name	BFI	DFIS	FSS, KFSS
What is assessed?	Severity	Impact	Impact and functional outcomes related to fatigue
No. of scale items	9	8	9
Scale type	11-point Likert	5-point Likert	7-point Likert
No. of sub-scales or factors	1	1	1
Target population	Cancer	General medical	Chronic medical
Standardisation sample(s) (n)	Cancer inpatients, outpatients and community-dwelling adults without cancer diagnosis	Individuals with flu-like illness	MS and SLE patients
Internal consistency	0.96	0.91	0.88
Test-retest reliability	-	-	0.84
Concurrent validity	Associated with POMS-F and FACT-F	Negatively associated with health, sleep quality and activity; positively associated with illness symptoms, rating of fatigue and number of hours work missed	Fatigue rated on visual analogue scale
Discriminative validity	Discriminated between patients based on haemoglobin levels, subjectively rated fatigue and performance status	-	Distinguished patients with MS or SLE from healthy subjects
Cutoff score	-	-	3/4
Sensitivity to change	-	Yes	Yes

Table 2.2: Multidimensional fatigue scales, characteristics and properties

Scale name	CIS	FAI	FIS, FFSS	FQ (FRS, CFS, FS)	FSI	MFI-20, MFI
What is assessed?	Phenomenology and severity	Phenomenology, severity, impact and possible triggers	Impact	Severity	Severity, impact and duration	Phenomenology, severity and impact
No. of items	20	29	40	11	13	20
Scale type	7-point Likert	7-point Likert	5-point Likert	Yes/No response or 4-point Likert	11-point Likert	7-point Likert
No. of sub-scales or factors	4	4	3	2	3	5
Target population	CFS	General medical	MS	CFS	Cancer	General medical
Standardisation sample(s) (n)	CFS	Lyme disease, CFS, post-Lyme Chronic fatigue, SLE, MS and dysthmia & controls	MS and hypertension	Primary care	Women who had received or undergoing treatment for breast cancer and women without cancer	Cancer and CFS patients, healthy subjects
Internal consistency	0.90	0.70 - 0.91	0.93	0.88 - 0.90	$>$0.94	0.84
Test-retest reliability	-	0.29 - 0.69	-	-	0.35 - 0.75 (clinical) 0.10 - 0.74 (controls)	-
Concurrent validity	Maslach Burnout Inventory-General Survey (MBI-GS) exhaustion scale	Subscale 1 with RAND Vitality Index, subscale 3 weakly with Enervation Scale	Sickness Impact Profile (SIP)	Revised Clinical Interview Schedule (CIS-R) fatigue question	POMS-F & SF-36-vitality	VAS-F
Discriminative validity	Discriminates amongst CFS or MS patients, healthy controls & different occupational groups	Discriminates between patients, controls and some differences between patient groups	Significant difference between scores of MS and hypertensive patients on all scales	Discriminates between patients with & without fatigue assessed on CIS	Sensitive to fatigue in both breast cancer population and in a noncancer population	-
Cutoff score(s)	-	-	-	-	-	-
Sensitivity to change	Yes	-	-	-	-	-

Performance Measures

Performance measurement as a general concept refers to any process used for collecting, evaluating, and/or reporting data regarding the performance of either an individual or a group. The definition of performance measurement depends on the reason why performance needs to be evaluated. As an example, scientists detect fatigue by measuring an individual's sustained attention and reaction time [22].

The Psychomotor Vigilance Task (PVT) is a frequently used tool to measure the speed at which subjects respond to a visual stimulus. The duration of the test is around 5-10 minutes and the device records reaction time and the amount of missed responses. The PVT test is simple in use and has been validated. Although it is sensitive to variations in fatigue levels, the results describe the level of fatigue that the subject feels the exact moment the test occurred.

Furthermore, an initial approach to performance assessment has been to divide performance into contributing abilities, essential to perform tasks and then assess effects of variables of interest on these contributing abilities. Over the years, several computerized Performance Assessment Batteries (PABs) have been devised for this purpose: the Criterion Task Set (CTS), the Walter Reed Army Institute of Research Performance Assessment Battery (WRAIR PAB), the Unified Tri-Service Cognitive Performance Assessment Battery (UTC-PAB), the Standardized Tests for Research with Environmental Stressors (STRES) and the most recent Synthetic work task (SYNWORK). Each battery, consists of a specific number of tasks measuring the neurobehavioral and cognitive performance. For instance, the WRAIR PAB includes the following tasks: Encoding/Decoding, 2-Letter and 6-Letter Visual Search, 2-Column Addition, Logical Reasoning, Digit Recall, Serial Addition/Subtraction, Pattern Recognition, Wilkinson Serial Reaction Time, Choice Reaction Time, Time Wall, Interval Production, Manikin, Stroop, Code Substitution, Matching to Sample, Delayed Recall and a number of self-assessments of physical and mental states [46]. This sort of tests has been demonstrated to be sensitive to the effects of sleep deprivation, jet lag, heat stress, physical fatigue, physical conditioning, atropine, hypoxia and sickle cell disorders [54].

To conclude, as it is previously highlighted, operator fatigue can be a major factor on ships. However, unlike other temporary impairments such as alcohol (which can be measured by the blood alcohol content), there is no direct way of measuring fatigue. It is only feasible to measure the "indicators" of fatigue, but not fatigue itself. Indicators that might be suitable for maritime data collection include:

- Quantity of work, for example, amount of freight checked by a maritime operator in an hour
- Quality of work, such as the types, timing, and severity of errors made
- Subjective reports, for example, asking operator if they are fatigued by means of interview, questionnaire, or log book
- Specialized physiological monitoring devices, for example, "brain-waves", EEGs, or visual measures
- Specialized psychological tasks, for example, on-screen tracking or reaction time tasks

Operator fatigue detection and prediction technologies (e.g. devices that estimate or predict fatigue based on either the maritime operator's state or behaviour), are currently areas of significant research and development work [23].

2.4 Countermeasures for fatigue

Countermeasures for drivers' fatigue in any mean of transportation, came after review of VTI's work [14]. Regarding the results at sea, the ship is characterized as an exceptional working place compared to the working places in other modes of transportation. The ship can be considered as an institution where the seafarer constantly lives and works at the same place and is physically isolated from his/her family. These circumstances unquestionably influence the level of fatigue and the possibilities of mitigating it, due to the absence of family matters that may increase the psychological stress.

After literature and internet research, Starren and colleagues divided countermeasures in two categories: reactive and proactive. Reactive countermeasures focus on reacting after the onset of fatigue, in agreement with the IMO guidelines. Strategic napping and caffeine consumption when required, are considered as reactive countermeasures and are frequently reported by a group of international maritime experts [50].

Proactive countermeasures aim to impede fatigue before it arises (long term prevention of fatigue) and are classified within categories: sleep and rest, scheduling, work characteristics/the workplace, health and other measures. The most commonly mentioned measures concerning sleep and rest, are a good sleeping environment with appropriate areas, a duration of 7-8 hours of uninterrupted sleep and 2 consecutive nights recovery sleep [50].

The guidelines of IMO on fatigue, support that sleep is the most effective strategy to protect oneself from the onset of fatigue. Strategic naps, regular well-balanced meals and exercise are important allies when it comes to fatigue mitigation. Additionally, a separate section of IMO, deals with fatigue mitigation measures and clearly points out that these countermeasures may simply mask the symptoms temporarily, rather than radically eliminating fatigue [6]. The countermeasures mentioned to provide short-term relief are the following:

- change in work routine, anything else that is new and different
- bright light, cool dry air, music and other irregular sounds
- caffeine, in regulated quantity in order to keep its stimulant effects
- muscular activity like running, walking, stretching and chewing gum
- conversation
- controlled and strategic naps, have an impact on alertness level and performance (an effective length for a nap is considered to be 20 minutes)

The following measures are examples of proactive measures and tools of a Fatigue Management System (FMS):

- The software Fatigue Audit Inter Dyne (FAID) is used in retrospective analysis of actual hours of work. FAID can be used as part of a fatigue risk management system to improve worker alertness and workplace safety. It is suited to many uses including the aviation industry, railways, truck transport and other areas where shift work and extended hours are potential problems. The software program using the FAID model is commercially available to company risk managers to see if enough sleeping opportunities are provided.
- The Sleep, Activity, Fatigue, and Task Effectiveness (SAFTE) was developed by the US Army Research Lab and has been validated by the US Department of Transportation, Federal Aviation Administration, and numerous other organizations. The SAFTE Fatigue Model represents a range of related sleep factors, like acute sleep disruption, cumulative sleep debt and the onset of sleep onset and wake-up times, and circadian disorders that affect a change in cognitive function [3].

- The Fatigue Avoidance Scheduling Tool (FAST) is a fatigue assessment tool based on the SAFTE model and was developed for the US Air Force and the US Army. FAST allows organizations to upload rosters and generates visual predictions of performance along with tables of estimated effectiveness scores. It is simply in use and has a variety of applications such as work schedule design and evaluation, safety and accident investigating tool. The data of fatigue are considered objective and can be used for comparisons. Therefore optimal schedules may be selected for proposed work periods or mission critical events [4].

- The UK Health and Safety Executive (HSE) Fatigue Index (FI) was developed attempting to move from the prediction of fatigue to the prediction of risk directly. The latest version of the system was updated with information relating to cumulative fatigue, time of day, shift length, the effect of breaks and the recovery from a sequence of shifts. Moreover, the final version can evaluate two separate indices, one related to fatigue (the Fatigue Index) and the other to risk (the Risk Index). The main differences of indices are due to the different trends with respect to time of day in fatigue and risk [7].

- The ISF Watchkeeper software is designed to show whether the working hours of crew are in compliance with the period of rest designated by regulations [7].

- The Crew Endurance Management System (CEMS) is a tool developed by the US Coast Guard and enables companies and crew members to manage the occurrence and effects of crew endurance risk factors.

2.5 Fatigue in Literature

Sanders and McCormick [30] pointed out the need to train human factors engineers and to use specialists on development teams that produce software with which humans will interact. In general human factors' studies can be classified into three types [23]:

- Descriptive studies characterize populations in terms of certain attributes (e.g., crew body size or engine room operator hearing loss).

- Experimental research tests the effects of different variables on behavior (e.g., navigation officer reading speed with varying levels of myopia (i.e., shortsightedness).

- Evaluative research assesses the effects of something (e.g., a new training regime) on a selected criterion (e.g., crew workload or errors).

It is mentioned that the investigation of accidents, incidents, near misses and errors could perhaps be added to this list as another type of transport human factors method. Over the last three decades, plenty of parties (e.g., organizations, classification societies, academic researchers) made attempts to research fatigue in the maritime domain. Some recent[2] studies and surveys are briefly reviewed below.

MAIB BRIDGE WATCHKEEPING SAFETY STUDY (2004)

The Marine Accident Investigation Branch (MAIB) studied collisions, groundings and near collisions that occurred between 1994 and 2003. Nautical inspectors figured out that a third of all groundings, involved a fatigued officer on the bridge. The majority of groundings took place between 0000 and 0600, when alertness and mental performance tend to decline according to Figure 2.9 and the watchkeeping officers were mainly following the two-shift system (6-h on and 6-h off working pattern).

MAIB concluded that fatigue is a contributory factor of accidents (82% of the investigated groundings). This is an indication that the recorded hours of rest on-board, which almost invariably show compliance with the regulations, are not having significant effect with regard to the bridge watchkeeping arrangements on many vessels. It was suggested that any actions taken to reduce levels of fatigue, must be mandatory on an international basis via IMO, by either amending current legislation or introducing new measures [26].

THE TNO REPORT FATIGUE IN THE SHIPPING INDUSTRY (2005)

The project of TNO about fatigue, carried out a survey of the relevant literature, discussed with different parties involved in maritime field about their point of view on the issue and suggested measures of (potential) relevance to prevent and manage fatigue.

In the report, the following measures are related to fatigue, based on the literature and the interviews [27] :

- lengthening of the resting period

- optimizing the organization of work

[2]Later than 2000

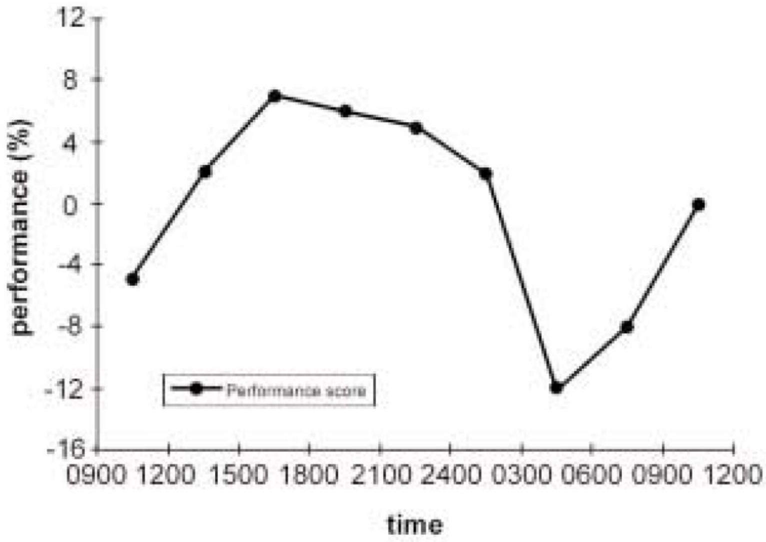

Figure 2.9: Accepted empirical levels of alertness and mental performance over time

- reducing administrative tasks
- less visitors / inspectors in the harbour / better co-ordination of inspections
- reducing overtime
- proper Human resource Management
- education and training
- development of a management tool for fatigue
- proper implementation of the ISM-code
- healthy design of the ship
- health promotion at work
- expanding monitoring of fatigue causes, behaviours or consequences, including near misses

According to Houtman et al. [27], more attention should be given to the: proper implementation of the ISM-Code, optimizing the organization of work onboard vessels, lengthening of the rest period and reducing administrative tasks onboard vessels in order to reduce fatigue. The most substantial measures are shown and assessed for the shipping industry and the maritime education in Table 2.3:

Table 2.3: A summary review of the implications and consequences of the measures to reduce fatigue in the shipping industry

Measures	**Estimated costs**	**Educational consequences**	**Additional remarks**
Add an Officer in Charge	Employer: € 99-121.000,-/year Sector -NL-: € 17,9-21,9 mln/year	Increased pressure: 3000 new crew members EU-wide Dutch/EU ship owners could train seafarers outside EU (already happens)	
Add a crew member, but NOT an Officer in Charge		Additional courses should be developed/ course units should be added to courses of seafarers	This proposed measure is hypothetical: these officers would not have a full time job. Delegation of tasks makes more sense
Delegating administrative tasks ashore using ICT	Costs may range from a fixed amount of € until $ 2,800 per month for 2,000 minutes	'Delegation' should be an issue in Masters and OIC training Training should involve the most recent en relevant ICT developments in this respect	The present ICT offers are not good enough yet
Changing shift system, e.g. 4-8/8-4	No additional costs	No immediate consequences for the maritime education	*Advantage*: Seafarers have an eight hour rest period without extra costs
Fatigue management tool	No indication of costs to be given; depends on what measures the organisation will adopt	No general indication of the consequences for maritime education; dependent on measures adopted by organisation	Links up with ISM-Code. Care should be taken to restrict the administrative burden of such a tool

SEAFARER FATIGUE: THE CARDIFF RESEARCH PROGRAMME (2006)

Cardiff University conducted a research concerning seafarers' fatigue. Emphasis was given on the quality of working life and not on specific groups of workers like the aforementioned studies. The methology of the programme entailed [49]:

- lengthening of the resting period
- A review of the literature
- A questionnaire survey of working and rest hours, physical and mental health
- Physiological assays assessing fatigue
- Instrument recordings of sleep, ship motion, and noise
- Self-report diaries recording sleep quality and work patterns
- Objective assessments and subjective ratings of mental functioning
- Pre- and post-tour assessments
- Analysis of accident and injury data

The analysis has shown that it is the combined effect of a range of factors that is associated with fatigue. The consequence of this conclusion is that changing one or two factors can have a disproportionately large impact. The development, implementation, and evaluation of strategies to address fatigue must be carried out jointly across all levels of the industry [49].

FATIGUE AT SEA: A FIELD STUDY IN SWEDISH SHIPPING (2007)

The Swedish project, performed by VTI, aimed to highlight the significance of fatigue at sea and draw the attention of the relevant stakeholders.

The data were collected by interviewing shipping companies and measuring the level of fatigue in two groups of bridge watch keepers on duty following different shift system (6 on/6 off and 4 on/8 off). Subjective sleepiness and stress estimations were performed once every hour, using Karolinska Sleepiness Scale (KSS). Electrooculography (EOG) was used to record eye movement behaviour, as an indicator of objective sleepiness. Reaction time test was made to examine performance. Subjective sleep length and quality were estimated by sleep diary and compared to the outcomes of actiwatches.

The most significant conclusions provided by the study analysis are the following [32]:

- Most of participants stated that 8 hours of sleep is needed regardless the work shift pattern.

- Fatigue levels are affected by the shift/watch system (shift rotation) and all tendencies in the results point in the same direction: officers in the 6x6 watch system are more tired than the ones in the 4x8 system.

- Actiwatch algorithm estimated the average amount of sleep around 6-7 hours per day, independent of the shift system.

- Sleep quality is low and sleep is mainly can be characterized as disturbed according to actiwatch results.

- Most Swedish companies do not generally regard fatigue as a matter of concern during normal conditions.

- Fatigue monitor equipment would be welcomed by the majority of personnel and all would install equipment if insurance premiums were lowered (say 30%).

CREW ENDURANCE MANAGEMENT SYSTEM

The Crew Endurance Management System (CEMS) [18] was developed by the U.S. Coast Guard in order to provide a tool that maritime companies could use to ensure the highest possible levels of performance and safety in their operations. The guide focused in two parts:

- the identification of specific factors affecting crew endurance in their particular operations

- the management of these factors toward optimizing crewmember endurance

The suggested practices and procedures aim to the full scope of endurance management, not simply to sleep management. The contributing factors affecting crew endurance in normal operations include a full range of environmental, physiological, operational, and psychological risk factors. The entire operational system of the vessel is analysed into various areas of risk (e.g. workload, shipboard environment, weather, and company policy) and the relationship between these areas of risk is illustrated in Figure 2.10.

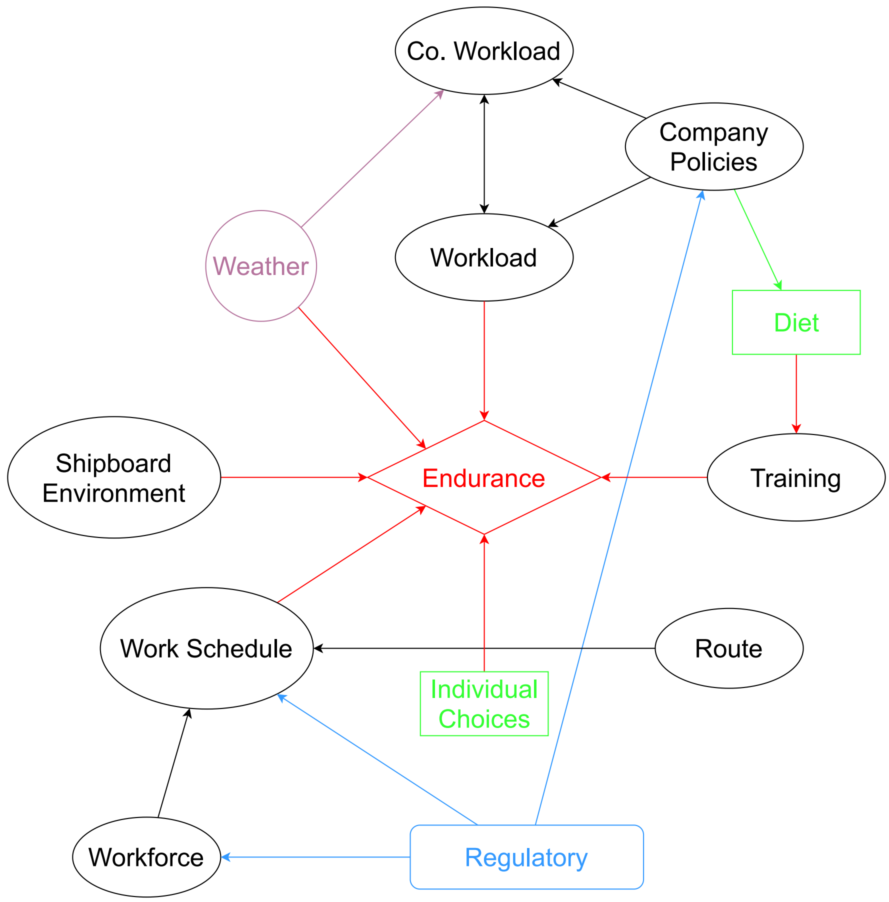

Figure 2.10: Operational analysis

STUDY ON THE ASSESSMENT OF SEAFARERS' FATIGUE (2012)

Within the context of master degree, Wang attempts to develop an evaluation model for seafarers' fatigue. The factors affecting navigation officers' fatigue are based on the classification of IMO [6]: crew-specific factors, management factors, ship-specific factors and environmental factors (Figure 2.11). The evaluation index system and weight of evaluating indexes are determined by applying the Analytic Hierarchy Process (AHP) and a fuzzy comprehensive algorithm.

The model was put into practice by estimating the fatigue level of a third officer occupied in the coastal industry along China's Coast. The result indicated that the model is suitable for the evaluation of seafarers' fatigue. From the proposed recommendations on mitigation of fatigue for maritime organizations, shipping companies and seafarers, the one that was not mentioned

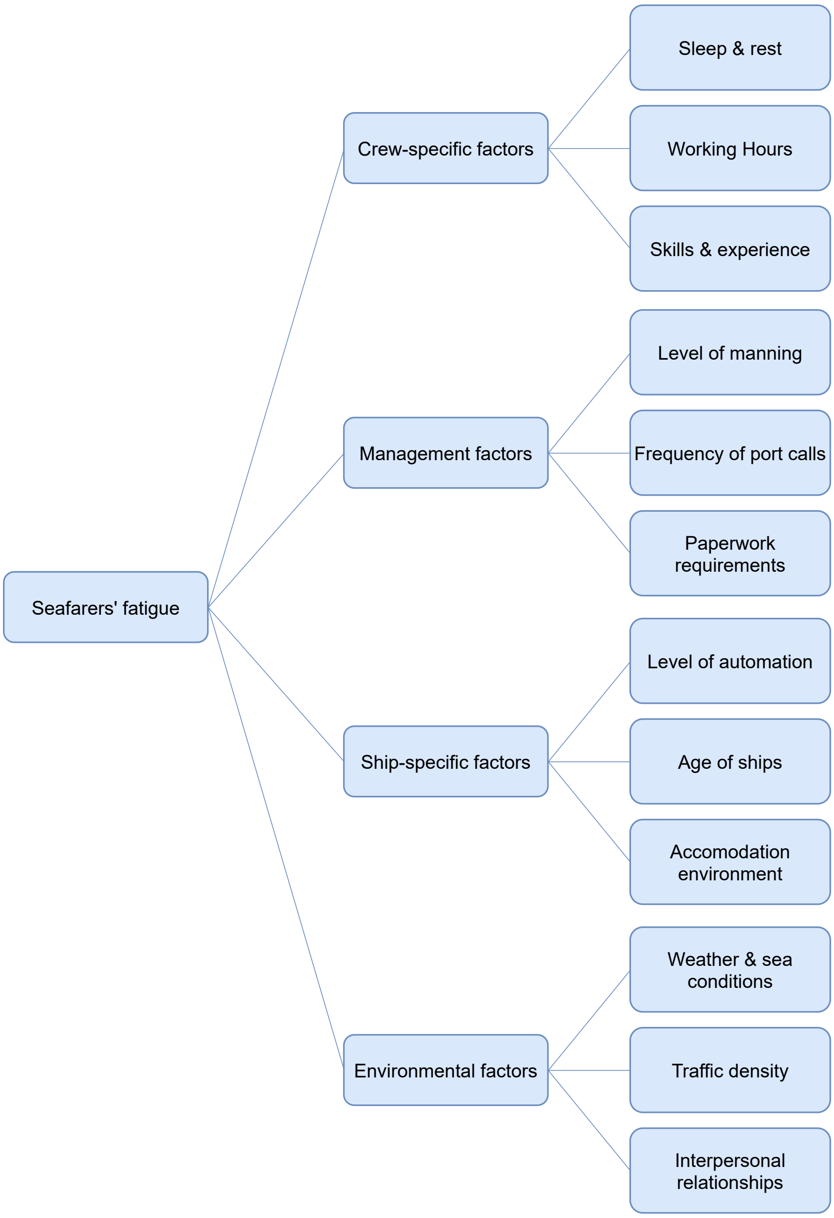

Figure 2.11: The structure of index system of seafarers' fatigue

in the above studies, is the development of proper sleep habits in an effort to ensure the sleep quality [56].

PROJECT HORIZON: A WAKE-UP CALL (2012)

The European Project Horizon is an attempt to research into the effects of sleepiness on the cognitive performance of maritime watch-keepers under different watch patterns, using ships' bridge, engine and liquid cargo handling simulators. The results provided, aim to be validated, scientifically and statistically, compared to previous subjective fatigue studies.

The participants were asked to follow two of the most common schedules used at sea: 6-h on/6-h off and 4-h on/8-h off. During the simulated voyages, participants were supervised and had to have to fulfill their duties including of cargo operations work, paperwork, reading and watching the TV without the permission to sleep during this period. The data needed to estimate fatigue was collected via: actiwatch, Electroencephalogam (EEG), Electrooculogram (EOG), Electrocardiogram (ECG) Psychomotor Vigilance Test (PVT), Karolinska Sleepiness Scale (KSS), Karolinska Drowsiness Test (KDT), Stress scores, Stroop test, sleep and wake diary, evaluation of performance, temperature in simulators and quarters, videos in all simulators and debriefing interviews. The range of measurements is adequate to provide input to marine-validated mathematical fatigue prediction models within a fatigue risk management system. One of the most concerning finding is about the two-shift system where half of the participants fell asleep during their shifts.

Finally the Project Horizon partners have developed a fatigue management toolkit for the industry, which seeks to provide guidance to owners, operators, maritime regulators and seafarers to assist them in organizing work patterns at sea in the safest and healthiest way possible [9].

PROJECT MARTHA (2016)

Project MARTHA's aim was to evaluate the existence of sleepiness and the psychosocial issues associated with long term fatigue and motivation. The participants of the study were a sample of volunteer seafarers in the naturalistic setting of work on-board their vessels. The research was conducted in both Europe and China and the participants were in charge of different marine occupations. Three main methods were used for data collection: questionnaires and interviews, on-board diaries and actigraphy data.

The results from the MARTHA project have indicated that fatigue and stress increase for most crew as the voyage length increases and motivation decreases. Captains suffer more than their colleagues from both fatigue and stress. Port work is particularly demanding: the results also show that no one on-board gets adequate sleep, with the night watch keepers being particularly at risk of falling asleep. High sleepiness levels can occur at any stage of the voyage but the quantity and quality of sleep deteriorates over long voyages. The results from the use of actigraphy have also confirmed many of the perceptions of seafarers from their interviews and weekly diaries [10].

2.6 Regulatory Framework

Fatigue can be treated effectively with the cooperation of three components: legislation, company policy and personal awareness/management. The regulations followed to manage the risk of fatigue in marine industry, have been formed by conventions adopted by the IMO and the ILO concerning the prevention of tiredness and fatigue at sea. A short list of the legislation in force follows below:

The ILO Instruments

The Maritime Labour Convention (MLC), 2006 constitutes ILO's instrument concern fatigue related aspects and consists of:

- Regulation 2.3 Hours of work and rest
- Regulation 2.4 Entitlement to leave
- Regulation 2.7 Manning levels
- Regulation 3.1 Accommodation and recreational facilities
- Regulation 3.2 Food and catering

The IMO Instruments

The IMO instruments containing related requirements on fatigue are:

- Resolution A.1047(27) Principles of safe manning
- Resolution A.772(18) Fatigue factors in manning and safety
- MSC.1/Circ. 1598 Guidelines on Fatigue
- International Safety Management (ISM) Code: Section 1.4 Safety management system requirements
- International Convention on Standards of Training Certification and Watchkeeping for Seafarers (STCW): Regulation VIII/1 (Fitness for duty), Regulation VIII/2 (Watchkeeping arrangements and principles observed)

Chapter 3

Research Method

3.1 Research Aims

The overall aim of the research was to study the effects of fatigue under an emergency situation, using ships simulators focusing on incidents of evacuation and fire. The main objects of interest were:

- Investigate and compare the quantity and quality of sleep both after the occurrence of an emergency and during a common day.
- Analyze the extent to which alertness, fatigue and stress can be divergent during the an emergency.
- Identify the prevalent indicators/symptoms of fatigue as long as an emergency lasts.

Other general aims were to evaluate the methodology used in the pilot study for data collection and analysis, establish a database that may be useful for further research related to the issues of fatigue and sleep deprivation in the maritime industry and examine the necessity of aptitude of the seafarers to cope with fatigue.

3.2 Method

The methodological approach of this study was developed under the following considerations: demonstrated sensitivity in measuring alertness and fatigue and the factors contributing to them; the relative cost of the measurement tools; and the relative intrusiveness of them during the process of simulations. According to previous studies on fatigue [45], it is more efficient to prefer applied approaches that have demonstrated sensitivity in field settings rather than developing new measures. Moreover, cost of the measurement tools is restricted because of the budget and time limitations. Due to the applied nature of this project, it is necessary to gather a fairly large sample within the budget.

The research method was substantially based on the combination of survey questionnaires, interviews, wrist-worn actimeters, self-report sleep logs and performance evaluation rating scales. Both objective and subjective measurement tools were used in order to gather the essential data.

Before launching into the data collection, the initial method went through a pilot test with the qualified staff (N=5) occupied at the ship's simulators. The participants went through the direct personal questionnaires during a one-on-one interview and undergone a fire-fighting simulation. This process provided extensive feedback about each section of the survey and determined the usage convenience of an actigraph during the simulations. The out coming information concluded to a revised version of the survey questionnaire with minor adaptation of its structure.

Measurement Tools

Actimeters

The Garmin Vivosmart HR was the device used as an actimeter. The smartband was worn on the wrist enabling to measure acceleration and heart beats, and in this way calculate physical activity and the amount of sleep obtained.

Survey Questionnaire

A survey was designed with the purpose to collect the data of interest. The questionnaire contained demographic information; details about the work habits, the sleep behavior on ship and at home; and collected background information related to general health and lifestyle. The survey was composed with the following sections:

- **Section 1: General information**, contained standard demographic questions (e.g. age, gender, marital status)
- **Section 2: About the job**, included items regarding the nature of the person's job, working hours, job's demands etc.
- **Section 3: About sleep patterns**, participants were asked about their sleeping behaviour both a typical working day and a regular off-duty day at home

- **Section 4: General health and well-being**, required data concerning lifestyle (e.g. smoking, exercise, coffee intake) and standardized questionnaires about general health (measured by Short Form (SF)-36), severity of fatigue (measured by Fatigue Questionnaire (FQ)) and perception of stress (measured by Perceived Stress Scale (PSS)).
- **Section 5: Fatigue symptoms and about training**, contained a large number of symptoms indicating the occurrence of fatigue. Participants were required to evaluate the level of experiencing them during the training. Also, they were asked whether they have previously taken part in any similar training or undergone an incident of fire.

Sleep Logbook

A logbook was developed to obtain self-report data on sleeping behavior and sleep characteristics as long as the training took place.

Performance Inventory

This tool was used to gather information about the alertness, stress and fatigue fluctuations on an hourly basis throughout the participation in the training. Participants were asked to complete numeric rating scales every hour to indicate the value that describes best the selected features of their performance. The self-assessment of alertness was assumed to be equal to the estimation of the sleepiness experienced and hence, KSS was used for this purpose. The other scales were similarly developed according to the KSS. The scales ranged: from 1 ("extremely alert") to 9 ("very sleepy, great effort to stay awake") regarding the sleepiness/alertness level; from 1 ("no distress, relaxed") to 9 ("extreme anxiety, felling tensed") regarding the level of experienced stress; and from 1 ("feeling refreshed, not fatigued at all") to 9 ("total fatigue & exhaustion, rest needed") regarding the feeling of fatigue.

3.3 Procedure

The pilot study was designed and completed in three phases. The *first phase* included a literature review and web research in order to establish a research protocol for the study of fatigue, during fire-fighting and evacuation training. The review of existing literature was based on:

- Surveys and reports on understanding and/or measuring fatigue in various industrial sectors, some are aforementioned in section 2.5.

- PubMed search using keywords as fatigue, alertness, sleep(iness), actigraphy, actiwatch.

- Websites of organizations, which are internationally acknowledged to play an important role concerning fatigue in the naval industry (e.g. IMO, MAIB).

The different types of data were collected in the *phase two*. It took place during simulator-based training courses, involving scenarios of evacuation and fire-fighting. Before the beginning of the course, the study was presented briefly to the trainees and invited them to take part in the research. Participation in the study was voluntary and confidential. All participants gave their approval. The anonymity was guaranteed by the assignment of a unique ID number to each participant.

The paper-pencil survey was handed out to the participants on the first day. They were also issued with a sleep diary every morning before the start of the training. Similarly, actiwatches were given to participants from the beginning of the course. Data from the actiwatches were obtained each day, immediately after the completion of the simulations and in the morning of the next day. During the simulations, participants were asked to rate the perceived levels of their fatigue, alertness and stress, every hour. After the ending of the course, trainees were asked to fill in the last section of the survey regarding the fatigue symptoms 5-point Likert scales. The completed surveys and actiwatches were returned and short interviews followed with complementary information on the prevalence of fatigue, its causes and consequences.

The *final phase* concerned the management and analysis of the collected data. The study findings mainly occurred after the statistical evaluation.

3.4 Data Analysis

A number of participants wore Garmin Vivosmart HR throughout their participation. Actigraphy recordings were analyzed using the software application Garmin Connect.

The direct personal surveys were used to create a data code-book. The statistical testing could only be applied to numerical data. As a result, the non-numerical variables were represented in coded form. The textual data were converted with the assistance of nominal and ordinal scales. According to nominal scales, numbers were used as labels to classify cases without implication of neither importance nor order (e.g. 1=female; 2=male). However ordinal scale is a naming scale, where variables were named to convey order but not exact values (e.g. 1=not at all; 2=low; 3=medium; 4=high; 5=very high).

Statistical analysis was conducted using Microsoft Excel and the statistics applied are mentioned in the respective text and tables.

Chapter 4

Findings

4.1 Participants

The sample of the study was 10 instructors and 54 trainees, who participated in the fire-fighting and evacuation schools. They were almost all men, with the exception of 3 female participants. The mean age was 30.8 years (SD=6.4, range 20-54), with the minority either married or in a defacto relationship (n=22.34%) of which a high percentage (n=17.70%) was living with children. Concerning the medical background data obtained, it was found that the mean BMI was 25.97 kg/m^2 (SD=3.34, range 17.24-37.87). According to WHO classification, this value of BMI is marginally above the cut-off limit point (25 kg/m^2) that corresponds to the overweight category indicating pre-obesity [11].

The participants of simulations could be distinguished into two groups; instructors (n=10) and trainees (n=54). The instructors were mariners occupied at the ship's simulators as permanent staff with mean working experience equal to 19 years. Most of the trainees were seafarers and only 11% (n=6) worked at marine companies for 12 years on average. Nine (17%) worked on vessels as officers of the bridge and have been in the industry for 17 years. A further 6 (11%) worked as engineers and their mean number of years at sea was 13. The remaining subjects (n=33, 61%) worked as crew members serving circa 7 years. The majority of mariners considered their job dangerous (32.8%), stressful (31.3%) and exhausting (45.3%) in a moderate level. Additionally, nearly half of the participants (47%) have involved in an incident or accident of fire during working and the majority (67%) have taken part again in fire-fighting training.

In terms of lifestyle, 23.4% of subjects were regular smokers and the most frequent daily coffee consumption was 1-2 cups. Over half of the sample reported drinking alcohol (68.8%) and exercising (79.7%) at least once a week.

Demographic data, occupational information and results of self-reported health status are shown in Table 4.1, Table 4.2 & Table 4.3.

Table 4.1: Background demographic and health-related information of the participants

Demographic data	
n	64
# of men	61
# of women	3
Age (years)	30.8 ± 6.4
Married/Living with a partner	34%
of which have children	77%
Single	66%
of which have children	33%
Weight (kg)	83.7 ± 11.8
Height (m)	1.79 ± 0.05
BMI ($kg\,m^{-2}$)	25.97 ± 3.39
Health-related behaviour	
Smoking	23.4%
Exercising	79.7%
Frequency of exercise	
once a week/30min-1h weekly training	33.3%
2-3 days per week/1-3h weekly training	39.2%
3-5 days per week/3-7h weekly training	17.6%
almost every day/7-15h weekly training	9.8%
Caffeine intake (cups per day)	
0	17.2%
1-2	68.8%
3-4	14.1%
Drinking alcohol	68.8%
Drinking days per week	
1	47.7%
1-2	34.1%
3-4	15.9%
5 or more	2.3%

Table 4.2: Occupational history and industry experience of the participants

Present position of sample			
Instructors	10 (16%)		
Trainees			
Masters/Mates	9 (14%)		
Engineers	6 (9%)		
Crew	33 (52%)		
Office	6 (9%)		
Years in Industry			
Instructors	19		
Masters/Mates	17		
Engineers	13		
Crew	7		
Office	12		
Level of . . . at work	*Danger*	*Stress*	*Fatigue*
None	1.6%	0.0%	0.0%
Mild	12.5%	31.3%	18.8%
Moderate	32.8%	31.3%	45.3%
High	31.3%	28.1%	31.3%
Very high	21.9%	9.4%	4.7%

Table 4.3: Miscellaneous information about the participants

Have participated in a fire-fighting school before	67%
Have experienced an incident of fire	47%

4.2 Health Questionnaires

Standardized questionnaires were selected as non-invasive medical instruments for the initial assessment of functional health and well-being in the sample. The SF-36 is a brief survey of a person's general health without referring to a specific disease. It includes eight multi-item scales concerning the following health concepts: (1)physical functioning, (2)role limitations due to physical health problems, (3)bodily pain,(4)general health perceptions, (5)vitality (energy/fatigue), (6)social functioning, (7)role limitation due to emotional problems and (8)mental health (physiological distress and psychological well-being) [57]. These eight sub-scales are summarized in scores for overall physical and mental health. The highest rating (with scores of 0 being the lowest and 100 being the highest) indicates better quality of the respondents' health.

The PSS is a simple instrument to measure the level of perceived stress. It is used to determine whether the situations in the respondent's life over the last month are appraised as stressful. Higher scores (minimum score is 0 and maximum total score is 56) indicate high perceived stress of the person during the last month.

Regarding FQ, it is a widely used multidimensional scale as a fatigue measure in many studies. The items contained evaluate fatigue-related symptoms and loading onto two dimensions; physical and mental fatigue [19]. A total fatigue score (range being from 0 to 42) is obtained by adding up all the items. High ratings denote the presence of a high severity level of fatigue.

Results of self-reported questionnaires are presented below in Table 4.4. Concerning the SF-36, only three of the aforementioned scales were taken into account: General Health (GH), Vitality (VT) and Mental Health (MH). The mean scores of the sample (GH=79.89, VT=60.00 and MH=65.57) are above 50, that is representative of a healthy profile and a high level of well-being for the factors of the sample's quality of life. Comparing results of SF-36 between instructors and trainees, there are minor deviations of mean values ($\%\Delta$GH=4%, $\%\Delta$VT=2% and $\%\Delta$MH=6%) and instructors' scores being slightly higher.

The perceived level of stress is considered low among the participants with an average score equal to 15 according to PSS. Similarly, the severity of fatigue is totally moderate and mean total FQ rating is around 14. Although FQ scores were continuously distributed with higher scores by trainees. The trainees' mental fatigue (FQ mental= 6) was estimated two times greater than the instructors' (FQ mental=3).

Table 4.4: Mean scores of SF-36, PSS and FQ and means comparison between instructors and trainees

Questionnaire	Total (N=64)	Instructors (N=10)	Trainees (N=54)	Means' comparison
SF-36 scales				
General Health	74.89	77.60	74.35	4%
Vitality	60.00	61.00	59.80	2%
Mental Health	65.57	69.20	64.86	6%
PSS	15	14	16	-12%
FQ scales				
Physical	8	7	9	-33%
Mental	6	3	6	-100%
Total	14	10	15	-53%

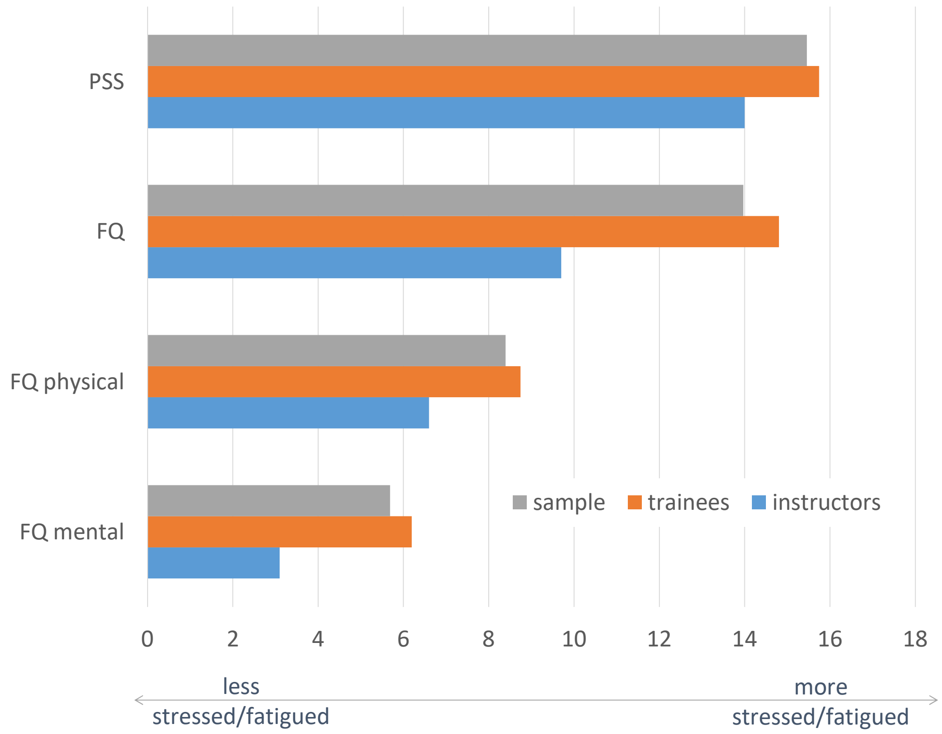

Figure 4.1: Mean scores of PSS, FQ, FQ physical and FQ mental

4.3 Heart Rates

During the fire-fighting simulations, heart rates were recorded from 2 instructors and 15 trainees via actiwatch. Heart rate values within a period were averaged out to generate means.

There were no significant heart rates differences between the two groups. In general, higher heart rate values and quicker heart rate changes were observed to be among trainees (Figure 4.2). The average heart rate for trainees was 101 beats/min, nearly 4% greater than instructors' value (97 beats/min). Likewise, maximum and minimum heart rate differed slightly, with trainees' values being above 4% and 9% respectively.

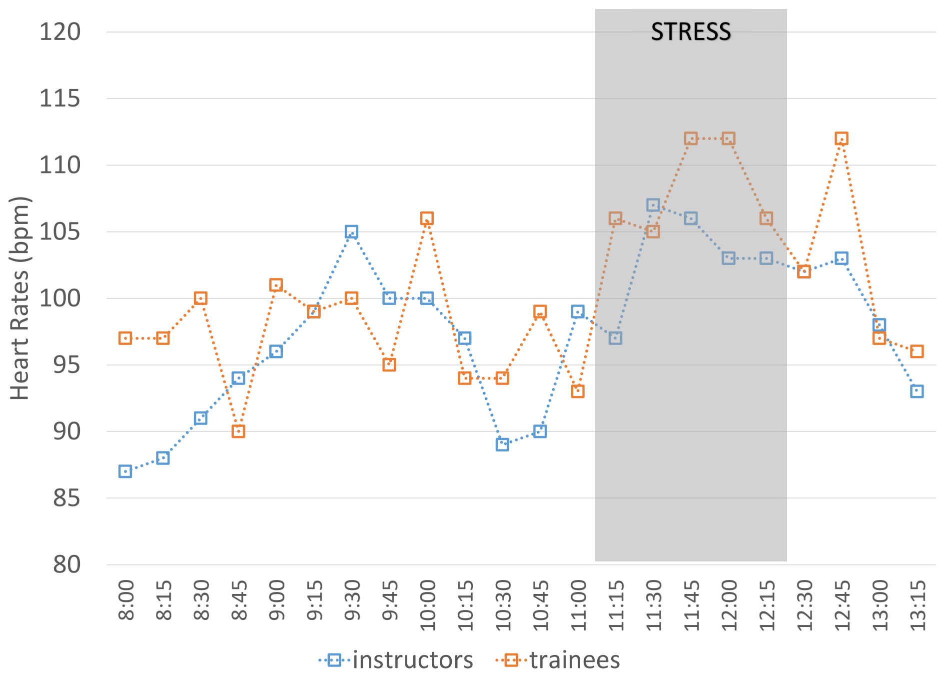

Figure 4.2: Mean heart rate responses (beats/minute) during fire-fighting simulations. The shaded area indicates the period of maximum stress exposure

The maximum heart rates manifested for both groups during the occurrence of the most demanding simulation, when stress-related heart rate changes were detectable. At this period of time (11:30-12:15), the mean heart rate exceeded 102 beats/min for instructors and 105 beats/min for trainees.When an individual is under stress, certain hormones are secreted.

These hormones trigger the fight-or-flight response accompanied with increased heart rate. In medical terms, the impact of experiencing a stressful situation is a higher heartbeat. However, the vice versa does not apply and high heart rates, are not necessarily indicators of stress.

The majority of trainees (n=9, 60%) have been involved in an incident or accident of fire while on duty. The heartbeat of these participants was lower relative to trainees with no fire incident experience (Figure 4.3). Results are summarized in Table 4.5.

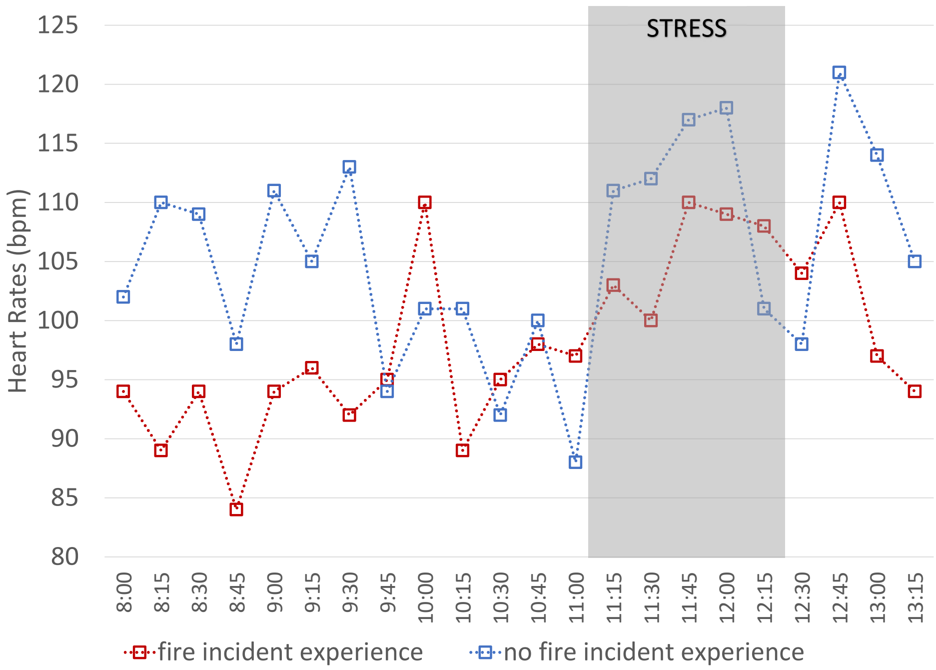

Figure 4.3: Mean heart rate responses (beats/minute) of trainees' sample during fire-fighting simulations. The shaded area indicates the period of maximum stress exposure

Table 4.5: Mean, maximum and minimum heart rate during fire-fighting simulation

Participant	Number	Heart Rate (beats/min)		
		Average	Max	Min
Instructors	2	97	107	82
Trainees	15	101	112	90
experienced fire incident	9	99	110	84
no fire incident experience	6	105	121	88

4.4 Self-reported Scales

The mean values of alertness, fatigue and stress scores from self-rating scores were compared for the instructors and the trainees in Figure 4.4, Figure 4.5 and Figure 4.6.

The alertness pattern during simulations featured similarities between the sample. Instructors appeared to be more vigilant than the trainees on an hourly basis. Additionally, both groups were at their peak performance during the most demanding period of the training. Alertness started to decline by the time the stress exposure was minimized.

In the case of fatigue, it was ascertained that the level of tiredness was overall moderate. Participants scored highest during the completion of training, along with impaired alertness. Trainees' feeling of fatigue increased consecutively with a regular pattern. Meanwhile, instructors showed a profile with two "dips"; the one early in the morning and the other just after the end of stress exposure.

There was a consistent pattern in the evaluation of stress levels between participants, although levels were slightly higher for trainees, similarly to fatigue rating. It was an expected feature to score the maximum value while the sample experienced the most stressful phase of the school. There was a disparity between instructors and trainees concerning the reduction of anxiety at the end. Specifically, the instructors seemed more relieved after the fulfillment of work.

Scales distribution

The multimodal distributions of the alertness, fatigue and stress scores among sample are thoroughly presented in Appendix A. The basic distributions of the variables are shown graphically with box plots in the following figures (4.7, 4.8 and 4.9) and the main statistical characteristics are summarized in

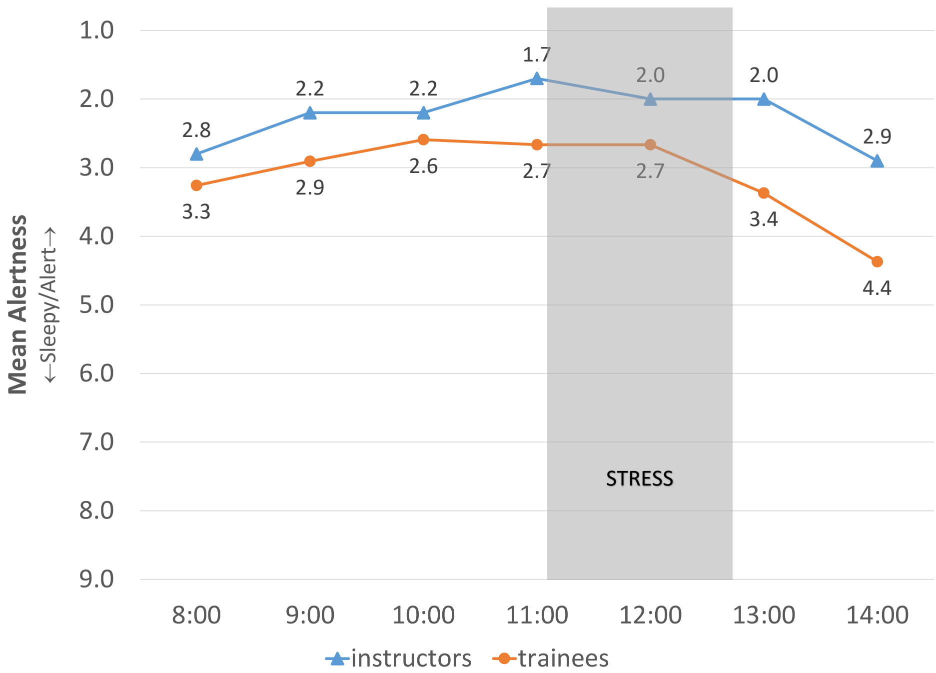

Figure 4.4: Time Course of Alertness, the shaded area indicates the period of maximum stress exposure

Table 4.6.

Mean alertness score was 2.26 ± 1.51 with range from 1 to 7, median value was 2 and most common score was 1 according to the total ratings of instructors. On the other hand, trainees' mean score was 3.12 ± 1.73 with range from 1 to 9, median and most frequent reported value was 3. The trainees who had been involved in a fire incident, declared the lowest values of alertness and their mean score was relatively close to instructors scoring. The maximum mean score (3.33 ± 1.73) was reported by trainees with no fire incident experience. Additionally, this sample of trainees noted similar distribution of the variable with the part of trainees, which participated the training for first time.

The instructors had a mean fatigue score of 4.30 ± 2.46 and the median value was 3, while overall trainees had a mean score of 4.82 ± 2.28 and the median value was 5. The range of scores was equivalent between instructors and trainees from 1 to 9. Extreme values of fatigue score over 7 were mostly present among trainees (25% of total ratings) who have not experienced either a fire incident or a similar training before. These groups of trainees have also

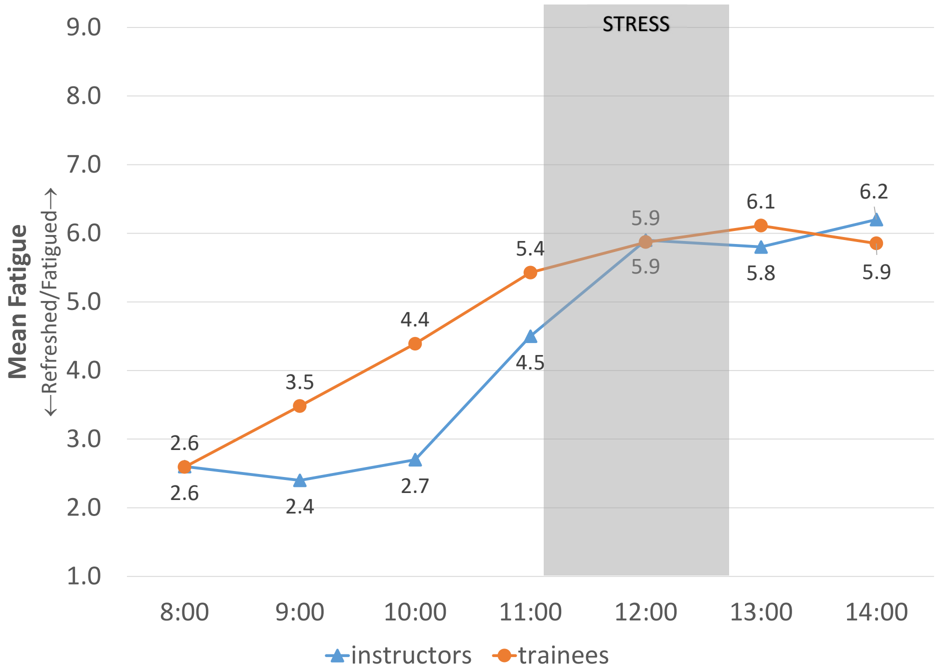

Figure 4.5: Time Course of Fatigue, the shaded area indicates the period of maximum stress exposure

showed many similarities in distribution and scored the highest mean value of fatigue, estimated around 4.94.

Stress data analysis pointed out that the lowest ratings belonged to trainees who have took part in training previously. Their mean score was 4.28±2.37, with median value equaled to 3 and 75% of total scores being under score 6. The distribution of the variable among the rest of the trainees fluctuated in higher scores. Specifically, participants trained for the first time had the maximum mean fatigue scores (4.74±2.32). Moreover, it is noted that the stress score distribution of instructors was somewhat different compared to trainees. The minority of their total ratings (25%) were above the extreme value of stress scores 7.

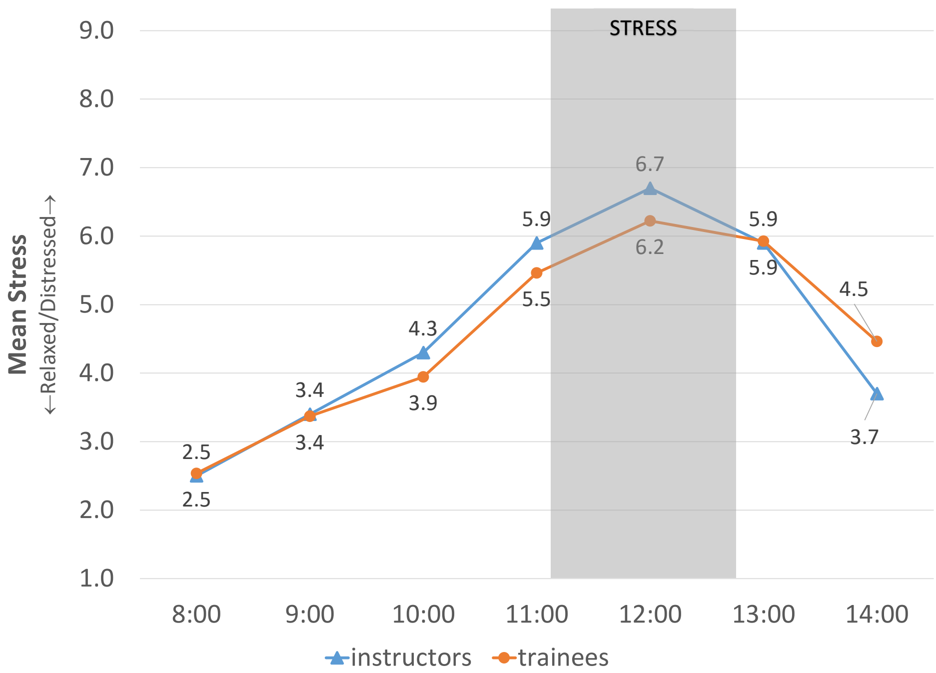

Figure 4.6: Time Course of Stress, the shaded area indicates the period of maximum stress exposure

Figure 4.7: Box plot of Alertness data

Figure 4.8: Box plot of Fatigue data

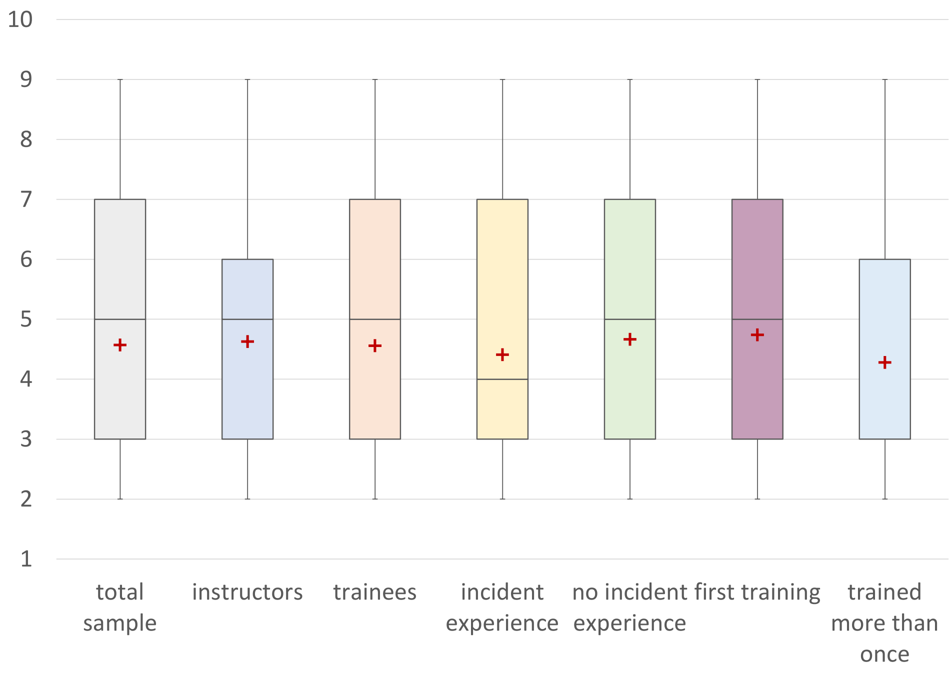

Figure 4.9: Box plot of Stress data

Table 4.6: Descriptive statistics of alertness, fatigue and stress

	Mean (±SD)	Min value	First quartile (25% of data)	Median value	Third quartile (75% of data)	Max value
Alertness						
Total sample	2.98 (±1.73)	1	1	3	4	9
Instructors	2.26 (±1.51)	1	1	2	3	7
Trainees	3.12 (±1.73)	1	2	3	4	9
experienced fire incident	2.82 (±1.75)	1	1	3	3	9
no fire incident experience	3.33 (±1.70)	1	2	3	4	9
first time training	3.11 (±1.62)	1	2	3	4	9
trained more than once	3.14 (±1.91)	1	1	3	4	9
Fatigue						
Total sample	4.74 (±2.32)	1	3	5	7	9
Instructors	4.30 (±2.46)	1	2	3	6	9
Trainees	4.82 (±2.28)	1	3	5	7	9
experienced fire incident	4.64 (±2.35)	1	3	5	6	9
no fire incident experience	4.94 (±2.23)	1	3	5	7	9
first time training	4.94 (±2.28)	1	3	5	7	9
trained more than once	4.63 (±2.28)	1	3	5	6	9
Stress						
Total sample	4.57 (±2.28)	1	3	5	7	9
Instructors	4.63 (±1.91)	1	3	5	6	9
Trainees	4.56 (±2.35)	1	3	5	7	9
experienced fire incident	4.41 (±2.50)	1	3	4	7	9
no fire incident experience	4.67 (±2.24)	1	3	5	7	9
first time training	4.74 (±2.32)	1	3	5	7	9
trained more than once	4.28 (±2.37)	1	3	3	6	9

4.5 Sleep diaries and Actigraphy

The information provided by the actigraphs and the sleep diaries were used to estimate the mean behavioral activity over the whole recording period. The collected data of sleep were analyzed for the following range of variables: time in bed, sleep latency, time asleep, time awake, sleep efficiency and sleep debt (Table 4.7).

Table 4.7: Definitions of sleep variables

Time in bed (hrs:mins)	The difference between bedtime and get-up time
Sleep latency (mins)	The difference between sleep onset time and bedtime
Time asleep (hrs:mins)	The actual time spent asleep determined from sleep start to sleep end, minus any wake time
Time awake (hrs:mins)	The actual time spent awake determined from sleep start to sleep end
Sleep efficiency (%)	The sleep duration expressed as a percentage of time asleep from bedtime to sleep end
Sleep debt	The difference between the reported duration of sleep at home a regular day and the average sleep duration while participating the training

The results are presented in Table 4.8, whereas the specific sleep characteristics studied during training, are shown in Table 4.9.There is a substantial difference between instructors and trainees in the measures 'time in bed' and 'time asleep' concerning the sleeping behavior during the occurrence of simulations. The instructors declared being asleep at least an hour more than the trainees. The rest of the measures ranged at similar levels among the sample. Moreover, it is noted that trainees' sleep duration was higher on a typical working day and their sleep decreased about 45 minutes throughout their participation in training.

Concerning the sleep characteristics, while the simulations took place, no significant differences were found. The tendencies suggested that the sample had no difficulty both in falling asleep and waking up. Admittedly, the sleep duration reported to be fairly adequate and the sleep was described to be peaceful. Hence, the majority of participants claimed to wake up feeling refreshed.

Table 4.8: Means of sleep data collected by logbooks and actigraphy

	Total (N=64)	Instructors (N=10)	Trainees (N=54)
During training			
Time in bed (hrs:mins)	5:45	7:04	5:30
Sleep latency (hrs:mins)	0:17	0:19	0:16
Time asleep (hrs:mins)	5:27	6:32	5:15
Time awake (hrs:mins)	0:17	0:19	0:16
Sleep efficiency	94%	92%	94%
Sleep duration recorded by actiwatch (hrs:mins)	5:41	6:30	5:33
During a regular day at home			
Time in bed (hrs:mins)	6:46	6:10	6:52
Sleep latency (hrs:mins)	0:18	0:23	0:17
Time asleep (hrs:mins)	6:22	5:31	6:31
Time awake (hrs:mins)	0:05	0:15	0:03
Sleep efficiency	94%	90%	95%
Sleep debt (mins)	55:45	47:09	44:25

Table 4.9: Sleep characteristics of participants during training

	Total (%)	Instructors (%)	Trainees (%)
Ease of falling asleep			
Not at all	0.0	0.0	0.0
A little	17.2	30.0	14.8
Fairly enough	35.9	30.0	37.0
Much	21.9	20.0	22.2
Very much	25.0	20.0	25.9
Ease of arising			
Not at all	4.7	10.0	3.7
A little	21.9	20.0	22.2
Fairly enough	32.8	20.0	35.2
Much	20.3	50.0	14.8
Very much	20.3	0.0	24.1
Sleep duration was adequate			
Not at all	9.4	0.0	11.1
A little	35.9	40.0	35.2
Fairly enough	37.5	60.0	33.3
Much	14.1	0.0	16.7
Very much	3.1	0.0	3.7
Waken up refreshed			
Not at all	7.8	0.0	9.3
A little	31.3	40.0	29.6
Fairly enough	42.2	60.0	38.9
Much	14.1	0.0	16.7
Very much	4.7	0.0	5.6
Sleep was restless			
Not at all	43.8	0.0	51.9
A little	39.1	60.0	35.2
Fairly enough	9.4	30.0	5.6
Much	6.3	10.0	5.6
Very much	1.6	0.0	1.9

4.6 Symptoms

The "symptom check-list" was adapted in agreement with IMO guidance on fatigue and included the physical and cognitive effects of fatigue (subsection 2.2.3).

According to a project of the U.S. Coast Guard Human Factors Program Research and Development, a predictive model was developed to determine the mariner fatigue contribution to a casualty [36]. The model concerned the evaluation of the Fatigue Index score based on casualty investigations. The Fatigue Index equation (4.6.1) included as factors the following three potential fatigue indicators: the number of fatigue symptoms reported, the working hour in the last 24 hours preceding the incident, and the hours slept in the last 24 hours preceding the incident. A Fatigue Index score greater than 50 was the criterion to classify any incident as a casualty with a fatigue contribution.

$$\begin{aligned} &Fatigue \quad [4.39 * (Fatigue\ Symptoms)] \\ &Index \quad = + [1.25 * (Hours\ Worked\ in\ Last\ 24 Hours)] \\ &Score \quad - [0.93 * (Hours\ Slept\ in\ Last\ 24 Hours)] + 39.75 \end{aligned} \tag{4.6.1}$$

Additionally, similar studies to Nishiharas' regarding the impact of thermal environment on productivity, have followed the Yoshitake's method to estimate the prevalent effects of fatigue [39]. The method required the evaluation of subjective symptoms of fatigue, which were divided into three categories: I-group "drowsiness and dullness", II-group "difficulty in concentration" and III-group "projection of physical disintegration". The categories were classified by calculating the rate of complaints (4.6.2) and three types of fatigue feeling were distinguished: general pattern of fatigue (I>III>II), typical pattern of fatigue for mental work and overnight duty (I>II>III) and typical pattern of physical work (III>I>II). General rate of complaints was defined as the rate of complaints about all thirty symptoms.

$$\begin{matrix} Rate\ of \\ complaints \end{matrix} = \frac{\begin{pmatrix} number\ of\ selected \\ symptoms\ of\ all\ subjects \end{pmatrix}}{\begin{pmatrix} number\ of\ terms\ concerned \\ * \, number\ of\ subjects \end{pmatrix}} * 100 \tag{4.6.2}$$

The breakdown of participants' responses concerning the short-term fatigue consequences after the training, is extensively presented in Appendix B. The basic distributions of the responses are shown graphically with box plots in the following figures (4.10 and 4.11) and the main statistical characteristics are summarized in Table 4.10 and 4.11.

Figure 4.10: Box plot of Symptoms data

It is noted that the majority of participants have experienced at least half of the fatigue symptoms and a part of trainees declared to have felt them all (thirty-four in total) according to the subjective ratings. The mean number of symptoms didn't differ significantly among the sample. The instructors had a mean symptoms score of 16.10 ± 5.07 with a range from 8 to 26. Furthermore, the maximum mean score (16.19 ± 7.97) was reported by trainees with no fire incident experience. Extreme values of symptoms score 1 was stated by trainees who have either been involved in a fire incident or participated in a similar training before.

Table 4.10: Descriptive statistics of fatigue symptoms

	Mean (±SD)	Min value	First quartile (25% of data)	Median value	Third quartile (75% of data)	Max value
Total sample	15.31 (±7.63)	1	10	14	20	34
Instructors	16.10 (±5.07)	8	13	16	18	26
Trainees	15.17 (±8.05)	1	9	14	21	34
experienced fire incident	13.68 (±8.11)	1	9	12	17	28
no fire incident experience	16.19 (±7.97)	4	12	14	21	34
first time training	15.33 (±7.60)	3	10	14	20	33
trained more than once	14.90 (±8.89)	1	9	13	22	34

Table 4.11: Descriptive statistics of Fatigue Index

	Mean (±SD)	Min value	First quartile (25% of data)	Median value	Third quartile (75% of data)	Max value
Total sample	58.56 (±9.25)	41	52	57	64	80
Instructors	54.48 (±7.36)	44	50	54	57	71
Trainees	59.31 (±9.43)	41	52	58	66	80
experienced fire incident	57.39 (±8.01)	41	52	58	63	72
no fire incident experience	60.63 (±10.20)	45	53	59	67	80
first time training	58.27 (±9.30)	41	52	56	63	80
trained more than once	60.95 (±9.61)	44	53	63	66	80

Figure 4.11: Box plot of Fatigue Index data

According to the Fatigue Index procedure, fatigue prevalence was obvious in the majority. The 75% of total scores were above the cut-off point. Therefore the occurrence of incidents during training could be calculated as a product of human factors and short term fatigue consequences. High values of Fatigue Index score were most frequent in trainees.

The order among three categories of the subjective symptoms of fatigue is shown in (Table 4.12). The type of fatigue feeling that participants experienced was the general pattern of fatigue (I>III>II). The higher general rate of complaints was among subjects with a lack of experience in a fire incident and followed closely by the instructors.

Table 4.12: The order among three categories of the subjective symptoms of fatigue

	Rate of Complaints (%)				Category
	I	II	III	General	
Instructors	54	32	49	45	I>III>II
Trainees	56	35	38	43	I>III>II
experienced fire incident	54	30	34	39	I>III>II
no fire incident experience	58	38	40	46	I>III>II
first time training	59	34	36	43	I>III>II
trained more than once	52	36	40	43	I>III>II

Chapter 5

Conclusions

The following is suggested by the standardized questionnaires:

- The sample's perception of stress indicated a moderate level of initial stress before the training.
- The self-evaluation of fatigue ranged in low levels with physical fatigue being slightly above mental fatigue.
- The instructors' scores suggested higher levels of functional health and well-being as well as lower levels of stress and fatigue.

The following is suggested by the heart rates measurement:

- It is verified that the higher values of heartbeat were recorded when the sample executed the most demanding and stressful part of the simulations.
- Trainees who had not been involved in a fire incident manifested the highest heartbeats during the course of the simulations.

The following is suggested by the evaluation of the self-reported scales:

- Trainees who had not experienced either a fire incident or a similar training before, showed the same tendencies. They claimed to be less vigilant, more fatigued and stressed compared to the rest of the sample.

The following is suggested by the sleep findings:

- There were no poor sleepers in the sample and the sleep quality was sufficient.
- Trainees reported to sleep less throughout their participation in training.

The following is suggested by the evaluation of fatigue symptoms:

- Trainees appeared to be less objective at evaluating the severity of fatigue indicators. Thus it is verified that people are not particularly good at determining when their own cognitive abilities have been adversely affected by fatigue.

Based on the overall findings, the following conclusions are drawn:

- Instructors showed better results compared to trainees. This is justified by the fact that they are qualified and familiar with the required procedures and the surrounding environment during an emergency. According to the majority of the measures, trainees who have either been involved in a fire incident or participated in a similar training before, showed the same tendency as the instructors. It is implied that such an experience cultivates a decrement in coping with the fatigue experienced during a stressful situation.

- Fatigue was identified as a human factor contributing to the individuals' performance during an emergency situation. Therefore, it is essential that seafarers develop the corresponding competencies so that they possess the required skills in order to cope with fatigue.

Appendices

Appendix A

Alertness, Fatigue & Stress Distribution

Table A.1: Alertness distribution for total sample, instructors and total trainees

Score	Total sample		Instructors		Trainees	
	Frequency	Percent	Frequency	Percent	Frequency	Percent
1	119	26.6	34	48.6	85	22.5
2	47	10.5	4	5.7	43	11.4
3	162	36.2	24	34.3	138	36.5
4	30	6.7	1	1.4	29	7.7
5	51	11.4	3	4.3	48	12.7
6	19	4.2	3	4.3	16	4.2
7	14	3.1	1	1.4	13	3.4
8	3	0.7	0	0.0	3	0.8
9	3	0.7	0	0.0	3	0.8

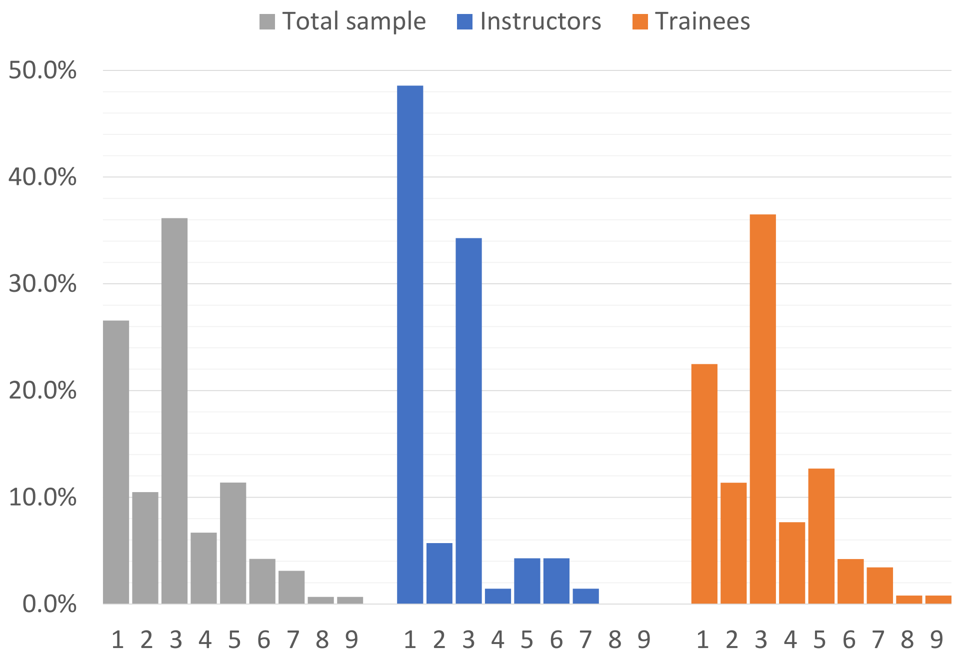

Figure A.1: Alertness scale distribution plot (percentage on total for each score) of total sample, instructors and total trainees

Table A.2: Alertness distribution for trainees regarding incident experience

Score	Incident experience		No incident experience	
	Frequency	Percent	Frequency	Percent
1	45	29.2	40	17.9
2	21	13.6	22	14.3
3	56	36.4	82	53.2
4	4	2.6	25	16.2
5	17	11.0	31	20.1
6	5	3.2	11	7.1
7	2	1.3	11	7.1
8	2	1.3	1	0.6
9	2	1.3	1	0.6

Table A.3: Alertness distribution for trainees regarding training experience

Score	First training		Trained more than once	
	Frequency	Percent	Frequency	Percent
1	43	18.6	42	28.6
2	36	15.6	7	4.8
3	84	36.4	54	36.7
4	19	8.2	10	6.8
5	30	13.0	18	12.2
6	12	5.2	4	2.7
7	4	1.7	9	6.1
8	2	0.9	1	0.7
9	1	0.4	2	1.4

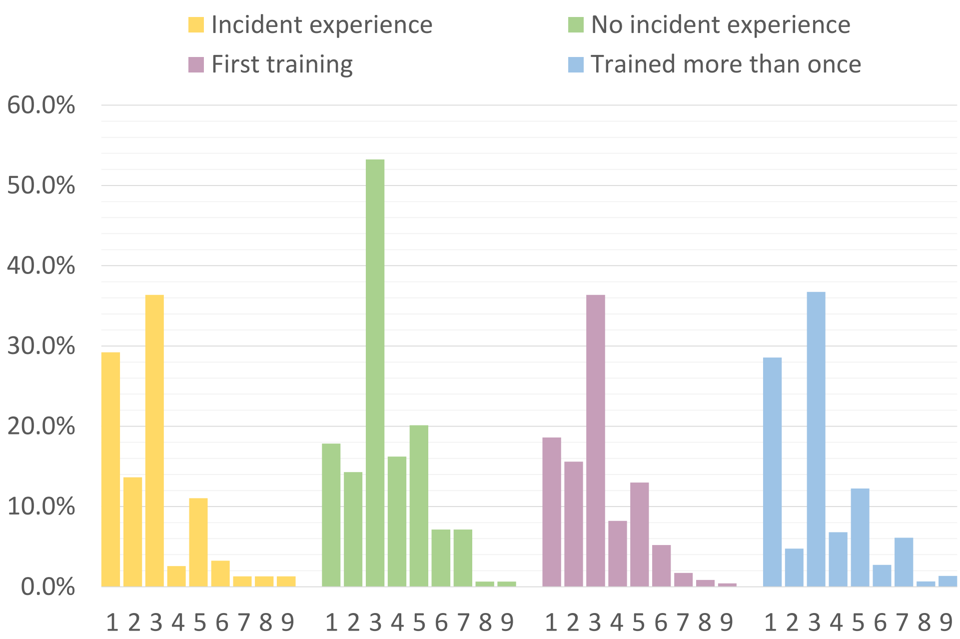

Figure A.2: Alertness scale distribution plot (percentage on total for each score) of trainees regarding incident and training experience

Table A.4: Fatigue distribution for total sample, instructors and total trainees

Score	Total sample		Instructors		Trainees	
	Frequency	Percent	Frequency	Percent	Frequency	Percent
1	49	10.9	10	14.3	39	10.3
2	37	8.3	11	15.7	26	6.9
3	81	18.1	15	21.4	66	17.5
4	35	7.8	1	1.4	34	9.0
5	53	11.8	5	7.1	48	12.7
6	71	15.8	11	15.7	60	15.9
7	71	15.8	9	12.9	62	16.4
8	31	6.9	6	8.6	25	6.6
9	20	4.5	2	2.9	18	4.8

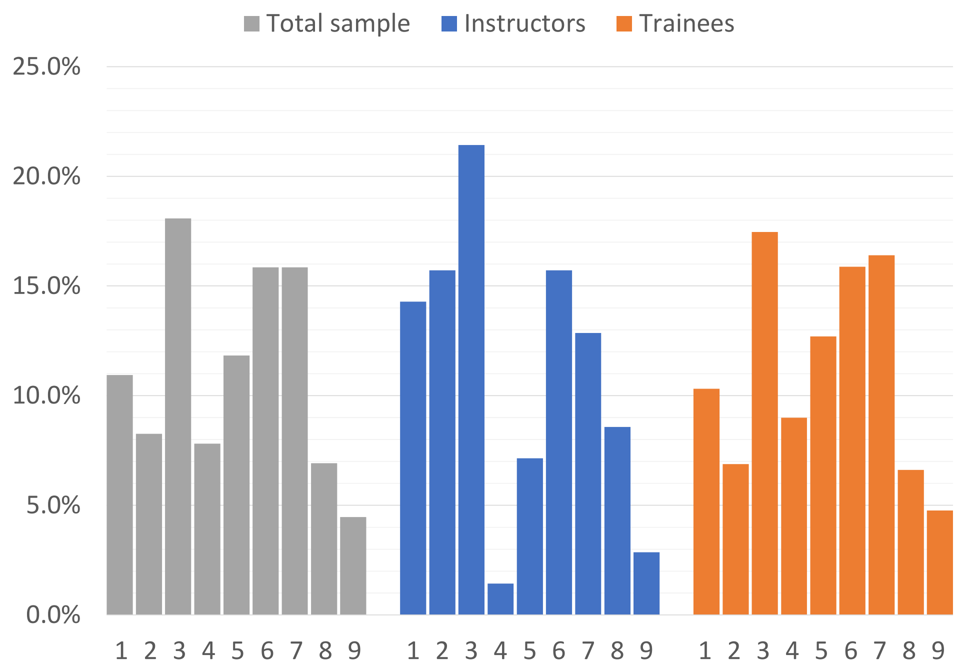

Figure A.3: Fatigue scale distribution plot (percentage on total for each score) of total sample, instructors and total trainees

Table A.5: Fatigue distribution for trainees regarding incident experience

Score	Incident experience		No incident experience	
	Frequency	Percent	Frequency	Percent
1	23	14.9	16	7.1
2	5	3.2	21	9.4
3	32	20.8	34	15.2
4	10	6.5	24	10.7
5	20	13.0	28	12.5
6	29	18.8	31	13.8
7	17	11.0	45	20.1
8	10	6.5	15	6.7
9	8	5.2	10	4.5

Table A.6: Fatigue distribution for trainees regarding training experience

Score	First training		Trained more than once	
	Frequency	Percent	Frequency	Percent
1	25	10.8	14	9.5
2	12	5.2	14	9.5
3	37	16.0	29	19.7
4	19	8.2	15	10.2
5	31	13.4	17	11.6
6	38	16.5	22	15.0
7	41	17.7	21	14.3
8	18	7.8	7	4.8
9	10	4.3	8	5.4

Figure A.4: Fatigue scale distribution plot (percentage on total for each score) of trainees regarding incident and training experience

Table A.7: Stress distribution for total sample, instructors and total trainees

Score	Total sample		Instructors		Trainees	
	Frequency	Percent	Frequency	Percent	Frequency	Percent
1	55	12.3	6	8.6	49	13.0
2	28	6.3	4	5.7	24	6.3
3	96	21.4	9	12.9	87	23.0
4	34	7.6	10	14.3	24	6.3
5	81	18.1	21	30.0	60	15.9
6	32	7.1	6	8.6	26	6.9
7	78	17.4	11	15.7	67	17.7
8	26	5.8	2	2.9	24	6.3
9	18	4.0	1	1.4	17	4.5

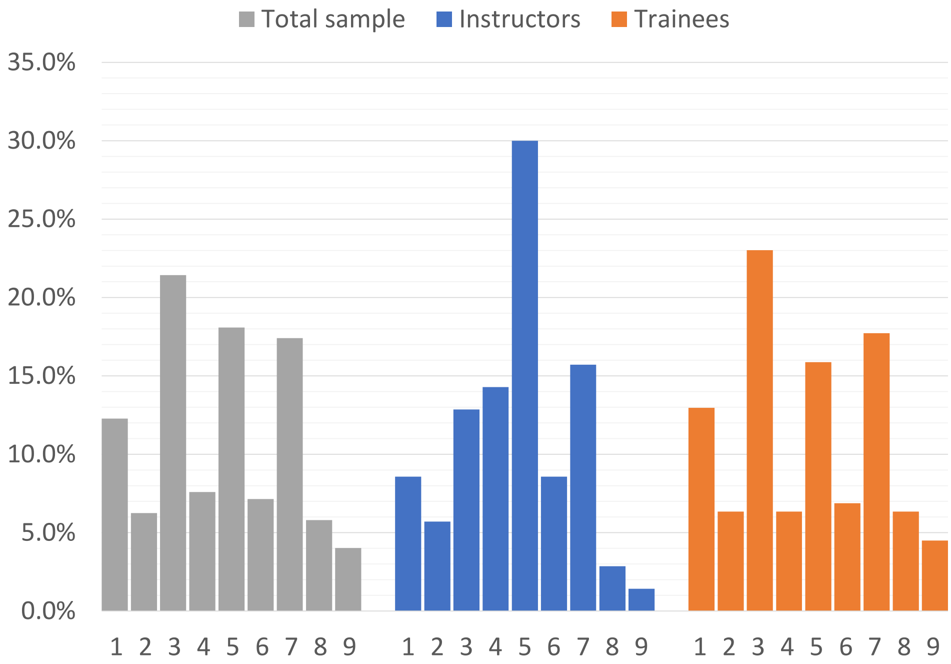

Figure A.5: Stress scale distribution plot (percentage on total for each score) of total sample, instructors and total trainees

Table A.8: Stress distribution for trainees regarding incident experience

Score	Incident experience		No incident experience	
	Frequency	Percent	Frequency	Percent
1	28	18.2	21	9.4
2	7	4.5	17	7.6
3	38	24.7	49	21.9
4	8	5.2	16	7.1
5	18	11.7	42	18.8
6	11	7.1	15	6.7
7	25	16.2	42	18.8
8	11	7.1	13	5.8
9	8	5.2	9	4.0

Table A.9: Stress distribution for trainees regarding training experience

Score	First training		Trained more than once	
	Frequency	Percent	Frequency	Percent
1	24	10.4	25	17.0
2	23	10.0	1	0.7
3	37	16.0	50	34.0
4	20	8.7	4	2.7
5	34	14.7	26	17.7
6	21	9.1	5	3.4
7	48	20.8	19	12.9
8	14	6.1	10	6.8
9	10	4.3	7	4.8

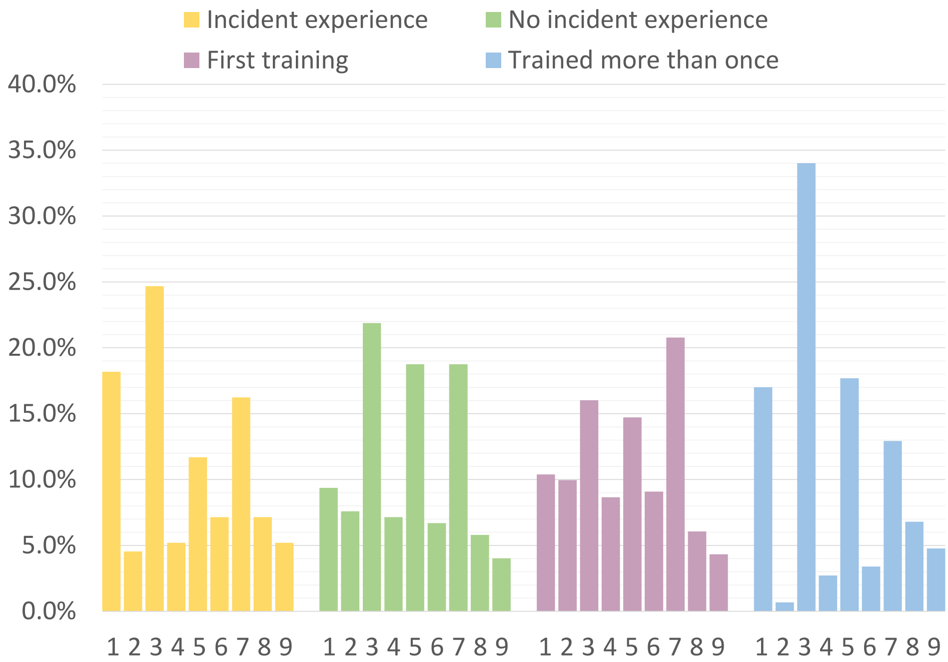

Figure A.6: Stress scale distribution plot (percentage on total for each score) of trainees regarding incident and training experience

Appendix B

Fatigue Symptoms

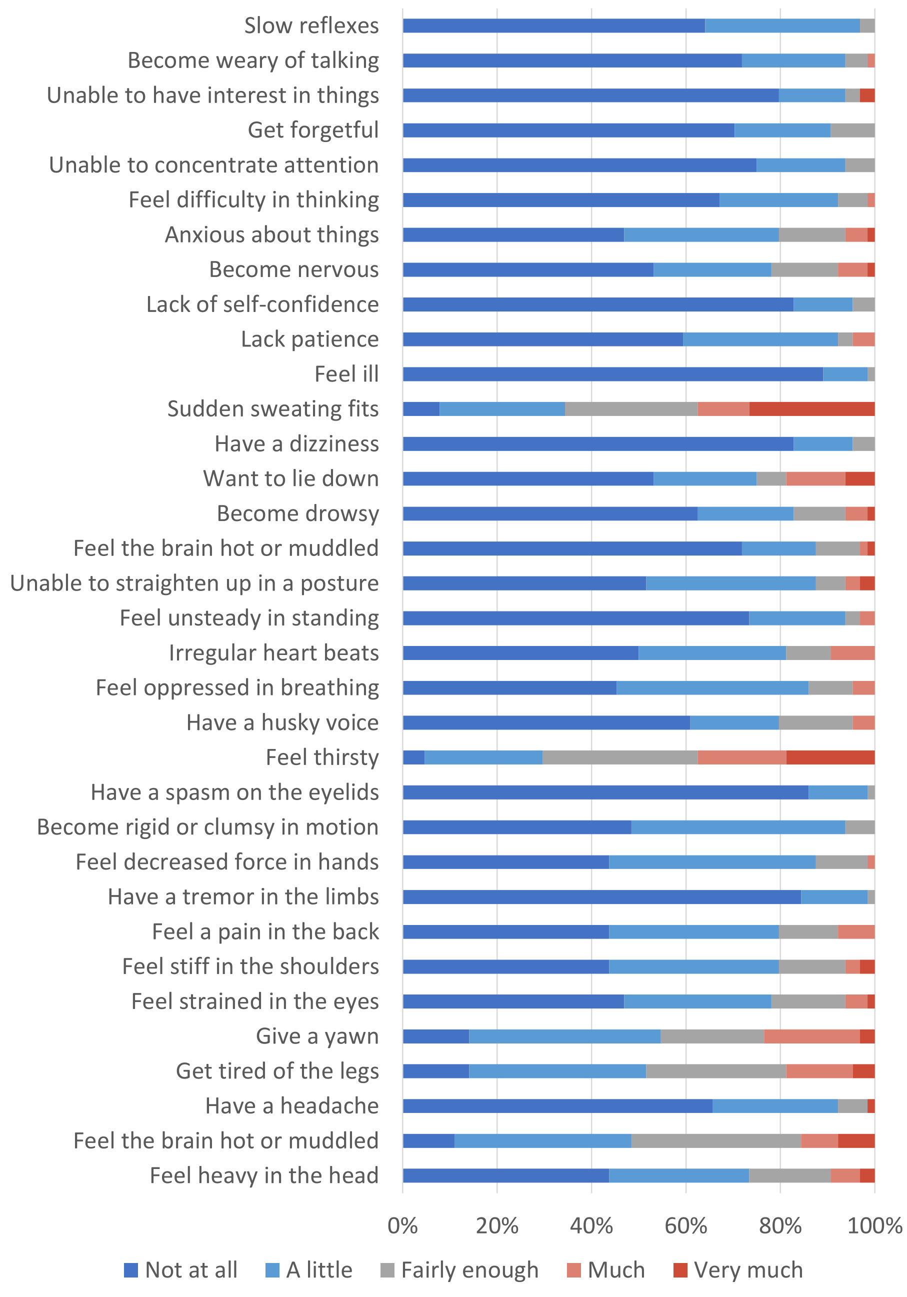

Figure B.1: Breakdown of total sample's responses regarding fatigue symptoms

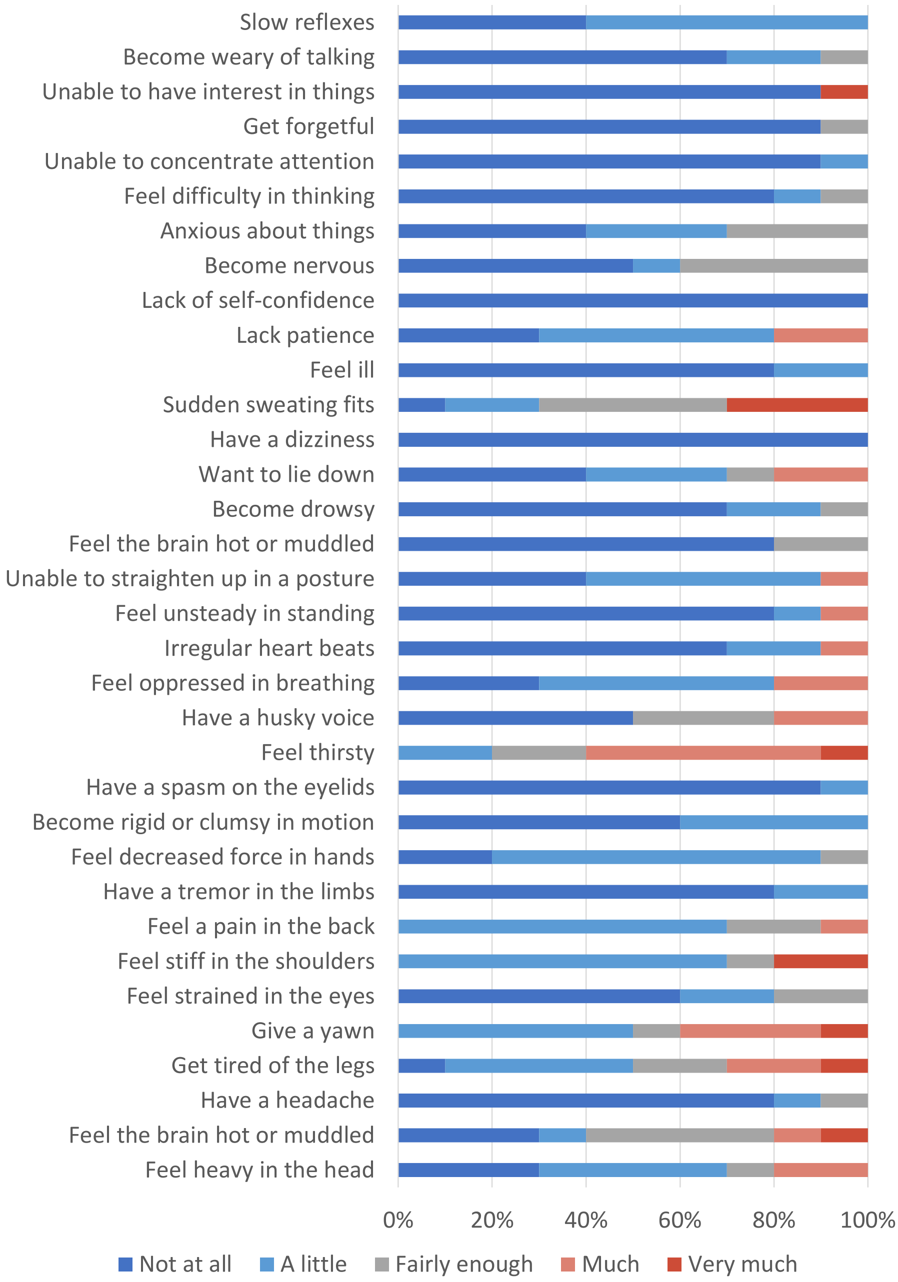

Figure B.2: Breakdown of instructors' responses regarding fatigue symptoms

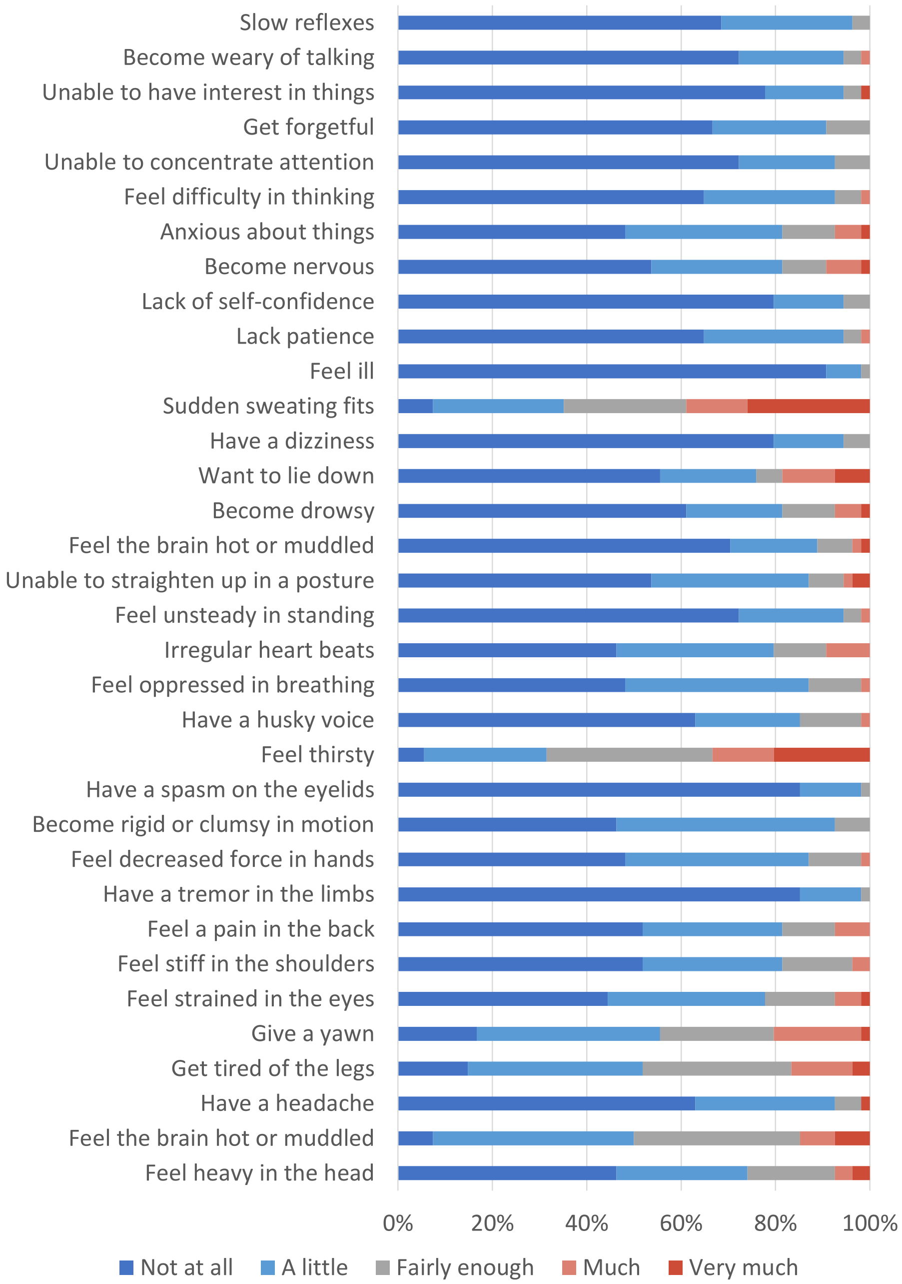

Figure B.3: Breakdown of total trainees' responses regarding fatigue symptoms

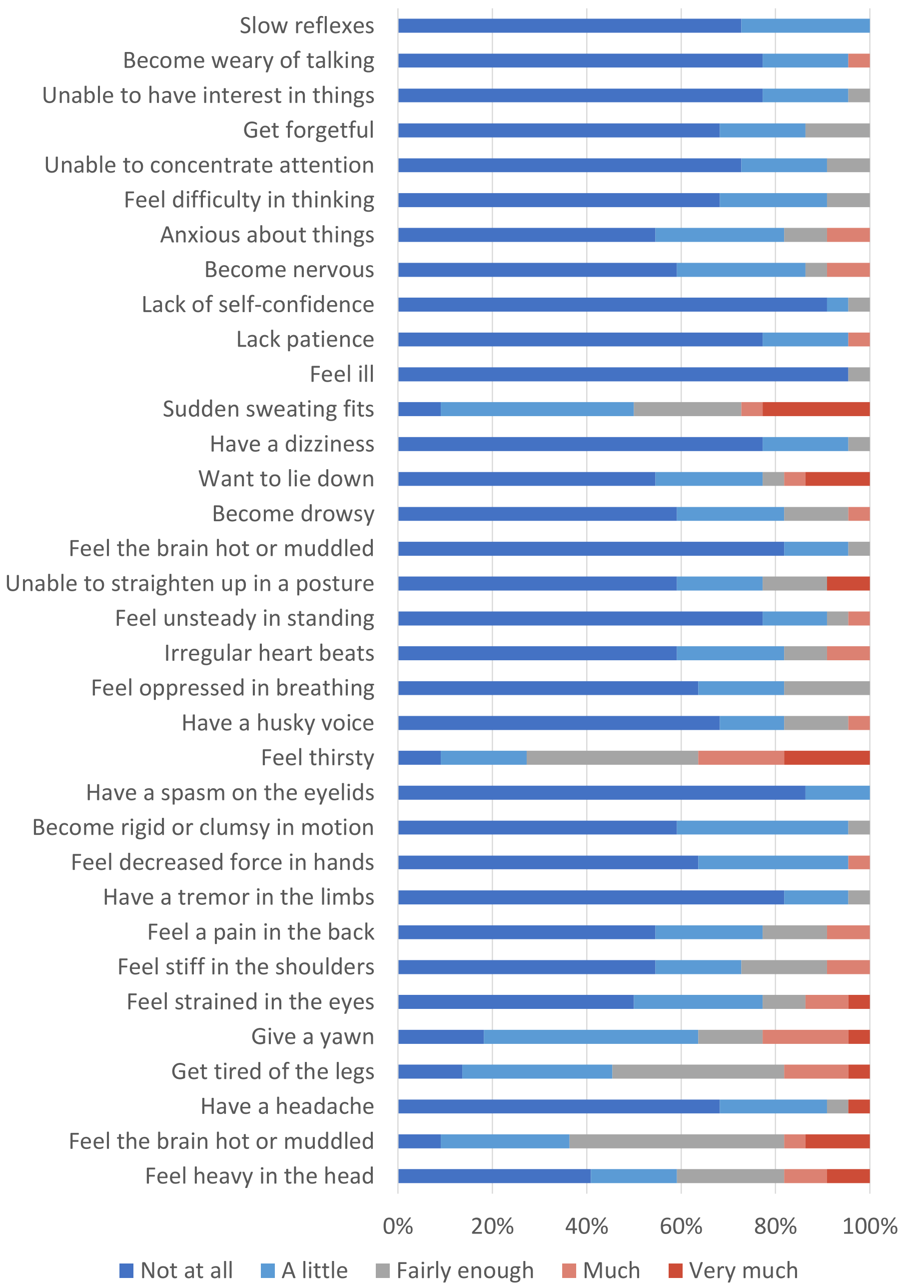

Figure B.4: Breakdown of trainees' responses regarding fatigue symptoms, who have been involved in a fire incident

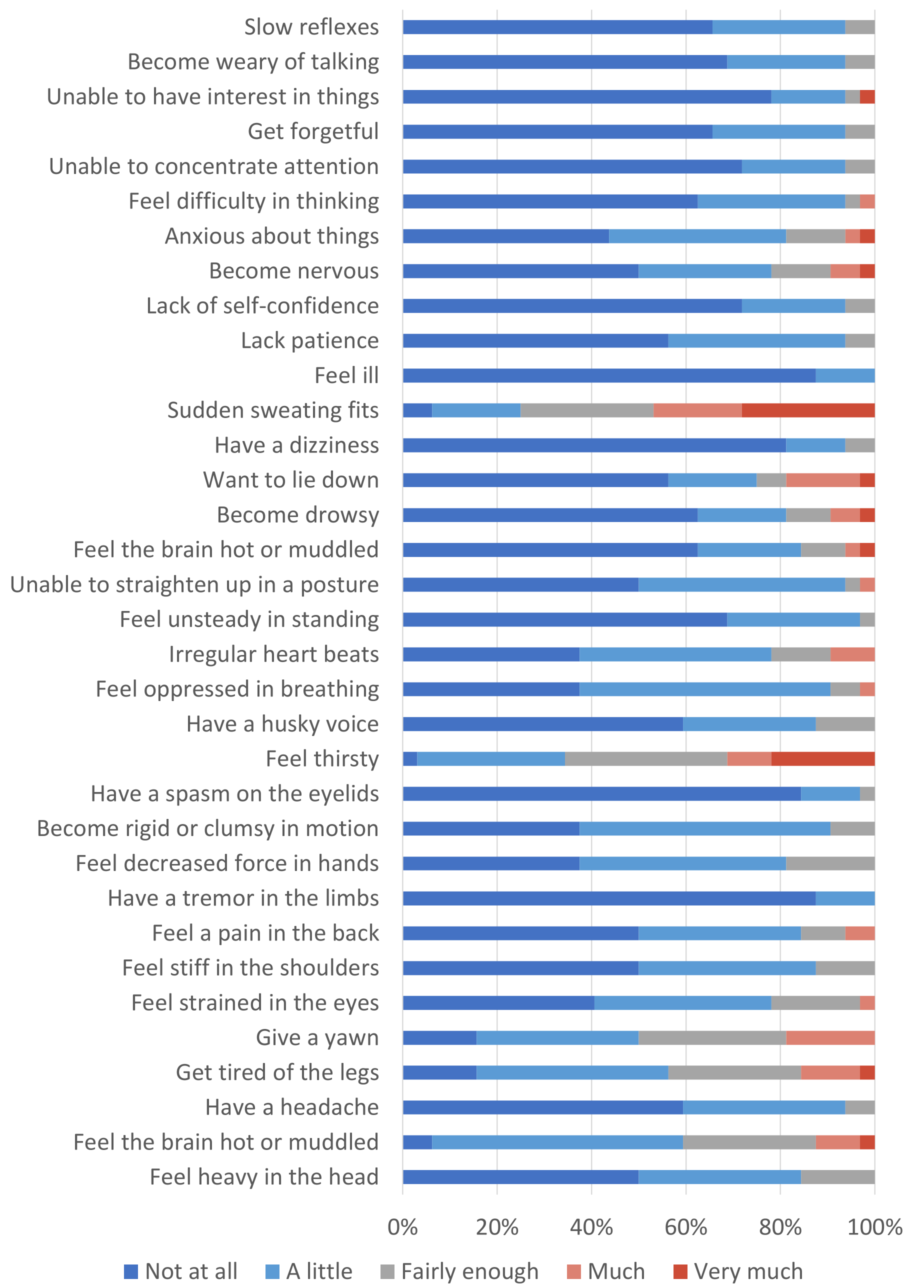

Figure B.5: Breakdown of trainees' responses regarding fatigue symptoms, who have no experience of a fire incident

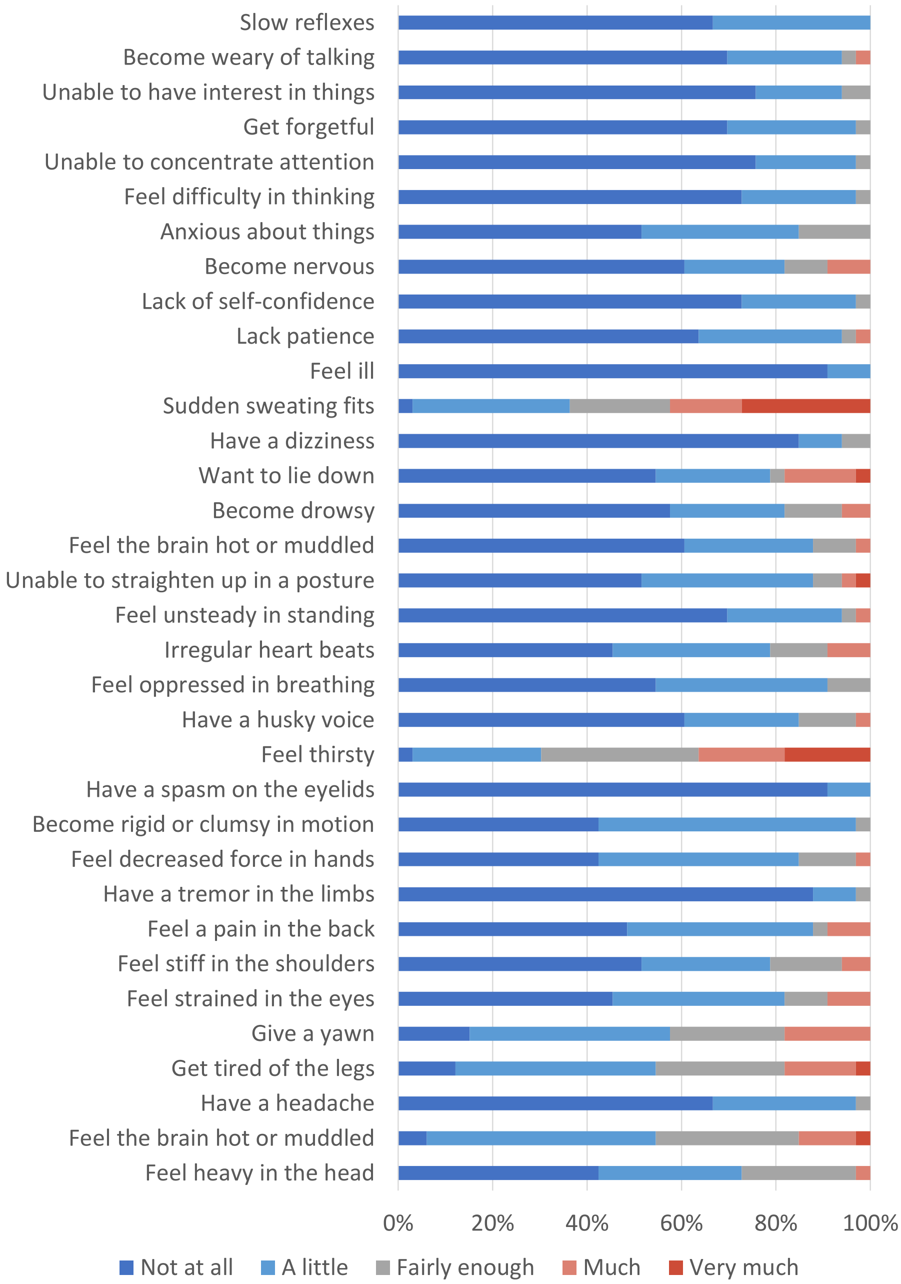

Figure B.6: Breakdown of trainees' responses regarding fatigue symptoms, who participated in a fire-fighting training for the first time

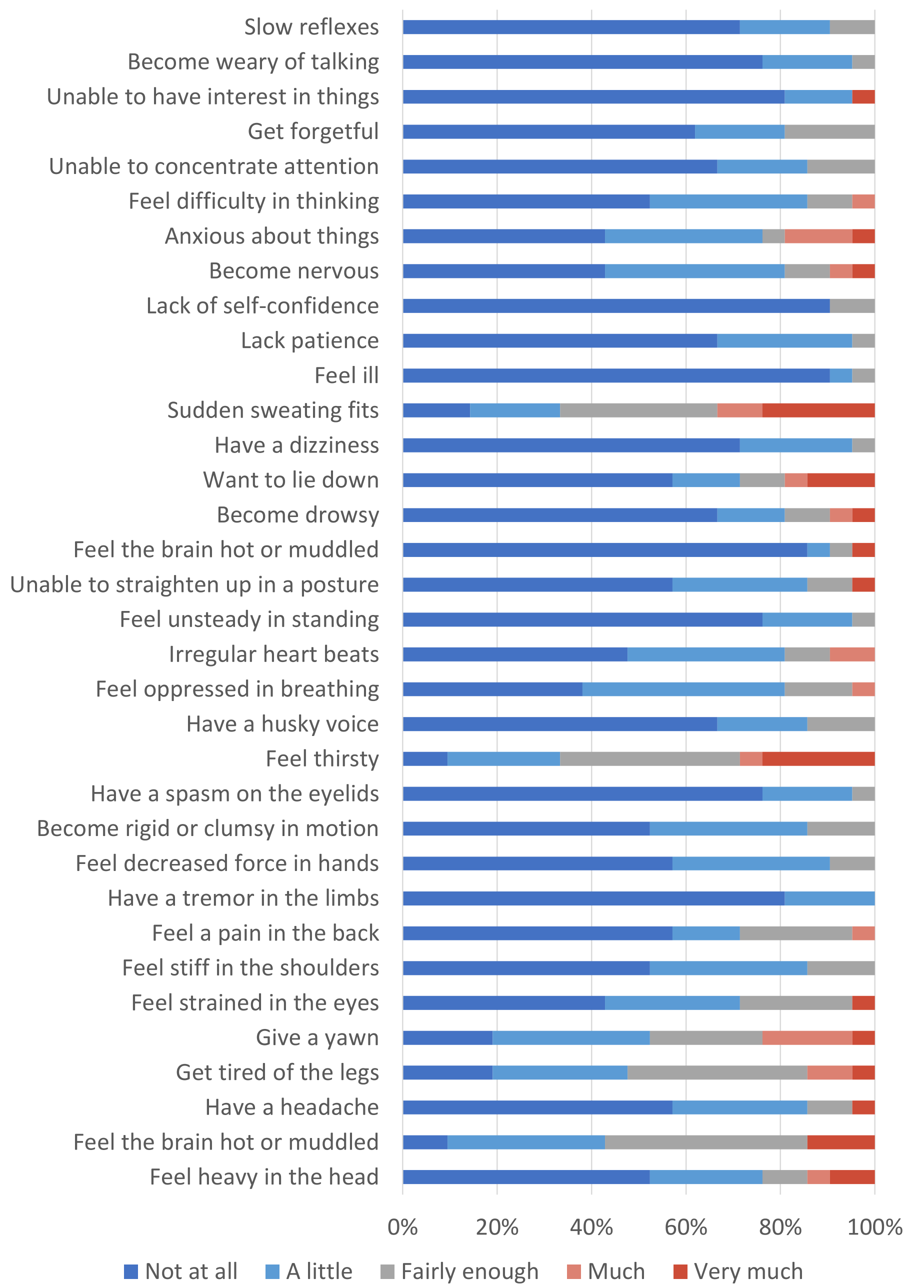

Figure B.7: Breakdown of trainees' responses regarding fatigue symptoms, who participated more than once in a fire-fighting training

Bibliography

[1] Annual Overview of Marine Casualties and Incidents 2019.

[2] Cool facts about your biological clock — EarthSky.org.

[3] Fatigue Science - Sleep Science Technology.

[4] Fatigue Science - Vancouver Airport Incident.

[5] Fatigue; The Columbia Electronic Encyclopedia.

[6] Guidance on Fatigue Mitigation and Management.

[7] ISF Watchkeeper.

[8] *An Overview of the Scientific Literature Concerning Fatigue, Sleep, and the Circadian Cycle.* Battelle Memorial Institute.

[9] Project Horizon: The Final Report.

[10] Project MARTHA: The Final Report.

[11] WHO - BMI Classification.

[12] Allen, P., Wadsworth, E., and Smith, A. Seafarers' Fatigue: A Review of the Recent Literature. 12.

[13] Anderson, M. *Contemporary Ergonomics and Human Factors 2012.*

[14] Anund, A., Fors, C., Kecklund, G., van Leeuwen, W., and Åkerstedt, T. Countermeasures for fatigue in transportation – A review of existing methods for drivers on road, rail, sea and in aviation. 65.

[15] Bell, J. Evaluation of the UK Rail Sector Initial Fatigue & Risk Index Thresholds: Identifying Good Practice.

[16] Berg, H. P. Human Factors and Safety Culture in Maritime Safety (revised). 343–352.

[17] Bird, D. R. A holistic approach to improving crew performance.

[18] Carlos A. Comperatore, PhD; Pik Kwan Rivera. Crew endurance management practices: A guide for maritime operations.

[19] Dittner, A. J., Wessely, S. C., and Brown, R. G. The assessment of fatigue: A practical guide for clinicians and researchers. 157–170.

[20] El-Sherief-Captain, M. S., and Elnabawy, M. N. Impact of fatigue on seafarer's performance. 14.

[21] Elsmore, T. F. SYNWORK1: A PC-based tool for assessment of performance in a simulated work environment. 421–426.

[22] Fatigue Science Inc. The Science of Sleep and Workplace Fatigue.

[23] Grech, M., Horberry, T., and Koester, T. *Human Factors in the Maritime Domain.*

[24] Gregory, D., and Shanahan, P. *The Human Element: A Guide to Human Behaviour in the Shipping Industry.* The Stationery Office (TSO).

[25] Herscovitch, J., and Broughton, R. Sensitivity of the Stanford Sleepiness Scale to the Effects of Cumulative Partial Sleep Deprivation and Recovery Oversleeping. 83–92.

[26] House, C., and Place, C. Bridge Watchkeeping Safety Study. 52.

[27] Houtman, I., Miedema, M., Jetinghoff, K., Annick, S., Heinrich, J., and Gort, J. Fatigue in the Shipping Industry.

[28] Jayakody, N. FATIGUE – Can we measure? 8.

[29] Kennedy, R. S., Turnage, J. J., and Osteen, M. K. Performance of Performance Tests: Comparison of Psychometric Properties of 24 Tests from Two Microcomputer-Based Batteries:.

[30] Laplante, P. A., Ed. *Encyclopedia of Software Engineering.* CRC Press.

[31] Lovell, C. R. Proposal for the Management of Work-Related Fatigue in Marine Port Pilots.

[32] Lutzhoft, M., Thorslund, B., Kircher, A., and Gillberg, M. Fatigue at sea: A field study on Swedish shipping.

[33] Lyons, E. W. Designing to deal with fatigue.

[34] Martinez de Oses, F. X., and Ventikos, N. P. A Critical Assessment of Human Element Regarding Maritime Safety: Issues of Planning, Policy and Practice.

[35] McCafferty, D. B., and Baker, C. C. Human Error and Marine Systems: Current Trends. 8.

[36] McCallum, M. C., and Raby, M. Procedures for Investigating and Reporting Human Factors and Fatigue Contributions to Marine Casualties. 92.

[37] Miller, C. B., Kyle, S. D., Melehan, K. L., and Bartlett, D. J. Methodology for the Assessment of Sleep. In *Sleep and Affect*. Elsevier, pp. 65–90.

[38] New Zealand, and Maritime New Zealand. *Fatigue Advisor Resource*. Maritime New Zealand.

[39] Nishihara, N., Yamamoto, Y., and Tanabe, S. Effect of thermal environment on productivity evaluated by task performances, fatigue feelings and cerebral blood oxygenation changes. 6.

[40] Parker, A. W., Australian Maritime Safety Authority, and Queensland University of Technology. *A Survey of the Health, Stress and Fatigue of Australian Seafarers*. Australian Maritime Safety Authority.

[41] Patrick Sherry. *Fatigue Countermeasures in the Railroad Industry: Past and Current Developments*. Transportation Law Journal.

[42] Perkins, W. Towards a fatigue management plan.

[43] Reyner, L., and Baulk, S. Fatigue in Ferry Crews: A Pilot Study. In *Managing Fatigue in Transportation*. Elsevier, pp. 339–354.

[44] Rosekind, M. R., Smith, R. M., Miller, D. L., Co, E. L., Gregory, K. B., Webbon, L. L., Gander, P. H., and Lebacqz, J. V. Alertness management: Strategic naps in operational settings. 62–66.

[45] Sanquist, T. F., Raby, M., Maloney, A. L., and Carvalhais, A. B. Fatigue And Alertness In Merchant Marine Personnel: A Field Study Of Work And Sleep Patterns. U.S. Department of Transportation.

[46] Schlegel, R. E., Gilliland, K., and Crabtree, M. S. Development of the UTC-PAB Normative Database. 286.

[47] Sheen, R. Fatigue and an alternative watch system.

[48] Sirois, W. G. Use of light to improve alertness in marine operations.

[49] Smith, A., Allen, P., and Wadsworth, E. Sefarers' Fatigue: The Cardiff Research Programme. 87.

[50] Starren, A., van Hooff, M., Houtman, I., and Buys, N. Preventing and managing fatigue in the Shipping industry.

[51] Strauch, B. Investigating Fatigue in Marine Accident Investigations. 3115–3122.

[52] Transportation Safety Board of Canada. A Guide for Investigating for Fatigue.

[53] Udo Trutschel, Bill Sirois, David Sommer, Martin Golz, and Dave Edwards. PERCLOS: An Alertness Measure of the Past.

[54] Vagias, N. A. A Bayesian Network Application for the Prediction of Human Fatigue in the Maritime Industry. 215.

[55] Vicente, K. J. *The Human Factor : Revolutionizing the Way People Live with Technology.* Routledge.

[56] Wang, H. Study on the assessment of seafarers' fatigue. 106.

[57] Ware, J., Kosinski, M., and Gandek, B. SF-36 health survey: Manual & interpretation guide.

[58] Xhelilaj, E., and Lapa, K. The Role of Human Fatigue Factor towards Maritime Casualties.