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Mapping the knowledge base for maritime health: 4 safety and performance at sea

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ABSTRACT

There is very little recent investigative work on the contribution of health related impairment and disability to either accident risks or to reduced performance at sea, the only exception being studies on fatigue and parallel data on sleep related incidents. Incidents where health related impairment, other than fatigue, has contributed are very rarely found in reports of maritime accident investigations. This may either indicate the irrelevance of these forms of impairment to accidents or alternatively point to the effectiveness of existing control measures. The main approach to risk reduction is by the application of fitness criteria to seafarers during medical examinations. Where there is a knowledge base it is either, as in the case of vision, a very old one that relates to patterns of visual task that differ markedly from those in modern shipping or, as with hearing, is based on untested assumptions about the levels of impairment that will prevent effective communications at sea. There are practical limitations to the assessment of cognitive functions as these encompass such a wide range of impairments from those associated with fatigue, medication, or substance abuse to those relating to age or to the risks of sudden incapacitation from a pre-existing illness. Physical capability can be assessed but only in limited ways in the course of a medical examination. In the absence of clear evidence of accident risks associated with health-related impairments or disabilities it is unlikely that there will be pressure to update criteria that appear to be providing satisfactory protection. As capability is related to the tasks performed, investigations need to integrate information on ergonomic and organizational aspects with that on health and impairment. Criteria that may select seafarers with health-related impairment need to be reviewed wherever the task demands in modern shipping have changed, in order to relax or modify them where indicated in order to reduce unjustifiable discrimination.

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Key words: maritime, seafarer, seaman, safety, capability, perfomance, illness, health, impairment, ergonomics

INTRODUCTION

The concept of 'the able-bodied seaman' has a history dating back to the days of sail, and the avoidance of accident risk and capability to perform duties have long been key parts of this concept. The main continuing contribution of health professionals to the reduction in accident risk lies in the application of fitness criteria during medical assessments of seafarers, and these relate both to routine and emergency duties. They may also be involved in policies for the control of the use of impairing medications, alcohol, or 'recreational' drugs as well as on the effects of working patterns on fatigue.

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Health-related impairment has not been identified as a major cause of maritime accidents. In consequence expertise in maritime health is only one contributor, and often a small one, to the prevention of accidents and disasters at sea and to ensuring that seafarers are able to work effectively. The boundary between the interests of the health professional and others with complementary skills in accident prevention is often unclear and may be contested. For the purposes of this review, evidence on impairment associated with illness and with physical and cognitive limitations of the sort that can be assessed in a clinical setting will be considered. The contribution of health-related factors to forms of impairment that have multiple causes, such as fatigue and mental distress, will also be noted.

Vision, hearing, musculo-skeletal limitations, and cardio-respiratory reserve are aspects that are commonly considered to form the safety-related parts of a seafarer health assessment. In addition, the likelihood of sudden incapacitation or cognitive impairment from a pre-existing medical condition or from medication used to treat it needs to be evaluated at the same time, as the prognosis of the condition is considered in terms of the risks of progression or recurrence while at sea.

Some infectious diseases may also pose a risk to safe vessel operation because of their spread among crewmembers, while rarely behavioural changes in one individual associated with a mental health condition or with a personality disorder may endanger vessel safety or put others at risk of physical harm. Because the sensory, cognitive, and physical demands of work at sea, as well as the risks of spreading infectious diseases, vary widely between different jobs afloat, most assessments need to be specific to a particular type of work. They also need to take account not only of routine duties but also of those that may be required in an emergency.

Many of the same impairments to capability that can create accident risks also have an adverse effect on performance of duties that are not safety critical. In practice, employers may gain productivity benefits from selection aimed at reducing accident risks, but at times they may also consider that additional selection criteria are indicated to ensure productivity. Such additions are not seen as a priority by maritime safety authorities and may be seen as unreasonably discriminatory by seafarer representatives.

TASK DEMANDS AND CAPABILITY REQUIREMENTS

Developing rational health-related criteria for a particular task requires a good understanding of the task demands, both routine and in an emergency. This form of analysis of duties in maritime transport is rare, for instance compared to similar work by the military or in other modes of transport. Ergonomic, behavioural, and organizational aspects as well as health aspects need to be considered. Questions are sometimes asked about health-related performance requirements when maritime technologies change, for instance the introduction of fast ferries with their need for rapid responses to external events or the use of larger inflatables, with high vibration levels, for lengthy passages. They are rarely answered using detailed investigations of task demands and the capabilities that correspond to them.

Health-related impairments are only relevant if they can be related to the functional capabilities that have been identified as appropriate for a person's duties. It is not 'fitness for duties' but 'fittedness for duties' that needs to be assessed. Any impairment that is constant is likely to influence capability to perform tasks in a predictable way. An impairment that is episodic or fluctuating will not have a constant effect on capability but will reduce reliability in that, while performance will normally be adequate, there will be times when it is reduced, often in a major way. The following forms of impairment are addressed in this review:

1. Vision: camera functions of eyes and visual information processing by brain.
2. Hearing: auditory functions of ears and auditory information processing by brain.
3. Cognitive functioning (other than vision and hearing): personal variables, and effects of over- and underload, fatigue, mental distress, medical conditions, medications, and other impairing substances.
4. Communication abilities by speech, text, or expression.
5. Mobility, strength, stamina, and dexterity: local musculoskeletal conditions, cardiorespiratory reserve, obesity, and other general medical conditions.
6. Other conditions relevant to the safe, healthy, and effective operation of the vessel.

Items 1–5 in this sequence reflect the functional basis for most work activities, where information is received from sense organs, decisions are taken based on this information and on past knowledge,

training, and experience, and these decisions are then expressed in actions taken, whether by means of communication to others or by physical activity. Similar approaches have been used for analysis in other modes of transport.

There is a large degree of consistency in the human performance envelope. Most people have broadly the same range of visual, hearing, and cognitive capabilities as well as similar communication skills and locomotor functions. Hence, impairment implies that a person is outside the limits of the human performance envelope that is needed for the task at issue. Thus, everyone will have limited vision at night, become fatigued if deprived of sleep, or become mentally distressed if work demands are unmanageable. Assessment aims to identify those beyond the lower end of the acceptable range of capability and reliability because of limitations caused by a disability or medical condition. It also aims to identify the scope for adapting duties so that they are within any performance limitations that a person may have. Adaptation of duties is, however, often not a practical option at sea.

Capabilities change with age. Where impairment leads to a slow and steady decline, this can be monitored by periodic individual assessments. Where it relates to a condition that may progress, resolve, or be episodic, both individual assessment and relevant aspects of the prognosis of the condition need to be considered. If the condition increases the probability of sudden incapacitation, but at other times the person is unimpaired, the acceptability of such an episode should be considered. In particular the amount of back up safety in the system, whether from work organization or mechanical means, is an important determinant of the frequency of episodes of incapacitation that are acceptable.

Working and living conditions at sea may have a major influence of the expression of any impairment. For instance, heat or cold can affect many aspects of performance, while noise and vibration as well as work demands can contribute to fatigue.

The final category (6) includes infections that can lead to illness in other crew members, whether from food handling or respiratory droplet spread, as well as those where seafarers may be vectors for transmission between ports. The rare personality or mental health conditions that may put other crewmembers in physical danger are also included.

METHODS

The primary indicator of the contribution of health-related factors to maritime safety will be information about incidents at sea leading to loss of life and to injury or illness, or to loss of or damage to vessels and their equipment. Most maritime safety incidents are multifactorial in origin and, apart from isolated case reports about physical or mental limitations contributing to incidents, the only sound bodies of information relate to the effects of fatigue as causes of navigational incidents and to outbreaks of food-borne infections. Most of the available incident reports are to be found in publications from national maritime accident investigation organisations [1]. Most records of food-borne outbreaks come from public health authorities, although there are a few overall reviews that focus mainly on passenger vessels [2].

A search for recent studies using Pubmed was used for the major forms of sensory impairment. ISMH abstracts and the references in the Textbook of Maritime Medicine were also reviewed [3, 4]. There were very few studies in either vision or hearing testing or performance in seafarers. Most of those on hearing related to noise-induced hearing loss. Similarly, a search for studies on impairment of cognitive performance in seafarers did not identify recent studies that were relevant to accident risks, other than those relating to fatigue [5, 6]. A small number of accident investigations identified contributions from medical conditions or medication [7].

Many of the safety-related criteria used to decide whether a person should work at sea have been in existence for over a century, if only applied erratically. As noted in the first article, colour vision conforms to this pattern, as do visual acuity testing and attempts to detect alcohol misuse. This history and the inherent conservatism of those who specify safety-related standards may be one of the reasons why there is only a very limited amount of modern investigative work on the safety-related criteria for work at sea and on their relationship to the requirements of current working practices. This review will necessarily be structured around the current fitness criteria, their limitations, and the consequences of these limitations rather than attempting to map a very limited field of recent investigative work.

RESULTS

VISION

Although formal studies have not been published there is little evidence from accident and incident reports to suggest that simple forms of visual impairment have been significant contributors to incidents at sea [8]. This could be a result of the vision testing regimes and fitness criteria that have long been used.

There was certainly evidence of incidents attributed to colour vision impairment in the late nineteenth century prior to testing, as noted in the first article [9].

The visual tasks in seafaring vary widely between different crewmembers, but most attention has been paid to those engaged in navigational lookout duties, where the significance of colours and patterns of lights or shapes, often in poor visibility and at night, has to be recognised. Those for engineers are different as they relate to close work often in difficult positions and to identifying the colour coding of wires, instruments, and controls. In emergencies all crewmembers may need the ability to evacuate a ship even without any of the visual aids they may normally use.

For simplicity, testing has been generally limited to high-contrast visual acuity, using Snellen or similar test types for distant vision and a reading card for near vision. Colour vision is usually tested initially with Ishihara or similar plates sometimes with the option of a coloured light lantern test for those who make errors on the Isihara test, or with the use of other forms of test that can identify the nature and severity of colour vision impairment [10]. Visual fields are not usually tested beyond simple Donders type confrontation, and other facets such as night vision are not normally part of the routine, although coloured light lantern tests will incidentally provide such information when they are performed. The levels at which criteria for acuity are set or those underlying the amount of impairment to colour vision that is acceptable were based on studies undertaken in the early part of the 20th century [11–13].

These test methods have been criticized because they do not test vision under difficult conditions of the sort often experienced by navigators at sea, where contrast is low, light levels are low, or where there may be glare [14–16]. In addition, the criteria for some important facets of vision, such as night vision or the adequacy of visual fields, cannot be determined effectively in the absence of good studies of the often complex visual demands of relevant tasks [17, 18].

In the absence of clear evidence of risk there is little pressure to investigate, but at the same time current standards are discriminatory. Around 5% of the male population is excluded from navigational duties because of colour vision requirements. Some investigations in related areas, such as naval and search and rescue personnel, are relevant. All show that visual performance is very dependent on the situation [19, 20]. There is a widespread view that those with actual or effective monocular vision may have reduced visual performance. Whether this is because of the danger of sudden impairment from an injury to the remaining effective eye, a belief that two eyes are needed for distant stereopsis, or because of concerns about a slower visual response is not clear. The latter is the only aspect that has a small evidence base from experimental settings [21].

Developments in ophthalmology such as the use of refractive surgery, phakic lenses to remedy cataracts or to improve refraction, and the use of orthokeratotic lenses to adjust the shape of the corneal surface to enhance acuity have posed challenges to the existing standards that have had to be answered in pragmatic ways or be based on experience ashore rather than being related to sound information about the visual demands of seafarers.

The eye is the organ that transduces images into nerve impulses, and all the effort has traditionally gone into testing its camera functions. The rest of the processes of visual cognition where nerve impulses are analysed to make patterns and evaluate their significance has not formed part of the assessment process, despite the evidence from other related tasks that this may well be a much bigger contributor to accidents than failures of camera function and that factors such as fatigue may play a large part in reducing visual perception and vigilance [22].

Performance in several key areas of visual function reduces with age. The ability to accommodate to different distances reduces in presbyopia and leads to a higher prevalence of spectacle use with age. In the same way the time taken to dark-adapt increases [23]. Opacities in the lens also increase the amount of light scatter, reducing acuity and increasing glare. Age is not considered when determining fitness standards or by making adaptations to duties, for instance to the time required in the dark before lookout duties commence.

HEARING

There is no available evidence indicating that hearing impairment in seafarers has contributed to accidents or incidents. Safety-critical risks from hearing impairment are mainly linked to correct understanding of commands and other communications, often given in noisy environments or over systems where the signal-to-noise ratio is low. Alarms must also be heard and interpreted.

Hearing was originally tested subjectively by whispered words; more recently pure tone audiometry has been used or, in a few cases, tests of speech

recognition [24]. The use of audiometry has often been confusing as it may both be used to assess safety-critical communication ability and to evaluate whether there has been any hearing damage from noise exposure. The test is the same but the interpretation of findings is different. The criteria used to decide on suitability to work at sea reflect onshore studies of the level at which impairment begins to interfere with communication, but these have not been validated in the maritime environment.

Like vision, auditory signals are processed in the brain in order to analyse their significance. Neither the importance of this nor the interactions between hearing thresholds and the ability to comprehend non-native languages have been investigated in seafarers.

While the use of spectacles or lenses to improve vision has long been accepted there are reservations about the use of hearing aids and cochlear implants in seafarers. In part these relate to concerns about whether the aids are robust enough to be reliable under maritime conditions and also to the quality of communications that they provide. In addition, if hearing is profoundly impaired there can be problems with arousal by an emergency alarm when the device is removed for sleep.

COGNITIVE FUNCTIONING

The ability of the brain to handle information and to respond to it in an effective and reliable way is essential for most tasks at sea. This is a highly complex topic and one that is only likely to be addressed in limited ways by maritime health practitioners. It is closely linked to the ability to develop competencies and to learn from training and experience. Cognition is impaired by fatigue and by mental distress. The large literature on these topics has not been considered in preparing this review.

The situations in which assessment of cognitive function or concern about impairment is most likely to arise when deciding on suitability for work at sea include the impairing effects of medication. Most psychoactive medications such as hypnotics, antidepressant, and anxiolytics are likely to have impairing effects, as are some antihistamines, strong analgesics, and insulin. Medical conditions adversely affecting cognition include: stroke, head injury, and early dementia. Substance abuse, mainly from alcohol or drug misuse, also has the potential to cause long-term as well as immediate impairment [25].

The functioning of cognitive processes and the actions based on them may be changed in complex ways in the presence of mental illness or personality disorders. These can adversely affect safety as well as imposing stresses on fellow crewmembers.

Sleep apnoea as well as many forms of pain can exacerbate fatigue by preventing effective recovery during sleep. Untreated sleep apnoea is known to increase crash risks in vehicle drivers, and this can be resolved by effective treatment [26].

The scope for producing a formal set of criteria against which the cognitive skills of an individual can be appraised is limited as there are so many variables and uncertainties. Minor levels of stable impairment may be amenable to assessment during a trial period of work, if this can be accommodated. More severe and episodic patterns have been handled in a precautionary way. Improved knowledge about the effects of health-related cognitive impairment on maritime safety would be useful. There is no evidence to indicate that its importance is comparable with the contribution of fatigue or mental distress to inattention and impairment, and studies of these could therefore be expected to yield greater benefits for safety.

A history of a relevant medical condition or form of treatment is the usual indicator that there may be an increased risk of sudden incapacitation. Most forms of sudden incapacitation, whatever their cause, are finally expressed as cognitive impairment, often through partial or complete loss of consciousness. These include faints, seizures, narcolepsy, cardiac events such as heart attacks, cardiac arrhythmias, stroke, and transient cerebral ischaemic attacks, and acute metabolic changes such as anoxia or hypoglycaemia induced by insulin.

Several aspects of sudden incapacitation need to be considered. First, for many of these conditions there will be an initial episode that cannot be anticipated. In some cases, such as cardiac events, the probability will increase with age. Safety systems need to take account of the foreseeable eventuality of initial events, for instance by having dual crewing in highly safety-critical situations. Second, an initial event may indicate a likelihood of recurrence or progression and the risk of subsequent events can sometimes be predicted. Third, the severity of events may show a characteristic pattern, for instance a recurrence of a cardiac arrhythmia is likely to cause a similar degree of disability to the previous episode.

Seafarers will always be a difficult group in which to study the probability and severity or immediate incapacitation, although some studies of vehicle drivers and of air pilots can be informative [27, 28].

Much of the information has to be derived from much larger onshore populations and here it is often hospital admissions or deaths rather than episodes of incapacitation that are recorded. It is difficult to see any option to extrapolating from these sources, but decisions taken about employment at sea based on them can seem to be arbitrary and inequitable. Information on the safety consequences of incapacitation at sea, other than by fatigue and sleep, is rare and related to isolated cases [29].

COMMUNICATION ABILITY

There is no sound evidence linking impairments of communication to maritime incidents, although there is a supposition that language differences may be important and could be expected to be far more common than the effects of disabilities or medical conditions on communication ability. They are likely to have a major effect on effective performance of tasks requiring teamwork. The contribution of health professional skills to the assessment of communication ability is peripheral. Most significant impairments will be identified at recruitment or during training. Nonetheless, the ability to communicate is essential to safety, and a few forms of impairment will be associated with medical conditions. It is unlikely that an improved knowledge base on these will significantly add to maritime safety.

PHYSICAL CAPABILITY

It would be difficult to develop studies that link impaired physical capability to accidents. There are, however, a number that look at measures that may be closely related surrogates, for instance the time taken to exhaust the air supply in self-contained breathing apparatus is shorter in those who are overweight [30]. Hence they are both more at risk in a hostile atmosphere as well as being less capable of performing their duties than other crewmembers. A few incident investigations link obesity to safety risks, although there may be a reluctance to identify the link in the event of other more apparent causes, especially if they relate to the victim. Examples include problems with entry into confined spaces and rescue from them, the safe use of rescue chutes, and slowed ship evacuation when vessels have had to be abandoned [31]. Work ability declines with age and an increased body mass index has a deleterious effect on the ability of older seafarers to do even moderate levels of work [32]. The high prevalence of obesity makes this the most frequent condition studied; however, many of the limitations on capability can be expected to be similar for less common physical disabilities.

Mobility, strength, stamina, and dexterity are all seen as important facets of the ability of a seafarer to perform their routine and emergency duties safely and effectively. Medical conditions affecting several systems of the body can contribute to impairment. However, in all cases where the impairment is stable functional testing is intuitively more appropriate than clinical assessment. In practice the requirement to complete physically demanding training courses on safety of life at sea and on firefighting provides valid practical tests at the start of a career, but one that is not required to be repeated thereafter and also not one that is geared to the assessment of individuals who are suspected of becoming impaired in the course of their careers or through illness.

Procedures have been recommended for the assessment of physical capability of seafarers in the clinic setting. In some cases these focus on the simulation of shipboard tasks such as climbing ladders and entering confined spaces [33]. Other methods such as step testing aim to assess stamina and in particular the cardio-respiratory reserve capacity that could be called on in a physically demanding emergency. A particular sub-set of such testing is the use of treadmill tests with electrocardiographic monitoring in those who have had cardiac events. While this is a test of reserve and stamina it is primarily used to estimate the probability of a recurrence of ischaemic heart disease. A few organisations have introduced more complex task simulations that assess a number of the features of physical demands at sea.

Where the level of impaired physical capability is not stable, for instance in conditions such as rheumatoid arthritis or multiple sclerosis, the same considerations as those applied to other long-term illnesses need to be adopted, that is estimation of the likelihood of impairing episodes in the future, their severity, and the speed of onset. Here the past pattern in the individual and in others with the same condition will be the best guide to risks.

Prosthetics are becoming an important aid to maintaining mobility. Internal ones such as hip and knee replacements need to be assessed in terms of current functional abilities and the likelihood of future complications, including any increased vulnerability to damage under shipboard conditions and the consequences of being distant from care should a complication arise. External prostheses used after an amputation may pose problems of mobility, which are capable of being assessed in the individual and

need to include the ability to perform emergency duties. The practicalities of putting on a prosthesis in an emergency also need to be considered.

OTHER CONDITIONS PLACING OTHERS AT RISK: INFECTIONS AND MENTAL ILL-HEALTH

There is a large body of evidence about gastrointestinal infections at sea, particularly on passenger vessels [34]. Routes of transmission are well established as are the precautions needed to minimize spread, and in particular measures to ensure that those who handle food do not pose a risk to others.

Similarly the scope for spread of respiratory infections of all sorts from influenza to tuberculosis has been well studied ashore and to a lesser extent at sea, but with every indication that onshore evidence can be readily extrapolated. One of the major features of life aboard is that crew members and any passengers come from a wide range of locations and may come aboard incubating strains of infections such as influenza that others on board do not have any resistance to. In the case of passengers these may include the young the old, the frail, and those with medical conditions that predispose them to infection. Well-established procedures from onshore practice such as immunization and exclusion or isolation of those who may be carriers are practiced on passenger vessels but not on other vessels.

Most other forms of infection, apart from some forms of skin and eye infection, are not transmission risks under working and living conditions at sea and so can be considered just in terms of the risks for the individual affected. The long established risks of transfer of disease from one country to another by the passengers and crew of ships have largely been surpassed as a problem by transfer by air. Controls are well codified and will not be reviewed.

The risks of aggression and injury to others from seafarers who become severely mentally disturbed, whether as part of a psychotic illness or as a feature of a personality disorder, have not been studied beyond occasional case reports. This risk is in all probability rare when compared to the personal distress and withdrawal that is a common feature of many forms of mental illness. Reductions in the availability of alcohol at sea have almost certainly contributed to a corresponding reduction in violence to others from alcohol-related disinhibition.

DISCUSSION

Compared with the knowledge base on illness in seafarers, that on the contribution of health-related impairment to accidents and incidents is weak. That said, there is little evidence of such impairments being significant primary causes of safety system failures. This, it could be argued, is because the current requirements for fitness are adequate, given the inherent robustness of many maritime safety systems. However, it may be that investigations are failing to uncover the role of personal impairment as a risk factor. Where safety systems are less robust, for instance where lean crewing means that fatigue in a single person can result in disasters or where a single infected food handler can create a large outbreak of food poisoning, harmful effects are seen.

What is beyond dispute is that most of the criteria used to determine safety-related aspects of capability have not been subject to any recent review to see if they are appropriate to modern conditions aboard. This may well mean that they discriminate against seafarers who are capable of working safely and effectively while at the same time allowing systems of work to be less safe than is optimal because of relevant individual limitations on performance that have not been recognised. To take account of both changing working conditions and to avoid discrimination, given that risk is closely related to task demands, any valid analysis needs to take account of how work is organized, its ergonomic features, and the overall robustness of the safety system as well as health related aspects.

In this situation the practicalities and requirements for more investigative work need to be evaluated. Current arrangements for fitness assessment are well established and relatively low in cost. The introduction of more specialized arrangements, for instance to measure visual function, will be costly and, unless they can be shown to be better predictors of risk than present methods are, they are likely to pose new problems of validity, with uncertainty about how many people are incorrectly classified as either fit or unfit. Also, changes pose challenges about how to handle those currently working as seafarers who inevitably meet the current criteria but who may not meet new ones. Conversely, there will be those who find they have been denied the ability to work at sea under old criteria but are now able to do so. These are issues that will concern both seafarers and ship operators, and so the case for change is hard to make.

Major changes in regulatory safety policy often come about because of a single major disaster or a series of less severe incidents. It is reasonable to assume that similar events would stimulate action

on the assessment of health-related impairment and disability as a limitation on the performance of safety critical tasks, but it would possibly be more intractable to remedy than other contributors to accidents because of the employment consequences for those adversely affected by any changes. Policies within business organisations are capable of more rapid change, but only where clear economic advantage can be seen. Here legal constraints such as equality and anti-discrimination requirements designed to maximize opportunities for those with disabilities and to avoid discrimination based on age or gender may limit the freedom of business, although perhaps less in a global industry like shipping that may choose the jurisdictions that are most operationally efficient and financially beneficial rather than those which are concerned with seafarer's legal rights.

It can be concluded that change to safety-related standards for impairment will be slow and incremental unless very good evidence of a clear pattern of preventable risk emerges. However, there may be a valid case for some relaxation in standards that, if coupled with careful monitoring of performance and incidents, could reduce discrimination in employment and thus let more people start and retain careers as seafarers.

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