The Importance of the Human Element in Ship Design

Thomas G. Dobie, M.D., Ph.D., FRAeS[1]

ABSTRACT

There is a critical need for human factors whenever technology and people interact. When systems function well, few seem to appreciate the human factors input that has led to this smooth operation; when disaster strikes, however, there is a sudden demand for rectification. Although many human factors efforts are aimed at the highest level of technology, they are required at all levels to ensure maximum efficiency. As the ship design evolves and crew sizes diminish, greater emphasis should be placed upon the human factor input in order to ensure safety and efficiency during both routine and emergency operations. Severe ship motions limit the human ability to operate command, control and communication systems, navigate, perform routine maintenance and prepare food. In an emergency, such operations as refueling at sea and damage control can be severely hampered. Commercial vessels are no different in terms of limitations of performance, only the detailed tasks may vary. The human element is susceptible to degraded performance in a number of ways. There are the purely physical limitations on both gross and fine motor skills imposed by heavy seas. The former physical limitations include standing, walking, and carrying out operational and maintenance tasks that include major physical movements required to perform mechanical operations. Fine motor skills include delicate control adjustment and computer operations. Knowledge of the sea/hull interaction and its effect on the crew can provide valuable information for improved ship and equipment design as well as establishing guidelines for efficient heavy weather operations. In addition, ship motion can cause significant mental degradation leading to overall performance decrement and increased potential for injury. Motion sickness is an example of this type of malady. Seasickness is the most common cause of motion sickness and can have a profound adverse effect on human performance. There is also the sopite syndrome, a human response to provocative motion characterized by drowsiness and mood changes. Not only can this lead to inefficiency and accident proneness, but it is not so readily identifiable by the sufferer or a supervisor. The author will address these issues and make recommendations to improve the incorporation of the human element in future ships.

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[1] Director, National Biodynamics Laboratory, College of Engineering, University of New Orleans, New Orleans, LA 70148

INTRODUCTION

There is a critical need for a human factors input whenever technology and people interact. When all is well and systems are functioning correctly and efficiently, few appreciate the significance of the human factors component that has led to the smooth operation. In emergency situations, however, there is an immediate demand for action in order to rectify the problem. Although many human factors efforts are aimed at the very highest level of technology, one should remember that they are required at all levels in order to insure maximum efficiency. This tells us that anywhere people and technology interact you will find human factors, a branch of engineering in which the primary emphasis is on the human input. In discussing the question of the human element on ship design, there are in a sense, two aspects. First, there is human-technological interaction of man and machinery, to which I have already alluded. Second, there is the additional human factors matter of operating and controlling equipment and systems on a moving platform. In other words, technology goes beyond the question of manipulating machinery and is concerned with structures, in this case ship structures, working and rest spaces, noise, vibration, temperature, and the effects of provocative motion. All of these factors play a significant part in how an individual reacts with technology. As ship design evolves and in particular as crew sizes diminish, much greater emphasis should be placed upon the human factors input in order to maximize safety and efficiency during routine and emergency operations. In heavy seas, severe ship motions limit the human ability to operate command and control and communication systems, carry out necessary navigational tasks, perform routine ship maintenance and prepare food. Should emergencies arise at sea, the situation is further worsened when crew numbers are reduced. All these factors relate to commercial vessels as well as to naval vessels. Only detailed tasks and operational procedures will vary.

The human operator working on a moving platform is susceptible to degraded performance in a number of ways. There are the purely physical limitations of both gross and fine motor skills involving whole-body motion imposed by heavy seas. These include standing, walking and carrying out operational and maintenance tasks that include major physical movement in order to carry out these mechanical operations. These physical limitations include what we call motion induced interruptions (MII) which occur when local motions cause a person to lose balance or slip, thereby interrupting whatever task is being performed. Fine motor skills include delicate adjustment of controls, computer operations, and certain maintenance tasks involving electronic boards and components.

Physical operations carried out on a moving platform also induce fatigue and degradation of mental effort leading to an overall decrement of human performance and increased potential for injury. Motion sickness is another example of a response to provocative motion that causes diminished performance. Seasickness is the most common form of motion sickness and has a profoundly adverse effect on human performance. These various physical difficulties and human responses may be found individually but on many occasions, they occur together. In addition, it may be difficult to tease out the specific causes of diminished performance, particularly in heavy sea states. For convenience, however, we shall address these specific issues separately, as far as possible, and make some recommendations on their management.

WHOLE-BODY MOTION

The effects of whole-body motions involve both motion-induced interruptions and motions induced fatigue. Motion induced interruption is the name given to a situation which occurs when local motions cause an individual to lose balance or to slip, therefore interrupting whatever task is being performed. This concept was introduced by Applebee, McNamara and Baitis in 1980. In defining this concept of loss of postural control, the original workers applied simple acceleration thresholds to task performance and then predicted that individuals would experience MII if those acceleration thresholds were exceeded. Calculations were made in the time domain to predict the occurrence of MII. In 1989, Graham extended this concept to the frequency domain thereby making it more conducive to the prediction methods of ship motion. The MII model predicts a loss of balance while standing when the tipping moment is greater than the righting moment provided by the individual's stance width. In the model related to frequency domain, the ratio of an individual's half stance width to the height of his or her center of gravity is defined as the tipping coefficient. This coefficient is then used to evaluate when a tip will occur. The result is expressed as the number of MII per minute.

In 1995, Baitis et al. published a report on motion induced interruptions based on experiments in the Naval Biodynamics Laboratory ship motion simulator. In this study they concluded that the magnitude of the coefficient of friction for surfaces typically found on the interior and exterior of a ship is usually much larger than either the lateral or fore and aft tipping coefficient, so that tipping MII will usually occur before sliding takes place. They also noted that the individual's MII did not necessarily occur according to the threshold crossing that is implied by a rigid body theory. Graham had suggested this simple postural stability model because of the difficulty of using an exact representation of the human body. His simple rigid body was based on one similar to the size and shape of the average human body.

Baitis et al. also noted that individual subjects had different techniques for maintaining their stabilization that were different for lateral as opposed to fore and aft MII. They concluded that real subjects were better at avoiding MII than would be anticipated using the rigid body model with nominal tipping coefficient. This is perhaps not surprising and of course would be significantly affected by experience. Individuals who had already gained their "sea legs" are better at maintaining an upright posture than are naïve subjects. The studies by Baitis et al.were carried out on a simulator which only had 3 degrees of freedom. They suggested that further work was necessary, such as including the missing ship motion components, in order to see what effect they had on the occurrence of MII. They felt that the addition of sway and yaw to the lateral ship motions would complicate an individual's ability to maintain an upright posture.

At the National Biodynamics Laboratory, we are about to start just such a study. We propose to carry out a number of simulator experiments in order to augment the existing experimental MII database previously developed by the Naval Biodynamics Laboratory and to which I have just referred. What was then the Naval Biodynamics Laboratory became the National Biodynamics Laboratory some three and a half years ago, so we still have the same ship motion simulator in which the initial study was performed. In addition, however, we now have a new 6 degrees of freedom motion platform as well. This will allow us to carry out further studies with the additional three degrees of freedom, albeit with a reduced heave component, as well as using the ship motion simulator at a later stage. The experimental design will complement the existing MII database by using motion profiles from current generation ship designs such as the CVN-X and DD21 series, whichever are available. We shall also study the addition of lateral acceleration to demonstrate, as was suggested in the earlier study, that vertical accelerations are of secondary importance in the occurrence of MII at the moderate level of ship motion.

The specific objectives of this research program are fourfold. First, to determine the degree to which the magnitude of various ship motions degrades human physical performance as measured by MII, fatigue and motion sickness. Second, to develop polar diagrams and a model of motion tolerance limits that can be used by ship handlers and design engineers alike to provide the best response to ship dynamics for onboard human performance objectives. Third, to field test the model to determine the degree to which such guidelines improve performance in both existing commercial and naval shipping and to extend our experimental investigation of motion effects with experienced and inexperienced subjects and different floor surfaces. Finally, we propose to transfer these technical guidelines to both naval and commercial authorities.

MOTION INDUCED FATIGUE

In this context we are taking this to mean that fatigue is the result or a biodynamics problem of what some refer to as "weariness after exertion" (Powell and Crossland, 1998), rather than the result of either lack of sleep or motion sickness. In 1989, Colwell, in reviewing naval biodynamics problems, felt that motion-induced fatigue was indeed significant. He suggested that this was an important matter for the naval community and which implied a higher incidence of mistakes, some of which may not be noticed by a supervisor. This is a complex matter, however, as Powell and Crossland wrote in 1998. Reports of motion-induced fatigue include other features, however, including lack of motivation. In their view central fatigue, as distinct from muscle fatigue (weariness after exertion) is perhaps the main contributor to fatigue at sea. This is in keeping with the results found by Baitis et al. (1995) during their MII study in which they reported that the measured levels of energy expenditure (muscle fatigue) were relatively small compared to the subjects' capacity to perform work. They did, however, recognize the fact that more severe ship motions could well raise the crew's energy expenditure to limits that could be significant. In this matter of human energy expenditure, Wertheim et al. reported in 1997 that they found that peak oxygen consumption, as a measure of physical workload, might indeed be lower in a moving rather than a stationary environment. This is an interesting observation but, as these workers stated, one which had no obvious theoretical explanation. This brings one back to the question of motivation as an explanation, rather than cardiorespiratory response. Before leaving this question of motion-induced fatigue, it must be said that without question it is much harder to work in a moving environment. Very much more muscular effort is involved in maintaining posture as well as carrying out a particular task. It is further complicated, as we shall see later, with the question of lack of sleep due to heavy workloads and to certain effects of motion sickness.

COGNITIVE PERFORMANCE

In modern ships, much of the work today is perhaps more mental than physical compared with the situation many years ago. It is clearly of interest, therefore, to know whether provocative motion has significant effects on the efficient performance of a cognitive task, with or without a small psychomotor component such as is required manipulating a computer terminal. This we shall address again in dealing with fine motor skills. In 1986, Wilson et al. conducted an experiment using the NBDL Ship Motion Simulator in an attempt to investigate the effects of single frequency heave and roll motions on cognitive performance. The experimental sessions were planned to last two hours but an unspecified number of subjects aborted before that time. These workers showed that four out of five subjects demonstrated significant slowing of cognitive processing during heave motion alone. They described this as extending from slight to large adverse effects across these four subjects whereas there was no such reported difference on the accuracy of performance during exposure to roll motion. They suggested that the subjects may have adopted a personal strategy whereby they reduced processing speed in order to maintain accuracy under these conditions. They noted little evidence that roll-only motion had any adverse effect on cognitive performance, in that only one of the five subjects exhibited any adverse effect on their cognitive processing during roll motion.

A year later, in 1987, Pingree et al. measured task performance on a hovercraft during mild and severe motion conditions while at sea. They found no significant adverse effects due to motion in terms of the three computer-based cognitive tasks which they used. During a simulator experiment at NBDL, cognitive tasks such as display manning and decision-making were carried out and Crossland in 1994 and Conwell Holcombe and Holcombe in 1996 reported on these. The study only found degradations in fine and gross motor movement but none in terms of cognitive skills. In 1996, Wertheim also reported that cognitive tasks were not directly affected by ship motion.

It seems, therefore, that there is really no hard evidence that there are any direct effects of provocative motion on cognitive performance, although there are clearly indirect effects such as degradations of fine motor skills and the subjective effects of motion sickness. It may be that individuals maintain a higher level of efficiency, both in terms of cognitive performance and performance in general, during provocative motion until such time as they are no longer able to do so. This may become clearer if one were to carry out longer duration exposures.

At the National Biodynamics Laboratory, we propose to investigate this matter further this summer. In this forthcoming study, we shall be exposing subjects to provocative motion for a period of 72 hours in our Ship Motion Simulator. There will be two subjects in the simulator on each occasion, and they will work a six hours on, six hours off shift routine. They will be exposed to heavy sea states on the order of sea state five, and to calm sea state represented by a static cab. We hope to tease out some of the cognitive effects, if indeed these do occur, and to ascertain whether they are primarily due to fatigue, or as a result of disturbed sleep, or whether they are caused by motion sickness due to exposure to heavy sea states. In a recent questionnaire study carried out in the NATO fleet during heavy weather, Colwell (1998) reported that disturbed sleep was particularly significant as a cause of performance decrement on the following day and motion sickness also adversely affected performance.

WHOLE-BODY VIBRATION

Whole-body vibration may affect subjective comfort, working efficiency and in the worst cases, health and safety. Although there have been many methods for rating the severity and defining the limits of exposure to whole-body vibration, none has been universally accepted. Although we are referring to whole-body vibration, in fact, vibration can be transmitted to the human body in a number of ways. First, as the name suggests, vibrations may be transmitted to the whole body surface simultaneously. Second, they may be transmitted to parts of the body surface such as the feet, or in the case of a seated crewmember, the buttocks. Third, vibrations may be applied to individual parts of the body. In addition, however, vibrations can affect human performance indirectly by affecting the stability objects in the operator's visual field, such as viewing visual display units which themselves may be vibrating. This causes blurring of vision and difficulty of interpretation.

In terms of whole-body vibration, this can conveniently be classified as either low frequency motion induced by sea conditions surrounding the vessel and vibrations of higher frequency originating from the engines, propeller shafts, and major pieces of onboard machinery. Higher frequency vibrations can also originate from hull responses following severe slamming in heavy seas. In general, whole-body vibration in the range from 2 – 12 Hz can have an effect on human performance (von Gierke et al., 1991). Even below that frequency range, however, Colwell (1989) reported that there were significant manual control problems during simulated surface effect ship motions in the range of 0.02 to 0.2 Hz, where the vertical RMS magnitudes were 0.5 to 1 g. The effects of whole body vibration are many and various. They may cause performance deficits, fatigue, accident-proneness and even health hazards. Nevertheless, the picture is not absolutely clear, and there are many differences of opinion on the effects of whole-body vibrations. It is not only dependent on many variables, but as Griffin pointed out in 1990, there is no one simple predictor for all individuals and every occasion. This is certainly a matter that should be addressed in the design of new vessels, and in the installation of new equipment upon vessels. Because of the effect it can have on fine motor skills, this in itself is a matter that requires further consideration.

GROSS AND FINE MOTOR SKILLS

When talking about whole-body motion and whole-body vibration, much of the significance lies in the effect of these provocative stimuli on gross and fine motor skills. This is a typical example of the interaction of these underlying variables and the mechanism whereby they interfere with performance. It is more difficult to carry out tasks requiring gross motor skills in a moving environment, than in a static environment. Again, the decrement of performance will vary with a number of factors. First, the severity of the hull/sea interaction, the weight and complexity of the components which call for performing a gross motor task, and the experience of the individual, both in carrying out the task and in standing and working on a moving platform. The latter is an important factor that will be discussed again latter under the question of adaptation to provocative motion.

We have already addressed the issue of the effect of whole-body vibrations on fine motor skills. However, they can also be affected by whole-body motion. This leads to a consideration of the type of controls being used onboard ship, whether these involve a keyboard, mouse, trackball or a touchscreen, and whether or not the operator's arms are supported or unsupported. In 1980, McLeod and Poulton carried out a study of the influence of ship motion on manual control skills. They found that the response to motion whilst carrying various tasks ranged from "virtual destruction" to a complete absence of adverse effects. In that study, they examined three manual control tasks which included: movement of the unsupported arms, continuous fine movement during which the arms were restrained, or ballistic manual tasks with an unsupported arm. They found that a tracing task that called for a continuous whole arm movement was, not surprisingly, very badly affected. In the case of a tracking task using fine movements with supported arms, this was affected but not badly so. Lastly, the ballistic task involving digit keying was virtually unaffected. These were relatively short duration tasks so that fatigue and what might be called chronic motion sickness, that is to say, motion sickness symptoms over long periods were not involved. They suggested that it would be beneficial to try to design the man-control interface onboard ships around motion-resistant tasks.

These matters are still of considerable interest and further work will be useful to get a better understanding of the various cognitive and physical gross and fine motor maneuvers on a moving platform particularly over a longer time period. At our laboratory, we are about to embark on such a study, as I have already mentioned. This will give us the opportunity to study these potential performance deficits and try to elucidate the significance of the added effects of motion sickness during the first 24 hours and perhaps the effects of adaptation during the last 24 hours of our 72-hour study. In addition we shall study the effects of fatigue and perhaps sleep disturbances during the overall period.

EFFECTS OF NOISE

We are all well aware that hearing loss can result from long term exposure to noise, but the non-auditory effects are less well defined. In general, they seem to act as a non-specific stressor, which means that it is difficult to identify the effects due to noise, versus other stressors, in the shipboard multi-stress environment. In terms of performance, noise can certainly have a profound effect on verbal communication that is both distracting and annoying. In noisy work areas, it is very difficult to hold a prolonged conversation over a distance of one meter if the noise level reaches 78 db(A).

It is most important to protect an individual's hearing from damage. This can be achieved by a combination of three basic precautions. First, by modifying the sound source so as to reduce the noise output. Second, by changing the transmission pathway so as to reduce the level of noise at the ear. Third, by reducing the duration of exposure to a potentially hazardous noise level, or by providing personal protective equipment and ensuring that it is correctly fitted and worn in a noisy environment. In certain naval conditions, such as on an aircraft carrier at night, crewmembers could be described as being "environmentally blind and deaf". For that reason, we are looking into the possibility of utilizing other channels of communication.

Communication methods and devices have traditionally relied on audiovisual modes to convey the message from a source to a recipient. These are capable of conveying considerable amounts of information within a reasonable time period with acceptable accuracy. A lesser known and relatively uncommon mode of communication is tactile communication. A tactile communication device (TCD) has been proven capable of communicating numbers to users with visual and hearing impairments and a control group (Gonzales, 1996). If advances in the TCD result in the ability to perceive complex messages, the outcome could be a silent and non-vision-dependent communication system. The discrimination of four numbers with little or no practice suggests the possible development of a watch or pager system with the TCD. If the alphabet or other symbols cab be perceived haptically, the perception of complex messages may be possible.

MOTION-INDUCED SICKNESS

Motion has long been recognized as an unpleasant consequence of employing some forms of transportation. Gay (1954) described motion sickness as a "physical state that develops in human beings and animals when they are subjected to oscillatory movements over which they have no control". As Birren (1949) pointed out, "Statistically there is nothing unusual about motion sickness, since more than half of the population may be made seasick and some investigators believe that everyone may be made motion-sick under appropriate conditions." In terms of seasickness, Birren believed that most people who experience a transient bout of motion sickness can exert themselves sufficiently to perform adequately when necessary. That is what he called "peak efficiency". He felt that this may not be closely related to the performance of the individual's normal daily routine, which he called "maintenance efficiency". It may be that for short duration exposures, individuals make extra effort to carry out their primary task.

Malaise, general discomfort, sweating, nausea, and vomiting characterize motion sickness. Provocative motion environments involve many forms of transport, such as ships, aircraft, air-cushioned vehicles, and automobiles, all of which are important to both military and commercial services. The characteristics of the underlying stimuli are essentially the same, however, and so are the subjective responses. There is no difference in the effects caused by these provocative motion stimuli, whether they occur at sea, in the air, on amusement park rides, in an automobile, or even when riding on a camel. It is for this very reason that the responses have all been labeled motion sickness.

Motion sickness can also be produced in the absence of expected motion. Visual motion alone is sufficient to produce sickness, as in the case of fixed-base simulators, or when viewing wide-screen movies. These are becoming more common sources of this malady with the rapid escalation in the use of simulation. In summary, motion sickness is a response to real or apparent motion to which a person is not adapted. It is, therefore, a normal response to an abnormal environment. The relief and ultimately the apparent immunity from motion sickness, which usually occur with practice, are also part of the normal response. In terms of the inexperienced sailor, seasickness is the predictable response to adequate motion stimuli. Hill (1936) stated, "There is a world of difference between this and the equally normal response to identical stimuli on the part of the seasoned sailor. The gap is bridged by the process of adaptation." He summarized this as follows: "The establishment immunity is Nature's cure, and to expedite this process is the single aim of rational treatment." Nevertheless, we believe that we can give Nature a helping hand, as we shall see later, in terms of speeding up the adaptation, both in terms of overcoming the malady and in preventing it.

There are many perfectly good reasons which make it difficult to give a precise figure for the incidence of motion sickness because, as is the case with almost all maladies, a number of factors are involved (Dobie, 2000); for example:

- The characteristics of the stimulus in terms of frequency, intensity, direction, and duration. Experiments on vertical oscillators, which simulate the heave component of ship motion, have shown that the incidence increases as the frequency of the oscillation falls. The most provocative frequency was shown to around 0.2 Hz.
- The susceptibility of the individual, based upon physiological characteristics, past experiences, psychological and personality factors.
- Individual activity at the time of exposure to the stimulus, e.g., passengers are usually worse off than drivers.
- Other factors, such as food, ambient air temperature, and certain odors.

The incidence of seasickness is extremely variable. For example, Hill (1936) estimated that over 90% of inexperienced passengers become seasick in very rough conditions and some 25% - 30% during the first two or three days in moderate seas. Chinn (1951) also reported that during the first two or three days of an Atlantic crossing, in moderate seas, 25%-30% of passengers on liners become seasick. In the United Kingdom, Pethybridge (1982) found that some 10% to 30% of naval crews suffered from seasickness during commonly experienced sea conditions and that this incidence rises to between 50% and 90% in the worst conditions. In the U.S. Navy, the Naval Medical Information Management Center reported that during the calendar years 1980 through 1992, 489,266 new cases of motion sickness were diagnosed and a further 106,932 revisits were recorded. This represents a significant loss of effective manpower and funds.

MANAGEMENT AND PREVENTION OF MOTION SICKNESS

There are basically two major aspects to this problem. First, an attempt must be made to reduce the levels of provocative motion to which the individual is exposed. This can be acheived by altering the design characteristics of the vessel or vehicle so as to minimize exposure to accelerations likely to cause problems. This approach can be taken a step further by locating the key work areas on a ship on the center line near the ship's center or rotation and design their workstations with the main axes of the hull. On the other hand, sleeping quarters could be located in areas calculated to experience mild provocative motion that might help to induce sleep. As far as the individual is concerned, it may help to provide an external frame of reference and we are currently investigating this possibility. It is also known to be protective if workstations and tasks are so designed as to minimize head movements, thereby reducing vestibular stimulation.

Commonly people get their "sea legs" after a few days at sea, depending on their previous encounters with seasickness and the severity of the of the sea state when they first return to sea. There are many anti-motion sickness drugs available and it is not feasible to review this approach here. Apart from that constraint, the pharmacological approach to the treatment of motion sickness introduces many problems. The drug actions are variable both in terms of individual responses and the effects of an operational situation on these responses. Some of the potential side effects are not acceptable when the user is in control of sophisticated or potentially hazardous equipment, or making complex operational command and control decisions.

In view of the potential problems associated with anti-motion sickness medications, some form of behavioral desensitization has much to offer for preventing or treating motion sickness, particularly for persons who are regularly exposed to provocative motion environments. This form of therapy is particularly relevant to an occupational situation, where the vast majority of individuals exposed to provocative motion are likely to be carrying out skilled or potentially hazardous tasks. It is this group of people who can gain the greatest benefit from non-pharmacological procedures.

Dobie (1963, 1974) first described the concept of cognitive-behavioral anti-motion sickness training. The rationale of this program is based on relieving a person's state of arousal associated with previous unpleasant responses to a provocative motion environment. Once the idea has been established in a person's mind that he or she may not have any "physical" reason for appearing to be more susceptible to motion sickness than others, this belief is reinforced by means of controlled exposures to non-specific provocative motion stimuli. While the technique appears to involve habituation and adaptation to a particular situation, our controlled studies have shown that mere repetitive exposure without counseling has not proven to be beneficial in protecting subjects against provocative motion. A key element in the cognitive-behavioral technique concerns the individual's ability to learn to control the focus of cognitive processes. Emphasis is always placed on the normality of this protective response to provocative situations.

In the author's opinion, the main difference between an individual who is apparently sensitive to motion and one who is seemingly not, is mostly a feature of the arousal which is created by exposure to a particular provocative motion environment. The so-called "resistant" individual enters that environment with zero arousal and can cope with a considerable amount of provocative stimulation before reaching his or her threshold of response (beginning to feel motion sick). At the same time, these relatively lengthy exposures to provocative motion allow time for habituation to take place. Howwever, the matter is quite different for people who have a history of motion sickness. These individuals enter a provocative motion environment with a varying degree of arousal dependent on previous motion experiences, particularly if these exposures have caused motion sickness. Depending on the degree of arousal, the subject gets closer to the onset of motion sickness (threshold of response) in a shorter time. In more severe cases, this can occur on entering (or even before entering) the provocative motion environment. This also means that each exposure will be relatively short before the onset of motion sickness, and consequently there is little time to habituate, so that person fails to get their "sea-legs" without help.

This program carries the highest success rate in the open literature and a long-term follow-up has shown that the protection afforded the individual remains with him or her (Dobie, 1974). We are now turning our attention to the question of prevention by means of facilitating adaptation to provocative motion environments. Although motion sickness is common on sea, in the air and in many virtual simulations of motion environments, extensive individual differences exist with regard to the ability to tolerate such provocative situations.

CONCLUSION

When designing a new vessel it is never too early to consider the human element. Optimal performance will only be achieved when the crew component is designed in from day one, rather than added at the last moment as an afterthought. Before we can begin to design an efficient person-machine system, we must have a very clear idea in all our minds what the final product is intended to do. That means that we must have as clear an understanding of what the person can and cannot do, equally as much as we know about the vessel's capabilities and its onboard technological systems and equipment. We must also have a working knowledge of how these human and non-human subsets interact so that we can optimize this union. This requires a multiple team effort including many and various disciplines. The goal is exciting and the ultimate prize is a highly efficient ship that can operate effectively under difficult conditions with the minimal human complement to ensure that successful outcome.

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