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MOTION SICKNESS HABITUATION IN THE NAVAL ENVIRONMENT

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MOTION SICKNESS HABITUATION IN THE NAVAL ENVIRONMENT

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May 1994

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Distribution Approved by R.T. Schmitke

Director / Technology Division

DREA TECHNICAL MEMORANDUM 94/211

Defence Research Establishment Atlantic
Centre de Recherches pour la Défense Atlantique

Canada

ABSTRACT

Motion sickness habituation describes adaptation to stimuli which produce motion sickness. Habituation is important, as it is a natural process which reduces the adverse effects of motion sickness symptoms. Since naval personnel experience relatively long exposures to provocative motions, it is necessary to quantify habituation as a preliminary step towards the goal of quantifying human performance at sea. Scientific and medical literature clearly substantiate the existence of habituation and describe its general behaviour, but a method for defining habituation to ship motions is not available. A brief review of motion sickness and habituation is presented and habituation data from experiments and sea trials are described. The significance of using motion sickness incidence (MSI) as an indicator of the severity of motion sickness is examined. An existing statistical method for predicting the initial exposure MSI is combined with an empirical fit to data for MSI habituation in ship motions. The potential applications and limitations for the MSI habituation model are discussed, and requirements for future research for modeling more complex and changing motions are briefly described.

Resumé

L'habituation, en ce qui a trait au mal des transports, consiste en l'acquisition progressive d'une insensibilité aux stimuli qui provoquent normalement ce mal. Cette insensibilité acquise est un processus naturel éminemment utile puisqu'il permet de réduire ou d'éliminer les symptômes les plus gênants du mal des transports. La forme la plus connue de ce dernier étant le mal de mer, on a donc jugé nécessaire de quantifier le processus d'habituation chez le personnel de la marine, qui est exposé de facon prolongée à ces stuimuli, à titre détape préliminaire en vue de l'évaluation du rendement humain en mer. Les publications scientifiques et médicales témoignent abondamment de l'existence du phénomène d'habituation et en donnent des descriptions générales, mais on n'a pas encore mis au point une méthode définissant ce phénomène par rapport au mal de mer. Le présent document examine donc brièvement la question de l'habituation aux stimuli du mal de mer, à partir de résultats portant sur les réactions du personnel au mouvement des navires en mer. On verra notamment comment l'incidence du mal de mer peut constituer une indication valable de la gravité de ce mal, et comment l'utilisation d'une méthode statistique éprouvée de prédiction des effects de l'exposition initiale aux stimuli du mal de mer, combinée à une méthode empirique, permet d'obtenir de précieux renseignements quant au phénomène d'accoutumance aux mouvements du navire. Il sera enfin question des applications et des limites éventuelles do modèle d'habituation, et de la nécessité d'une modélisation plus complexe des mouvements du navire, pour les travaux de recherche à venir.

Executive Summary

Existing national procedures and international standards for modeling the effects of ship motions on humans are not adequate for the naval environment for at least three important reasons:

- they are not expressed in terms that are related to task performance (common indices are "comfort", "ride quality", "decreased proficiency", and "percent vomiting");
- they do not cover the full spectrum of problem types encountered; and
- they are based almost exclusively on short-term exposures to motion.

Continuing trends of diminishing crew size and increasing complexity of naval tasks highlight the importance of developing dependable models and criteria for assessing human performance at sea. This Technical Memorandum describes a method for defining habituation, which is the reduction in motion sickness incidence due to adaptation over long-term exposure to motion. This method does not solve all of the problems described above, but it does provide a new approach for estimating more realistic values of motion sickness incidence in the naval environment.

Contents

Nomenclature

a	RMS vertical accelerations (g)
A_i	coefficients used to calculate MSI_I
B_i	coefficients used to calculate MSI_I
C_i	coefficients used to calculate $h(t)$
f	modal frequency (Hz)
$h(t)$	habituation function, $h(t) = MSI(t)/MSI_{MAX}$, for $t_I < t < t_F$
I	arbitrary numerical index denoting severity of motion sickness symptoms
IR	Illness Rating [29], measure of severity of motion sickness symptoms determined by subjective assessment of well being (ranges from IR = 0 for "I felt all right" to IR = 3 for "I felt absolutely dreadful")
LBP	Length Between Perpendiculars (m)
MII	Motion-Induced Interruption (i.e. slide/stumble) [2, 15, 16]
MSI	Motion Sickness Incidence: percent of population who vomit
MSI_I	initial exposure MSI statistical model, McCauley *et al.*, 1976 [34]
MSI_{MAX}	maximum initial exposure MSI, $MSI_{MAX} = MSI_I$ at $t = t_I$
$MSI(t)$	motion sickness incidence at any time t
SS	Sea State
t_I	time when initial exposure maximum MSI occurs ($MSI(t) = MSI_{MAX}$)
t_F	time when full habituation is reached ($MSI(t) = 0$)
t_{99}	time at which MSI_I reaches 99% of its theoretical maximum
ω_e	frequency of encounter (rad/s)
$\zeta_{1/3}$	significant waveheight (m)
Δ	full load displacement (tonnes)
$\Phi(z)$	cumulative distribution function of standardized normal variable z

1 Introduction

Current research at the Defence Research Establishment Atlantic (DREA) on predicting the effects of ship motions on warship operability uses the 'systems approach' as a basis for defining the ship's activities. With this approach, the operational effectiveness of any particular activity is assessed by modeling the interaction between systems and sub-systems involved in the activity. Since most activities involve human participation, it is necessary to develop models to quantify the effects of ship motion on human performance.

The effects of ship motions on human performance can be separated into four general categories [7]: motion sickness; Motion-Induced Interruptions (MII)[1]; motion-induced fatigue; and whole body vibrations.

This paper describes recent work at DREA on developing a model for predicting motion sickness incidence (MSI) in the naval environment. MSI is simply the percentage of a population who vomit when exposed to provocative motions. A key difference between the naval environment and many other ship motion environments is the relatively long duration of exposure to motions. As discussed later, existing statistical models allow us to predict MSI from the amplitude, frequency and duration of exposure to motion; however, these models are only valid for short-term exposures (e.g. passenger ferries). In order to predict MSI in the naval environment, the mitigating effects of habituation must also be quantified. Motion sickness habituation describes adaptation to provocative stimuli which produce motion sickness. Habituation is important, as it is a natural process which reduces the adverse effects of motion sickness symptoms.

The paper begins with a brief review of existing literature on motion sickness and habituation in general. The concept of a "habituation function" for quantifying habituation is introduced, and is then used as the basis for examining experimental and trials data on habituation. The significance of using MSI as an indicator of the severity of motion sickness, as opposed to some more inclusive measure of overall symptom severity, is examined. An existing statistical method for predicting initial exposure MSI is described and then combined with an empirical fit of the habituation function to habituation data for MSI in ship motions. The potential applications and limitations for the MSI habituation model are discussed, and requirements for future research to develop a methodology for modeling more complex and changing motions are briefly described.

This new method does not quantify the effects of ship motions on human performance; however, it does provide more realistic predictions of MSI statistics in the naval environment. The ultimate goal of quantifying human performance requires further research to determine the relationship between motion sickness, fatigue and performance.

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[1] MIIs describe loss of balance events due to sliding or stumbling [2, 15, 16]

2 Review of Motion Sickness and Habituation

Figure 1 shows the general form of the variation of motion sickness incidence (MSI) of a population for continuing exposure to ship motions, where MSI is the percentage of the population who vomit. On initial exposure, MSI rapidly rises to some maximum value, after which MSI gradually declines as some or all of the population become habituated. The habituation function described later provides a method to estimate this variation of MSI over time.

The effects of motion sickness on human performance are intuitively clear, but are not well quantified. Results from subjective questionnaires used on human performance trials with two RN frigates by Pethybridge, Davies and Walters, 1978 [41], state:

> "About 5% of both crews indicated that they could not work during bouts of sea-sickness, whilst a further 50% had some difficulty in working on these occasions."

The author has obtained similar anecdotal information during recent trials on a Canadian frigate. When a young seaman on lookout duty was asked if he had any problems with motion sickness, he responded: "No, except when it gets rough, and then everybody gets sick."

One indicator of the extent of motion sickness problems in the naval environment is that approximately 12% of naval personnel use drugs at sea to prevent or treat motion sickness [7]. Questionnaire responses indicate from 4 to 13% of the naval community "always get sick" in "rough" conditions [6, 41]. Conversely, the proportion of naval personnel who "never get sick" is significant, at approximately 32% (arithmetic mean of figures cited in [1, 6, and 41]).

Degradation of human performance caused by motion sickness has been documented (e.g. [27, 41, 50]), but the cause-and-effect relationships are still not known. Current trends towards having significantly smaller crews on future warships suggests that problems associated with motion sickness may become critical.

Theories on the causes of motion sickness generally agree that a primary contributor is "sensory conflict", induced by one or both of the following mechanisms (following Reason, 1978 [43]):

1. visual-inertia conflict, where the motion perceived from visual stimuli conflicts with that perceived by the vestibular receptors (i.e. inner ear: semicircular canals and otolith organs);
2. canal-otolith conflict, in the absence of visual stimuli, a conflict in preceived motion between the semicircular canals (angular motion sensors) and the otolith organs (linear motion sensors).

In each mechanism, at least three combinations of sensory conflict exist. For example, in visual-inertia conflict, motion sickness can be induced by:

1. simultaneous but conflicting visual and vestibular information (e.g. moving the head while wearing an optical device that distorts vision);
2. visual perception of motion in the absence of vestibular stimuli (e.g. motion sickness in a stationary flight simulator); and,
3. vestibular perception of motion in the absence of visual stimuli (e.g. elevator sickness).

Selected references providing further insight on the causes and symptomatology of motion sickness include: Reason, 1978 [43, 44]; Benson, 1988 [4]; Griffin, 1990 [21] and 1991 [22]; and Money, 1991 [36]. Additional references of particular interest to the naval community are: Newman, 1976 [38]; Wiker, Pepper and McCauley, 1980 [51]; Muir, 1983 [37]; Thomas, Guignard and Willems, 1983 [46]; Pingree, 1988 [42]; and Griffin, 1991 [23].

As mentioned earlier, habituation is adaptation to provocative stimuli. In this case, it is the reduction in the incidence and severity of motion sickness in response to long-term exposure to ship motions. Habituation is a natural process which alleviates the effects of motion sickness, and it is very significant in the naval environment.

Money, 1970 [35]; Reason, 1978 [44]; and Wiker, Pepper, and McCauley, 1980 [51] provide useful introductions to the process of habituation. Newman, 1976 [38], provides a good general discussion of habituation and of the hypothetical 'tracking' of habituation with a changing motion environment.

The requirement to model habituation in the naval environment is aptly demonstrated by results of simultaneous seakeeping trials with two RN frigates reported by Andrews and Lloyd, 1980 [1]. During these trials, the ship with higher MSI (37%) experienced average vertical accelerations of approximately 0.125 g RMS at the bridge, and the ship with lower MSI (26%) experienced higher accelerations of approximately 0.160 g RMS. This discrepancy is explained by the relative durations of exposure [1]; the ship with higher accelerations and lower MSI was on its fourth day at sea, while the ship with lower accelerations and higher MSI was on its second day.

A more complete review of the literature on motion sickness, habituation and other biodynamic problems (i.e. fatigue, MII, and vibration) is provided in reference [7].

3 Habituation Function, $h(t)$

Figure 2 shows the same curve of the typical variation in MSI over time as used in Figure 1, with annotation to define important features. The following three phases can be identified with respect to time:

- initial exposure, $0 < t \leq t_I$
- continuing exposure, $t_I < t < t_F$
- fully habituated, $t \geq t_F$

In the initial exposure phase [44], MSI increases from zero at time $t = 0$ to some peak value, MSI_{MAX}, at time $t = t_I$. In the continuing exposure phase [44], habituation is being acquired, and so MSI decreases over time. In the final phase, full habituation is achieved (statistically speaking), at time t_F.

The concept of "full" habituation is worth discussing briefly. Habituation data from sea trials described in the next section clearly show that full habituation occurs in moderate and less severe conditions; however, this is not necessarily the case for more severe conditions. As mentioned earlier, a significant proportion of naval personnel always get sick in rough weather. Also, the ISO standard 2631/3 [33] indicates that about five percent of the "normal travelling public" never adapt to low-frequency (e.g. ship) motions.

Note that an "after-effect" phase is also defined for habituation [44], but since this corresponds to the time after exposure to motion has ceased, it is not evident in Figure 2 (which assumes constant motions). As discussed later, the loss of habituation which occurs during the after-effect phase must be quantified to model MSI when the motions change over time.

The "habituation function", $h(t)$, is defined as the ratio of MSI at any time during the continuing exposure phase divided by the maximum peak value of MSI encountered in the initial exposure phase.

$$h(t) = MSI(t)/MSI_{MAX}, \quad t_I < t < t_F$$

where $MSI(t)$ is the motion sickness incidence at any time during $t_I \leq t \leq t_F$, and MSI_{MAX} is the magnitude of the initial exposure peak value of MSI, which occurs at $t = t_I$. The definition here is based on MSI; however, the same relative formulation can be used for other measures of motion sickness severity.

This habituation function is used as the basis to examine experimental and trials data on habituation in the following section. Then, an empirical fit for the habituation function to these data is defined, and is combined with an existing method for predicting MSI_{MAX} to provide a method for estimating $MSI(t)$ for continuing exposure to constant ship motions.

4 Habituation Data

Figure 3 shows values of the habituation function for data from a wide variety of experiments and trials, including: ship motions [25, 47, 14, 34, 26]; aircraft motions [24]; and rotating chair experiments [52]. These curves include data for both MSI and measures of lesser symptom severity.

While it is evident that no simple relationship exists, these data do establish a definite trend of reduced response over time. Note that for clarity, the initial peak values, where $h(t) = 1.0$, are not shown on this figure. By definition, each curve will reach $h(t) = 1.0$ at some time during the first day (when the maximum response occurs); however, since these times are not available for all curves, they are not included.

It seems generally accepted that rates of gaining and losing habituation are relatively constant in very different circumstances [20]; however, since habituation is specific to the stimuli involved [9, 14, 18, 19], the remainder of this paper will only consider ship and ship-like motions.

Figure 4 shows the data from Figure 3 which are for ship and ship-like motions only. Habituation curves for both MSI (solid lines) and less severe sickness symptoms (dashed lines) are included. The sources used in this figure are described below and Appendix A tabulates the data used to calculate the habituation curves.

1. Walters, 1964 [47]: British seamen on five "small" RN ships who were "affected by sea sickness in any way" during cruises in the North Atlantic lasting at least four days, and for conditions which were "moderately rough or worse". This description implies that a wide variety of symptom severity is included in these data; however, this may not be the case. The data for this study were gathered by the ship's medical officer, based on the number of people who reported sick for reasons associated with motion sickness. Thus, as noted in [47], these data are probably conservative, as it is not likely that seamen would report to sick bay unless their symptoms were significant.
2. How *et al.*, 1988 [25]: "mean seasickness score", for 61 Republic of Singapore Navy seamen on a 2,490 tonne Landing Ship (Tank) during drug therapy trials in the South China Sea. All 61 seamen were in the placebo group, and so they received no drugs. The severity of symptoms for days 0 and 1 on curve 2 is described in [25] as being equivalent to about half-way between Malaise II and III on the Graybiel scale [17], which can be described "moderate" (as opposed to "none", "slight", or "severe"). The ship motions experienced during this trial were not reported; however, from the authors' description [25] it appears that the first four days of the trial (shown here on curve 2) were performed in sea states 3 and 4.
3. McCauley *et al.*, 1976 [34]: observed MSI for 34 "susceptible" subjects in ship motion simulator experiments. These data are the combined results of two experiments: twenty subjects in motions with RMS vertical acceleration of $a = 0.22$ g at a modal frequency of $f = 0.25$ Hz; and fourteen subjects with $a = 0.33$ g at $f = 0.25$ Hz. Both experiments used two hour exposures on consecutive days. These data are combined into a single set to reduce experimental scatter by considering a larger sample size. Both motion conditions produced very high initial exposure MSI values of similar magnitude (75 and 78%, respectively). Note that six of the thirty-four subjects in these experiments were female. It is generally agreed that females are more susceptible to motion sickness (by approximately 5% according to ISO standard 2631/3 [33]); however, no significant difference in habituation rates between males and females was found in this experiment.
4. How *et al.*, 1988 [25]: observed MSI for same subjects and conditions as curve 2.
5. Kanda, Goto and Tanabe, 1977 [26]: observed MSI for 54 cadets from the University of Mercantile Marine (Japan) during training cruises on the G-MARU (displacement ≈ 5,100 tonnes, length overall = 115 m). RMS vertical accelerations of $a \approx 0.05\ g$ were experienced on the first two days; and then decreased to 0.02g on the third day (note that these correspond to days 0, 1 and 2 of Figure 4). Note that these data are for observed MSI during the four-hour watch periods.

5 MSI as an Indicator of Motion Sickness

Since MSI is relatively easy to quantify, and since methods exist to predict its magnitude from the motions encountered (as discussed later), it would be desirable to use it in a habituation model to indicate the incidence and overall severity of motion sickness; however, some potential problems with selecting MSI for this purpose must be addressed.

A number of authors (e.g. [38, 46, 51]) note that significant motion sickness symptoms can be present with little or no MSI. Intuitively, it seems reasonable to expect that human performance degradation is associated with the overall severity of motion sickness symptoms. Thus, selecting MSI as a parameter to indicate the severity of motion sickness may not be appropriate; however, the relationship between overall symptom severity and MSI can be explored by examining recent work by Lawther and Griffin on developing an "illness rating" [29,30,31,32]. This illness rating (IR) was developed to provide a measure of the overall severity of motion sickness in terms of its impact on subjective well being. The IR is a scalar index, which is weighted to lie in the range 0 to 3. A value of IR = 0 corresponds to "I felt all right"; IR = 1 is "I felt slightly unwell"; IR = 2 is "I felt quite ill"; and IR = 3 is "I felt absolutely dreadful".

Figure 5 shows values of IR plotted as a function of observed MSI (%), based on data from Table 2 of [29]. Also shown in this figure is an arbitrary straight-line fit. The positive value for IR with MSI = 0 is consistent with observations cited above that motion sickness effects are observed with little or no MSI. Additional published data on IR [30,31,32,4] indicate that the straight line fit shown in Figure 5 may not be the best; however, these newer data all suggest that some straight line fit is appropriate. Regardless of which line provides the best fit, the fact that this simple relationship exists provides some useful information. If one can assume that a predictable relationship exists between the illness rating and performance degradation, then it is reasonable to suggest that MSI can be similarly related to performance. Unfortunately, there are no data available to justify the assumption that either MSI or any measure of overall symptom severity can be related to human performance degradation. As stated earlier, further research is required to determine the relationship between motion sickness and human performance. Thus, until more definitive answers are available, it appears that either MSI or some measure of overall symptom severity must be used to indicate the incidence and severity of motion sickness. Since MSI is relatively easy to quantify, it is a more attractive candidate; however, any differences between habituation for MSI versus that for overall symptom severity must also be considered.

In order to compare habituation for symptoms and MSI, we should only consider data where the people and motions are the same. The two sea trials described earlier provide good opportunities. Figure 6 shows habituation curves for "moderate" symptom severity (open symbols) and for MSI (solid symbols). The data from How *et al.* [25] (for the placebo group) are denoted by dashed lines, and those from Kanda, Goto and Tanabe [26] are denoted by solid lines. The data used to calculate these habituation curves are tabulated in Appendices A.2 and A.6, respectively; and the data for MSI are shown as curves (4) and (5) in Figure 5.

For each trial (i.e. compare same line-types), the following two observations can be made: (i) the amount of habituation acquired for symptoms is less than for MSI; and, (ii) the rates of habituation for symptoms and MSI are very similar. The first observation is consistent with all other data on motion sickness at sea; the number of people experiencing "moderate" or "slight" motion sickness symptoms is greater than those who only vomit. Also, this is consistent with the trend that relatively less severe symptoms tend to linger longer than MSI. The second observation is more important for the habituation model; if the rates of habituation for symptoms and MSI are similar, then the apparent relationship between initial MSI and overall symptom severity (as discussed above for IR) is preserved for continuing exposures.

Thus, for the purpose of developing a habituation model, it appears that selecting MSI as the indicator of motion sickness incidence and severity is no worse (nor better) than other parameters which measure overall symptom severity.

Before discussing the habituation model in detail, it is appropriate to note that MSI and other indicators of motion sickness symptoms share a common deficiency; they do not include fatigue. Most papers describing motion sickness symptoms [e.g. 4, 35, 37, 49] are careful to identify drowsiness and lethargy (or appropriate synonyms) as separate and different symptoms and either explicitly, or by omission, indicate that fatigue is not a symptom. This is consistent with the definition of fatigue as "weariness after exertion"[2], and the distinction is more than simply pedantic, as discussed in [7]. Regardless of how fatigue is produced, the combined effects of fatigue and motion sickness are worse than either alone [10, 11]. This may be especially important for sustained naval operations in relatively harsh conditions, where long periods of high sea states are often encountered (e.g. winter in the northern North Atlantic).

5.1 Predicting Initial Exposure MSI

There are two existing methods for predicting initial exposure MSI from the amplitude, frequency, and duration of exposure to ship motions.

1. Motion Sickness Incidence (MSI), McCauley *et al.*, 1976 [34], and O'Hanlon and McCauley, 1974 [39]; and,
2. Vomiting Incidence (VI), Lawther and Griffin, 1987 and 1988 [30, 32].

In both cases, the incidence of motion sickness is expressed in units of percent, representing the percent of the population which has vomited after exposure of a specified duration. Note that this is a cumulative measure.

Reference [7] reviews these two methods in detail, including comparing the accuracy of the two methods for predicting MSI observed in experiments and at sea. A total of 73 motion conditions were used; 51 from ship motion simulator experiments [34,39], and 22 from at-sea observations [29]. This comparison shows that the "MSI" method models these data to within an average error of 3% and standard deviation of 7%, and the "VI" method models these data to within an average difference of 4% and standard deviation of 9%.

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[2] The Concise Oxford Dictionary, 1978

Thus, while both methods are reliable, the MSI method is slightly more accurate. Also, as discussed in [7], the "VI" method significantly overpredicts MSI for large amplitude motions and for relatively long durations of exposure. Therefore, the MSI method will be adopted here for predicting MSI during the initial exposure phase.

Following McCauley *et al.*, 1976 [34], the initial exposure motion sickness incidence, MSI_I (%), is defined as follows. The subscript I is used to emphasize that this method is only used during the initial exposure phase.

$$MSI_I = 100\,\Phi(z_a)\Phi(z_t')$$

where $\Phi(z)$ is the cumulative distribution function of the standardized normal variable z,

$$\Phi(z) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{z} e^{-\frac{1}{2}\chi^2} d\chi$$

The standardized normal variables z_a and z_t' are defined as follows.

$$z_a = \frac{\log_{10} a - \mu_a(f)}{\sigma_a}$$

$$z_t' = \frac{z_t - \rho z_a}{\sqrt{1-\rho^2}}, \qquad z_t = \frac{\log_{10} t - \mu_t}{\sigma_t}$$

where a is the RMS vertical acceleration (g), f is the modal frequency (Hz) of a, and t is the duration of exposure (min). The remaining parameters are defined by McCauley *et al.* [34] as follows, to fit the data from ship motion simulator experiments described in references [34] and [39].

$$\mu_a = 0.87 + 4.36\,\log_{10} f + 2.73 \log_{10}^2 f$$

$$\mu_t = 1.46$$

$$\sigma_a = 0.47$$

$$\sigma_t = 0.76$$

$$\rho = -0.75$$

After manipulation, this method reduces to the following equations.

$$\begin{aligned} MSI_I =&\ 100\,\Phi(z_a)\Phi(z_t') \\ z_a =&\ A_1 \log_{10} a + A_2 \log_{10} f + A_3 \log_{10}^2 f + A_4 \\ z_t' =&\ B_1 z_a + B_2 \log_{10} t + B_3 \end{aligned}$$

where the constant coefficients A_i and B_i are shown in Table 1.

Table 1: Coefficients for Calculating MSI_I

i	A_i	B_i
1	2.128	1.134
2	-9.277	1.989
3	-5.809	-2.904
4	-1.851	-

Values of Φ for positive values of z_a and z_t' can be obtained from most standard mathematical handbooks. For negative values of z_a and z_t', the following relationship can be used.

$$\Phi(-z) = 1 - \Phi(z)$$

Since the MSI_I method is based on uni-modal and relatively narrow-banded motions, it cannot be used to predict MSI for broad-banded motions (e.g. surface effect ships), or for multi-modal motions where significant energy occurs at more than one discrete frequency (e.g. simultaneous long-crested seas and decaying swells). As discussed in [7], a variety of attempts have been made to create different 'frequency weighting' methods and statistical models to deal with these more complex motions, but none have been successful. The primary problem is an almost complete absence of experimental and trials data on MSI in these conditions.

5.2 Habituation for MSI in Ship Motions

Figure 7 shows the following habituation curves for MSI in ship motions.

- $MSI_{MAX} = 76\%$, McCauley *et al.* [34] ship motion simulator experiments (curve 3 in Figure 4; data tabulated in Appendix A.3)
- $MSI_{MAX} = 34\%$, How *et al.* [34] sea trials (curve 5 in Figure 4; data tabulated in Appendix A.5)
- $MSI_{MAX} = 12\%$, Kanda, Goto and Tanabe [34] sea trials (curve 6 in Figure 4; data tabulated in Appendix A.6)

The initial exposure MSI_{MAX} peak values are used to identify these data in subsequent figures and discussion.

The sea states which would produce ship motions corresponding to these values of MSI can be estimated by comparing values of MSI_{MAX} calculated using the MSI_I method with predicted ship motions for a variety of sea states. Table 2 shows vertical accelerations and sea states for equivalent motions on a warship ($\Delta \approx 4650$ tonnes, LBP = 121 m), with a speed of 20 knots in long-crested head seas.

Table 2: Equivalent Sea States for MSI_{MAX} on a Warship

MSI_{MAX} (%)	a (g)	ω_e (s^{-1})	f (Hz)	$\zeta_{1/3}$ (m)	SS
34	0.09	1.09	0.17	2.25	high 4
12	0.05	1.58	0.25	1.25	high 3

where a is the RMS vertical acceleration at the bridge (g), ω_e is the encounter frequency (rad/s), f is the encounter frequency in (Hz), $\zeta_{1/3}$ is the significant waveheight (m), and SS is the sea state.

The encounter frequencies for these two conditions are both close to the peak frequency of human sensitivity to motion sickness at about 0.2 Hz [29,34]; which indicates that very provocative motions are often experienced during normal naval operations.

The value of $MSI_{MAX} = 76\%$ is higher than could be reasonably expected in contemporary frigates and destroyers. This is for two reasons. First, as discussed earlier, MSI values exceeding about 70% are rarely encountered in the naval environment (approximately 32% "never get sick"). Second, the vertical accelerations corresponding to a predicted value of $MSI_{MAX} = 76\%$ could occur in high sea state 7; however, for the encounter frequency to be high enough to provoke 76% MSI, the ship speed would be well in excess of 30 knots. A more reasonable ship speed for sea state 7 would be only a few knots, in which case a value of $MSI_{MAX} \approx 45$ to 50% could be expected. Very high values of MSI_{MAX} approaching 100% have been observed in lifeboats during emergencies [28]; however, this is well outside the scope of normal warship experience.

Also, the data for $MSI_{MAX} = 76\%$ are for two hour exposures to motion on consecutive days, and so the day-to-day reduction in MSI due to habituation observed here is not necessarily the same as would be observed at sea. Drug therapy experiments by Glaser [12,13] on 179 subjects using rubber rafts in a swimming pool fitted with a wavemaker show that significant habituation is obtained after three or four one-hour exposures to severe motions, despite the interval of from 48 to 72 hours between exposures. In the first experiment, MSI fell from 56% on day 0 to 20% on day 3, and in the second, MSI fell from 54% on day 0 to 6% on day 3. Unfortunately, the variation of drug treatments (each subject took a different treatment on each day), and unquantified variation in times between exposures means that these data cannot be used to define habituation on consecutive days.

6 Empirical Fit for Habituation Function

The following empirical fit for the habituation function, $h(t)$, was developed from the MSI data in Figure 7.

$$\begin{aligned} h(t) &= C_1 \log_{10} t + C_2, \quad \text{for } t_I < t < t_F \\ t_I &= 10^{(1.0-C_2)/C_1} \\ t_F &= 10^{(-C_2/C_1)} \end{aligned}$$

where , $h(t)$ is the habituation function ($h(t) = MSI(t)/MSI_{MAX}$), t_I is the time at which the initial exposure peak value MSI_{MAX} occurs, and t_F is the time to full habituation (i.e. when $MSI(t) \Rightarrow 0$).

The coefficients C_1 and C_2 are evaluated as follows.

$$\begin{aligned} C_1 &= 0.194\sqrt{MSI_{MAX}} - 2.20 \\ C_2 &= 0.64 \end{aligned}$$

All times are defined in units of days, and *MSI* is defined in units of percent.

The constant coefficient $C_2 = 0.64$ is the average value of $h(t)$ at $t = 1$ (day) for the three curves in Figure 7. The coefficient C_2 is defined by slopes of the $h(t)$ vs. time curves, plotted to a base of $\log_{10} t$, as shown in Figure 8. The logarithm of time was selected for two reasons: (i) straight-line segments provide fairly good fits to the data (although not much different than for the linear t graph in Figure 7); and, (ii) the same straight-line fits provide realistic values for t_I. The values of t_I for each curve are noted at the top of Figure 8, with subscripts to denote the corresponding MSI_{MAX} values. This last feature is important, as in order to combine the habituation function with a method for estimating MSI_{MAX}, both methods must agree on when MSI_{MAX} occurs.

Figure 9 shows the fit of the empirical habituation function to the three data sets with $MSI_{MAX} = 76$, 34, and 12%, including $h(t)$ during the first day of exposure. The variation of t_I (where $h(t) = 1$) with the magnitude of MSI_{MAX} agrees with trends observed in experiments and at sea; in severe conditions, people tend to get motion sick more quickly and recover more slowly than in less severe conditions. As mentioned above, t_I values predicted by $h(t)$ are realistic; however, they do not agree completely with the same times predicted by MSI_I.

6.1 Time of Exposure to Reach MSI_{MAX}

Figure 10 shows the variation of initial exposure MSI predicted MSI_I (solid lines), and the observed MSI_{MAX} values. Also in this figure are curves which show the times at which MSI_{MAX} is predicted to occur by the empirical fit t_I (dashed line) and by the MSI_I method (dotted line). The purpose of presenting this figure is to discuss using t_I from the empirical habituation model as input to the MSI_I model for predicting the magnitude and time at which MSI_{MAX} occurs; however, a few details of this figure must first be clarified.

The curve defining predicted times for MSI_{MAX} from the MSI_I method is defined by the time at which 99% of the MSI_I maximum will occur, t_{99}. This time is calculated from the statistical properties of the MSI_I model as follows, using the same notation as defined earlier.

$$t_{99} = 10^{(2.33 - B_1 z_a - B_3)/B_2}$$

where z_a (which models the effects of acceleration and frequency) and the coefficients B_i are terms in the MSI_I model. The constant 2.33 is the value of z_t' corresponding to the cumulative distribution function value of $\Phi(z_t') = 0.99$.

In other words, for any particular constant values of acceleration, a, and frequency, f, t_{99} is the time at which the MSI_I model reaches 99% of its theoretical maximum value. Increasing the time of exposure beyond t_{99} will not increase the predicted value of MSI_{MAX} by more than one percent. The curve for t_{99} shown in this figure was calculated for various values of acceleration, a, at a constant frequency of $f \approx 0.17$ Hz. Similar curves of t_{99} for higher and lower frequencies are shifted slightly to the right of the curve in Figure 10.

The observed MSI_{MAX} values of 76 and 12% are placed at the times of observation; 2 hours for 76%, and 4 hours for 12%. The observed value of $MSI_{MAX} = 34\%$ is simply the maximum MSI recorded on the first day of the trial [25]; the reasons for plotting this value at the time predicted by t_I are discussed below. The curve of MSI vs. t for $MSI_{MAX} = 12\%$ is calculated using the MSI_I method with the acceleration and frequency of motion measured on the trial ($a = 0.048$ g, and $f = 0.17$ Hz). The curves for MSI_{MAX} of 76 and 34% are calculated using representative motions of $a = 0.33$ g and $f = 0.2$ Hz for 76%, and $a = 0.087$ g and $f = 0.16$ Hz for 34%. These 'representative' motions are used in the first case because the experiments with 76% MSI include a higher proportion of "susceptible" subjects than the "normal" population modelled by MSI_I. Thus, MSI would be underpredicted using the real motions from the experiment ($a = 0.22$ and 0.33 g, $f = 0.25$ Hz). In the second case, no ship motions were recorded, and so acceleration and frequency values corresponding approximately to 12 knots in sea state 4 are used for $MSI_{MAX} = 34\%$.

The calculated MSI values for $MSI_{MAX} = 12\%$ agree well with the observed value after four hours of exposure ($t = 0.167$ days), but MSI_I predicts that MSI will continue to increase up to a value of about 16% after 12 hours. This data point is shown in Figure 10 as an open triangle. This is consistent with the results of the trial [26]. MSI observations were made from the time of departure through the watch keeping period, but were not reported for this particular group (which is the only one for which consistent habituation data can be obtained). For another group, relatively low MSI was also observed before and after the watch (when many people would lie down). The proportion of reported off-watch MSI indicates that an overall daily maximum MSI of 16% is quite reasonable for the "habituation" group.

Now, back to the main purpose for presenting Figure 10. For MSI values less than about 20%, the MSI_I method predicts that the time of maximum MSI occurs after twenty-four hours of exposure. This is an artifact of the statistical method, since no such long exposures were tested. The observations from [26] on the second day, where on-watch MSI falls to about 8%, clearly shows that significant habituation has occurred. Thus, it is not reasonable to expect that MSI increases throughout all of the first day. For example, if the first watch began at 0800 hours ($t = 0$), then the time of exposure at $t = 1$ (day) corresponds to 0800 on the next day. The estimated time of maximum MSI from the empirical $h(t)$ fit at about 0.55 days appears reasonable. Using t_I as input to the MSI_I model instead of t_{99} does not make a large difference in the predicted magnitude of MSI_{MAX}. In this case, MSI_{MAX} at t_I is 16.3%, and the corresponding value at $t_{99} = 25$ hours is 16.8%.

For values of MSI from about 35 to 45%, the times and magnitudes predicted for MSI_{MAX} using t_I and t_{99} are in very close agreement. For MSI values above about 45%, the magnitude of MSI_{MAX} predicted using t_I is not significantly different from the 'real' value, as time is already past the '99%' threshold. For the 76% case, $MSI_{MAX} = 77.1\%$ at t_{99}, and 77.7% at t_I. The real value of MSI observed in this experiment was 76.5% (as shown in Appendix A.3) for an exposure of two hours. The difference between the observed and t_{99} values indicates that a slightly higher MSI might have been observed by running the experiment for a few minutes longer ($t_{99} = 2.6$ hours).

For MSI values above about 45%, the habituation function t_I predicts MSI_{MAX} at a greater time than t_{99}; however, this is not a real problem. The threshold of 99% was arbitrarily selected for the purpose of discussion; if a threshold of 99.9% is used instead, then the corresponding "t_{999}" curve is actually to the right of t_I at high MSI. In any case, since this method is devised to estimate MSI on a daily basis, a small difference in the predicted times to MSI_{MAX} on the first day is not significant, as can be seen later when discussing the variation of MSI over three to four days.

Also, as mentioned above, the t_{99} curve shifts to the right for frequencies above or below $f \approx 0.17$ Hz. For high MSI values, this means that the time to MSI_{MAX} predicted by t_{99} and by t_I are in closer agreement. For low MSI values, the times to MSI_{MAX} estimated with t_{99} are even less realistic.

7 MSI Habituation Model

The method proposed for estimating $MSI(t)$ for continuous exposure to constant ship motions is obtained by combining the initial exposure method of McCauley *et al.* [34], with the empirical habituation function model, $h(t)$, as follows.

$$MSI(t) = \begin{cases} MSI_I & 0 < \ t \le t_I, \ \text{initial exposure} \\ h(t) MSI_{MAX} & \mathrm{t}_0 < \ \mathrm{t} < \mathrm{t}_F, \ \text{continuing exposure} \\ 0.0, & \mathrm{t} \ge \mathrm{t}_F, \ \text{fully habituated} \end{cases}$$

The methods for calculating MSI_I, $h(t)$, t_I, and t_F were defined earlier, and are summarized in Appendix B.

As discussed earlier, it is recommended that t_I from the empirical habituation model should be used as input to the MSI_I model to determine the time of occurrence and magnitude of MSI_{MAX}. This does not make a significant difference in the predicted magnitude of MSI_{MAX}, and ensures that unrealistically high values for the time to maximum MSI are not predicted for relatively low MSI; however, since t_I is a function of MSI_{MAX} (see Appendix B), an iterative process is required. A practical solution is to estimate MSI_{MAX} by solving MSI_I at time t_{99} and then calculate t_I from the empirical fit.

Figure 11 shows the predicted variation of MSI with time for the three conditions described earlier. In all cases, the agreement between predictions and observations are good. For the 12% case, the dashed line indicates that the predicted value of $MSI_{MAX} = 16\%$ for the full day is used (open symbol) instead of the 12% value observed during the four hour watch period (solid symbol near $t = 0$). Thus, the observed values of MSI are somewhat lower than estimated by the MSI habituation model; however, the differences are not large. If 'scaled' values were used for MSI on days 1 and 2 to account for off-watch MSI, then the agreement would be closer. Details on the procedures and data used to calculate $MSI(t)$ were discussed in the previous section.

The good agreement with data from sea trials ($MSI_{MAX} = 34$ and 12%) suggests that the MSI habituation model is adequate for estimating the variation of MSI with time for contemporary frigates and destroyers up to about sea state 5 ($\zeta_{1/3} \leq 2.5$ m). The close agreement with experimental data in more severe motions ($MSI_{MAX} = 76\%$) suggests that the MSI habituation model may be adequate for estimating $MSI(t)$ in higher sea states, but as discussed earlier, the experiments from which these data are derived are not necessarily representative of conditions at sea.

8 Applications and Limitations

In general, two types of criteria can be used to assess the effects of ship motions on operability [7]; absolute criteria, and relative (or comparative) criteria. Absolute criteria are the most desirable; however, since the relationship between human performance, MSI and other measures of symptom severity is not known, absolute criteria are not available for motion sickness. MSI is a good parameter for use as a relative criterion, as its value can be estimated from data which are not platform-dependent (i.e. the amplitude, frequency and duration of exposure of motions). Platform-dependence can be illustrated by considering "personnel" criteria which are in common use today [3,8,45]. These criteria assign SSA[3] limit values of 8 degrees for roll angle, 3 degrees for pitch angle, 0.4 g for vertical acceleration and 0.2 g for lateral acceleration. These angular criteria are based on many years of experience with monohull warships, and so are valid for comparing operability of similar ships, but they cannot be used with confidence for ships which are significantly different in size or shape, because of fundamental differences in the characteristic frequencies and amplitudes of their motions. Note that the 0.4 g limit on vertical acceleration (= 0.2 g RMS) is related to MSI[4], but it does not reflect the frequency dependence of motion sickness.

Baitis, Applebee and McNamara, 1984 [2], used the MSI_I method to illustrate the effects of varying ship speed and heading on motion sickness. Also, the British Standards Institution [5] presents quantitative guidelines for estimating motion sickness incidence,

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[3] Significant Single Amplitude, SSA = 2.0 RMS for ship motions.

[4] The 50% MSI_I contour corresponds closely with the "Vibration Ride Quality Index" limit of 0.2 g RMS for "long-term severe" conditions proposed as a design limit for navy personnel by Payne, 1976 [40].

using the "VI" method of Lawther and Griffin [29], discussed earlier. Unfortunately, the general seakeeping analysis and operability assessment community has not adopted this approach.

By combining the MSI_I model with a habituation function, we are able to estimate more realistic values of MSI in the naval environment than would be estimated using either MSI_I or another initial exposure method alone. MSI values estimated for different motion conditions can be used to compare differences in ship type, ship size and locations within individual ships.

Three main limitations are imposed on this approach:

1. the relationship between MSI and human performance is not known;
2. the method is not adequate for complex motions (e.g. broad-banded motions of surface effect ships and hovercraft, and multi-modal wave spectra associated with simultaneous developing seas and decaying swells); and,
3. the method is not adequate for motions which change over time (e.g. slow changes related to weather and geographic location; and, rapid changes related to operational tactics such as sprint and drift sonar operations).

As discussed earlier, the first limitation applies equally to MSI and all other indicators of motion sickness symptomatology. The second and third limitations are a direct consequence of the lack of data on motion sickness in complex and changing motion environments [7]. Thus, while this approach does not quantify human performance degradation and it is not applicable for many realistic motion environments, it does provide a significant improvement over the more traditional "personnel" criteria described earlier.

Note that MSI should not be the only "human factors" consideration for operability assessment and ship design. It is important to also consider Motion-Induced Interruptions [2,15,16], fatigue and whole-body vibrations. As discussed in [7], there are no satisfactory methods for modeling fatigue. The procedures for establishing tolerance limits for whole-body vibrations are well developed, although the links to performance are not well established.

Past work by medical and scientific researchers indicates that using questionnaires to obtain subjective assessment of the presence and severity of sickness symptoms shows good agreement with objective assessment (e.g. [48]). This suggests that a large and very useful database on the incidence and severity of motion sickness could be obtained for relatively little effort by widespread distribution of a suitable questionnaire. If ship motions are also recorded, then a great deal of information would be available for comparison with existing models, and for developing new statistical estimators for complex and changing motions. Unfortunately, the self-assessment of fatigue and performance is not validated, and so further laboratory experiments and trials are required to determine the relationship between motion sickness, fatigue and human performance.

9 Concluding Remarks

A method has been described for estimating the variation of motion sickness incidence (MSI) with time, for continuous exposure to constant ship motions. This MSI habituation model uses the statistical method of McCauley *et al.* [34] to predict the magnitude of MSI encountered during initial exposure to motion, and then estimates the reduction in MSI due to habituation over subsequent days using an empirical fit to experiment and trials data. This model should be an adequate tool for estimating MSI habituation in conditions up to about sea state 5, for frigate-sized ships with characteristically uni-modal and narrow-banded motion spectra.

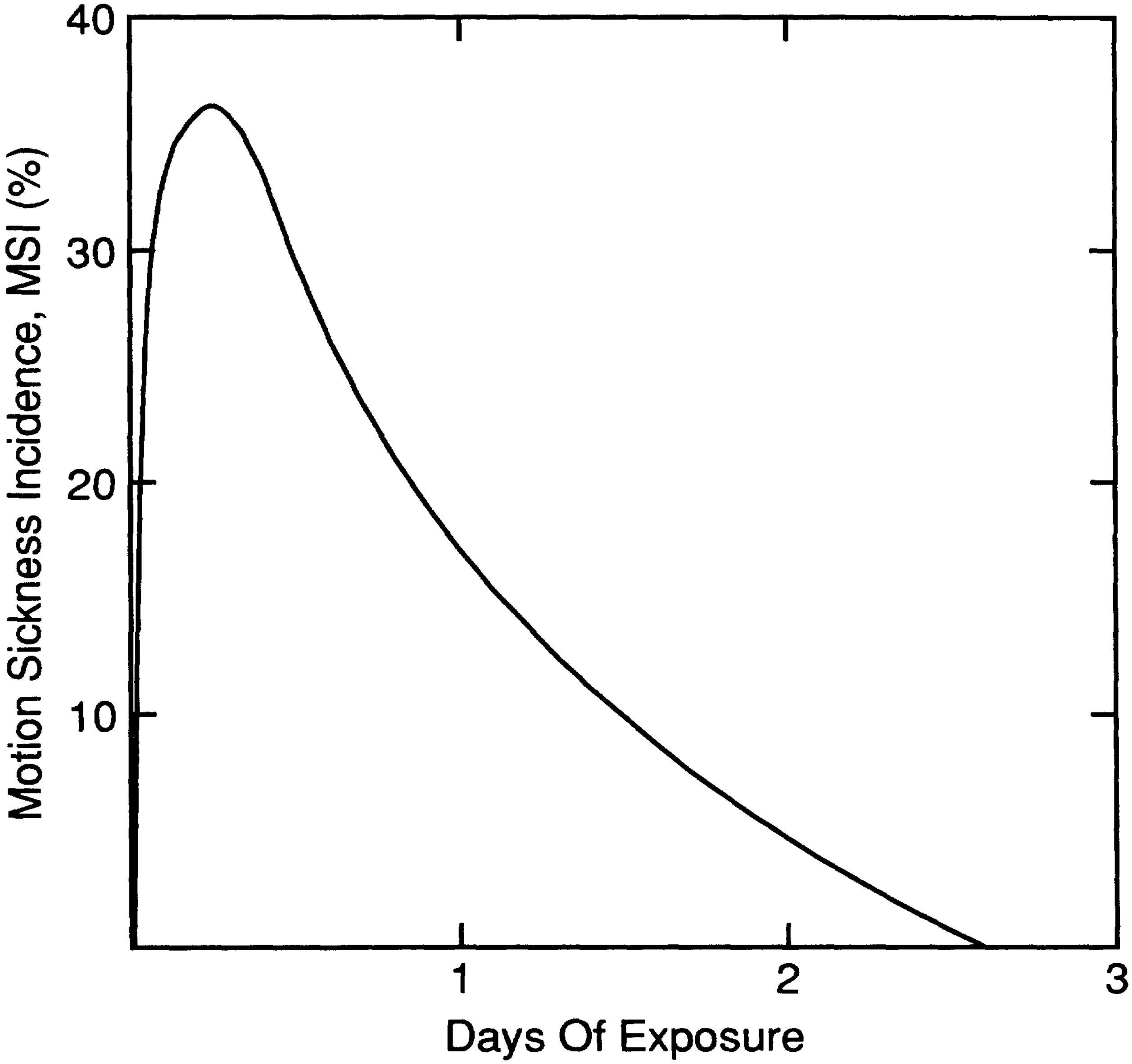

Fig.1 Habituation: Reduction in Motion Sickness

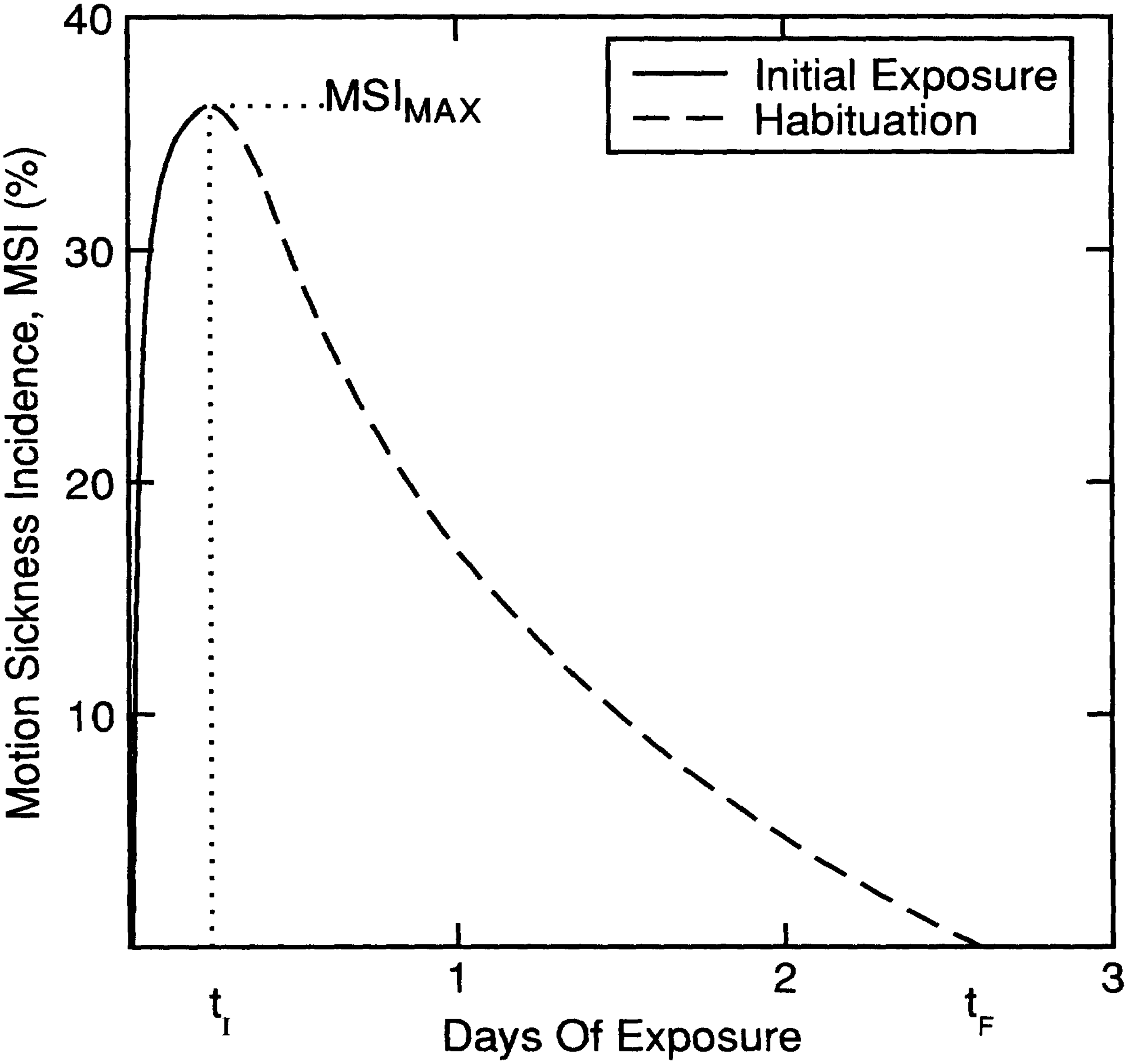

Fig.2 Peak Value of Motion Sickness Incidence

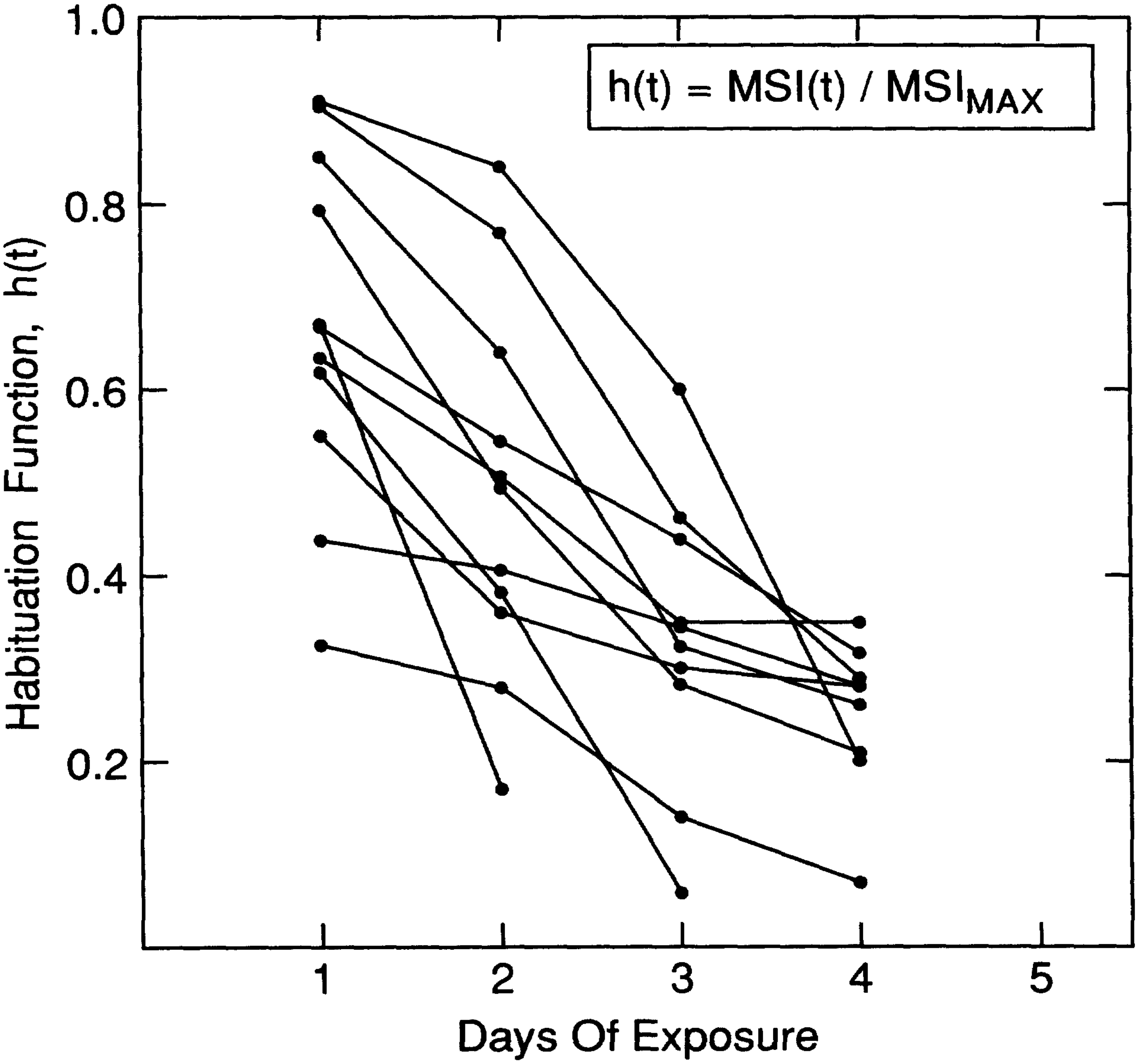

Fig.3 Habituation to Various Motions
(Ship, Aircraft, Rotating Chair)

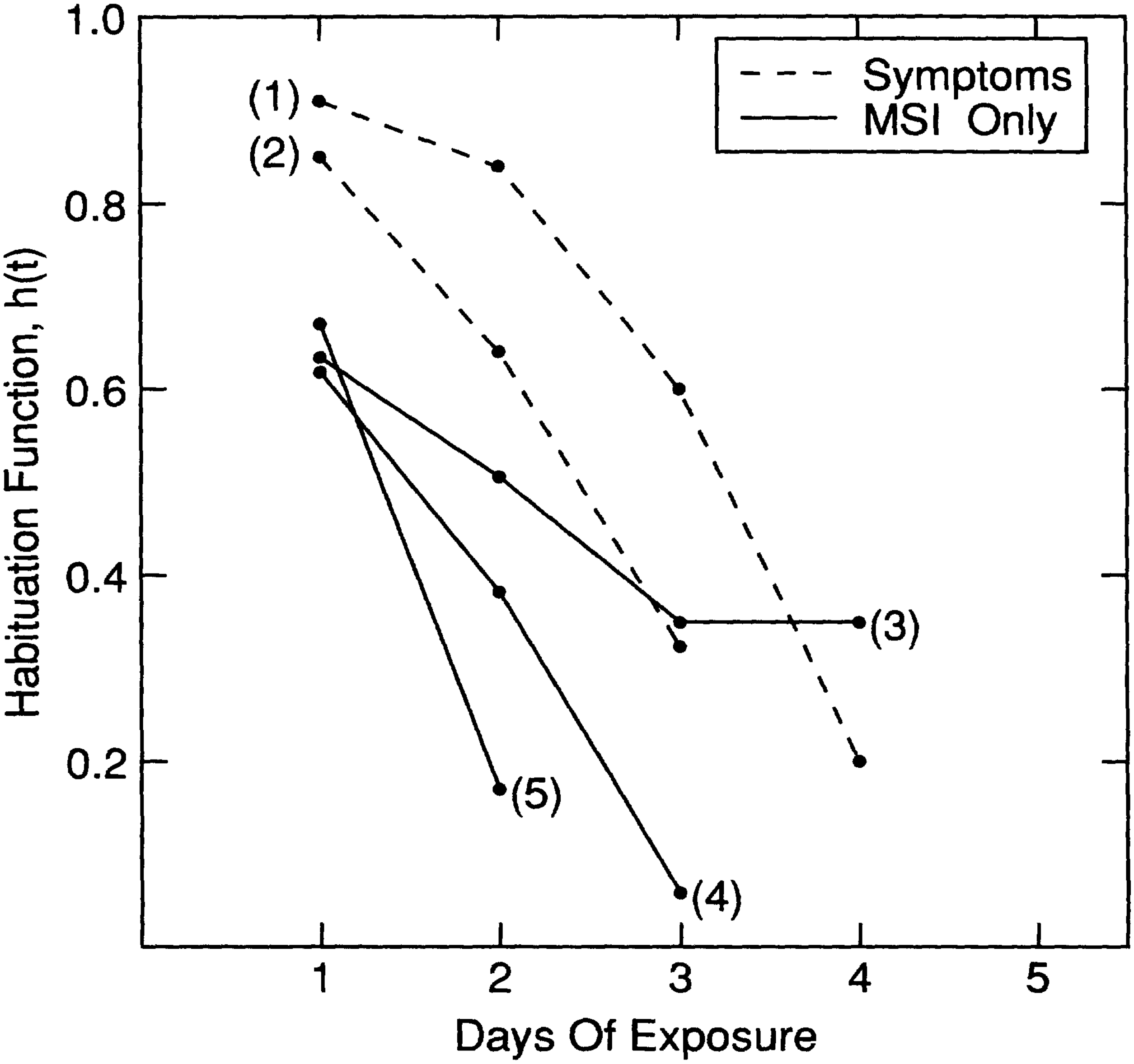

Fig.4 Habituation to Ship Motions (Symptoms and MSI)

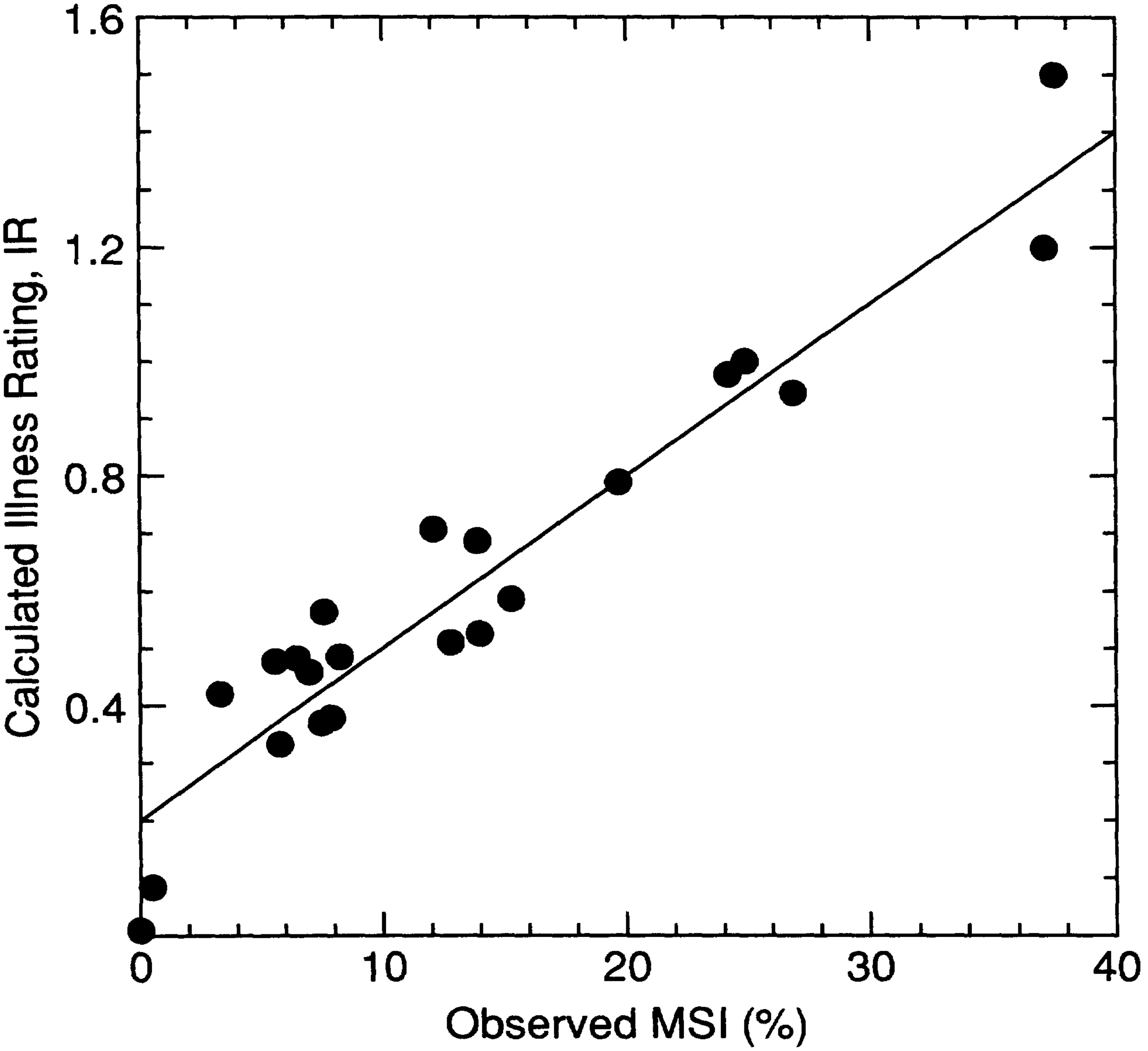

Fig.5 Illness Rating vs. Motion Sickness Incidence

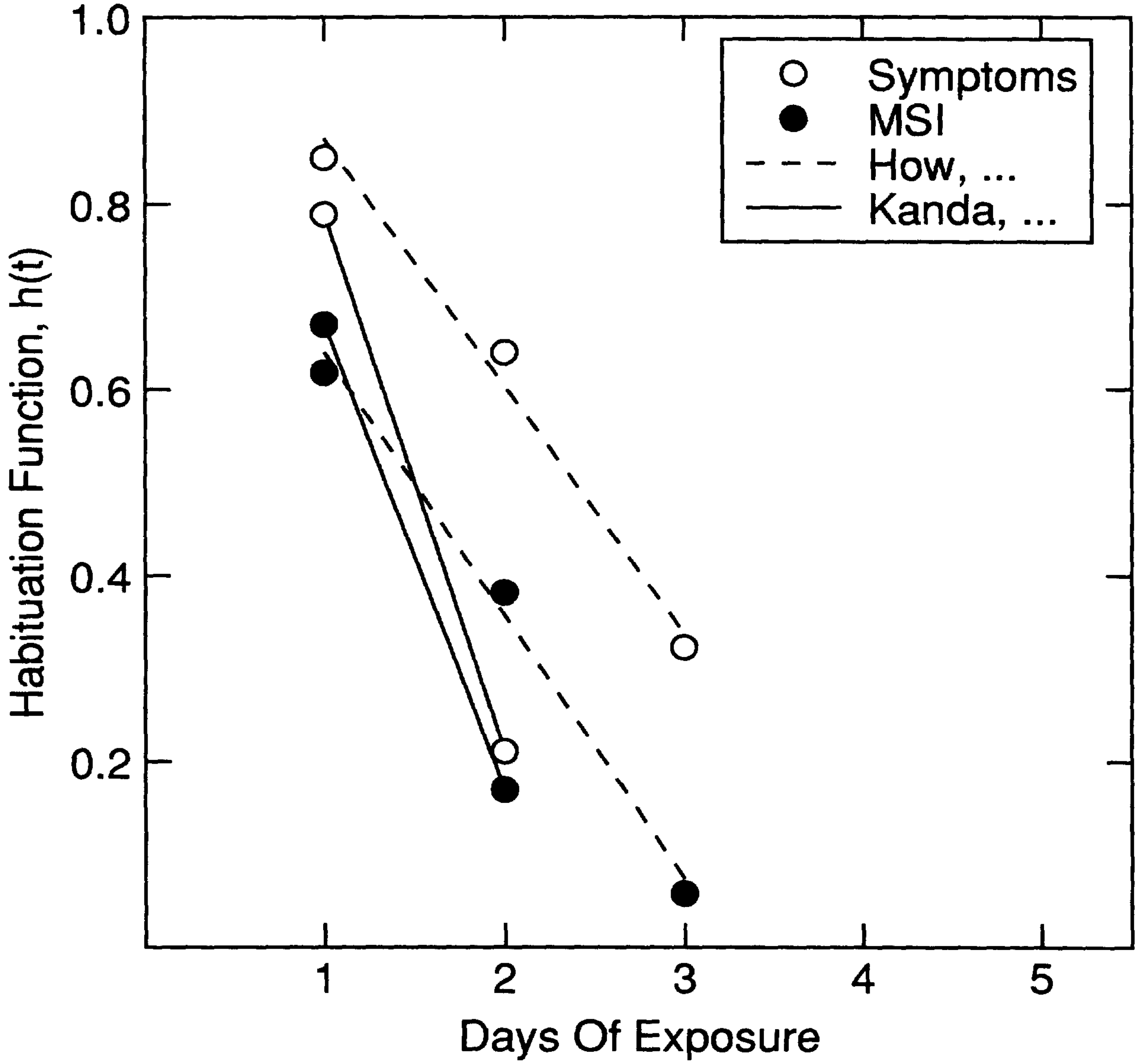

Fig.6 Comparison of Habituation Rates for MSI and Symptoms .

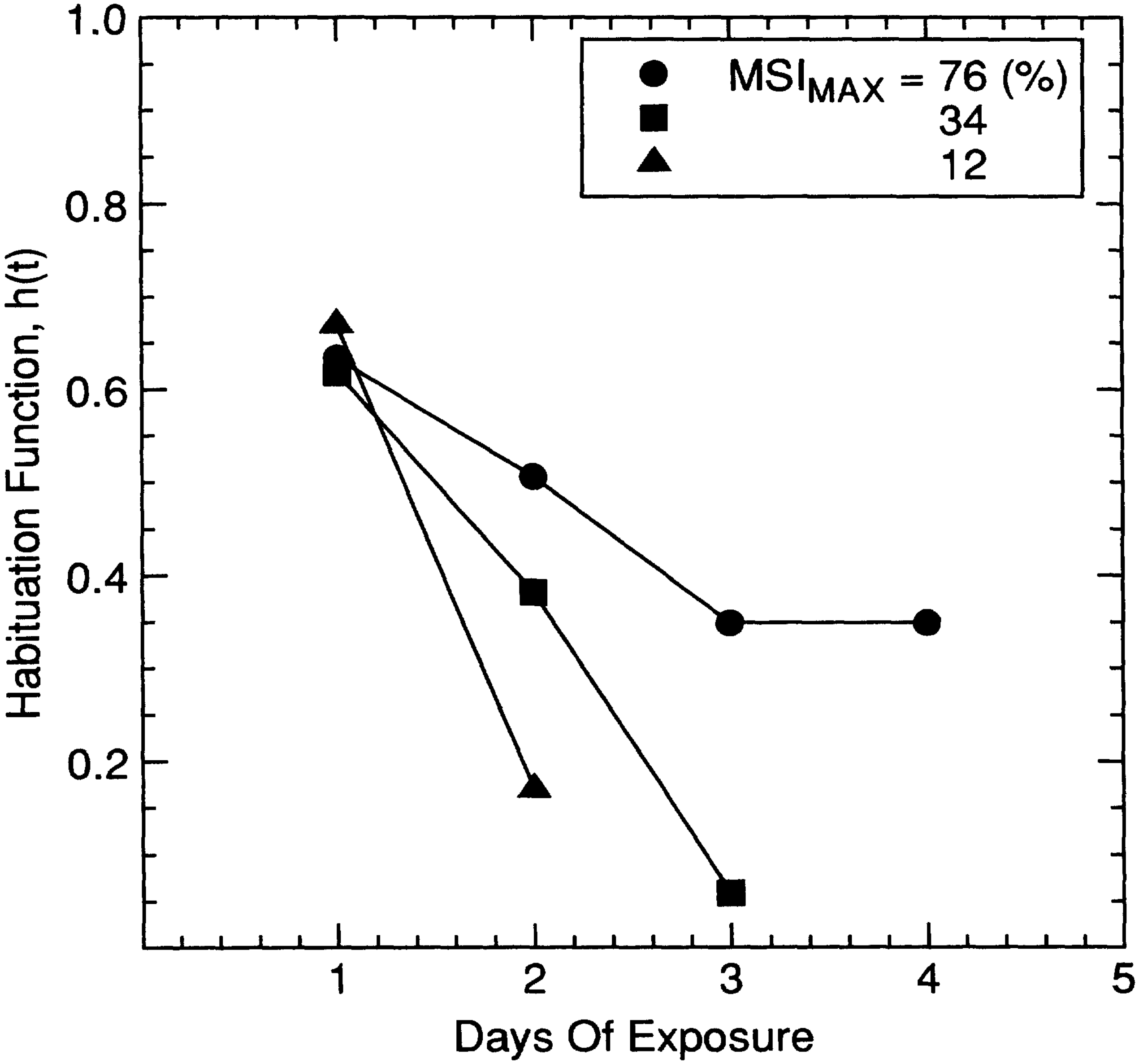

Fig.7 Habituation for MSI in Ship Motions

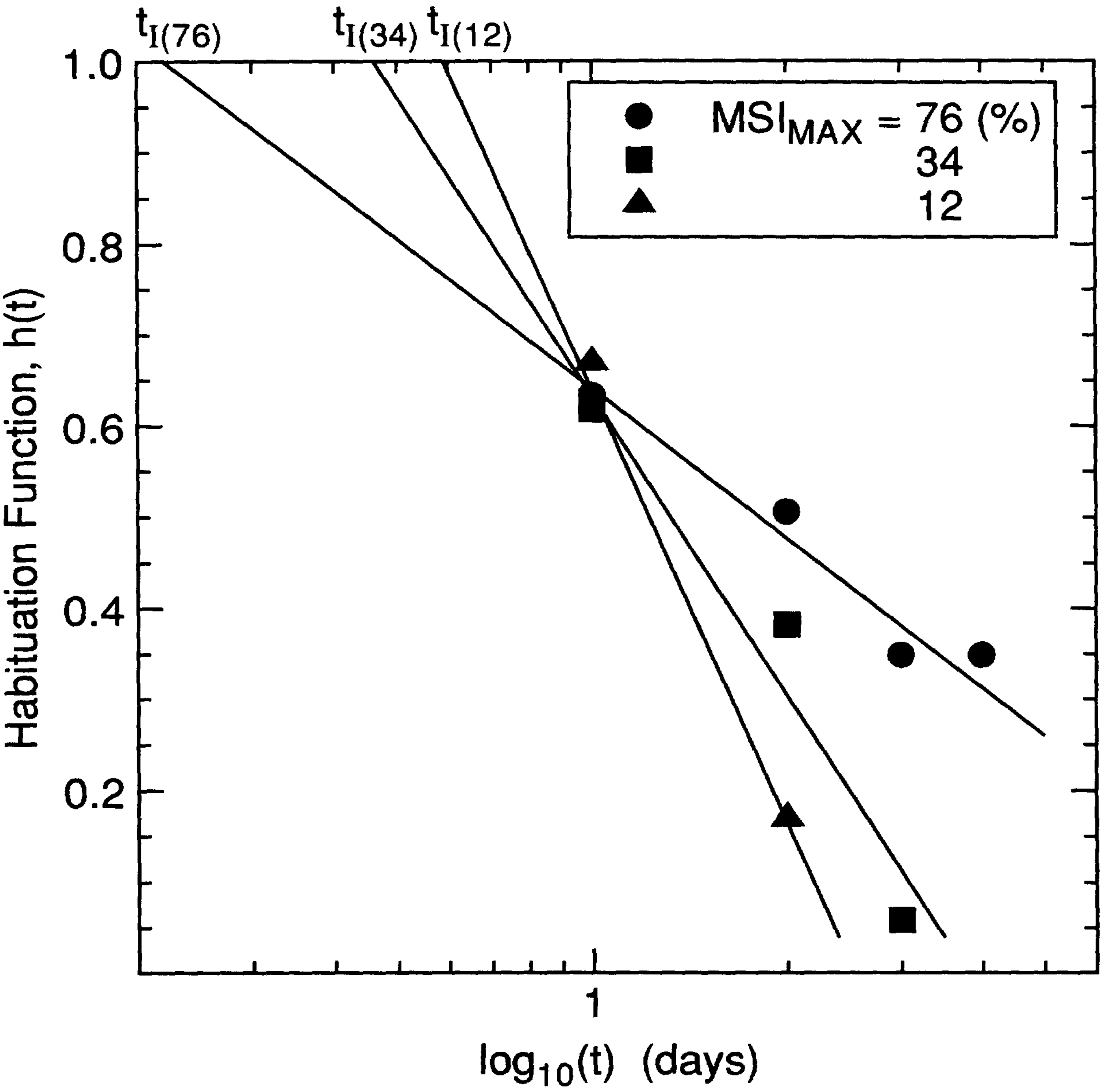

Fig.8 Habituation Function vs. Log(Time)

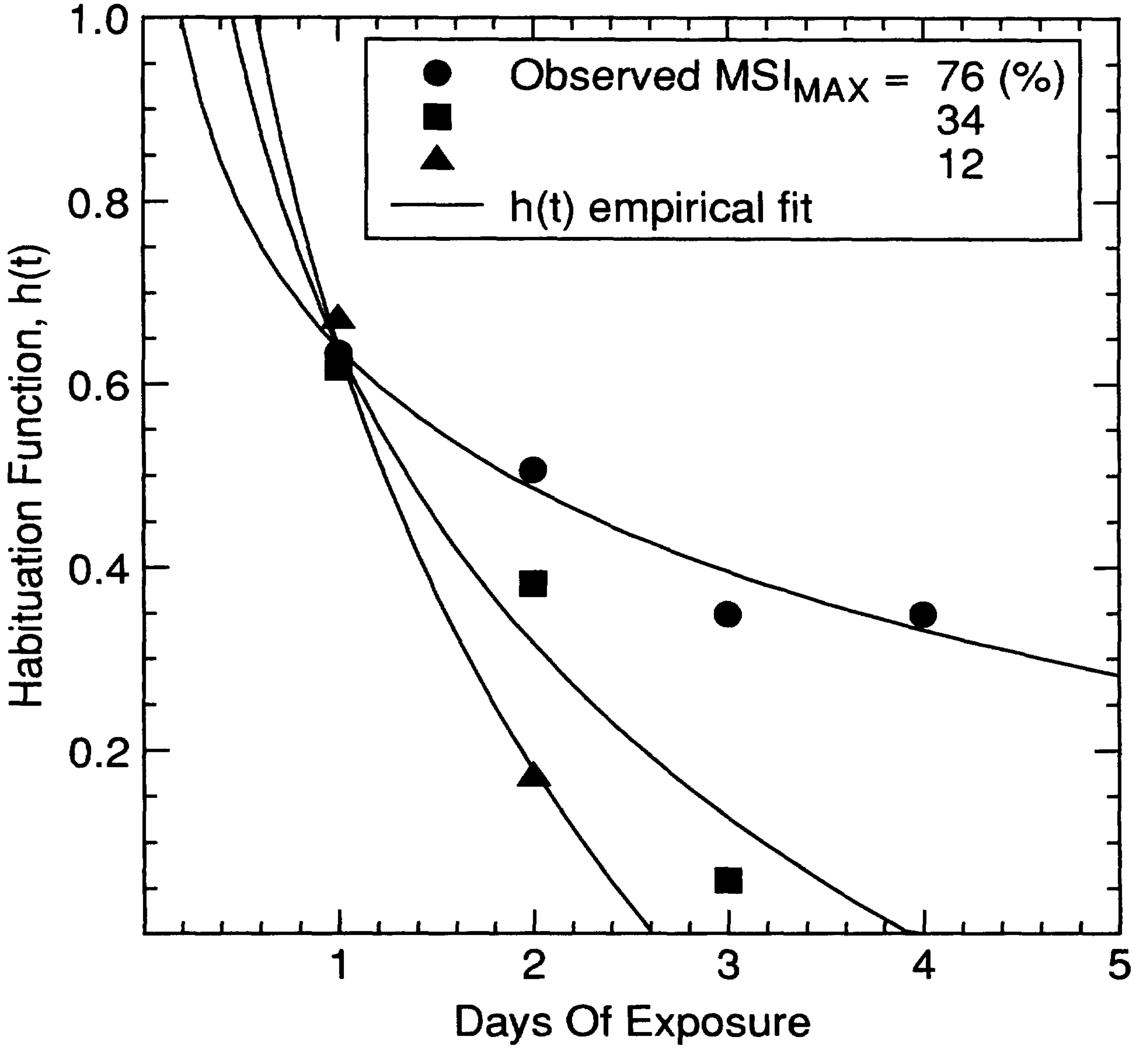

Fig.9 Comparison of Observed MSI with h(t) Empirical Fit

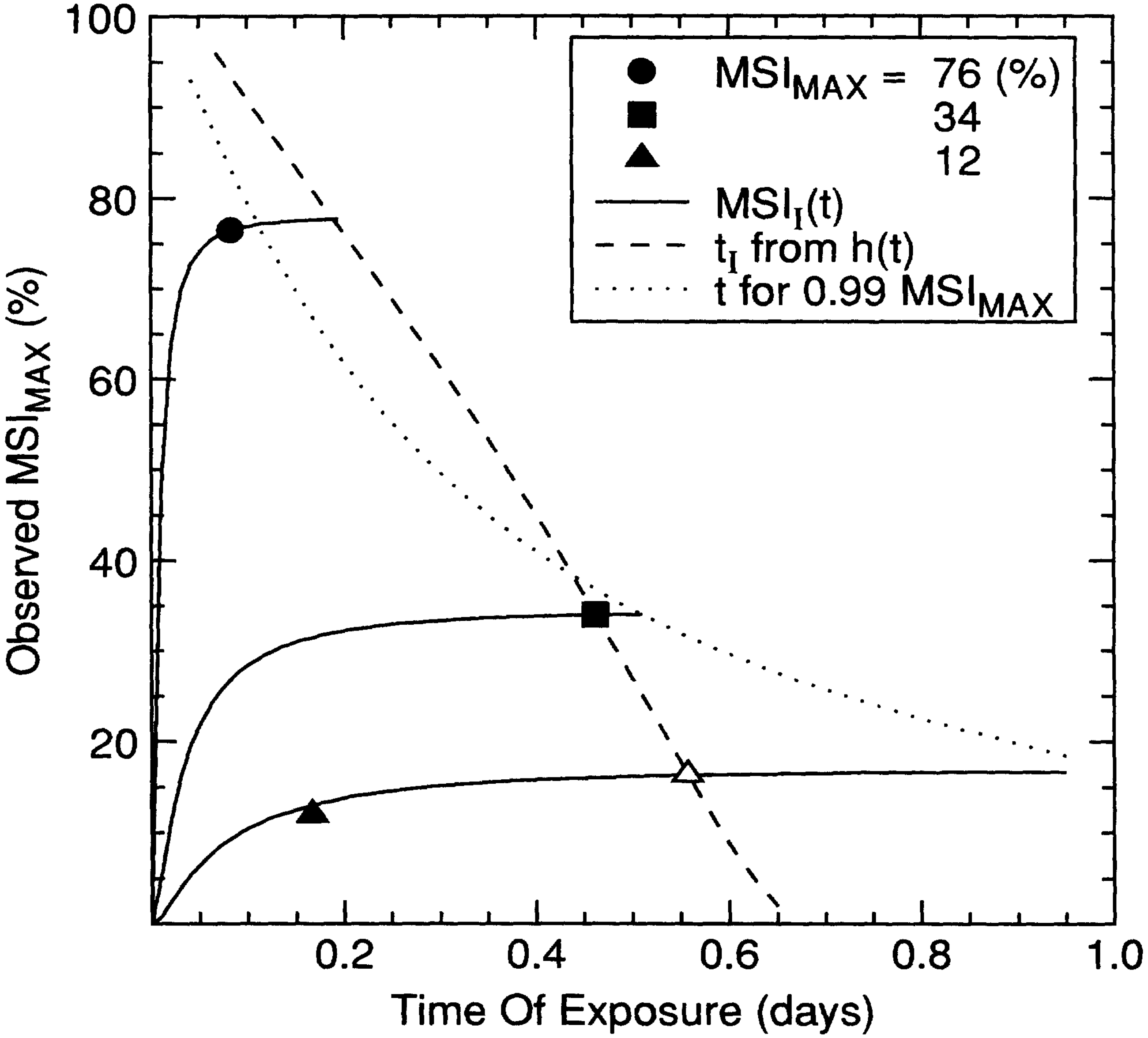

Fig.10 Time of Exposure to Reach MSI_{MAX}

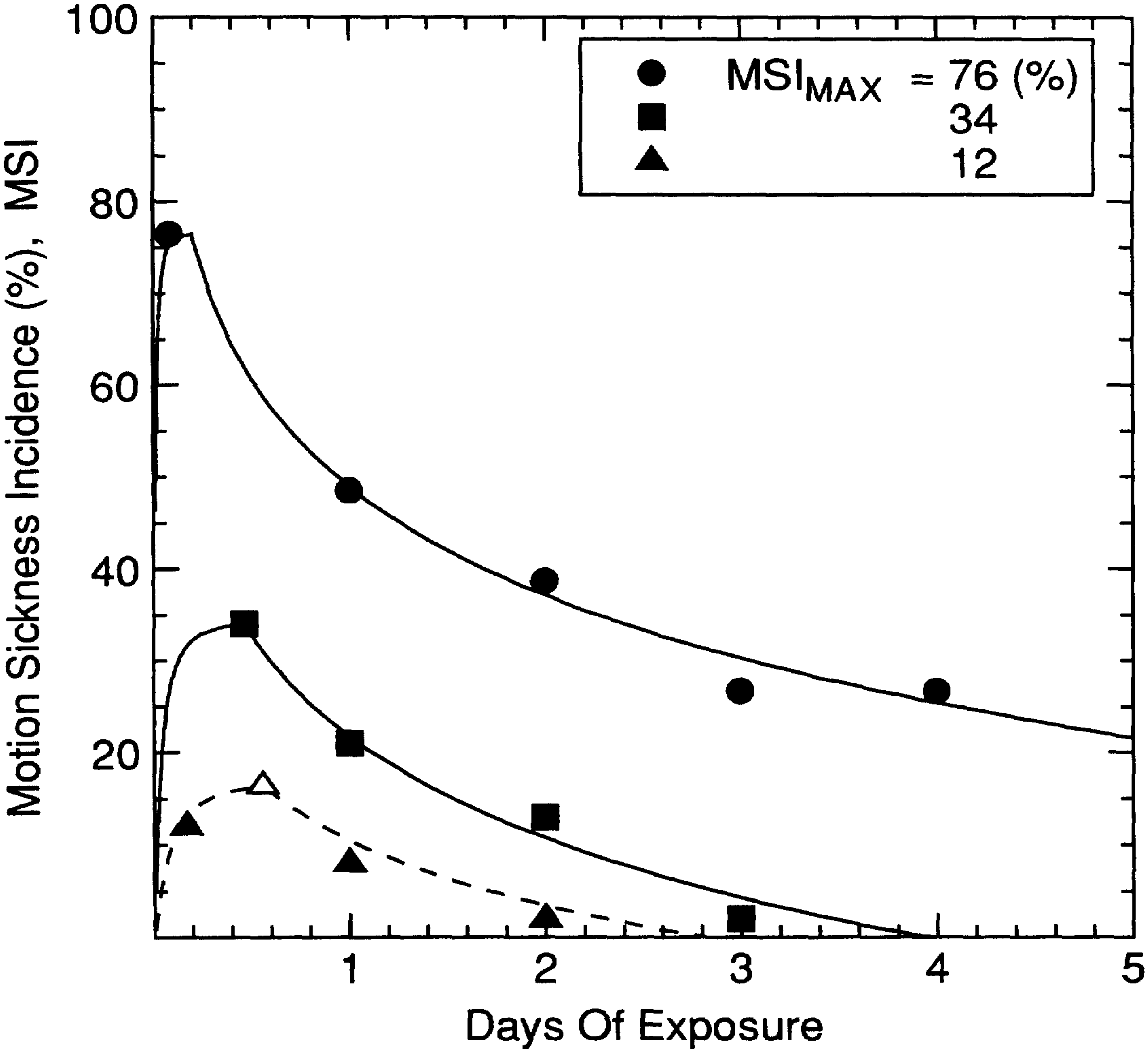

Fig.11 MSI(t) Predictions, Ship Motions

Appendix A: Habituation Data

A.1: Walters, 1964 [47], Symptoms

The habituation data shown in Figure 4 as curve 1 are based on observations of motion sickness symptoms shown in Table III of Reference [47].

Day	I (%)	$h(t)$
0	21.9	1.00
1	19.9	0.909
2	18.4	0.840
3	13.2	0.603
4	4.4	0.201

where I is the percent of crew who were "affected by sea sickness in any way" [47], and $h(t)$ is the habituation function, $h(t) = I(t)/I_{MAX}$. Due to the reporting mechanism used in this trial, it is likely that these figures represent more severe symptoms than implied by the description; however, this cannot be quantified.

A.2: How *et al.*, 1988 [25], MSI and Symptoms

The habituation data from How *et al.* for MSI and symptoms are taken from Figures 3 and 1, respectively, in Reference [25].

	MSI		Symptoms	
Day	*MSI*	$h(t)$	I	$h(t)$
0	34	1.00	3.00	1.00
1	21	0.618	2.55	0.850
2	13	0.382	1.92	0.640
3	2	0.059	0.97	0.323

where I is the "mean score of seasickness" [25], and $h(t)$ is the habituation function, $h(t) = I(t)/I_{MAX}$. The scoring system used in [25] for these values of I varies from $I = 0$, for "totally well", through $I = 4$, for "very dizzy, almost vomiting". As discussed before, a score of $I = 2$ corresponds to "moderate" severity of symptoms (Malaise II on the Graybiel scale [17]).

A.3: McCauley *et al.*, 1976 [34], MSI

The habituation data shown in Figure 4 as curve 3, and in Figures 7 to 11 as $MSI_{MAX} = 76\%$, are derived from observed MSI shown in Figures 1 and 2 of [34]. These represent two experiments, identified below by subscripts 1 and 2. Experiment 1 had RMS vertical accelerations of $a = 0.22g$, experiment 2 had $a = 0.33$ g, and both were at a modal frequency of $f = 0.25$ Hz and exposures of two hours.

	Exp. 1		Exp. 2		Exp. 1 + Exp. 2			
Day	N_1	$N_{(MSI)1}$	N_2	$N_{(MSI)2}$	N_{1+2}	$N_{(MSI)1+2}$	MSI_{1+2} (%)	$h(t)$
0	20	15	14	11	34	26	76.5	1.00
1	20	12	13	4	33	16	48.5	0.634
2	20	8	11	4	31	12	38.7	0.506
3	20	6	10	2	30	10	26.7	0.349
4	20	6	10	2	30	10	26.7	0.349

where N_i is the total number of subjects in experiment 'i', $N_{(MSI)i}$ is the number of subjects who vomited in experiment 'i', and MSI_{1+2} is $N_{(MSI)1+2}/N_{1+2}$ on each day.

On days 3 and 4, the values of N_2 and $N_{(MSI)2}$ used here are one greater than shown in Figure 2 of [34]. This was done to account for a subject who was asked to leave the experiment "because of extreme susceptibility to motion sickness".

A.4: Kanda, Goto and Tanabe, 1977 [26], MSI and Symptoms

The habituation data from Kanda, Goto and Tanabe for MSI and symptoms are based on observations in Table 2 of [26] for group G.

	MSI		Symptoms	
Day	MSI	$h(t)$	I	$h(t)$
0	12	1.00	26	1.00
1	8	0.667	22	0.846
2	2	0.167	6	0.231

where MSI is the percent of subjects experiencing "serious" Grade III symptoms, and I is the percent of subjects experiencing "moderate" Grade II and Grade III symptoms (Grade 0 = "none", Grade I = "slight", and Grade III = "extremely unpleasant sensations, vomiting, loss of desire to do anything").

Appendix B: Summary of MSI Habituation Model

A method for estimating MSI for continuing exposure to constant ship motions is summarized below. Initial exposure MSI is estimated using the statistical method of McCauley *et al.*, 1976 [34], and the reduction in MSI due to habituation with continuing exposure is estimated using the empirical habituation function, $h(t)$. This method should normally be used to estimate MSI on a daily basis only; however, it is possible to 'track' MSI as a function of time. Note that time is in units of minutes for MSI_I, and in units of days for $h(t)$. MSI is in units of percent.

$$MSI(t) = \begin{cases} MSI_I & 0 < \; t \le t_I, \text{ initial exposure} \\ h(t)MSI_{MAX} & \mathrm{t}_I < \; \mathrm{t} < \mathrm{t}_F, \text{ continuing exposure} \\ 0.0, & \mathrm{t} \ge \mathrm{t}_F, \text{ fully habituated} \end{cases}$$

$$\begin{aligned} MSI_I &= 100\,\Phi(z_a)\Phi(z_t') \\ z_a &= A_1 \log_{10} a + A_2 \log_{10} f + A_3 \log_{10}^2 f + A_4 \\ z_t' &= B_1 z_a + B_2 \log_{10} t + B_3 \end{aligned}$$

where $\Phi(z)$ is the cumulative distribution function of z (from standard mathematical tables), a is the RMS vertical acceleration (g), f is the modal frequency (Hz), and t is the time of exposure (min). The coefficients A_i and B_i are defined in Table B.1.

$$\begin{aligned} h(t) &= C_1 \log_{10} t + C_2 \\ t_I &= 10^{(1.0-C_2)/C_1} \\ t_F &= 10^{(-C_2/C_1)} \end{aligned}$$

where t_I is the time (days) at which the initial exposure peak value MSI_{MAX} occurs, and t_F is the time (days) to full habituation. The coefficients C_i are defined in Table B.1.

The magnitude of MSI_{MAX} is estimated by solving MSI_I at time t_I; however, since t_I is dependent on MSI_{MAX}, an iterative process is required. A practical solution is to estimate MSI_{MAX} by solving MSI_I at time t_{99} and then calculate t_I using the method above.

$$t_{99} = 10^{(2.33-B_1 z_a-B_3)/B_2}$$

where t_{99} (min) is the time at which 99% of the theoretical maximum for MSI_I is reached.

Table B.1: Coefficients for Calculating $MSI(t)$

i	A_i	B_i	C_i
1	2.128	1.134	$0.194\sqrt{MSI_{MAX}} - 2.20$
2	-9.277	1.989	0.64
3	-5.809	-2.904	-
4	-1.851	-	-

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DOCUMENT CONTROL DATA

(Security classification of title, body of abstract and indexing annotation must be entered when the overall document is classified)

1. ORIGINATOR (The name and address of the organization preparing the document. Organizations for whom the document was prepared, e.g. Establishment sponsoring a contractor's report, or tasking agency, are entered in section 8.)

Defence Research Establishment Atlantic
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2. SECURITY CLASSIFICATION (Overall security of the document including special warning terms if applicable.)

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3. TITLE (The complete document title as indicated on the title page. Its classification should be indicated by the appropriate abbreviation (S,C,R or U) in parentheses after the title.)

Motion Sickness Habituation in the Naval Environment

4 AUTHORS (Last name, first name, middle initial. If military, show rank, e.g. Doe, Maj. John E)

Colwell, James L.

5. DATE OF PUBLICATION (Month and year of publication of document.)

May 1994

6a. NO. OF PAGES (Total containing information. Include Annexes, Appendices, etc.)

41

6b. NO. OF REFS (Total cited in document.)

52

6. DESCRIPTIVE NOTES (The category of the document, e.g. technical report, technical note or memorandum If appropriate, enter the type of report, e g. interim, progress, summary, annual or final. Give the inclusive dates when a specific reporting period is covered.)

DREA Technical Memorandum

8. SPONSORING ACTIVITY (The name of the department project office or laboratory sponsoring the reseach and development. Include the address.)

Defence Research Establishment Atlantic
P.O. Box 1012, Dartmouth, N.S. B2Y 3Z7

9a. PROJECT OR GRANT NUMBER (If appropriate, the applicable research and development project or grant number under which the document was written. Please specify whether project or grant.)

1AP

9b. CONTRACT NUMBER (If appropriate, the applicable number under which the document was written.)

10a. ORIGINATOR'S DOCUMENT NUMBER (The official document number by which the document is identified by the originating activity. This number mrst be unique to this document.)

DREA Technical Memorandum 94/211

10b OTHER DOCUMENT NUMBERS (Any other numbers which may be assigned this document either by the originator or by the sponsor.)

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Motion sickness habituation describes the acquisition of adaptation to stimuli which produce motion sickness. This acquired habituation is important, as it is a natural process which reduces the adverse effects of motion sickness symptoms. Since naval personnel experience relatively long exposures to provocative motions, it is necessary to quantify habituation as a preliminary step towards the goal of quantifying human performance at sea. Scientific and medical literature clearly substantiate the existence of habituation and describe its general behaviour, but a method for defining habituation to ship motions is not available. A brief review of motion sickness and habituation is presented and habituation data from experiments and sea trials are described. The significance of using motion sickness incidence (MSI) as an indicator of the severity of motion sickness is examined. An existing statistical method for predicting the initial exposure MSI is combined with an empirical fit to data for MSI habituation on ship motions. The potential applications and limitations for the MSI habituation model are discussed, and requirements for future research for modelling more complex and changing motions are briefly described.

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94-04020
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