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Susceptibility to seasickness

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This paper explains part of the observed variability in passenger illness ratings aboard ships by gender, age and sickness history. Within the framework of a European project, 2840 questionnaires, gathered on several ships operating all over Europe, were analysed. Gender, age and sickness history all had a highly significant effect on seasickness. Furthermore, these effects could be characterized by two fixed parameters describing a general age effect, a third parameter dependent on sickness history and a fourth parameter dependent on gender. Female illness ratings peaked at an age of 11 years, 1.5 times as high as male ratings, which peaked at an age of 21 years. At higher ages, illness ratings decrease to only 20% of their maximum, reducing gender differences to zero. Passengers with a previous history of seasickness rated their illness about two times higher than those who had not felt sick before.

Keywords: Motion sickness; Seasickness; Susceptibility; Gender; Age; Sickness history

1. Introduction

Motion sickness, by definition, involves sickness induced by motion. There are, however, many factors affecting sickness severity, which lead to a large variability in the observed motion dependency. These include environmental effects, such as temperature and smells (Alcobia and Silva 1999), as well as personal factors, such as gender, age and predisposition. The organ of balance within the inner ear is crucial in the genesis of motion sickness. People without functioning organs of balance (such as deaf mutes) do not suffer from any kind of motion sickness (Irwin 1881, James 1882, Kennedy *et al.* 1968, Money 1970, Reason and Brand 1975). Although vision is also important (Brandt *et al.* 1971, Probst *et al.* 1982, Lackner and Graybiel 1987, Griffin and Newman 2004), it

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is not essential, since motion can induce sickness in blind people (Desnoes 1926, Graybiel 1970). Because motion sickness is characterized by drowsiness, headache, pallor, thermal effects, stomach discomfort, nausea and ultimately vomiting, the vegetative system is highly involved as well. Because of these interactions and the functional variability of all the subsystems involved, motion sickness (susceptibility) may vary both in between and within people. However, some general trends can still be observed, such as the dependency on gender and age.

It is generally agreed, for example, that females are more susceptible to motion sickness than males. Most observations in this respect regard seasickness. Nieuwenhuijsen (1958) observed that females were about 1.5 times more susceptible than males were, where passengers below the age of 10 years were typically most susceptible. Probably the most extensive survey on passengers of ferry ships has been performed by Lawther and Griffin (1986, 1988), who found mean illness ratings (*IR*s) of females to be about 1.7 times those of males. These differences have also been observed in crews of round-the-world yacht races. Turner and Griffin (1995) found that females felt ill on 7% of the days vs. 3.6% for males (differing by a factor of 1.9). The incidences of vomiting for females and males were 2.9% and 1.1%, respectively (a factor of 2.6). They also found that the self-rated pre-race susceptibility was a significant predictor of a higher susceptibility during the race. Pre-race *IR*s for children appeared to be 1.1 times higher than adult ratings. Similar findings have been reported by Grunfeld and Gresty (1998), who, in addition, observed that female ratings showed a cyclical pattern coinciding with their menstrual cycle, the least sickness being observed around the time of ovulation. Finally, Hain *et al.* (1999) observed that mainly (middle-aged) women suffer from mal-de-debarquement (i.e. sickness symptoms) equal to those of motion sickness when returning to an earth-fixed environment.

Similar observations have been made in other forms of transportation. Bakwin (1971) observed that 23.3% of girls and 16.6% of boys felt sick in cars (differing by a factor of 1.4). In a tilting train environment, Förstberg (2001) observed female nausea ratings to be 3.9 times as high as male ratings. In public road transport, Turner and Griffin (1999) found about 4/3 more illness in females than in males. When considering the incidence of vomiting, this difference even increased to a factor of 3. In addition, they found that illness was greatest between the ages of 10 and 12 years, during which illness was five times higher than that at the age of 80 years. Turner *et al.* (2000) found 21.6% of females felt ill in short-haul flights vs. 12.4% of male passengers (a factor of 1.7). Here again, the difference was even larger when focusing explicitly on nausea: 13.6% and 4.1%, respectively (a factor of 3.3).

In a laboratory setting, Coriolis stimulation has been shown to be an effective stimulus to provoke sickness. Here, subjects are typically rotated about an earth vertical axis while making head movements. This induces illusory tilt about a third axis, which is often accompanied by nausea, possibly even after the first head movement. Cheung *et al.* (2001) used Coriolis stimulation to study the effect of the menstrual cycle in more detail, but did not obtain a positive result. With this same stimulus, Cheung and Hofer (2002) furthermore showed that female and male *IR*s, as well as nausea-related physiological parameters were equal. A popular way of inducing sickness in the laboratory is to apply optokinetic stimulation using a cylinder with internal vertical stripes rotating about the subject. In this way, Jokerst *et al.* (1999) also found that females show higher *IR*s and that this was independent of the gender of the experimenter. Interestingly, Park and Hu (1999) observed no gender differences using such a stimulus, while the sickness history self-ratings showed a higher female susceptibility. Using a typical virtual environment, Stanney *et al.* (1999) found that female sickness ratings were 3.4 times higher than male ratings. They also observed a high correlation between sickness history and present sickness.

Using self-ratings in large cohort studies, Abe *et al.* (1970) found the female susceptibility to motion sickness in all ages to be about 4.0 times that of males, while specifically during childhood this ratio was only 1.9. Lentz and Collins (1977) and Dobie *et al.* (2001) also found in similar trials that females were more susceptible than males. In addition, Dobie *et al.* did not find an interaction between age and gender, sex differences remaining stable across age. Furthermore, the latter authors argued that males are not less inclined to admit illness, as is sometimes assumed. Kitahara and Uno (1967), lastly, observed that females and elderly people felt more sick in tilted buildings (due to earthquakes); however, they argued that this was likely due to the fact that females and the elderly also spent more time in these buildings than males did.

As far as is known, there are only three reports contradicting this majority of data indicating that females are more susceptible than males. Levy and Rapaport (1985) reported no difference between males and females in a drug trial on sailing yachts, Woodman and Griffin (1997) reported no gender differences when using Coriolis stimulation and Kennedy *et al.* (1996) found that males were even more sick than females when using circular vection as the provocative stimulus.

These data most clearly show an effect of gender on motion sickness susceptibility, followed by age and sickness history. A quantitative description of these dependencies and their interactions has, however, never been formulated. This paper describes a first attempt at such a description, based on a large study aboard different ships operating in several European sea areas.

One consideration concerns the use of anti-motion sickness medication. In this respect, it is consistently found that people taking medication still suffer more from sickness than others (Nieuwenhuijsen 1958, Lentz and Collins 1977, Lawther and Griffin 1988), females typically taking more medication than males do. In this paper, medication will not be dealt with explicitly. Implicitly, it will partly be accounted for by gender and partly it will cause some further unexplained variability. The same reasoning holds for the consumption of alcohol.

2. Methods

Within a European project (COMPASS, see acknowledgement) data have been collected on the comfort of passengers related to ship motion. Questionnaires have been deployed on four ships, comprising two large conventional mono-hull cruise-ferry ships and two smaller fast catamarans, operating in the Mediterranean Sea, North Sea and Baltic Sea. Questions were taken from questionnaires used and validated previously by the Universities of Southampton and Strathclyde/Glasgow and by TNO (e.g. Turner and Griffin, 1995, Bos *et al.* 2005). This questionnaire was translated into Swedish, Finnish, Norwegian, Greek, Spanish and Italian, and back to English to check for accuracy of translation. Questionnaires were distributed personally to as many passengers as possible when approaching the harbour and collected personally at disembarkation, as well as through boxes at the exits. Young children were assisted by those responsible for them. Although the complete questionnaire deployed consisted of 20 items asking for other comfort-related issues (such as postural balance, air quality, noise and sleep quality), the present study focuses only on those questions explicitly related to sickness. These questions are shown in appendix A. Each answer to the third question on illness was given a number (0 = 'I felt alright'; 1 = 'I felt slightly unwell'; 2 = 'I felt quite ill'; and 3 = 'I felt absolutely dreadful'), which number is explicitly referred to as *IR* in the remainder of this paper.

Although motions were recorded during these voyages, this paper focuses only on the variability in observed *IR*s due to gender, age and sickness history, motion being thus regarded as an implicit variable essential for causing motion sickness.

3. Results

A total of 3150 questionnaires were returned, of which 29 (0.9%) were disregarded because their *IR* was zero, despite one or more sickness symptoms being checked. Table 1 shows the frequencies of the factors causing most discomfort and of the sickness symptoms observed when seasickness was an issue.

To study the effect of age, gender and sickness history on the observed *IR*s, data were complete for 2840 passengers. Table 2 shows the gender, age and sickness history distributions of these passengers.

Using the *IR* as the dependent variable and the given categorization for age as the independent, an ANOVA revealed highly significant main effects for gender ($p < 0.001$), age ($p < 0.001$) and history ($p < 0.001$). All two-way interactions were significant too (gender*age: $p < 0.02$; gender*history: $p < 0.02$; age*history: $p < 0.05$). Figure 1 shows mean *IR*-values vs. age, separated out for gender and sickness history. In figure 1, the number of passengers included in each mean is represented by the radius of the corresponding circle, the maximum number being 128.

Table 1. Frequency table of discomfort issues and sickness symptoms (percentages are given in parentheses relative to the 3121 valid questionnaires).

No. 1 Discomfort (only one possibility allowed)		Sickness symptoms (multiple possibilities allowed)	
None or missing	1037 (33.2)	Drowsiness	809 (25.9)
Seasickness	612 (19.6)	Feeling hot or sweating	366 (11.7)
Noise	319 (10.2)	Headache	341 (10.9)
Vibration	272 (8.7)	Stomach awareness	223 (7.1)
Unsteadiness	260 (8.3)	Dizziness	220 (7.0)
Air quality	245 (7.9)	Nausea	201 (6.4)
Discomfort while sitting	134 (4.3)	Mouth watering	105 (3.4)
Other	242 (7.8)	Cold sweating	82 (2.6)
		Change in skin colour	78 (2.5)
		Vomiting	49 (1.6)

Table 2. Gender, age and sickness history distributions (percentages are given in parentheses relative to the 2840 complete sets of questionnaires).

Gender		Age (years)		Sickness history	
Female	1433 (50.5)	4–12	133 (4.7)	Not sick before	1784 (62.8)
Male	1407 (49.5)	13–24	668 (23.5)	Sick before	1056 (37.2)
		25–42	911 (32.1)		
		43–60	824 (29.0)		
		61–88	304 (10.7)		

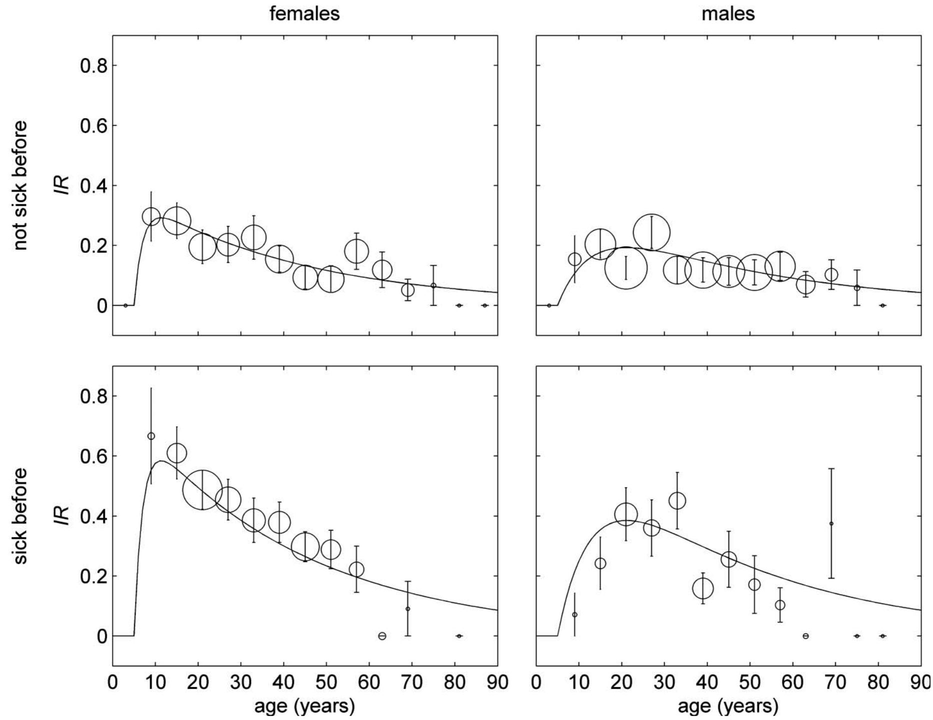

Figure 1. Mean illness ratings (*IR*) differentiated for gender, age and sickness history. Error bars indicate the SEM. Solid lines give the fits according to equation (1) using the parameters of table 1. The radius of each circle is proportional to the number of passengers included in each mean.

From the data as plotted in figure 1, it is obvious that female ratings are higher than male ratings and passengers with a previous history of seasickness give higher ratings than those who had not felt sick before. Regarding age, there was a fast logarithmic increase at childhood and a slow exponential decrease at older ages. Furthermore, there seems to be an age below which no sickness was reported. The general trend in age dependency may therefore be described by a susceptibility function S:

$$S = A\left[\exp\left(-\frac{y-a}{b}\right) - \exp\left(-\frac{y-a}{c}\right)\right], \tag{1}$$

$0 \leq S \leq 3$, with y the age in years, a the age below which there is no sickness and b and c time constants describing the age dependency as observed. The parameter A determines the amplitude of the function (which is different from its maximum). Because the current data showed virtually no sickness below the age of 5 years, $a = 5$ was fixed first. The other parameters can next be obtained by minimizing the sum of squares of the differences between observed and theorized *IR*s. Because A, b, and c may or may not depend on gender and sickness history, this minimization procedure was applied iteratively on the four subsets of data separately. Raw data were used here and not the averaged samples as shown in figure 1. The first iteration showed that the parameters b were strikingly close to $b = 40$ years in all cases. In a second iteration with b fixed accordingly, it appeared that the parameters c were equal within all female data ($c = 2$) and within all male data ($c = 8$). In the last iteration, with b and c fixed accordingly, it appeared that the parameters A could be taken equal for all passengers not sick before ($A = 0.36$) and those with a history of sickness ($A = 0.72$). A parameter summary is given in table 3. The fits using these parameters have been added to the plots in figure 1. The goodness of these fits was quantified by the correlation coefficients relating the means shown vs. the matching predicted ratings, which came to 0.91 (females not sick before), 0.75 (males not sick before), 0.96 (females sick before) and 0.71 (males sick before). These correlations were all highly significant, with $p < 0.004$.

Given the parameters of table 3, figure 2 shows the distribution of the calculated individuals' susceptibility for the current population for 5 years and above. Note that, although the theoretical upper limit for S is 3, the calculated susceptibility values S are all well below 1.

Although there were only 24 (0.8%) passengers who felt absolutely dreadful, a Chi-square test revealed no significant difference between the number of female and male passengers in this category. Note, lastly, that there were 49 passengers who also vomited, but of whom apparently a large number did not fill out the other relevant questions.

4. Discussion and conclusions

When discomfort is at issue, seasickness is by far the largest factor judged to be the cause by a normal (European) population of ferry passengers (about 20% of all cases

Table 3. Characteristic parameters describing the susceptibility according to equation (1) based on observed illness ratings ($0 \leq IR \leq 3$) for different groups of passengers.

Gender	Sick before	A (0..3)	a (years)	b (years)	c (years)
Female	no	0.36	5	40	2
	yes	0.72	5	40	2
Male	no	0.26	5	40	8
	yes	0.72	5	40	8

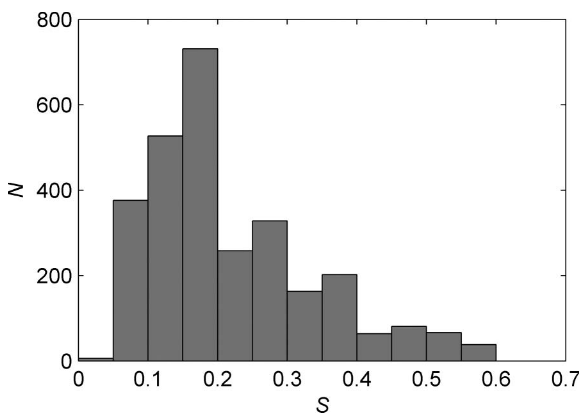

Figure 2. Histogram of observed susceptibilities calculated by equation (1), using the parameters from table 1.

considered). All other factors were judged most important by only about 10% or less of the passengers. When suffering from sickness, drowsiness was experienced most often and vomiting the least. This is in line with other observations under mild motion conditions (e.g. Bos *et al.* 2005). Although more passengers may have vomited than are included in this survey, the small number of them is another indication that, on average, the motions under consideration have been rather moderate. When motions are more vigorous, results and conclusions may be different. More vigorous motions, however, are encountered less often and the current data and conclusions are appropriate for average ferry operations. Because of the large impact of seasickness, this factor was analysed in more detail by means of the *IR*, a number ranging from 0 = 'I felt alright' to 3 = 'I felt absolutely dreadful'.

Using ship motion as an implicit parameter causing seasickness, the present data show that gender, age and sickness history can explain a significant part of the variability in observed *IR*s. Interactions between these factors were significant and the main effects were even highly significant.

The data shown in figure 1 could all be described well with the susceptibility function S according to equation 1. In fact, S is just another expression of the *IR*, but given explicitly as a function of gender, age and sickness history. Because all motions encountered in the trials described here were rather moderate, all the mean *IR*s shown in figure 1 are less than 1 despite the scale ranging from 0 to 3. This can also be read as that, on average, passengers felt somewhere in between alright and slightly unwell. The correlations between observed and predicted means were all high and the calculated chance that there was no correlation was significantly low. This included the males sick before category (see bottom right graph of figure 1), which included the least number of passengers, the largest variability and the least consistent behaviour. This might be explained by a larger variability among men, including boys, possibly denying their sickness. As can be inferred from figure 1, there were also more females than males with a previous history of seasickness. Because no significant difference was observed here in the numbers of females and males feeling absolutely dreadful, which is a symptom that is hard to deny, the above observations support the assumption that females are more open-minded on their sickness. This assumption is furthermore supported by the observation that extreme responses show no gender difference. This is in line with Woodman and Griffin (1997) and Cheung and Hofer (2002), who studied gender effects using a highly provocative stimulus, but opposes the conclusions by Turner and Griffin (1999), Turner *et al.* (2000) and Dobie *et al.* (2001). Further research may therefore still be required to determine the extent to which the observed differences between male and female susceptibility may be biased by under-reporting of symptoms.

In the present data, no sickness was reported below a certain age. This is reflected by the parameter a in equation (1). Here, $a = 5$ years was chosen. In the literature, this minimum age is assumed to be about 2 years (Reason and Brand 1975). Due to the nature of the current study by means of a questionnaire and self-ratings, no specification could be given below the age of 5 years since hardly any data were obtained from younger passengers.

Of the other parameters, A characterizes sickness history ($A = 0.36$ for those not sick before and $A = 0.72$ for passengers who had been sick before). Passengers with a history of sickness were thus twice as susceptible as those not sick before. The fact that passengers who had not been sick before did feel unwell in the present study (and the other way round) may be explained partly by differences in ship motion. There also may have been passengers for whom this was their maiden voyage. Assuming the current population to be representative for other ferry routes as well, one may calculate a mean history factor from the above numbers, giving:

$$A = \frac{1784 \cdot 0.36 + 1056 \cdot 0.72}{2840} \approx 0.5. \qquad (2)$$

The parameter c accounts for the interactions as revealed by the ANOVA. Interestingly, c primarily describes the increase of illness in young passengers, which apparently differs for girls and boys. It thus indirectly also results in different overall susceptibilities. If c in equation (1) is smaller, S will be larger. With $c = 2$ for females, $c = 8$ for males and $b = 40$ describing the decrease of illness at older ages, the model (1) thus shows an illness peak for females at the age of 11 years, being about 1.5 times that of males at the age of 21 years. This is illustrated in figure 3, where, in addition, the characterization of a mixed population is shown with $c = 5$.

The gender difference observed here is at the low end of the differences reported in previous studies (e.g. Nieuwenhuijsen 1958, Abe *et al.* 1970, Bakwin 1971, Lawther and Griffin 1986, 1988, Turner and Griffin 1995, 1999, Stanney *et al.* 1999, Turner *et al.* 2000, Förstberg 2001).

As with Turner and Griffin (1999), the present data show a difference of about a factor of 5 between passengers aged 10 and 80 years. The age dependency given here is more specific than described previously, with a new observation that females peak at a younger age than males. However, more research is needed to confirm this finding since only a minority of respondents in this study were aged below 10 years. The interaction between gender and age as observed here seems to oppose the conclusions by Abe *et al.* (1970), who found a gender ratio of 1.9 during childhood and 4.0 during later life. Yet, these data do suggest that male and female susceptibilities are already increasing at a different rate during childhood, which is in line with the present observation. Dobie *et al.* (2001) found no interaction between gender and age. Different age groups studied may explain this difference, where the present data do not distinguish between male and female ratings at higher ages either (see figure 3), due to the same large time constant of $b = 40$ years for both genders.

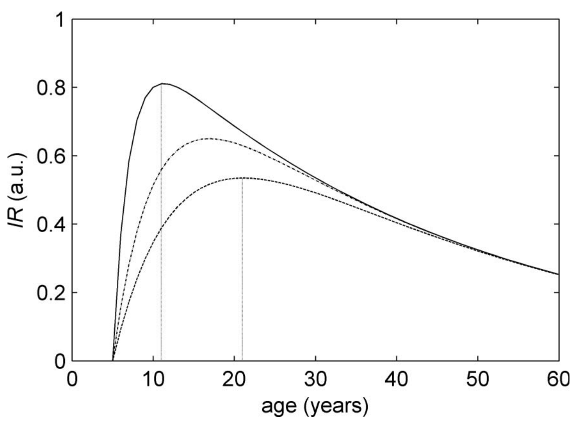

Figure 3. Predicted illness rating as a function of age for females (solid line, $c = 2$), males (dashed line, $c = 8$) and a mixed population (dotted line, $c = 5$).

International Organization for Standardization (1997), lastly, suggests that motion sickness incidence may be predicted by:

$$IR = K_m \times MSDV_z. \tag{3}$$

Here, K_m is a constant, which may vary according to the exposed population (personal factors), but which has a value of 1/3 for prediction of the percentage of people from a mixed population who may vomit during exposures up to about 6 h. $MSDV_z$ is the motion sickness dose value, a variable depending on motion and time given by:

$$MSDV_z = \left(\int_0^T a_w^2(t)dt \right)^{1/2}, \tag{4}$$

where $a_w(t)$ is the acceleration in the vertical axis, after applying a frequency filter to account for the human sensitivity to different frequencies of motion. This study shows that motion sickness might be predicted more accurately, using gender, age and/or sickness history to explain part of the variability, by using the distribution of susceptibility values calculated for the current population (for passenger ages of 5 years and above), as shown in figure 2. Hence, the above equation may be extended by:

$$IR = K_m \times S' \times MSDV_z, \tag{5}$$

where S' is the susceptibility S according to equation (1) divided by the mean susceptibility, which was 0.22 in the present study, and using the parameters given in table 3.

The $MSDV_z$ according to ISO 2631–1 only takes account of vertical motion, which tends to be dominant on conventional ships. On other types of vessels (high speed, unconventional hull forms) more sickness may be induced by motions in other axes. Models have been recently developed that estimate the degree of provocation from motions in all six translational and rotational axes (Bos and Bles 1998, Bos *et al*. 2002, Verveniotis and Turan 2002).

Returning to the primary objective of this paper, it is concluded that gender, age and sickness history can explain a significant part of the variability in observed *IR*s aboard ships.

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Appendix A: Questionnaire

The Illness Ratings ($IR = 0$–3) after the third question options were not included in the version actually deployed.

Your age and gender

	Male	*Female*
Gender (please tick one box)	☐	☐
Enter your age in years		____________

Have you ever suffered from sickness on ships?

	No	*Yes*
Please tick one box	☐	☐

Which of the following corresponds most closely to the worst you felt on this voyage?
(please tick one box only)

	IR
I felt alright	☐ = 0
I felt slightly unwell	☐ = 1
I felt quite ill	☐ = 2
I felt absolutely dreadful	☐ = 3

Have you felt any of the following on this voyage? (please tick all appropriate boxes)

Feeling hot or sweating	☐
Headache	☐
Change in skin colour	☐
Mouth watering	☐
Cold sweating	☐
Drowsiness	☐
Dizziness	☐
Stomach awareness	☐
Nausea (feeling sick)	☐
Vomiting	☐

Which of the following have caused you the most discomfort during this voyage?
(please tick one box only)

Seasickness	☐
Discomfort while sitting	☐
Unsteadiness/loss of balance while standing	☐
Difficulties with tasks of activities	☐
Noise	☐
Vibration	☐
Air quality	☐
Other (specify)________________________	☐
No discomfort experienced	☐
