Predictive ability of motion sickness susceptibility questionnaire for seasickness individual difference in Chinese military personnel

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Abstract

Background Motion sickness susceptibility questionnaire (MSSQ) has been widely used for assessing individual differences in motion sickness. The present study tried to investigate its efficacy for predicting seasickness susceptible (SUS) and insusceptible (INSUS) subjects among Chinese military personnel.

Methods Two cohorts of young male army volunteers were exposed to real ship motion (n=125) and laboratory vertical oscillation motion (n=77). Predictive ability of the MSSQ and its vomiting (MSV) and nausea (MSN) subscales (including child and adult subitems) was examined via analyzing area under the curve (AUC) of receiver operating characteristic (ROC) with seasickness susceptibility defined by Graybiel score or nausea latency.

Results Higher Graybiel scores and lower percentage of INSUS subjects was observed in the ship motion trial than the vertical oscillation trial. MSSQ and its subscales positively correlated with the Graybiel score in both trials. The MSN child showed no predictive ability for the INSUS subjects, leading to lower AUC of the MSN than the MSSQ and the MSV for INSUS prediction in ship motion (0.587 vs. 0.647 and 0.644, $P < 0.01$) and vertical oscillation trial (0.696 vs. 0.761 and 0.788, $P < 0.01$ and 0.05) when seasickness susceptibility was defined by Graybiel score. Lower AUC in the MSN than the MSSQ (0.691 vs. 0.758, $P < 0.05$ and 0.01) was observed due to invalidity of MSN child when susceptibility was defined by nausea latency in the vertical oscillation trial. The prediction ability of SUS did not differ among the MSSQ and its subscales in both trials. Relative to the ship motion trial, the vertical oscillation trial showed higher predictive efficacy of the MSSQ for the Graybiel score-defined SUS subjects (0.840 vs. 0.686, $P < 0.05$) as a result of higher AUC in both the MSV (0.840 vs. 0.690, $P < 0.05$) and the MSN (0.806 vs. 0.651, $P < 0.01$).

Conclusions The MSSQ was effective for predicting seasickness susceptibility in young male Chinese military members, but the efficacy varies with motion intensity and complexity and the vomiting scale should be recommended for application.

Background

Motion sickness is a complex response induced by real or illusive motion in unadapted individuals [1]. Travelers usually experience seasickness, airsickness, carsickness and train sickness, while space sickness always affect astronauts under microgravity conditions. Sensory conflict caused by mismatch between afferent motion perception information and anticipated ‘internal model’ of past motion experience initiates motion sickness within minutes of provocative motion exposure [2–5]. Cardinal motion sickness clinical manifestations include drowsiness, dizziness, increased salivation, cold sweating, facial pallor as well as nausea and vomiting [1,6,7]. Physiological dysfunctions and malaise induced by motion sickness could lead to remarkable cognitive performance decline and judgment impairment resulting in incapacity to perform duties and extra accidental risks in military members exposed to aerospace and nautical environment [8–10].

There are great individual differences in motion sickness susceptibility among healthy populations [11]. Assessment of susceptibility was preliminary for randomization of stratification in motion sickness clinical research and was also prerequisite for making population-based habituation training or medication intervention. Simulators for certain types of motion or virtual reality could support evaluation of individual differences in motion sickness only in a few specialized laboratories [12,13]. However, utilization of these facilities for assessing large populations of civilians or military members is limited due to high cost and logistic supporting difficulties. For overcoming these obstacles, classic motion sickness susceptibility questionnaires (MSSQ) applicable for all kinds of motion sickness have been built and subsequently ungraded to improve practicability. In 1949, Benson created the first version of motion sickness history questionnaire which has been used to clarify primarily sensory characteristics related to motion sickness susceptibility [14]. In 1975, Reason and Brand established a long-form MSSQ (MSSQ-Long) based on the Benson's questionnaire [15,16]. The MSSQ-Long was designed to inquire about the frequency of feeling 'sick or nauseated' and 'vomited' (on separate tick boxes) while travelling on various types of vehicle (i.e. cars, buses or coaches, trains, airplanes, small boats, and ships) and funfair devices (i.e. swings, roundabouts, Big Dippers) during childhood (before the age of 12 as a child) and adulthood (over the last 10 years as an adult). The limitation of the MSSQ-Long was its over-length unfit for large surveys. In 2006, Golding developed a short-form MSSQ (MSSQ-Short) to compromise between time cost and validity via simplifying the scoring system and the survey items of the MSSQ-Long [15,17].

Nowadays, the MSSQs are widely used for estimating population distribution as well as gender and age differences for motion sickness susceptibility [18,19]. However, different levels of motion frequency and participants' ability to recall motion sickness nausea and/or vomiting experience might affect the accuracy of the questionnaires [18]. The deletion of the vomiting questionnaires, as a most remarkable reduction process in the MSSQ-Short relative to the MSSQ-Long, potentially increase the risk of underestimation of extremely motion sickness susceptible individuals in large populations [17]. Most importantly, whether the MSSQ could be used as an effective tool for screening susceptible (SUS) and insusceptible (INSUS) individuals from a specific population still remained unclear. Given that seasickness is the most dramatic and debilitating form of motion sickness in the Chinese military, the present study tried to investigate the predictive ability of the MSSQ containing both nausea and vomit questionnaires for individual difference in seasickness susceptibility in young male Chinese military subjects. We analyzed the predictive efficacy of the MSSQ and its subscales for discriminating seasickness SUS and INSUS subjects in a real ship motion trial. Given that vertical motion relative to gravity is the most crucial factor for induction of seasickness, we further validate the results in a laboratory vertical oscillation motion trial under controlled experimental conditions.

Methods

Participants

Two cohorts of young healthy male Chinese Han volunteers (age < 35 years) were recruited from the army for real ship motion (n = 125) and vertical oscillation motion trials (n = 77). All participants declared

no history of drug addiction or long-term medication. This research complied with the tenets of the Declaration of Helsinki and was approved by the Institutional Review Board at Second Military Medical University (Shanghai, PR China). The informed consent was obtained from each participant in writing. MSSQ was filled out by each participant immediately after the signing of the informed consent. In the real ship motion trial, 10 subjects who had no experience of exposure to any types of motion listed in the MSSQ tick boxes have been discarded in the following analysis (n = 115 remained).

MSSQ establishment

The MSSQconsisted of both vomiting (MSV) and nausea (MSN) subscales which was established based on MSSQ-Long and the MSSQ-Short [20,21]. In each subscale, motion sickness experience during childhood before the age of 12 and during adulthood over the last 10 years was surveyed using 2 separate MSSQ-Short style tick boxes containing five-grading options on the score of vomit or nausea (never traveled or not experienced, 0 = never, 1 = rarely, 2 = sometimes and 3 = frequently) for different types of transport. (Table 1). Given that roundabouts and big dippers were scarcely played in the volunteers, they were excluded in the transport type list ('T' column) making it shortened from 9 to 7 types (cars, buses, trains, aircraft, small boats, large ships and swings). Thus, both the MSV and the MSN subscales encompass childhood and adulthood part which contained 35 items each (7-motion types × 5-grading options). Count the number of transportation types that were never traveled or experienced (the number of ticks in the 't' column) and total the sickness (felt nauseated or vomited) scores in each tick box. The MSSQ and its subscales were calculated with the following formula.

$$\text{MSV child} = \frac{\text{total vomit score} \times 7}{7 - \text{number of types not experienced as a child}}$$

$$\text{MSV adult} = \frac{\text{total vomit score} \times 7}{7 - \text{number of types not experienced as an adult}}$$

$$\text{MSV subtotal} = \text{MSV child} + \text{MSV adult}$$

$$\text{MSN child} = \frac{\text{total nausea score} \times 7}{7 - \text{number of types not experienced as a child}}$$

$$\text{MSN adult} = \frac{\text{total nausea score} \times 7}{7 - \text{number of types not experienced as an adult}}$$

$$\text{MSN subtotal} = \text{MSN child} + \text{MSN adult}$$

$$\text{MSSQ total} = \text{MSV subtotal} + \text{MSN subtotal}$$

Seasickness susceptibility definition

Seasickness susceptibility was assessed based on the Graybiel rating score (motion sickness severity) or the latency to become nauseated (nausea latency or tolerance to motion) [22]. The Graybiel scale was

designed to survey multiple dimensions of motion sickness characterized by the degree of 6 representative cardinal symptoms: nausea syndrome on a five-point scale of 0 (no nausea or vomit), 2 (epigastric discomfort), 4 (slight nausea without vomit), 8 (moderate or severe nausea without vomit) or 16 (vomit or retch) as well as skin color, salivation, cold sweating and drowsiness on a four-point scale of 0 (no symptom), 2 (slight), 4 (moderate) or 8 (severe) and headache or dizziness (0 and 1). Seasickness susceptibility was defined by the Graybiel score (SUS ≥ 8, INSUS ≤ 2) [7,23] or nausea latency (SUS ≤ 10 min, INSUS > 40 min).

Apparatus and procedures

During the week prior to the experiment, all participants were inquired about the signs and symptoms of the gastrointestinal system (stomach and abdominal pain or discomfort), the central nervous system (headache, dizziness, insomnia or drowsiness) and the vestibular and hearing system (vertigo or tinnitus) each day. They all declared not feeling discomfort or sickness and being ready for the following experiment.

In the real ship motion trial, the participants were randomly assigned to two separate landing ships (length: 54 m, width: 9.2 m, displacement: 400 tons) which departed at about 8:00 a.m., cruised at about 12 knots side by side along a predefined route at sea and came back at 11:00 a.m. During the whole voyage, all subjects were asked to be seated in the center of the main cabin (length: 30 m; width: 7 m; depth: 5 m) with the hatch cover closed. The weather was generally clear and the sea state was Degree 4 (wave height: 1.25–2.50 m) on the Douglas Sea Scale [24]. As for the limited number of researchers, we were incapable of recording the nausea latency of the 115 subjects. All participants were asked to fill out the Graybiel scale immediately after landing and seasickness susceptibility was evaluated only based on the Graybiel scores.

A vertical motion simulator composed of steel frame (length×width×height: 1.30 m×1.30 m×4.85 m), chain transmission device, servo motor with controllers and four separate plexiglass cabins (length×width×height: 1.20 ×0.90×1.85 m) was used in the vertical oscillation trial. Sinusoidal vertical oscillation with variable frequency and magnitude could be produced by the servo motor controlled by programmable logic controllers. Participants were asked to be seated in the cabins separately without motion for 5 min. Then they were exposed to vertical sinusoidal vertical oscillation [frequency: 0.5 Hz, root mean square (RMS): 2.0 m/s^2] continuously for 1 h. The acceleration parameters were set to produce moderate motion sickness dose value with the incidence of vomit less than 10 % according to the study of O'Hanlon and MeCauley [25]. Motion sickness signs and symptoms for each subject were recorded every 5 min during the vertical motion by a rater through simultaneous communication and observation using walkie-talkies and video cameras equipped in each cabin. Graybiel rating and the nausea latency were determined by another rater via replaying the video after the trial.

Statistics

The IBM SPSS Statistics 21 software was used for the following statistical analysis. T test analysis was conducted to examine the difference in demographics between two cohorts. Wilcoxon nonparametric analysis was conducted to test the differences in Graybiel score as well as MSSQ scores due to non-normal distribution determined by Shapiro-Wilk analysis. Correlation analysis was conducted using Pearson test. The MedCalc version 19.1.7 was used to construct the receiver operating characteristic (ROC) curve for assessing predictive ability of. Differences in area under the ROC curve (AUC) as a measure of the predictive ability of the MSSQ and its subscales to discriminate SUS and INSUS subjects were compared by Delong's test [26].

Results

Table 2 showed that there was no significant difference in subjects' demographics between the real ship motion and the vertical oscillation trials. High reliability scores of MSSQ were obtained in both trials (test-retest r = 0.92 and 0.90). The ship motion trial showed significantly higher Graybiel scores (Wilcoxon test: $Z = -3.381$, $P < 0.01$), but lower percentage of INSUS subjects ($\chi^2 = 4.89$, $P < 0.05$) than the vertical oscillation trial. The percentage distribution of Graybiel score-defined and nausea latency-defined seasickness susceptibility (SUS and INSUS subjects) showed no difference in the vertical oscillation trial. Incidence of nausea was significantly higher than incidence of vomiting in both trials ($\chi^2 = 9.44$ and 5.78, $P < 0.01$ and 0.05), while no difference was observed in nausea or vomiting incidence between two trials.

The levels of the MSSQ and its subscale scores showed no difference between two trials (Table 3). Childhood item total scores (MSV child + MSN child) was significantly higher than the adulthood ones (MSV adult + MSN adult) in both trials (ship motion: 10.43 ± 12.51 vs. 7.59 ± 9.22, Wilcoxon test: $Z = -3.475$, $P < 0.01$; vertical oscillation: 9.91 ± 9.95 vs. 7.27 ± 9.30, Wilcoxon test: $Z = -2.769$, $P < 0.01$). Significant positive correlations of the MSSQ and its subscales with the Graybiel score were observed in both trials. In the vertical oscillation trial, there was a significant negative correlation between Graybiel score and nausea latency ($r = -0.840$, $P < 0.001$). The MSSQ and the MSV subtotal (and its subitems), but not the MSN subtotal (or its subitems), showed negative correlations with the nausea latency (Table 3).

In the real ship motion trial, all the MSSQ, and its subscales and subitems, except for the MSN child and the MSN subtotal, had significant and similar AUC values of the ROC curve established for predicting the SUS and the INSUS subjects defined by the Graybiel score (ROC analysis: $P < 0.05$ or 0.01; Table 4). The MSN child and the MSN subtotal showed no predictive ability for the INSUS subjects (ROC analysis, $P > 0.05$), while the MSN child also had lower AUC for SUS and INSUS prediction than the MSV adult (0.620 vs. 0.699 $Z = 1.975$, $P < 0.05$; Figure 1A) and the MSV child (0.651 vs. 0.558, $Z = 2.66$, $P < 0.01$, Figure 1C), respectively. Although the correlation of the MSN subtotal with the MSSQ total was high ($r = 0.943$), the MSN subtotal had significantly lower AUC for INSUS discrimination than the MSSQ total and the MSV subtotal (AUC: 0.587 vs. 0.647 and 0.644, $Z = 2.91$ and 2.59, $P < 0.01$; Figure 1D). No significant difference was observed in AUC values among the MSV subtotal, the MSN subtotal and the MSSQ total for SUS prediction (Figure 1B).

In the laboratory vertical oscillation trial, there was no significant difference in AUC values for prediction of SUS among the child and adult subitems or among the MSV subtotal, the MSN subtotal and the MSSQ total. (Figure 2A and B for Graybiel score-defined SUS and Figure 3A and B for nausea latency-defined SUS). The MSN child showed no discriminating ability for the INSUS subjects defined by either Graybiel score or nausea latency in contrast to other MSSQ subscales and subitems which had significant AUC for prediction of both the SUS and the INSUS subjects (ROC analysis: $P < 0.05$, 0.01 or 0.001, Table 4). The AUC values of the MSN child for discriminating INSUS subjects were significantly lower than those of the MSV child (Graybiel score-defined: 0.592 vs. 0.747, $Z = 2.57$, $P < 0.05$; Figure 2C; Nausea latency-defined: 0.637 vs. 0.803, $Z = 2.22$, $P < 0.05$; Figure 3C). Similar to the ship motion trial, the vertical oscillation trial also showed lower AUC in the MSN subtotal than that of the MSSQ total and the MSV subtotal in predicting INSUS subjects defined by the Graybiel score (AUC: 0.696 vs. 0.761 and 0.788, $Z = 2.784$ and 2.10, $P < 0.01$ and 0.05; Figure 2D), despite a high correlation of the MSN subtotal with the MSSQ total ($r = 0.95$). Lower AUC in the MSN subtotal than the MSSQ total was also observed when INSUS subjects were defined by nausea latency (AUC: 0.691 vs. 0.758, $Z = 2.145$, $P < 0.05$ and 0.01; Figure 3D). In contrast, the MSV subtotal did not differ from the MSSQ total in prediction of both SUS and INSUS subjects defined by the two criteria. Relative to the real ship motion trial, the laboratory vertical oscillation trial showed significantly higher predictive efficacy of the MSSQ total for the Graybiel score-defined SUS subjects (0.840 vs. 0.686, $Z = 2.126$, $P < 0.05$) as a result of higher AUC in both the MSV subtotal (0.840 vs. 0.690, $Z = 2.519$, $P < 0.05$) and the MSN subtotal (0.806 vs. 0.651, $Z = 2.582$, $P < 0.01$).

Discussion

The present study demonstrated the effectiveness of the MSSQ for discriminating seasickness SUS and INSUS subjects from normal young male Chinese military samples exposed to real ship motion and laboratory vertical oscillation. High consistency in the MSSQ scores between two trials indicated reliability of the questionnaire and repeatability of the survey procedure. The vertical oscillation trial showed estimating efficacy of the MSSQ and its subscales regardless of the definition of seasickness susceptibility (severity or latency). However, the MSN child was found to be an invalid item which might decrease the prediction efficacy of the MSSQ for discriminating INSUS subjects. Higher predictive ability for SUS differentiation was found in subjects exposed to vertical oscillation motion than those exposed to complex real ship motion indicating that motion pattern might affect the accuracy of the MSSQ.

Previous studies have validated significantly negative correlations of the MSSQ-Long and the MSSQ-Short scores with nausea latency to varieties of controlled provocative laboratory motion stimulus (shorter tolerance time in subjects with higher MSSQ scores) [18,19,21,27]. Nevertheless, the correlation r values differed greatly among the cross-coupled Coriolis rotation, vertical oscillation and horizontal oscillation studies [21,28]. Consistently, the present study also showed that the MSSQ as well as its MSV subscales negatively correlated with the nausea latency in the laboratory vertical oscillation trial but the r values (−0.37 and −0.34) were slightly weaker than those observed for MSSQ-Long (−0.45~0.42) in previous vertical and horizontal oscillation studies [21]. Such discrepancy might possibly be related to the higher vertical oscillation frequency at 0.5 Hz used in the current study in contrast to 0.30 Hz in the

previous studies. Another possible explanation is the elimination of the funfair facilities (roundabouts and big dippers) in our questionnaire leading to lower subscores in childhood survey items than those of the MSSQ-Long. The current study also found positive correlation of the MSSQ and its subscales with Graybiel grading score. The greater correlations of the MSSQ with the Graybiel score than with the nausea latency indicated that the MSSQ, designed for investigating motion sickness frequency in the past, tended to characterize the 'magnitude' rather than the 'threshold' aspect of initial sensitivity to a motion challenge [29].

The present study showed significant prediction ability of the MSSQ total for SUS and INSUS in both the real ship motion and the vertical oscillation trials via ROC analysis. However, we found an ineffectiveness of the MSN child for INSUS prediction which might be the cause for the less prediction efficacy for the MSN (corresponding to the MSSQ-Short) than the MSV and the MSSQ total in INSUS estimation. Our results echoes the Golding's observation in the MSSQ-Short study which showed a gradual increase in deviation when approaching the INSUS zone of the regression line in the correlation analysis between the MSSQ-Short and nausea latency[17], suggesting that the MSSQ-Short might be unfit for identifying motion resistant individuals. Meanwhile, higher AUC values of the MSV subtotal for both SUS and INSUS prediction relative to the MSSQ total were observed, although the differences did not achieve statistical significance. The current study indicated that the MSN child subitem substantially decrease the efficacy of the MSN and the MSSQ for estimating the INSUS among young adults. It is no doubt that people normally have lower ability to recall childhood experiences than adulthood ones, which might decrease the accuracy for childhood surveys relative to the adulthood counterparts. Another more likely explanation was the reduction in susceptibility with age, as was indicated by lower adulthood item total scores than the childhood ones, consistent with other studies showing greater susceptibility in adolescents than adults [28]. Monozygotic and dizygotic twin studies showed higher contribution of motion sickness heritability in childhood than in adulthood [30]. In general, motion sickness susceptibility peaks at around 9 to 10 years old and decreased with aging thereafter possibly due to aging-related adaptation and/or exposure-induced habituation [29]. We speculate that childhood subscores, when combined with the adulthood ones, might possibly become a confounding factor leading to over-representation of SUS subjects among young adults.

Greater motion sickness responses indicated by higher Graybiel score and lower percentage of INSUS subjects in the ship motion trial than the vertical oscillation trial indicated differential susceptibilities to various motion stimulation patterns in a specific population. Consistently, remarkable differences in the predictive ability of the MSSQ for both SUS and INSUS subjects between two trials was also observed. It is noteworthy that individual differences in initial susceptibility depend on general factors among normal individuals as well as specific factors associated with sensitivity to various type of motion [17]. The widely accepted evolutionary hypothesis of motion sickness proposed by Treisman states that nausea and emesis in response to motion would be an accidental by product of a defense system for getting rid of ingested neurotoxins [34]. It is reasonable to presume that physiological and anatomical variance in this system could serve as a major neural basis for the general factor of motion susceptibility. Previous studies have demonstrated that increase in threshold in vestibular saccular correlates with high

susceptibility to seasickness or vertical oscillation [35,36]. In addition, motion sickness susceptibility differs greatly in individuals exposed to various motion challenges. Earth vertical linear motion was more nauseogenic than horizontal motion, while motion tolerance to horizontal and vertical motion also varied with the frequency and acceleration of the imposed oscillation [37–39]. Low correlations among responses to various types of motion challenges suggest that differed sensitivity in vestibular apparatus might contribute to specific aspect of motion sickness susceptibility [29]. Given that nearly all subjects can be sensitive when a motion stimulus is sufficient, it is a prerequisite to define the intensity and motion pattern when describing individual differences in motion sickness susceptibility. The results of our study indicated that the MSSQ, as a predictor of general motion susceptibility, might produce systemic error in estimating individual susceptibility to specific motion type with high intensity and complex acceleration pattern such as the ship motion at sea. Additionally, personal factors including food consumption, physiological state and psychological personality as well as environmental factors such as low air quality, high temperature and humidity might be potential influential factors of motion sickness susceptibility that may also potentially affect the accuracy of MSSQ [40]. A limitation of the current study was that we did not examine the gender effect on the efficacy of the MSSQ. Further investigation should be made to evaluate seasickness susceptibility in females who also service in the military and are more prone to suffer from motion sickness than males.

Conclusions

The MSSQ was basically effective for predicting seasickness susceptibility in normal young male Chinese military members, no matter whether the susceptibility was defined by sickness severity or by endurance time. Invalidity of child nausea subitem caused low efficacy of nausea subscales for discriminating seasickness insusceptible individuals, while the vomiting subscale seemed to be more reliable to and should be recommended for application. The prediction of the MSSQ for susceptible individuals was less effective in the real ship motion trial than the vertical oscillation trial, suggesting that specific factors including motion intensity and complexity as well as environmental factors (field vs. laboratory) might affects the accuracy of the MSSQ.

Abbreviations

MSSQ: motion sickness susceptibility questionnaire; SUS: susceptible; INSUS: insusceptible; MSV: MSSQ vomiting subscales; MSN: MSSQ nausea subscales

Declarations

Ethics approval and consent to participate

This research complied with the Declaration of Helsinki and was approved by the Ethics Committee at Second Military Medical University (Shanghai, PR China). The informed consent was obtained from each participant in writing.

Consent for publication

Not applicable.

Availability of data and materials

The datasets used and analyzed during the current study are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

LP, RQ and SX gathered the raw data and completed seasickness assessment for both the ship motion and the laboratory vertical oscillation trial. MY and SY helped with seasickness assessment for both trials. XR and GL helped with data collection, data analysis and figure preparation. YC designed the study, performed data analysis and wrote the manuscript. All authors read and approved the final manuscript.

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Tables

Table 1. Motion sickness susceptibility questionnaire (MSSQ)

This questionnaire is designed to find out how susceptible to motion sickness you are, and what sorts of motion are most effective in causing that sickness.

e following questions ask about how often you **felt nauseated** when travelling or riding the lowing types of transport or entertainment (tick boxes)

Part A. **As a child (before age 12)**, how often you **felt nauseated**

	Never Traveled or Not Experienced	Never Felt sick	Rarely Felt sick	Sometimes Felt sick	Frequently Felt sick
Cars					
Buses or Coaches					
Trains					
Aircrafts					
Small boats					
Large ships, e.g. Ferries					
Swings in playgrounds					
T	t	0	1	2	3

Part B. **As an adult (Over the last 10 years)**, how often you **felt nauseated**

	Never Traveled or Not Experienced	Never Felt sick	Rarely Felt sick	Sometimes Felt sick	Frequently Felt sick
Cars					
Buses or Coaches					
Trains					
Aircrafts					
Small boats					
Large ships, e.g. Ferries					
Swings in playgrounds					
T	t	0	1	2	3

2. The following questions ask about how often you **vomited** when travelling or riding the following types of transport or entertainment (tick boxes).

Part A. **As a child (before age 12)**, how often you **vomited**

	Never Traveled or Not Experienced	Never Felt sick	Rarely Felt sick	Sometimes Felt sick	Frequently Felt sick
Cars					
Buses or Coaches					
Trains					
Aircrafts					
Small boats					
Large ships, e.g. Ferries					
Swings in playgrounds					
T	t	0	1	2	3

Part B. **As an adult (Over the last 10 years)**, how often you **vomited**

	Never Traveled or Not Experienced	Never Felt sick	Rarely Felt sick	Sometimes Felt sick	Frequently Felt sick
Cars					
Buses or Coaches					
Trains					
Aircrafts					
Small boats					
Large ships, e.g. Ferries					
Swings in playgrounds					
T	t	0	1	2	3

Note: This questionnaire is established based on the Golding's MSSQ-Short with modification [33,34].

Table 2: Demographics and motion sickness characteristics in real ship motion and vertical oscillation trials

	Real ship motion	Vertical oscillation
Demographics		
Sample size	115	77
Age (yrs.)	22.45 ± 2.69	21.51 ± 2.75
Height (cm)	172.08 ± 4.54	172.67 ± 5.35
Weight (kg)	64.18 ± 8.33	67.93 ± 6.68
BMI	21.64 ± 2.37	22.19 ± 1.74
Motion sickness characteristics		
Graybiel score	7.84 ± 9.03 *	4.88 ± 7.33
Susceptibility distribution n (%)		
SUS (Graybiel score ≥ 8)	36 (31.30)	20 (25.97)
INSUS (Graybiel score ≤ 2)	47 (40.87) *	44 (57.14)
SUS (Nausea latency ≤10 min)	—	20 (25.97)
INSUS (Nausea latency > 40 min)	—	47 (61.04)
Incidence of nausea	38 (31.67)	18 (23.38)
Incidence of vomiting	18 (15.65)	7 (9.09)

Note. BMI: body mass index; MSSQ: Motion Sickness Susceptibility Questionnaire; SUS: susceptible; INSUS: insusceptible.

* P < 0.05 compared with the corresponding vertical oscillation data.

Table 3. Scores of the MSSQ and its subscales and their correlations with Graybiel score and nausea latency

	Real ship motion		Vertical Oscillation		
	Mean	Correlation with Graybiel score (r)	Mean	Correlation with Graybiel score (r)	Correlation with nausea latency (r)
MSV subtotal	10.03 ± 11.08	0.38 ***	9.17 ± 11.05	0.51 ***	-0.37 **
MSV child	5.92 ± 6.83	0.40 ***	5.34 ± 6.88	0.45 ***	-0.33 **
MSV adult	4.11 ± 5.09	0.32 **	3.87 ± 5.56	0.47 ***	-0.32 **
MSN subtotal	8.08 ± 7.41	0.34 ***	8.13 ± 7.18	0.38 **	-0.24
MSN child	4.56 ± 7.08	0.28 **	4.69 ± 5.53	0.33 **	-0.18
MSN adult	3.52 ± 4.44	0.35 ***	3.49 ± 4.69	0.27 *	-0.18
MSSQ total	18.03 ± 17.33	0.38 ***	17.18 ± 16.15	0.50 ***	-0.34 **

Note. MSV: motion sickness vomiting subscale; MSN: motion sickness nausea subscale; MSSQ: motion sickness susceptibility questionnaire. * P < 0.05, ** P < 0.01, *** P < 0.001 derived from Pearson’s correlation test.

Table 4. Area under ROC curve (AUC) for prediction of seasickness susceptibility by the MSSQ and its subscales

	AUC for SUS (95% CI)			AUC for INSUS (95% CI)		
	Real ship motion (Graybiel score-defined)	Vertical oscillation (Graybiel score-defined)	Vertical oscillation (Nausea latency-defined)	Real ship motion (Graybiel score-defined)	Vertical oscillation (Graybiel score-defined)	Vertical oscillation (Nausea latency-defined)
MSV subtotal	0.690 (0.584-0.797) **	0.840 (0.739-0.913) ***#	0.753 (0.641-0.844) ***	0.664 (0.570-0.750) **△△	0.788 (0.681-0.872) ***△	0.747 (0.635-0.839) ***
MSV child	0.659 (0.546-0.772) **	0.824 (0.721-0.901) ***	0.772 (0.662-0.860) ***	0.651 (0.556-0.738) **¶¶	0.747 (0.635-0.840) ***¶	0.734 (0.621-0.829) ***¶
MSV adult	0.699 (0.593-0.805) **	0.779 (0.669-0.866) ***	0.687 (0.570-0.789) **	0.633 (0.537-0.721) **	0.793 (0.686-0.876) ***	0.730 (0.616-0.826) ***
MSN subtotal	0.651 (0.539-0.763) **	0.806 (0.701-0.887) ***##	0.668 (0.552-0.772) *	0.587 (0.492-0.678)	0.696 (0.581-0.795) **	0.670 (0.553-0.773) **
MSN child	0.620 (0.505-0.736) *	0.768 (0.658-0.857) ***	0.631 (0.513-0.738)	0.558 (0.462-0.650)	0.592 (0.474-0.703)	0.609 (0.490-0.719)
MSN adult	0.650 (0.539-0.761) **	0.750 (0.637-0.842) ***	0.661 (0.543-0.766) *	0.617 (0.522-0.706) *	0.751 (0.638-0.843) ***	0.704 (0.578-0.811) *
MSSQ total	0.686 (0.578-0.794) **	0.816 (0.717-0.903) ***#	0.719 (0.604-0.815) **	0.647 (0.552-0.734) **△△	0.761 (0.651-0.851) ***△△	0.725 (0.611-0.821) ***△

Note. ROC: receiver operating characteristic; AUC: area under ROC curve; SUS: susceptible; INSUS: insusceptible; CI: confidence interval; MSV: motion sickness vomiting; MSN: motion sickness nausea; MSSQ: motion sickness susceptibility questionnaire.

* $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$ for ROC analysis;

# $P < 0.05$, ## $P < 0.01$ compared with the AUC values in the real ship motion trial;

¶ $P < 0.05$, ¶¶ $P < 0.01$ compared with the corresponding AUC values of MSN child in the same trial;

△ $P < 0.05$, △△ $P < 0.01$ compared with the corresponding AUC values of MSN subtotal in the same trial;

Figures

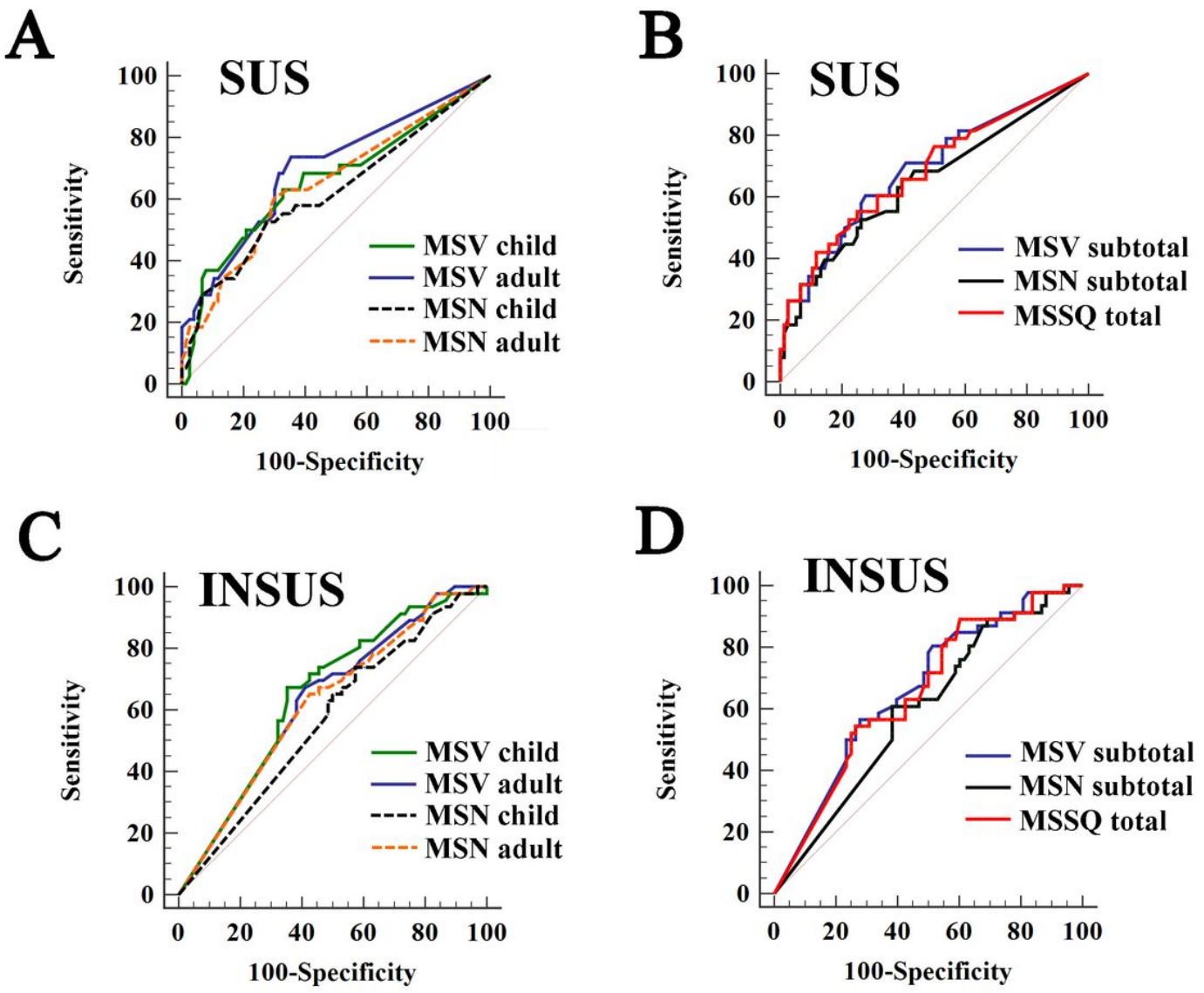

Figure 1

Figure 1

Receiver operating characteristic (ROC) curve of the MSSQ adult and child subitems (A and C) as well as the ROC curve of the MSV subtotal, the MSN subtotal and the MSSQ total (B and D) established for the prediction of the seasickness susceptible (SUS) and insusceptible (INSUS) subjects defined by Graybiel score in the real ship motion trial. MSV: motion sickness vomiting; MSN: motion sickness nausea; MSSQ: motion sickness susceptibility questionnaire.

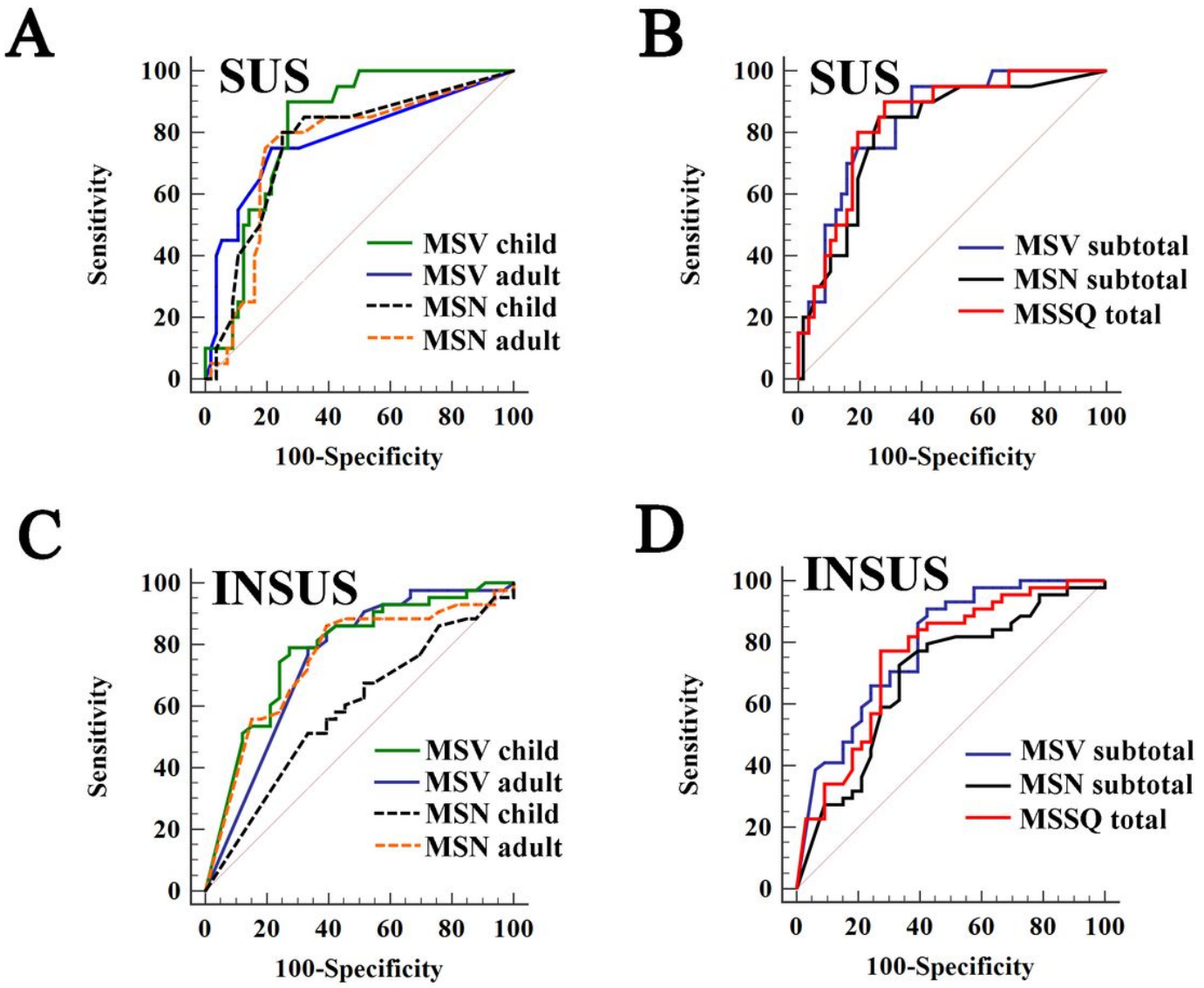

Figure 2

Figure 2

Receiver operating characteristic (ROC) curve of the MSSQ adult and child subitems (A and C) as well as the ROC curve of the MSV subtotal, the MSN subtotal and the MSSQ total (B and D) established for the prediction of the seasickness susceptible (SUS) and insusceptible (INSUS) subjects defined by Graybiel score in the vertical oscillation trial. MSV: motion sickness vomiting; MSN: motion sickness nausea; MSSQ: motion sickness susceptibility questionnaire.

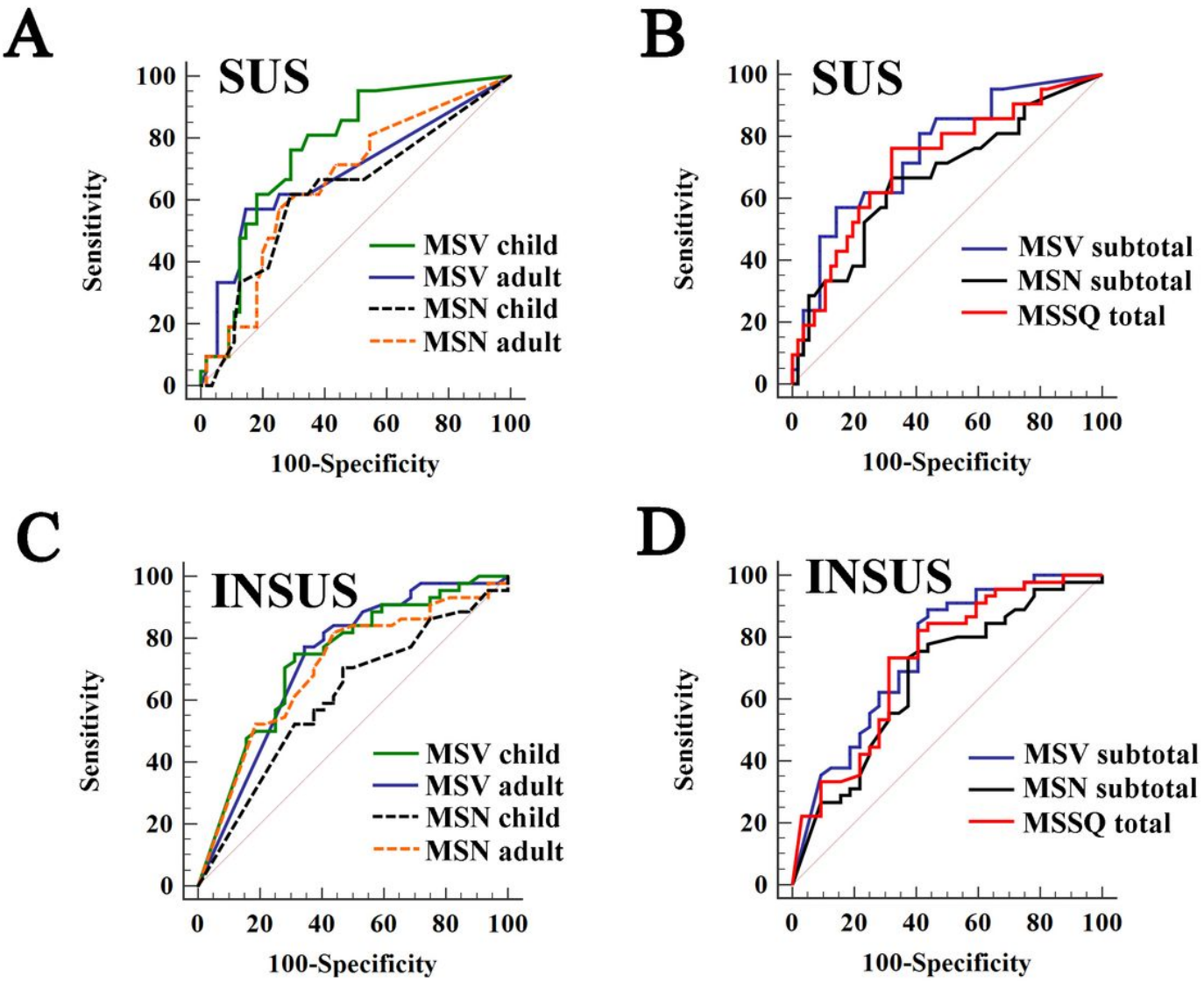

Figure 3

Figure 3

Receiver operating characteristic (ROC) curve of the MSSQ adult and child subitems (A and C) as well as the ROC curve of the MSV subtotal, the MSN subtotal and the MSSQ total (B and D) established for the prediction of the seasickness susceptible (SUS) and insusceptible (INSUS) subjects defined by nausea latency in the vertical oscillation trial. MSV: motion sickness vomiting; MSN: motion sickness nausea; MSSQ: motion sickness susceptibility questionnaire.