Motion Sickness and Resting Energy Expenditure in Chinese Male Adults

Jun-Qin Wang; Rui-Rui Qi; Lei-Lei Pan; Wei Zhou; Li-Li Zhang; Yi-Ling Cai

BACKGROUND: Motion sickness can influence energy homeostasis by enhancing thermolysis. This study tested the hypothesis that resting energy expenditure (REE), as the major component of thermogenesis, might also play a role during motion sickness.

METHODS: The effect of seasickness on REE at sea was examined in 71 healthy Chinese male volunteers. Change in REE, heart rate variability (HRV), blood ghrelin levels, and leptin levels were observed across baseline, voyage, and recovery stages. Seasickness severity was assessed using the Graybiel motion sickness questionnaire (GMSQ), and the nausea syndrome rating (NSR) of each participant was also evaluated. REE was examined by indirect calorimetry. HRV was derived from the electrocardiogram to analyze cardiac sympathovagal activity. Blood ghrelin and leptin levels were tested by radioimmunoassay.

RESULTS: In subjects with severe seasickness during the voyage, the GMSQ and NSR scores were higher than in subjects with slight and moderate seasickness. The REE declined significantly compared to baseline and recovery levels and was lower than in subjects with slight and moderate seasickness. Cardiac sympathetic activity was significantly decreased, while vagal activity was increased. Plasma ghrelin levels were also significantly increased and were negatively correlated with the measured REE levels and positively correlated with NSR as well as change of HRV LF/HF ratio from baseline.

DISCUSSION: Severe motion sickness induces REE suppression, which may be attributed to dramatic alteration of sympathovagal activity and plasma ghrelin levels in humans.

KEYWORDS: motion sickness, energy expenditure, heart rate variability, ghrelin.

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Motion sickness is a normal physiological response to unfamiliar body accelerations during passive locomotion in vehicles such as cars, boats, planes, trains, spacecraft, etc.[21] Currently, motion sickness is thought to be caused by conflict between auditory, visual, vestibular, and proprioceptive sensory inputs, leading to a mismatch between the actual and the anticipated internal model of the spatial environment.[21] Nausea and vomiting are typical manifestations of motion sickness.[10] Recently, it was demonstrated that provocative motion may also influence energy homeostasis. In humans, centrifugation enhanced heat loss via peripheral vasodilatation and sweating and also aggravated hypothermia during the succeeding cool water immersion procedure.[18] Such thermolysis effects were also observed in rats and musk shrews exposed to rotation in the horizontal plane and were related to nausea induced by motion sickness.[17] Nevertheless, on the other side of energy balance, the effect of motion sickness on thermogenesis is still unknown.

In humans, total thermogenesis is composed of resting energy expenditure (REE), diet, and physical activity-induced thermogenesis; REE is the major component. However, to the best of our knowledge, no study has investigated the amount of REE in humans experiencing motion sickness, especially under conditions of real vehicular motion, or compared this REE with normal static conditions, which may provide information regarding diet management in travelers. In the meantime, the autonomic nervous system, especially the sympathetic nervous system, plays an important role in the regulation of REE via

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controlling interscapular brown adipose tissue (BAT) thermogenesis.[19] It has been reported that motion sickness can also inhibit BAT activity in animals.[17] Therefore, we hypothesized that motion sickness may alter REE due to the perturbed sympathovagal activities under the condition of enhanced heat loss.

Previous studies have confirmed that the ghrelin/leptin endocrine system plays key roles in maintaining energy balance.[25] There is some evidence suggesting that ghrelin may also act centrally to regulate sympathetic activity and alter the cardiovascular response to stress.[9] A recent study investigated the correlation between visually induced nausea, plasma ghrelin level, and cardiac sympathetic index.[4] Nevertheless, the interrelationship between the amount of REE, sympathovagal activity, and ghrelin/leptin levels during passive motion stimulation has not yet been determined. Therefore, in the present study, we investigated the alteration of REE, heart rate variability (HRV), and blood ghrelin and leptin levels in a healthy Chinese male population during a single voyage at sea and analyzed the intercorrelations between these variables.

METHODS

Subjects

A total of 71 healthy male individuals participated in the experiments [mean age: 20.13 ± 1.97 yr; mean height: 170.96 ± 4.11 cm; mean body weight: 61.63 ± 6.48 kg; mean body mass index (BMI): 21.05 ± 1.85]. The experimental protocol conformed to the ethical guidelines of the Declaration of Helsinki as well as the American Psychological Association's Ethical Principles of Psychologists and Code of Conduct (2002, including 2010 Amendments)[29] and was approved by the Ethics Committee for the Second Military Medical University (Shanghai, PR China). All participants chosen were volunteers and informed consent was obtained in writing from each participant.

Equipment

The experiment at sea was performed on two landing ships. Each vessel is 54 m long and 9.2 m wide and has a displacement of 400 tons. Oxygen consumption ($\dot{V}O_2$) and carbon dioxide production ($\dot{V}CO_2$) was measured using a portable metabolic unit (Cosmed K4B^2, Rome, Italy) during the REE testing. A Biopac MP150 system (Santa Barbara, CA) was used to measure electrocardiograms and respiration rate and the data were recorded using Biopac AcqKnowledge 4.8.1 software.

Procedure

Our study was performed as part of the voyage of an annual Transportation Training Program At Sea which lasted about 4 wk and was launched by the army in July 2012. The experiment consisted of the following four stages. At stage 1, the volunteers ($N = 80$) were selected from 100 army recruits on the first 2 d when their personal information (age, medical and genetic history) and basic anthropometric data (height, body weight, and BMI) were collected. Nine people with self-reported health problems or BMI > 24 or < 18.5 were excluded. The remaining participants completed the Motion Sickness Susceptibility Questionnaire (MSSQ) to report their motion sickness history.[5] At stage 2 (baseline), the Graybiel motion sickness questionnaire (GMSQ), nausea syndrome rating (NSR), REE, and HRV baseline data were collected on land between 09:30–10:00 on day 3. All participants were asked to be seated on a chair and remain relaxed and conscious for at least 30 min to avoid any influence of anxiety or physical activity. They then received REE measurement and HRV monitoring simultaneously for 5 min immediately after a 5-min adaptation session during which they wore the experimental apparatus. At stage 3 (voyage), participants were randomly assigned to the two separate vessels ($N = 35$ in one ship and 36 in another), which departed from the Ri Zhao harbor (Shan Dong Province, PR China) at 08:00 and came back at 16:00 on day 4. At sea, the weather was generally clear and the sea state was Degree 3 (wave height: 0.5-1.25 m) on the Douglas Sea Scale from 08:00 to 10:30 according to the ocean weather forecast reported by the Meteorological Bureau of Shan Dong Province.[3] The time course (09:30-10:00) and the main procedures of REE and HRV testing on the ship were the same as those at the baseline stage. The research was conducted in the center of the main cabin (length: 30 m; width: 7 m; depth: 5 m) with the hatch cover open and the ships cruising at approximately 12 kn side by side along a predefined route. At stage 4 (recovery), GMSQ, NSR, REE, and HRV data were collected again on land to verify the recovery on day 5.

During each experimental session from stages 2-4, venous blood samples (5 ml) were collected at the participants' own convenience immediately after each physiological monitoring session, and all subjects completed the GMSQ at the end.[10] Participants were assigned to different seasickness severity groups based on their total GMSQ score at sea (slight: 1-2, moderate: 3-7, severe: ≥ 8).

The NSR of each participant was scored using a 16-point scale (0 = no nausea or vomiting, 2 = epigastric discomfort, 4 = slight nausea without vomiting, 8 = moderate or severe nausea without vomiting, and 16 = vomiting or retching) according to the GMSQ rating criteria.[10] To limit the potentially confounding effects of diet and physical activity on REE, as well as autonomic responses and hormone levels, all participants were instructed not to intake any food or beverages except for water for 12 h before the test and to avoid smoking, drinking, and doing vigorous exercises during the measurement period.

Measured REE (meREE) was examined using indirect calorimeters, which has been confirmed to be an appropriate measure for minute-by-minute energy expenditure.[1] Before each test, the K4B^2 was calibrated against room air and a reference gas (16.04% O_2 and 5.03% CO_2) after being warmed up for 30 min according to the manufacturer's instructions. The participants wore the portable unit using a light chest harness and wore a face mask (Hans-Rudolph) to cover their mouth and nose. The data were collected for each breath during testing and then averaged every 5 s for 5 min (for a total of 60 data points), during which the $\dot{V}O_2$ and energy expenditure state remained stable. During testing, the temperature and relative humidity were approximately 25°C and 60%, respectively. The

data from the Cosmed K4B^2 was downloaded and stored on a PC for further analysis after all of the tests were completed. REE was computed using the Weir formula: REE (KJ · min^{-1}) = (3.9 × $\dot{V}O_2$ +1.1 × $\dot{V}CO_2$) × 4.184.[27] Predicted REE (preREE) was calculated with Liu's equation for males: REE = 58.07 × body weight (kg) + 1740.50 × height (cm) − 714.35 × age (yr) + 227.36. This equation has been confirmed to be the most appropriate for predicting basal metabolic rate in healthy Chinese subjects.[13]

Electrocardiograms were measured using wireless transducers for 5 min. All signals were transmitted simultaneously to the BIOPAC data acquisition system. HRV was analyzed based on the recording of the electrocardiograms and was determined using the algorithm conforming to the frequency domain algorithm according to current guidelines of the manufacturer. The power spectral density of HRV was produced using a Welch periodogram and analyzed mainly in low frequency (LF: 0.04-0.15 Hz) amplitude (indirect index of sympathetic activity), high frequency (HF: 0.15-0.5 Hz) amplitude (indirect index of parasympathetic activity), and the LF/HF ratio (indicator of relative sympathetic/vagal activity). The measurement of LF and HF of HRV in this study was in milliseconds. Changes of HRV indexes during the voyage from baseline (delta LF, HF, and LF/HF) were also calculated. Respiration rate was also monitored with a respiration transducer to measure thoracic expansion and contraction with filters set at 10 Hz.

In the radioimmunoassay, each blood sample was divided immediately into a 2-ml aliquot, which was dispensed into an EDTA-coated tube and used to test total plasma ghrelin level, and a 3-ml aliquot, which was dispensed into a plastic tube and used to test serum leptin level. The blood samples were immediately centrifuged for 15 min at 3500 rpm at 4°C, then separated and stored at −80°C prior to analysis. Plasma levels of ghrelin and serum levels of leptin were measured using modified radioimmunoassay commercial kits (North Institute of Biological Technology Co., Beijing, China). All sample measurements were performed in duplicate.

Statistical Analysis

Statistical analysis was conducted using the SPSS v.13.0 program. All variables were tested for normality and homogeneity of variance using the Kolmogorov-Smirnov test and Levene test, respectively. Chi-squared analysis was performed to compare the constituent ratios of the number of subjects in the different seasickness severity groups on the two separate ships, and no significant differences were observed. Thus, the data obtained from the subjects in each severity-based group on the two ships were pooled for further analysis. One-way ANOVA analysis was used to compare the overall differences among the seasickness severity groups at each stage. One-way ANOVA for repeated measures was performed using the General Linear Protocol to analyze the differences across stages. When a significant result was obtained, LSD post hoc analysis was then used to perform multiple comparisons. Pearson correlation coefficients were used to determine the correlation between different variables. All data are presented as the mean ± SEM. A P-value of $P < 0.05$ was considered statistically significant.

RESULTS

In all of the participants, GMSQ score was significantly increased [$F(2,70) = 55.095$, $P = 0.001$] and meREE [$F(2,70) = 3.153$, $P < 0.05$] was significantly decreased at sea. There was also a significant increase in HF [$F(2,70) = 3.486$, $P < 0.05$], a decrease in LF/HF ratio [$F(2,70) = 3.753$, $P < 0.05$] of HRV, and an increase in plasma ghrelin levels [$F(2,70) = 4.386$, $P < 0.05$] during the voyage (**Table I**). No significant difference was observed in respiratory rate across the baseline, voyage, or recovery stages (16.14 ± 2.82 vs. 15.98 ± 2.95 vs. 16.04 ± 2.96 bpm, $P > 0.05$).

When the participants were assigned to the slight, moderate, or severe seasickness groups, no significant difference in the constituent ratios of the numbers of subjects in each group was observed between the two separate ships (slight $N = 10$ vs. 12, moderate $N = 11$ vs. 13, and severe $N = 12$ vs. 13; $\chi^2 = 0.667$, $P > 0.05$). There were no significant differences in demographics (age, weight, height, or BMI), preREE, baseline levels of meREE, or blood hormone levels between the groups (**Table II**). MSSQ scores were significantly different among the three severity-based groups [$F(2,70) = 4.487$, $P < 0.05$, severe > moderate > slight]. Severe subjects had higher LF [$F(2,70) = 3.795$, $P < 0.05$], lower HF [$F(2,70) = 5.965$, $P < 0.01$], and higher LF/HF ratio [$F(2,70) = 4.357$, $P < 0.05$] of HRV at baseline than slight and moderate subjects (Table II).

Fig. 1 shows that GMSQ and NSR scores at sea were significantly increased in the severe group, and GMSQ score was also increased in the moderate group compared with the slight group. The meREE decreased significantly in the severe group compared with the baseline and recovery level ($P < 0.01$). The

Table I. Change of the GMSQ Score, REE, HRV, and Blood Hormone Levels in All Participants at the Baseline, Voyage, and Recovery Stages.

	BASELINE	VOYAGE	RECOVERY
Seasickness assessment			
GMSQ score	0.03 ± 0.17	8.73 ± 9.41$^{**\Delta\Delta}$	0.05 ± 0.18
Energy expenditure			
MeREE (KJ · min^{-1})	4.68 ± 0.47	4.17 ± 0.42$^{*\Delta}$	4.63 ± 0.32
HRV analysis			
LF (ms^2)	30.34 ± 11.67	26.28 ± 9.24	30.58 ± 11.42
HF (ms^2)	56.56 ± 19.54	65.31 ± 14.08$^{*\Delta}$	57.34 ± 20.30
LF/HF ratio	0.84 ± 0. 64	0.42 ± 0.24$^{*\Delta}$	0.84 ± 0.48
Blood hormone			
Ghrelin (pg · ml^{-1})	483.395 ± 222.1	539.77 ± 241.75$^{*\Delta}$	478.61 ± 242.35
Leptin (pg · ml^{-1})	2.03 ± 0.79	1.93 ± 0.77	2.04 ± 0.77

GMSQ: Greybiel motion sickness questionnaire; REE: resting energy expenditure; MeREE: measured resting energy expenditure; HRV: heart rate variability; LF: low frequency; HF: high frequency;
$^*P < 0.05$, $^{**}P < 0.01$ compared with baseline levels; $^{\Delta}P < 0.05$, $^{\Delta\Delta}P < 0.01$ compared with recovery levels.

Table II. The Demographics, MSSQ Score, and the Baseline Levels of REE, HRV, and Blood Hormones in the Seasickness Severity-Based Groups.

	SLIGHT ($N = 22$)	MODERATE ($N = 24$)	SEVERE ($N = 25$)
Demographics			
Age (years)	19.95 ± 1.19 (18-23)	20.64 ± 2.56 (17-28)	19.4 ± 1.65 (18-21)
Height (cm)	171.15 ± 3.44	170.91 ± 4.23	170.00 ± 5.68
Weight (kg)	59.9 ± 5.42	63.05 ± 7.19	62.00 ± 9.09
BMI (kg/m^2)	20.45 ± 1.78	21.55 ± 1.91	21.17 ± 2.65
MSSQ score	43.10 ± 56.56	61.61 ± 67.84*	91.95 ± 78.23**$^{\Delta}$
Energy expenditure			
meREE (KJ/min)	4.76 ± 0.40	4.73 ± 0.57	4.57 ± 0.37
preREE (KJ/min)	4.43 ± 0.23	4.55 ± 0.31	4.52 ± 0.40
HRV analysis			
LF (ms^2)	27.93 ± 8.47	26.34 ± 5.42	36.75 ± 8.46*$^{\Delta}$
HF (ms^2)	64.29 ± 16.50	66.39 ± 7.61	39.35 ± 11.07**$^{\Delta\Delta}$
LF/HF ratio	0.57 ± 0.23	0.43 ± 0.12	1.53 ± 0.58*$^{\Delta}$
Blood hormones			
Ghrelin (pg/ml)	462.25 ± 139.32	486.12 ± 134.67	474.14 ± 126.96
Leptin (pg/ml)	2.01 ± 0.73	2.07 ± 0.72	2.01 ± 0.75

MSSQ: Motion Sickness Susceptibility Questionnaire; REE: resting energy expenditure; meREE: measured resting energy expenditure; preREE: predicted resting energy expenditure; HRV: heart rate variability; LF: low frequency; HF: high frequency.
* $P < 0.05$, ** $P < 0.01$ compared with slight group; $^{\Delta}P < 0.05$, $^{\Delta\Delta}P < 0.01$ compared with moderate group.

meREE during the voyage was also lower in the severe group than the slight and moderate groups.

Fig. 2 shows the changes of HRV indexes across the baseline, voyage, and recovery stages. There were significant differences across stages in LF [$F(2,24) = 16.948$, $P < 0.001$], HF [$F(2,24) = 37.453$, $P < 0.001$], and LF/HF ratio [$F(2,24) = 23.918$, $P < 0.001$] in the severe group, but not in the slight and moderate groups ($P > 0.05$). Compared with baseline and recovery levels, the HF component at sea in the severe group was significantly increased ($P < 0.001$, Fig. 2B), while the LF component and LF/HF ratio was significantly decreased ($P < 0.001$, Fig. 2A and C). No significant differences were observed in any HRV index between baseline and recovery levels in severe subjects or among the three groups at sea ($P > 0.05$). There was no change in respiratory rate across the baseline, voyage, and recovery stages in severe subjects (16.75 ± 2.19 vs. 15.26 ± 3.45 vs. 16.97 ± 2.82 bpm, $P > 0.05$). Changes in HRV indexes at voyage from baseline were greater in the severe group than in the moderate and slight groups [delta LF 113.67 ± 124.21 vs. 40.44 ± 64.84 vs. 26.90 ± 21.26 ms^2, respectively, $F(2,70) = 7.36$; delta HF 238.66 ± 138.84 vs. 35.12 ± 17.67 vs. 26.20 ± 13.21 ms^2, $F(2,70) = 16.44$; delta LF/HF ratio 1.11 ± 0.35 vs. 0.15 ± 0.11 vs. 0.08 ± 0.14, $F(2,70) = 12.98$, $P < 0.001$], while no significant difference was found between the slight and moderate groups.

Fig. 3A shows that ghrelin levels in the severe group changed significantly across the three stages [$F(2,24) = 5.984$, $P < 0.01$]. At the voyage stage, plasma ghrelin levels in the severe group were significantly increased compared to baseline ($P < 0.05$) and recovery levels ($P < 0.01$) and were also higher than plasma ghrelin levels in the slight and moderate groups [$F(2,70) = 3.149$, $P < 0.05$]. Plasma ghrelin levels were negatively correlated with meREE levels ($r = -0.541$, $P < 0.01$, **Fig. 3B**) and positively correlated with NSR scores ($r = 0.474$, $P < 0.01$, **Fig. 3C**) and delta LF/HF ($r = 0.409$, $P < 0.01$, **Fig. 3D**). There were no significant differences in serum leptin levels across the baseline, voyage, and recovery stages in the slight (2.01 ± 0.73 vs. 1.93 ± 0.89 vs. 2.12 ± 0.45 ng · ml^{-1}), moderate (2.07 ± 0.72 vs. 1.77 ± 0.74 vs. 1.97 ± 0.62 ng · ml^{-1}), or severe group (2.01 ± 0.75 vs. 2.09 ± 0.74 vs. 2.05 ± 0.65 ng · ml^{-1}), and there were no differences in serum leptin levels between these groups at any stage ($P > 0.05$).

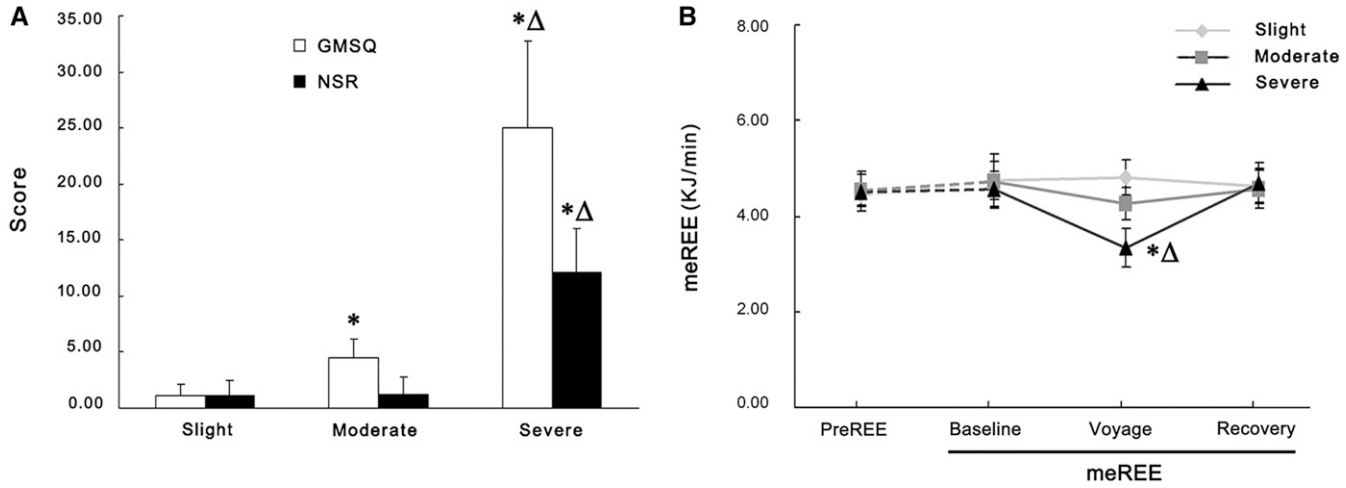

Fig. 1. Change of seasickness symptom scores and REE in three seasickness severity-based groups. A) GMSQ (white bars) and NSR (black bars) scores during the voyage in the slight, moderate, and severe seasickness groups. B) The preREE and meREE at the baseline, voyage, and recovery stages in each group. Light grey diamonds represent the Slight group, darker grey squares the Moderate group, and black triangles the Severe group. Data presented are expressed as the mean and the vertical bars represent SEM. *$P < 0.05$ compared with the slight group; $^{\Delta}P < 0.05$ compared with the moderate group.

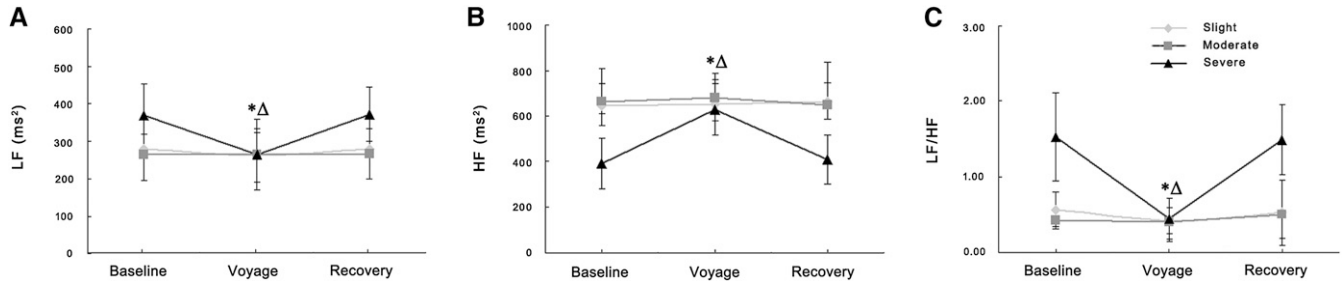

Fig. 2. Change of HRV indexes in three seasickness severity-based groups. A) Averaged LF, B) HF, and C) LF/HF ratio during 5-min monitoring session at the baseline, voyage, and recovery stages in the slight, moderate, and severe seasickness groups. Light grey diamonds represent the Slight group, darker grey squares the Moderate group, and black triangles the Severe group. Data presented are expressed as the mean and the vertical bars represent SEM. $^{*}P < 0.001$ compared with baseline levels in the severe group; $^{\Delta}P < 0.001$ compared with the recovery levels in the severe group.

DISCUSSION

The present study measured REE under standard conditions in humans exposed to passive ship motion which lead to different grades of seasickness severity. The measured baseline and recovery REE were comparable to the values predicted by Liu's equation and were equivalent to the measurements obtained from healthy Chinese adults in previous studies.[23] Interestingly, subjects with severe seasickness on two separate ships showed similar REE alteration patterns during the voyage, suggesting that REE suppression is attributable to severe motion sickness, but not due to other confounding factors. These results also support the idea that thermogenesis, in addition to thermolysis, is also involved in thermoregulation during motion sickness and the apparent decline in REE may play a role. Furthermore, we found that REE was decreased during the voyage by approximately 26.65% from baseline and approximately 28.85% from the recovery level in severe seasickness subjects. Such remarkable changes cannot be attributed to individual differences, which can only account for approximately 3-8% of the variance.[22] Our results suggest that both sympathovagal and endocrine responses that were also significant during the voyage may be responsible for REE decline in subjects with severe motion sickness.

First of all, severe seasickness subjects had much greater nausea/vomiting than slight and moderate subjects. These observations are in agreement with the HRV results showing that the HF component was lower in the severe seasickness group than in the slight and moderate groups at baseline and declined dramatically during the voyage. These results are consistent with the finding that vagal tone enhancement precedes strong nausea during visually induced motion sickness.[11] It indicates that gastrointestinal symptoms induced by provocative motion may be attributed to drastically increased parasympathetic activity in severely affected individuals. Meanwhile, LF and LF/HF ratio, as sympathetic indexes, were also decreased significantly in the severe group during the voyage, suggesting that sympathetic activity may decline. However, this is in contrast with the observation that the severity of virtual reality-induced motion sickness was associated with increments in the LF and LF/HF ratio.[12] Given the facts that humans are sensitive to lower frequency vertical sinusoidal ship motion simulation at approximately 0.2 Hz, which can actually activate the otolith organs,[6] and low-frequency (0.008–0.4 Hz) sinusoidal galvanic vestibular stimulation can exert powerful inhibitory effects on sympathetic activity via the activation of the otolith organs,[2] we thus presume that the increased vagal activity and decreased sympathetic activity in severe subjects might be induced by the over-activation of the otolith organs via low-frequency linear acceleration along the direction of gravity during the voyage at sea. Since the sympathetic nerve modulates energy expenditure in BAT and supports at least part of REE,[15] individuals with low resting sympathetic nervous activity may be at risk for body weight gain resulting from a low resting metabolic rate.[24] It is

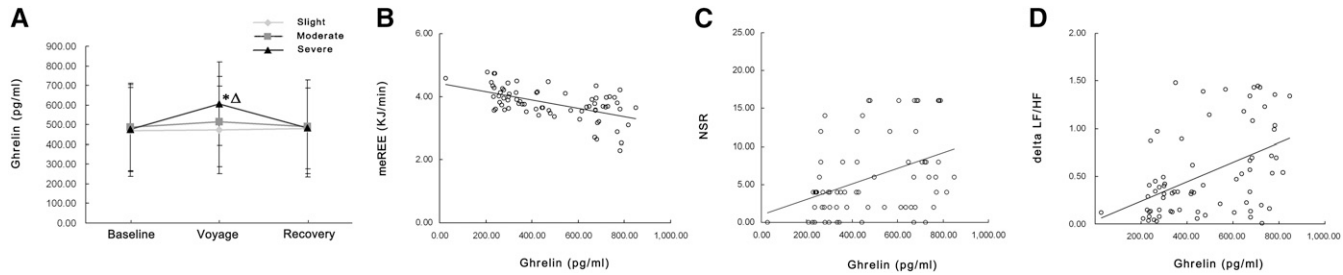

Fig. 3. Change of plasma ghrelin levels in three seasickness severity-based groups. A) Averaged plasma ghrelin levels at the baseline, voyage, and recovery stages in the slight, moderate, and severe seasickness groups. Correlation between plasma ghrelin levels and B) meREE, C) NSR score, and D) delta LF/HF ratio of all participants at the voyage stage. Light grey diamonds represent the Slight group, darker grey squares the Moderate group, and black triangles the Severe group.

also reasonable that a severe motion sickness-related decrement in REE may be due to a robust decline of sympathetic activity during the voyage.

Secondly, it has been reported that complete blockade of sympathetic activity by systemic administration of the β-adrenergic receptor inhibitor propranolol only reduced REE between 3 and 5% in healthy adult humans, while a much greater decrease in REE was observed in severe subjects in this study.[14] Thus, the decline of REE may also be related to the increased plasma ghrelin levels during the voyage. Ghrelin can suppress sympathetic activity and decrease the LF and LF/HF ratio of HRV in humans.[7,9] Elevated ghrelin secretion also directly decreases heat production via down-regulating thermogenesis-related mitochondrial uncoupling proteins in BAT and eliciting lipogenesis in both white adipose tissue and hepatocytes.[20] In addition, ghrelin secretion is regulated by the parasympathetic system. Circulating ghrelin levels rise during sleep around midnight in humans when cardiac vagal activity dominates.[26] Fasting-induced elevation in ghrelin levels can be prevented by subdiaphragmatic vagotomy.[28] As elevated plasma ghrelin levels correlated with decreased meREE levels and enhanced autonomic reactions, we hypothesized that severe seasickness-induced vagus tone enhancement might promote ghrelin secretion, which might consequently suppress both REE and sympathetic activity. In practice, since REE accounts for approximately 60-70% of total energy expenditure, the dramatic inhibition of REE may increase the risk of weight gain and obesity. Our findings support the idea of diet restriction for travelers experiencing motion sickness, especially during a voyage at sea.

A limitation of the current study is that the LF and LF/HF ratio used as measures of sympathetic activity are still in controversy. Nevertheless, these indexes only fail to reflect sympathetic activity well under conditions of orthostatic stress and pharmacological intervention[8,16] and are commonly used in studies on motion sickness.[12] In addition, as a limitation of the monitoring period, we have not demonstrated whether REE suppression persisted during the whole voyage or after the removal of the motion stimulus. Further studies should be performed to investigate the effect of repeated or long-term motion stimulation on body weight and body composition.

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