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End-tidal CO_2 relates to seasickness susceptibility: A study in Antarctic voyages

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ABSTRACT

Objective: To investigate the relationship between end-tidal CO_2 ($EtCO_2$) and seasickness (motion sickness at sea) during an Antarctic voyage.
Methods: In this study, we measured $EtCO_2$ and severity of seasickness using the subjective symptoms of motion sickness (SSMS). We sampled $EtCO_2$ and SSMS every 3–4 h for 3 days from the date of sail in 16 healthy subjects. This experiment was performed on an icebreaker (standard displacement: 12,650 t).
Results: Since 2 subjects dropped out because of severe motion sickness, available data were collected from 14 subjects. On analysis of all data of all subjects grouped together, there seemed to be a significant negative correlation between $EtCO_2$ and SSMS ($R = -0.27$, $P = 0.0005$). However, in individual subjects, this correlation was not obvious. During the voyage, $EtCO_2$ level in the seasickness susceptible group was lower than that in the non-susceptible group ($P = 0.018$). Both $EtCO_2$ increasing in the non-susceptible group and decreasing in the susceptible group contribute to the difference in $EtCO_2$ levels. We suggest that the cause of this increase in $EtCO_2$ level in the non-susceptible group was unwitting slow and deep breathing to resist seasickness.
Conclusion: We revealed that for seasickness during an Antarctic voyage, $EtCO_2$ level relates to susceptibility, but not occurrence or severity. Measurement of $EtCO_2$ levels may be useful to identify seasickness-susceptible persons and to efficiently prevent seasickness.

1. Introduction

Motion sickness is thought to result from conflict among vestibular, visual, and somatosensory systems [1]. Vestibular information is well known to be essential to the occurrence of motion sickness and subjects with non-functional labyrinths resistant to motion sickness [2,3]. Owing to the vestibular-autonomic nervous connections, motion sickness elicits not only physiological responses but also various unpleasant symptoms, including recurrent vomiting, severe general fatigue, and decrease in blood pressure [4]. Motion sickness can lead to serious disturbances in certain individuals. There are several widely used subjective indicators for grading motion sickness in research such as Subjective Symptoms of Motion Sickness (SSMS) [5] and illness rating [6]. To obtain useful

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objective indicators, various parameters of physiological responses such as electrogastrography [7], heart rate variability [8] and electrodermal activity [9], have been evaluated; however there are few well-established objective indicators for the grading or diagnosis of motion sickness to date [10–12]. Furthermore, some of these indicators are applicable only to specific stimuli, so indicators that are useful in motion sickness induced by various stimuli are far fewer [13].

Concerning the relationship between the vestibular system and physiological response, vestibular stimulation is well known to influence respiratory neurons, which presumably contribute to respiratory rhythm [14]. In a recent study using a linear sled apparatus in which subjects were exposed to fore-aft horizontal sinusoidal movement, Mert et al. [15] showed that a decrease in end-tidal CO_2 ($EtCO_2$) was related to the development of motion sickness. Moreover Nakanishi et al. [16] have shown that a decrease in $EtCO_2$ tends to correlate with the severity of motion sickness induced in cars while watching DVDs on winding roads. $EtCO_2$, the percentage concentration or partial pressure of carbon dioxide at the end of exhalation, approximately coincides with the partial pressure of CO_2 in arterial blood, a normal value for which is 35–45 mmHg [17]. $EtCO_2$ monitoring has mainly been used in anesthetic management because $EtCO_2$ correlates with the reciprocal of minute ventilation in a healthy human, and a sudden increase in $EtCO_2$ may be caused by a lethal metabolic enhancement, such as malignant hyperthermia [18]. Lately, the American Heart Association has recommended $EtCO_2$ measurement for safe tracheal intubation in emergency resuscitation [19]. There are several portable $EtCO_2$ monitoring devices convenient for not only emergency medical use but field research as well. Hence, if this association between $EtCO_2$ and motion sickness is confirmed in natural, not experimental, conditions, $EtCO_2$ measurement can be an efficacious and practical objective motion sickness indicator.

Because seasickness is the most prevalent form of motion sickness, afflicting even the most experienced sailors [4], seasickness is not only one of the most important types of motion sickness, but also an appropriate type to evaluate sick subjects in natural conditions. However, it is largely unknown whether and how $EtCO_2$ relates to seasickness. The aim of this study was to examine the relationship between changes in $EtCO_2$ and seasickness. For this purpose, our researchers went aboard an icebreaker as members of the 54th Japan Antarctic Research Expedition (JARE54) and conducted this investigation at ''the roaring forties'' latitude during an Antarctic voyage, in which seasickness is the most common and most problematic medical issue [20].

2. Methods

2.1. Subjects

The study involved 16 volunteers (14 men, 2 non-pregnant women; mean age 37.2, range 23–53 years). All subjects belong to the JARE54 team, as part of which they received a thorough medical examination, and were certified free of cardiopulmonary, renal, otological, or other systemic disease. No subject was medicated, including motion sickness prevention medicine.

The experimental procedure was performed in accordance with the Declaration of Helsinki, and had Ethical Committee (National Institute of Polar Research, Tokyo, Japan) approval. The experimental procedure was explained to the subjects and written informed consent was obtained before the experiment. Subjects were free to withdraw from the study at any time.

2.2. Experimental conditions

This study was performed on the ''AGB 5003 Shirase'' (standard displacement: 12,650 t, length: 138 m, width: 28 m) during an Antarctic voyage. ''Shirase'' is an icebreaker operated by the Japan Maritime Self-defense Force. ''Shirase'' departed from Harumi Port (Japan) without the JARE54 members and arrived in Fremantle Port (Australia) on Nov 25, 2012. After embarkation of the JARE54 members at the Fremantle Port, ''Shirase'' began its voyage to the Antarctic Ocean on Nov 30, 2012. Thus, all subjects participated in this study without habituation to seasickness.

2.3. Apparatus and questionnaire

Prior to the experiment, all subjects answered a questionnaire concerning motion sickness history. In this questionnaire, subjects were asked how frequently they become sick in 4 vehicles: cars, ships, airplanes, and rides at amusement parks. The sickness frequency scoring is defined as follows: Never = 0, Rarely = 1, Sometimes = 2, Often = 3. The summation of scores for all 4 vehicles was used as a history score. If a participant had never ridden in some of the listed vehicles, history score was calculated as the summation of the scores of all vehicles, multiplied by the coefficient (which was defined as 4 in this case), divided by the number of the vehicles in which the subject had ridden.

$EtCO_2$ (mmHg) was measured with a capnometer based on non-dispersive IR absorption (EMMA, Masimo Co., Irvine, USA). EMMA is a portable mainstream type capnometer, which is only slightly affected by humidity upon exhalation or open air. This apparatus measures and displays the $EtCO_2$ in each respiratory cycle, but cannot be connected to any recording devices. Therefore, an examiner recorded $EtCO_2$ data by hand.

The severity of seasickness was graded by Graybiel et al.'s standard motion sickness questionnaire, ''Subjective Symptoms of Motion Sickness'' [5], with which symptoms of motion sickness (nausea, dizziness, drowsiness, headache, warmth, sweating, and salivation) were assessed. We used the questionnaire translated to Japanese by Hirayanagi et al. [21].

2.4. Procedures

This experiment was performed over 3 days, from Nov 30, 2012 (the date of departure) to Dec 2, 2012. Data were collected every 3–4 h, from 9:00 to 21:00, so that each subject, in principle, received sampling trials 13 times. In these 3 days, subjects were permitted to live freely, with prohibitions only on alcohol consumption and physical exercise.

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