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Postural dynamics and habituation to seasickness

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ABSTRACT

The computerized dynamic posturography (CDP) test examines the response pattern to simultaneous, multimodal sensory stimulation. The purpose of this prospective, controlled study was to investigate whether postural dynamics evaluated by CDP are related to seasickness severity and the process of habituation to sea conditions. Subjects included 74 naval personnel assigned to service aboard ship and 29 controls designated for shore-based positions. Study participants performed a baseline CDP test, and subsequent follow-up examinations 6 and 12 months after completion of their training. On those occasions they also completed a seasickness severity questionnaire. Longitudinal changes in postural parameters were examined, as well as a possible correlation between baseline CDP results and final seasickness severity scores. The results indicated longitudinal habituation to seasickness. Reduced scores were found for sensory organization sub-tests 3 and 5 in the first follow-up examination, reflecting increased weighting of visual and somatosensory input in the maintenance of balance. Scores in the second follow-up examination were above baseline values, indicating increased reliance on vestibular cues. These significant bimodal changes were found only in study subjects having the highest degree of habituation to seasickness. A significant decrease in motor response strength was found in parallel with increased habituation to seasickness. Baseline CDP results and postural control dynamics were not correlated with subjects' final seasickness severity score. These results suggest a potential role for CDP in monitoring the process of habituation to unusual motion conditions.

Motion sickness is a normal, universal physiological response to unfamiliar motion patterns, whether real or apparent [12]. The most dramatic form of motion sickness is seasickness; other forms are space sickness, airsickness, carsickness, and the recently described cybersickness, which is common in virtual environment systems that present an optical depiction of inertial motion [1]. The development of seasickness symptoms follows a sequence that varies with the intensity of the stimulus and the susceptibility of the individual. Its main signs and symptoms include epigastric awareness, perioral and facial pallor, cold sweating, salivatory changes, retching, and recurrent vomiting. Repeated exposure to the provocative stimulus results in habituation, in which decreased susceptibility to rough sea conditions may be maintained in spite of significant intervals between voyages, sometimes as much as several weeks [15]. Our current understanding views motion sickness as the result of a conflict between the information processed within a multimodal sensory system, whose function is to determine the individual's motion relative to the environment. This has been termed the "neural mismatch theory" [11]. A sensory conflict occurs when the integrated sensory signal is at variance with previously stored motion patterns. This results in motion sickness. The conflict is eventually settled when the anticipated relations between the sensory inputs are updated. This induces habituation to the new motion patterns, including a modified motor response [6]. Although the neural mismatch theory is the most widely accepted explanation for the development of motion sickness, there are other hypotheses which might add to our understanding of its pathogenesis. Riccio and Stoffregen [13] suggested that motion sickness is caused by instability of body postural control. This theory predicts an increased incidence of sickness when external motion is imposed at a frequency of 0.1–0.3 Hz, because this interferes with the naturally occurring sway activity. The increased sensitivity to this frequency range has been verified by field studies showing that the greatest incidence of seasickness on board conventional ships is associated with heave, surge and sway acceleration frequencies of about 0.2 Hz [5,10]. Both theories are compatible with the hypothesis that postural responses might reflect both susceptibility to motion sickness and the habituation process. A previous cross-sectional study conducted in our laboratory [14] searched for possible relations between postural control and seasickness susceptibility. The computerized dynamic posturography (CDP)

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test was employed to evaluate the response pattern to simultaneous, multimodal sensory stimulation. The results suggested that seasickness-susceptible subjects depend more on somatosensory and visual input, and less on vestibular input, for maintenance of balance.

The hypotheses underlying the present study were that postural strategy would be modified with repeated exposure to sea conditions, that these changes would reflect increased habituation to the non-terrestrial motion, and that baseline postural parameters would be correlated with future susceptibility to seasickness.

Subjects were 120 male naval recruits aged 18–22 years. The study group included 90 men in basic training, who had been assigned to serve aboard naval vessels which would be making regular voyages. Their training included multiple voyages aboard small vessels in the Mediterranean, mostly in moderate sea conditions. Subjects were engaged in the various activities normally undertaken by naval crew during a voyage, and most of the time were alert and physically active. The control group consisted of 30 recruits designated for shore-based positions.

A detailed history was taken from all study participants to exclude previous cochlear or vestibular pathology. Otoneurological examination included otoscopy, bedside testing for static, dynamic, positional and positioning nystagmus, and postural tests. Pure tone air and bone, speech and impedance audiometry were carried out. Exclusion criteria included past vestibular or cochlear pathology, positive findings on otoneurological examination, and hearing loss or abnormal findings in impedance audiometry. All study participants performed a baseline CDP test when recruited to the study, and subsequent follow-up examinations 6 and 12 months after completion of their training (first and second follow-up examinations, respectively).

CDP was performed using the EquiTest system (NeuroCom International Inc., Clackmas, OR) according to the standard test protocol [3]. The device has a computer-controlled force platform, which is able to move abruptly in translational or pitch directions as well as in synchrony with a visual surround. The force data are collected and analyzed automatically by the system's computer. The vertical and horizontal forces applied to the platform are measured by transducers, and the data collected are used to locate the center of foot pressure. The patient's height and force data are used to estimate the vertical location of the body's center of gravity and the angle of sway. The CDP procedure is divided into two parts. The sensory organization test (SOT) assesses the use of sensory information by measuring postural sway under conditions in which visual and somatosensory feedback is altered. The change in sway angle is used to move a visual surround or the support surface in synchrony with the individual's sway. The influence of a lack of somatosensory and visual information on stability is evaluated, as is the subject's ability to use vestibular input to maintain balance. The SOT is organized into a series of six conditions of increasing difficulty. The first three conditions are performed on a firm surface with eyes open, eyes closed, and finally with the subject's vision sway-referenced. The final three conditions are performed with the support sway-referenced, with eyes open, eyes closed, and with the subject's vision sway-referenced. Results of the SOT are calculated based on the maximum peak-to-peak anterior-posterior sway expressed as an equilibrium score ranging from 0 to 100, with 0 indicating loss of balance and 100 indicating perfect stability. The test conditions are described in Table 1.

Table 1
Sensory organization test conditions.

Parameter	Description		
	Platform	Eyes	Visual surround
Condition 1	Stable	Open	Stationary
Condition 2	Stable	Closed	Stationary
Condition 3	Stable	Open	Moving
Condition 4	Moving	Open	Stationary
Condition 5	Moving	Closed	Stationary
Condition 6	Moving	Open	Moving
Composite	Average of conditions 1–6		

The second part of the CDP is the Motor Control Test (MCT). Successful mobility in the environment requires an individual to react to sudden external disturbances of balance. The MCT evaluates maintenance of balance, expressed by the motor responses to unexpected backward and forward translations and up-and-down pitch movements of the support surface. The latency of the response and the ability to minimize sway are a functional correlate of the long loop pathways, including the peripheral nerves, ascending and descending spinal pathways, and brain structures. The adaptation protocol exposes the subject to 5 trials each of pitch perturbations towards the subject and towards the ground. Rotation causes the subject to sway by repeatedly rotating the force plate about its *X*-axis. This demonstrates the subject's ability to adapt automatic movement responses to recurring surface movements. The sway induced by the platform's translations generates angular momentum. To counteract this sway, the subject generates an active response in the opposite direction. The Response Strength parameter measured in degrees/second is the angular momentum produced by the subject's response.

The study participants did not take any medications for at least 48 h before CDP testing. None consumed drugs or alcohol. The CDP follow-up tests in the study group were conducted at least 72 h after disembarking from a voyage, and it was verified that the subject had no symptoms of mal de debarquement [9].

Susceptibility of the study group subjects to seasickness was determined by a seasickness questionnaire, which they completed after their initial exposure to sea conditions and immediately before the follow-up CDP examinations. The questionnaire, adapted from Wiker et al. [19], scores actual seasickness severity during sailing. Seasickness is rated on a scale from 0 to 7, where a score of 7 is given to the most severe grade of seasickness.

All participants received a comprehensive explanation of the study's goals and testing procedures, and gave their informed consent before they started the tests. The Israel Defense Forces Medical Corps Human Research Committee approved the study protocol and testing procedures.

Longitudinal changes in seasickness severity scores and CDP parameters were studied by repeated measures one-way ANOVA. A possible correlation between baseline CDP parameters and the Wiker scores found after the initial sailing experience and the first and second follow-up evaluations were examined by the Spearman non-parametric correlation test. The extent to which the variance in SOT and MCT results in the course of the study may be explained by improvement in the Wiker scores was analyzed by repeated measures two-way ANOVA. For this analysis, subjects were assigned to two habituation groups according to the difference between their baseline and final scores on the seasickness severity scale. The factors used for the two-way ANOVA were the time points and the habituation group.

Statistical analysis was performed using SPSS software (SPSS, Inc., Chicago, IL) on a personal computer.

The baseline and two follow-up examinations were completed by 74 subjects (61.7%) in the study group and 29 (97%) in the control group. The dropouts in the follow-up examinations were due to the unique occupational conditions of the study population. As military personnel, some of the subjects were deployed in remote bases following their training period, and follow-up examinations were very difficult to complete. Others changed their occupation, and were not exposed to sea conditions during the whole of the study period, while still others transferred from the Navy to other