Diaphragmatic Breathing and Its Effectiveness for the Management of Motion Sickness

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BACKGROUND: Motion sickness is an unpleasant physiological state that may be controlled via nonpharmacological methods. Controlled breathing has been shown to maximize parasympathetic nervous system (PNS) tone and may have the ability to decrease motion sickness symptoms.

METHODS: The effects of slow diaphragmatic breathing (DB) in a motion sickness-inducing environment were examined within motion sickness susceptible individuals. Subjects ($N = 43$) were assigned randomly to either an experimental group trained in slow DB or a control group breathing naturally at a normal pace. The experimental group was trained using a digital video that helped them pace their diaphragmatic breathing at six breaths/min. During the study, subjects viewed a virtual reality (VR) experience of a boat in rough seas for 10 min. Motion sickness ratings along with heart rate and respiration rate were collected before, during, and after the VR experience.

RESULTS: Results indicated that the experimental group was able to decrease their breathing to eight breaths/min during the VR experience. This breathing rate was significantly slower than those in the control group. We found that DB subjects, compared to those in the control group, displayed significantly greater heart rate variability and reported feeling less motion sickness during exposure to the VR experience than those in the control group.

DISCUSSION: Results indicate possible benefits of using slow DB techniques in a motion sickness inducing environment.

KEYWORDS: self-regulation, heart rate variability, seasickness.

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Motion sickness is an unpleasant physiological state that includes gastrointestinal, central, peripheral, and sopite symptoms.[4] The frequent problems that arise from motion sickness involving these four dimensions have led to the development of numerous medicinal treatments. Unfortunately, medicinal treatments are often accompanied by adverse side effects, including mental or physical sedation.[18] The adverse side effects can be enough to dampen a personal vacation or to diminish the performance capacity of an individual working in a motion sickness provoking environment. A potential nonmedicinal treatment not accompanied by unwanted side effects involves the use of a slowed breathing pace and diaphragmatic breathing (DB) mechanics. Although the autonomic nervous system does not function similarly in every situation, motion sickness is usually accompanied by an increase in sympathetic activity and decrease in parasympathetic activity.[5] Therefore, this intervention strategy of slow diaphragmatic breathing may be particularly helpful as it increases an individual's capacity to self-regulate symptoms of motion sickness by diminishing sympathetic tone.[7,18]

Previous research investigating the use of breathing strategies for diminishing physical activation has yielded encouraging results.[7,9,18] Specifically, findings suggest that controlled breathing,[18,19] pranayamic breathing,[6] and slow-paced breathing[8] may lead to increased parasympathetic nervous system (PNS) tone. Interestingly, the combination of slow paced breathing and DB mechanics has led to improvements in the overall life quality of patients with gastroesophageal reflux disease,[6] asthma,[10,15] and chronic obstructive pulmonary disease.[17] These disorders also involve disturbed physiological states and are characterized by disrupted breathing patterns. Furthermore, controlled breathing may be useful in

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decreasing motion sickness symptoms.[1,18,19] Specifically, subjects who were instructed to control their breathing throughout an exposure to off-vertical axis rotation showed overall desensitization to the motion and a reduction in symptoms compared to control subjects.[19] Controlled breathing has also been related to reduced frequency and intensity of nausea ratings in whole body motion.[1] Importantly, controlled breathing did not specifically include teaching slow-diaphragmatic breathing techniques.[1,19]

In our own research, slow paced breathing using DB mechanics was found to reduce symptoms of motion sickness in a virtual reality (VR) motion sickness inducing environment.[13] These results indicated that subjects breathing approximately 11 breaths/min had fewer motion sickness symptoms when compared to a control group breathing at 16 breaths/min. While these results were encouraging, the 11 breaths/min pace is considerably higher than the pace of 3-7 breaths/min that Lehrer et al.[12] suggested would maximize PNS tone. Therefore, we were interested in helping individuals achieve these slow diaphragmatic breathing rates in a short period of training time.

In 2009, Zautra et al.[20] incorporated a visual aid to teach subjects quickly how to maintain a slow breathing pace in a study focused on examining the effects of slowed breathing on thermal pain sensitivity. Prior to the pain sensitivity trials, a computer generated set of visual images of an oval changing in size was presented to subjects to help pace each participant's breath training. The images expanded (inhalation) and contracted (exhalation) at the desired breathing pace. The subjects were asked to match the movement of the oval with their breathing rate during the study. In the present study, this use of moving ovals was adopted as a supplement to the Russell and Carlson protocol to achieve a more effective method to help subjects reduce their DB pace. For the current study, the visual aid was slightly modified from the original Zautra et al.[20] model and combined with additional instructions for using DB mechanics.

The current study had two objectives: 1) to determine if the incorporation of a visual/audio pacing practice video improved subjects' abilities to maintain a slowed diaphragmatic breathing pace during a VR video; and 2) to determine if the combination of slow breathing and DB techniques were an effective method for increasing PNS tone, as measured by heart rate variability (RSA), and controlling motion sickness symptoms. First, it was hypothesized that the subjects in the experimental (slow DB) group trained in slow DB by the visual pacing cue would decrease their breathing to a significantly lower rate than those subjects in the control group. Furthermore, two hypotheses were made in regard to objective two: 1) subjects in the slow DB group would show higher PNS tone (as measured by RSA) when compared to a group breathing at a faster pace with no DB instruction; and 2) subjects in the slow DB group would report lower increases in motion sickness from baseline levels during the sea motion VR experience as compared to subjects in the control group breathing normally at a more natural pace.

METHODS

Subjects

The study consisted of motion sickness susceptible male and female undergraduates from the University of Kentucky. Procedures followed were in accordance with the University of Kentucky Institutional Review Board, who approved the research protocol. Subjects were prescreened with the Motion Susceptibility Questionnaire Short Form (MSSQ).[3] Subjects were between the ages of 18-27 and included 37 Caucasians, 2 African American, and 4 Asian subjects. Exclusion criteria included students who had medical conditions such as asthma, high blood pressure, panic disorders, anxiety disorder, gastrointestinal disorder, neurological disorder, or scores below the mean level of the overall population of individuals completing the MSSQ prescreening questionnaire.

Subjects were randomly assigned using a coin toss to either the experimental group or the control group. The experimental group was trained in slow DB techniques and the control group was trained to breathe normally at a natural pace. Used in this study were 43 subjects, 8 men and 35 women, with 22 randomly assigned to the control group and 21 to the experimental group. Research subjects were volunteers recruited from undergraduate psychology classes. Subjects, who signed up for the study online and met the prescreening criteria, were called or emailed by an undergraduate psychology student to schedule an appointment. The participant was seen by either a male or female experimenter who conducted the study individually with each person. An equal number of subjects in each group were seen by the male or female experimenters in order to control for biases that might arise from the sex of experimenters.

Equipment

Two physiological measures were collected: heart rate (bpm) and respiration rate (breaths per minute, rpm). RSA in the high frequency spectrum was calculated from the physiological data because of its usefulness in providing a quantitative measure of parasympathetic activity. MindWare RSA 3.0 software (MindWare, Gahana, OH) was used to determine each participant's RSA; the procedure first involved reviewing each participant's data to insure there were no artifacts in the recordings that would influence RSA determinations. Once the data were "cleaned," the Mindware protocol was used to calculate the high frequency spectrum of heart rate variability. Heart function was recorded using three Ag/AgCl electrodes with shielded leads connected to a BioPac ECG100C electrocardiogram amplifier module. The Lead I configuration was used for heart rate measurement and the sampling rate was set to 2000 samples/s. Electrocardiogram sensors were attached in accordance with standard laboratory protocol.[14] Respiration data were obtained as breaths per minute using the respiration module for the BioPac MP100 system (Biopac, Santa Barbara, CA). The respiration sensor was placed around the abdomen just below the rib cage. Data were stored using Acqknowledge software (Biopac) and analyzed with the MindWare data analyses protocol.

Research Measures

MSSQ. This prescreening questionnaire[3] was given to a pool of undergraduate students to determine a possible list of seasickness susceptible subjects. Subjects who completed this questionnaire who scored above the mean of the undergraduate sample from which the subjects were drawn and were willing to participate were then scheduled for an appointment.

Heart rate variability. Heart rate variability is a physiological index that has demonstrated usefulness in providing a quantitative measure of parasympathetic activity and an index of autonomic balance. Heart function was recorded using three Ag/AgCl electrodes with shielded leads connected to a BioPac ECG100C electrocardiogram amplifier module. Sampling rate was set to 2000 samples/second and the Lead I configuration was used and sensors attached in accord with standard laboratory protocol.[14] Before analyzing heart rate, respiration rate, and RSA, the physiological data were assessed for artifacts and cleaned if necessary. MindWare RSA 3.0 software was used to detect potential artifacts and manual cleaning was done to ensure accurate measurements. All data were cleaned in 30-s segments and segments that had over 30% artifacts were not included in the analysis. Artifacts were defined as unreadable physiological segments due to technological malfunction or excessive participant movement that could not be corrected.

Respiration rate. Respiration rate was recorded using the respiration module for the BioPac MP100 system. Respiration rate was recorded as breaths per minute.

Demographic questionnaire. Subjects completed questions regarding their gender, age, and year in school.

Motion Sickness Assessment Questionnaire. Subjects were instructed to rate their motion sickness before and after the experiment with the Motion Sickness Assessment Questionnaire (MSAQ).[2] Subjects indicated the extent to which they felt each emotion on a 9-point scale: (1 = not at all, all the way to 9 = severely). The questionnaire measures the gastrointestinal, central, peripheral, and sopite-related components of motion sickness. The sum of points from all 16 items were divided by 144 and then multiplied by 100%. This yielded the overall motion sickness score. The coefficient alpha for these five items was 0.74 and 0.88 in previous studies.

Seasickness/nausea level. During the experiment, subjects were given brief instructions to rate their level of seasickness on a 4-point scale (1 = no symptoms, 2 = initial symptoms, 3 = mild nausea, 4 = moderate nausea). The subject was asked, "How do you feel?" every 60 s during the VR video and the subject responded with the corresponding number that indicated their current level of seasickness.

Self-efficacy rating. Self-efficacy rating (SER) is a self-report measure created by the researchers to assess the subjects' level of confidence that they could resist developing seasickness symptoms. Statements such as "how confident are you that you could successfully recognize the signs that you are becoming seasick" were assessed with a 7-point Likert scale of responses that ranged from "not at all confident" to "very confident". The items were summed to attain a self-efficacy score.

Perceived realism of ocean swells video. Subjects were asked two questions about the perceived realism of the video: "During the video, how real did it look?" and "During the video, how real did the motion of the boat feel?" Responses were made on a 7-point scale (ranging from 0 = not at all real to 6 = very real) and were summed to form a perceived realism scale.

Procedure

If students agreed to participate, they were scheduled to meet the experimenters for one 50-min session. Each participant was randomly assigned to either the control or experimental group. All subjects were asked if they followed directions to abstain from food, alcohol, and tobacco products for at least an hour before the appointment. Subjects who followed directions began the session by completing three forms: the MSAQ[2], the SER form, and a demographic sheet. Subjects indicated the extent to which they felt each emotion/symptom on a 9-point scale: (1 = not at all, to 9 = severely).

After completing the forms, physiological sensors were attached to subjects and heart rate and respiration rates were obtained during a 5-min baseline while the participant sat quietly. Next, depending on which group the participant was randomized to, they were briefed on slow DB techniques or an attention control manipulation designed to control for the effects of observing the visual display. Each manipulation was delivered to all subjects by a prerecorded CD and was followed by a 5-min breathing practice session using the appropriate visual display. The subjects paced breathing by following an oval that expanded (inhale) and retracted (exhale). The oval expanded and retracted at a pace of 6 breaths/min for the DB group and 12 breaths/min for those in the control group. Both videos included a soft tone that corresponded with the oval beginning to expand. The auditory tones were also heard during the VR experience for both groups as an audible cue to begin the appropriate breathing cycle.

Before the 10-min VR experience began, the laboratory assistants reminded the subjects to pace their breathing with the tones for the duration of the VR experience and the experimental group was reminded to breath using their stomach as previously instructed. During exposure to the 10-min VR experience, a laboratory assistant took nausea ratings on a 4-point scale (1 = no symptoms, 2 = initial symptoms, 3 = mild nausea, 4 = moderate nausea) every minute. The experiment was terminated if a rating of four was reached. Only one subject stopped early due to reaching a nausea rating of 4. The subject was in the experimental group and the corresponding data were used in all statistical analyses.

At the end of the VR video, subjects rested quietly while a 5-min post baseline physiological assessment was obtained.

After the post baseline, the subjects filled out three forms: MSAQ-post, SER-post, and a perceived realism questionnaire. The perceived realism measure asked how real the video looked and felt to the subject. Once the materials were completed, subjects were excused from the study.

Statistical Analyses

All analyses were performed using SPSS 21 (IBM SPSS Statistics for Windows, Version 21.0; IBM Corp., Armonk, NY). Preliminary analyses were conducted in order to ensure no differences existed between the control and experimental groups in motion sickness susceptibility, respiration rates, heart rates, and RSA at baseline. A mixed between-within subjects analysis of variance was used to examine the main effects of time and treatment as well as the interaction between time and treatment for both RSA and respiration rates. Based on our a priori hypotheses, post hoc independent sample *t*-tests were then used to evaluate this interaction. The MSAQ scores were also analyzed using a mixed between-within subjects analysis of variance. A post hoc independent samples *t*-test was used to determine if the experimental group experienced a smaller increase in motion sickness symptoms in comparison to the control group. Following investigation of the main hypotheses, an exploratory analysis was performed using a one-way ANOVA.

RESULTS

Mean MSSQ scores between the slow DB group (19.37) and the control group (22.41) indicated no significant differences in motion sickness susceptibility [$t(41) = 1.05$, $P = 0.3$]. Following this, mean respiration rates, heart rates, and RSA values were compared at baseline between the slow DB group and the control group. There were no significant differences in mean respiration rates between the slow DB (15.74) and control group (14.67) [$t(38) = -1.22$ $P = 0.23$]. Next, mean heart rates for the slow DB group (77.98) and the control group (13.47) were evaluated and found not to be significantly different [$t(38) = -0.973$, $P = 0.34$]. Lastly, mean RSA for the control subjects (6.94) and the DB subjects (15.74) were investigated and suggested that no significant differences existed at baseline [$t(38) = 0.38$, $P = 0.71$].

In order to ensure that the VR experience was an effective method for inducing seasickness, a matched-pairs *t*-test was performed with the control subjects' pre-VR and post-VR MSAQ scores. Results showed that the control group MSAQ post-VR experience scores were significantly higher than the pre-VR MSAQ scores [$t(41) = 7.24$ $P < 0.001$].

The effectiveness of the digital practice video was then assessed. A mixed between-within subjects ANOVA was conducted to compare respiration rates between control and experimental subjects across two time periods (prebaseline and during the VR video). There was a significant main effect for time [Wilks' Lambda = 0.408, $F(1, 41) = 55.037$, $P < 0.001$], with both control and experimental subjects showing a decrease in respiration rates across the two time points (see **Table I**). There was also a significant interaction between participant condition and time [Wilks' Lambda = 0.468, $F(1, 41) = 43.217$, $P < 0.001$], with the contrast indicating a significantly greater decrease in respiration rates in the slow DB group compared to the control group, as predicted ($P < 0.001$). Thus, the training video proved effective in reducing the breathing rates of those in the experimental group.

A mixed between-within subjects ANOVA was also used to determine if subjects in the slow DB group, compared to those in the control group, displayed greater PNS tone as measured by a decrease in RSA between prebaseline and RSA during the VR video. Results indicated that there was a significant main effect for time [Wilks' Lambda = 0.693, $F(1, 41) = 16.8$, $P < 0.001$], with both control and experimental subjects showing an increase in RSA across the two time points (see Table I). There was also a significant interaction between participant condition and time [Wilks' Lambda = 0.767, $F(1, 41) = 11.553$, $P = 0.002$], with the contrast indicating a significantly greater increase in RSA in the slow DB group compared to the control group as predicted ($P < 0.03$).

A mixed between-within subjects analysis of variance was also conducted to compare scores on the MSAQ between control and experimental subjects across two time periods (pre and post). There was a significant main effect for time [Wilks' Lambda = 0.421, $F(1, 41) = 56.358$, $P < 0.001$], with both control and experimental subjects showing an increase in MSAQ scores across the two time points (see Table I). There was also a significant interaction between participant condition and time [Wilks' Lambda = 0.897, $F(1, 41) = 4.72$, $P = 0.036$], with the contrast indicating a significantly greater increase in MSAQ scores in the control group compared to the slow DB group, as predicted. Table I provides the means and SDs for the slow DB and control group in regard to pre-MSAQ scores, post-MSAQ scores, respiration rates at prebaseline and during the VR experience, and RSA values at prebaseline and during the VR experience.

A secondary analysis was used to further evaluate subjects' nausea/motion sickness during the VR experience. Slow breathing DB (experimental) subjects who consistently maintained an average breathing rate of 7 rpm or less were grouped together ($N = 12$), while subjects who averaged greater than 7 rpm were placed in a separate group ($N = 9$). These two groups were compared to the control group using an ANOVA. An overall nausea/seasickness score was determined for each participant by subtracting their self-reported seasickness/

Table I. Means and Standard Deviations for Variables of Interest Used in Mixed Between-Within Subjects ANOVAs.

MEASURE	SLOW DB GROUP	CONTROL GROUP
MSAQ score at prebaseline	1.50 (0.75)	1.29 (0.31)
MSAQ score at postbaseline	2.48 (1.06)*	3.03 (1.40)
Respiration at prebaseline	15.74 (2.91)	14.67 (2.60)
Respiration during VR experience	8.54 (2.75)**	14.40 (1.53)
RSA at prebaseline	6.81 (1.14)	6.94 (0.93)
RSA during VR experience	7.67 (0.89)*	7.07 (1.06)

* Significant difference between dichotomized groups at $P < 0.05$.
** Significant difference between dichotomized groups at $P < 0.001$.

nausea rating at minute 1 from their rating at minute 10. The results indicated that there was a significant difference in the seasickness ratings among the three groups [$F(2, 40) = 3.293$, $P = 0.047$]. Evaluating the mean changes in seasickness level showed that subjects in the slow breathing DB group that maintained a rpm of 7 saw an increase of 0.0 in nausea/seasickness levels, while subjects in the slow DB group breathing above 7 rpm and those in the control group saw an average increase in ratings of nausea/seasickness levels of 0.78 and 0.70, respectively.

DISCUSSION

The purpose of this study was to examine the effectiveness of a visually and audibly mediated slow DB intervention in a motion sickness inducing environment. Furthermore, we wanted to determine if those subjects trained in slow DB breathing exhibited greater RSA and less motion sickness symptoms compared to the control subjects. Results indicated that the respiration rates for those in the DB group were significantly less than those in the control group and near to the goal of breathing at a rate of 3-7 rpm, as established by Lehrer et al.[12] Moreover, the slow breathing DB subjects showed significantly higher RSA values than the control group while also reporting fewer motion sickness symptoms. The slow diaphragmatic breathing, as taught by audio instructions and visual practice, resulted in achievement of lower breathing rates and reduced motion sickness severity as compared to those in the control group. These findings expand research that has shown controlled breathing to be a possible protective factor against motion sickness.[1,19]

The results also showed that the differences in MSAQ scores were significantly less for the subjects in the slow breathing DB group as compared to those in the control group. Furthermore, the secondary investigation indicated that achieving the ideal breathing rate of 3-7 respirations per minute prevented the development of motion sickness symptoms. These findings, while not representing outcomes from a true experimental design, suggest that the slow DB intervention will be the most effective within the breathing rate range of 3-7 respirations per minute, and research should continue to explore how to use the teaching protocol so that such rates are reliably obtained. However, the slow DB training protocol used in this study did decrease subjects' susceptibility to the development of motion sickness symptoms overall. The results indicate slow rate DB was an effective technique for reducing motion sickness severity and may serve as an effective behavioral intervention for motion sickness in other venues.

One possible limitation of this research was that subjects were not asked if they had previous experience with DB breathing training. Prior training experiences may have influenced the ability of subjects to follow the specified breathing rates. Studies in the future should also investigate the role of the subjects' motivation in learning the DB mechanics and slow paced breathing. Even though volunteer undergraduate subjects with a history of motion sickness participated in this study, all of them may not have been motivated to learn the new breathing skills.

One of the purposes of this study was to improve subjects' acquisition of the DB pattern and slow paced breathing. Past studies have introduced this breathing technique to subjects over a series of training sessions either with a clinician or through self-practice.[11,16,17] This study involved only one 50-min session and, therefore, required an efficient and effective training technique for altering breathing pattern and rate. The results suggest that the audio instructions in combination with the visual images aided subjects in mastering the slow DB in a short period of time. Besides drug therapy, few strategies for coping with motion sickness have been studied. The application of slow DB, a nonpharmacological method for controlling seasickness symptoms, is therefore a positive alternative to pharmacological methods. Overall, the current study indicates that the DB training protocol with the digital practice video was successful in decreasing subjects' bpm and increasing their RSA. Furthermore, the experimental subjects trained in slow DB breathing reported a smaller increase in seasickness symptoms when compared to the control subjects. The use of this now experimentally validated training protocol should continue to be investigated for its potential use in preventing motion sickness and addressing other important clinical problems (e.g., chronic pain) that are characterized by low RSA levels.

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