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Use of Controlled Diaphragmatic Breathing for the Management of Motion Sickness in a Virtual Reality Environment

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Abstract Evidence indicates that activation of the parasympathetic nervous system (PNS) suppresses physiological responses associated with motion sickness. Research also shows paced breathing increases PNS activation; the current study examines the use of paced diaphragmatic breathing (DB) training to quell motion sickness symptoms. Healthy participants (N = 60) were pre-screened for motion sickness susceptibility. Participants were then randomly assigned to either a control condition, focusing on environmental awareness, or to an experimental condition implementing paced DB. Following this, participants were exposed to a virtual reality (VR) motion sickness experience, while heart rate variability, breathing rate (RPM), and motion sickness ratings were collected. Results demonstrated participants in the DB condition had higher PNS activation and reported fewer motion sickness symptoms during the VR experience than the participants in the control condition. Results suggest that the DB protocol can be used to significantly increase PNS tone and decrease the development of motion sickness symptoms.

Keywords Breathing rate · Heart rate variability · Motion sickness · Diaphragmatic breathing · Parasympathetic nervous system

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Introduction

Motion sickness may be defined as the physiological and perceptual responses to discrepancies among sensory information circuits most commonly involving vision, balance, and movement. Affected individuals suffer gastrointestinal, peripheral, central, and sopite symptoms from motion sickness inducing stimuli. When exposed to motion sickness inducing stimuli, these four systems produce symptoms including but not limited to nausea, hot/warm sensations, lightheadedness, and fatigue (Gianaros et al. 2001). When symptoms of motion sickness are present, individuals can be quite distressed and unable to function well. In the present study, we focused on reducing motion sickness symptoms induced by a virtual reality experience involving movement on the sea.

Since motion sickness on water, or seasickness, is generally a debilitating ailment for those experiencing it, there has been extensive research on treatments for its most salient symptoms: nausea, fatigue, and vomiting (Sherman 2002). The most common treatments include ingesting ginger or various drugs that affect central nervous system functioning (Lien et al. 2003). Until recently, one of the more widely used drugs was dimenhydrinate. This medication leads to reduced vestibular senses and therefore, motion sickness symptoms are less likely to occur or are less intense. Dimenhydrinate, however, must be taken well in advance of exposure for full effectiveness and will often produce side effects including drowsiness and sedation (Walther 2005; Wood et al. 1990; Heer and Paloski 2006).

More recent research suggests medications with the active ingredient meclizine or scopolamine can prevent or reduce motion sickness symptoms (Heer and Paloski 2006; Paule et al. 2004). Similar to dimenhydrinate, both meclizine and scopolamine depress central nervous system

functions. Meclizine may also affect the medullary chemoreceptor trigger zone and scopolamine may act by inhibiting signals of motion sickness from the inner ear to the brain stem, but both mechanisms of action are not completely understood (Watcha and White 1992; Pyykkö et al. 1985). While meclizine and scopolamine are effective treatments, they often precipitate significant side effects including drowsiness and mental sedation (Paule et al. 2004).

Since the medications mentioned above can result in undesirable side effects, there is a need for further research on non-pharmacologic measures that are able to manage motion sickness symptoms. Indeed, the repercussions from these medications can be quite serious for those performing jobs at sea that demand mental attention and vigilance. Because of the desire to avoid the negative physiological and mental side effects from motion sickness medications, we focused our investigation on behavioral interventions that are able to mediate or prevent the negative symptoms.

Past research for self-regulatory strategies to control motion sickness included exploring the role of standing positions, restriction of vision, and food remedies, but the most effective avenue for treatment appears to be linked with activation of an individual's parasympathetic nervous system (Stoffregen et al. 2010; Bowins 2010). Research has shown that higher activity of the parasympathetic nervous system before exposure to motion sickness inducing stimuli results in minimal increases in motion sickness (Uijtdehaage et al. 1992). Also, studies show reduction in parasympathetic nervous system activity before exposure to motion sickness inducing stimuli consistently leads to the development of motion sickness symptoms during exposure (Hu et al. 1991; Gianaros et al. 2003). Gianaros et al. (2003) demonstrated that a strong negative relationship exists between motion sickness levels and respiratory sinus arrhythmia levels; it is important to note that respiratory sinus arrhythmia is a reliable measure of parasympathetic tone. These data suggest that diminished parasympathetic nervous system activity can precipitate motion sickness symptoms; they also suggest that strategies designed to enhance parasympathetic nervous system activity may be useful in reducing motion sickness symptoms.

One potential method for increasing parasympathetic nervous system tone is to slow an individual's breathing rate (Jerath et al. 2006; Joseph et al. 2005). Previous research also suggests that slowed breathing may provide some protection against motion sickness symptoms (Sang et al. 2003; Jokerst et al. 1999). Theoretically, the few minutes of delayed onset for symptoms in the laboratory could translate into substantial protection in the natural environment (Sang et al. 2003).

There were, however, several methodological issues with these early studies evaluating the effectiveness of breathing training on motion sickness symptoms. Recent research suggests achieving maximal activation of the parasympathetic nervous system, requires diaphragmatic breathing at a pace of 3–7 respirations per minute (Lehrer et al. 2010a, b). The study by Sang et al., provided no instructions on respiration rate and only requested participants, "…to focus and control your breathing; try to breathe gently and regularly" (16, pp. 109). Without the use of a diaphragmatic breathing technique, it was not likely the full benefits of these strategies were obtained.

In the current study, the purpose of using a diaphragmatic breathing technique in conjunction with a slow paced breathing protocol was to increase activation of the vagus nerve and subsequently the parasympathetic nervous system (Hamdan et al. 1999). The vagus nerve is the conduit for many motor parasympathetic fibers. Large numbers of these fibers are found in the heart and act as a braking system that slows heart rate and contributes to increased heart rate variability. There is also evidence that stimulation of the vagus nerve through breathing control causes a baroreflex response that lowers heart rate and also increases heart rate variability (Cottin et al. 2008). Since heart rate variability is a reliable physiological index that has demonstrated usefulness in providing a quantitative measure of parasympathetic tone, we focused our efforts on increasing heart rate variability (Kulur et al. 2009). We believed that the addition of controlled diaphragmatic breathing would magnify the effects of slowed breathing rate for reducing motion sickness symptoms.

The objective was to apply diaphragmatic breathing as a self-regulatory strategy and to measure the effects of this breathing strategy on physiological, cognitive, and behavioral responses in a motion sickness inducing environment. The hypothesis for the study was as follows: participants in the diaphragmatic breathing intervention condition, compared to those who are in the control condition, would display reduced respiration rates and motion sickness symptoms, as well as greater heart rate variability during exposure to a sea motion virtual reality experience.

Methods

Participants

Sixty motion sickness susceptible male and female college-aged students from the University of Kentucky were recruited for the study and assigned randomly to the experimental conditions. Participants in the diaphragmatic breathing condition consisted of six males and 25 females, while participants in the control condition consisted of six males and 23 females. Participants who had medical conditions such as asthma, high blood pressure, panic

disorders, anxiety disorder, gastrointestinal disorder, or neurological disorders were excluded from participation. All participants were volunteers and given course credit for participation. The Institutional Review Board for the protection of human participants approved this research and all participants completed informed consent before undergoing any study procedures.

G*Power software was used to calculate the necessary sample size for a mean difference in a two independent groups design (Faul et al. 2009). After reviewing previous research in the field, the effect size for the study was determined to be medium to large (Sang et al. 2003; Jokerst et al. 1999; Carlson et al. 2000). Power of 80 % was determined to be acceptable and with the model predictors (i.e. overall model) a sample size of 60 participants allows for an 80 % power with an $\alpha = 0.05$. Therefore, our sample size of 60 yields adequate power (81 %) for our intended analysis and accounts for the possibility of lost data.

Selection Criteria

During a pre-screening session for all introductory psychology undergraduates, participants were administered the Motion Sickness Susceptibility Questionnaire short-form (MSSQ; Golding 2006). The participants with a history of motion sickness and scores above the mean level (total score of 15) for the sampled undergraduate population on the MSSQ-short-form were randomly invited to participate. They were then randomly assigned with a random numbers table to either the control or the diaphragmatic breathing condition. The mean MSSQ-short-form score for included participants was 24.37. The project was described to qualifying participants as: "A study using virtual reality to explore self-control and responses to seasickness. This project will use virtual reality to study how training in self-control procedures influence a person's responses to seasickness."

Data Acquisition

Heart rate function was recorded using three Ag/AgCl electrodes with shielded leads connected to a BioPac ECG100C electrocardiogram amplifier module and were recorded as beats-per-minute. Data were stored using Acqknowledge software (Biopac, Santa Barbara, CA, USA) and analyzed with MindWare analysis system (MindWare, Gahanna, OH, USA). Sampling rate was set to 1,000 samples/second with a Lead I configuration of the sensors in accord with standard laboratory protocol (Carlson et al. 2000). Heart rate variability was defined as high-frequency (0.15–0.40 Hz) spectrum heart rate variability and was also analyzed with MindWare software. We defined our measure of heart rate variability as the 0.15–0.40 Hz range because it most accurately represents respiratory sinus arrhythmia otherwise understood as variation in heart function due to an altered respiration rate (Lehrer et al. 2010a, b; Berntson et al. 1997). Respiration rate was recorded as breaths-per-minute using a BSL-SS5LB respiratory effort transducer and amplifier module for the BioPac MP100 system. The respiration sensor was placed around the abdomen just below the rib cage and right above the navel.

Self-efficacy scores involving beliefs about managing motion sickness symptoms were collected prior to the virtual reality experience using a six-item questionnaire. Items like, "How confident are you that you could successfully recognize the signs that you are becoming seasick?" or "How confident are you that you could successfully control the symptoms of seasickness overall if you were on a boat?" were answered on a seven-point Likert type scale and used to investigate the potential influence of self-efficacy on motion sickness outcomes.

In order to quantify the construct of motion sickness, we used the 16-item Motion Sickness Assessment Questionnaire (MSAQ; Gianaros et al. 2001). Participants rated items on a 1–9 Likert type scale (1 = minimal symptoms and 9 = maximum symptoms) such as, "I felt sick to my stomach." or "I felt hot/warm." Participants were instructed to rate their motion sickness before and immediately following the virtual reality experience with the MSAQ. During the virtual reality experience, participants were given instructions to rate their level of motion sickness on a four-point motion sickness self-rating scale (1 = no symptoms, 2 = initial symptoms, 3 = mild nausea, 4 = moderate nausea). The participants rated their level of motion sickness with this scale every minute by responding to a verbal prompt from the experimenter. Following the experiment, participants were instructed to rate the realism of the video by answering the following questions on seven-point Likert type scale: "During the virtual video, how real did it look?" and "During the virtual video, how real did the boat motion feel?"

Motion Sickness Experience

During the motion sickness experience, participants wore a 3D head mounted goggle set with over the ear headphones. Following a sound check, a 10-min color video of ocean swells in a stormy sea began. The video was created using a purchased computer-generated video that was edited to run for exactly 10-min. The participant experienced a fluctuating view of a stormy dark blue horizon and that then followed the wave downwards until only water was visible. The movement of the waves was at a .063 Hz frequency.

Heart Rate Variability and Respiratory Sinus Arrhythmia Analysis

Heart rate variability data were translated to tachograms and arbitrarily separated into 30-s segments to facilitate analysis and classification. All recordings were visually examined and cleaned before any preliminary analyses were conducted. Each 30-s epoch was examined for non-sinus beats, electrical malfunctions, and double recorded beats. An epoch with over 30 % erroneous beats was not included in calculations. All pre-baseline and experiment recordings had less than two or five missing epochs respectively. After data were cleaned, the data was averaged over 1-min epochs.

Although heart rate variability was analyzed in terms of respiratory sinus arrhythmia during the experiment, the authors decided not to take into account breathing period and depth as covariates. While there are several arguments for the removal of respiratory parameters, we believe that the amplitude of respiratory sinus arrhythmia is indexed by tonic vagal cardiac tone (Donchin et al. 1985; Pagani et al. 1986; McCabe et al. 1985; ŽEmaitytė et al. 1984a, b). We openly admit that there are significant arguments against this type of analysis but until conclusive evidence can be given that respiration induced variance in respiratory sinus arrhythmia is a direct result of inspiratory and expiratory phasic changes in vagal heart tone, we believe our the results as presented are robust (Eckberg 1983; Grossman 1983; Grossman and Svebak 1987; Grossman et al. 1991).

Statistical Analysis

Data analyses were performed with SPSS 21. Prior to investigation of a priori hypothesis two-tailed independent sample *t* tests were used to establish no significant baseline differences between the two conditions on all included measures. Likewise, to evaluate the potential differences between all measures, except the $MSAQ_{post}$, collected during the motion sickness experience, two-tailed independent sample *t* tests were computed assuming equality of variances. The $MSAQ_{post}$ measure did not satisfy Levene's Test for equality of variances and was therefore reported assuming unequal variances. An exploratory analysis using Pearson's bivariate two-tailed correlations examined the relationships between breathing rate and self-reported sickness ratings. No further transformations were made to data or figures and no participants were removed from analyses.

Procedures

After completion of the initial paper and pencil surveys, physiological sensors were attached to monitoring equipment and a 5-min baseline assessment was taken for respirations per minute, heart rate, and heart rate variability. Next, depending on the participant's condition, they were briefed on diaphragmatic breathing techniques or they received an attention control manipulation that involved instructions on being aware of one's surroundings. An attention control condition was purposefully designed to control for a range of potential confounds that might exert an influence on research outcomes. Each manipulation was delivered by pre-recorded audio CDs to control for experimenter demand and to standardize delivery of the procedures; the scripts are presented in full below.

1. Experimental Group

Breathing rationale

We are very interested in understanding your responses to the study procedures. Breathing so that the stomach is moving in and out rather than breathing with your chest can help relax you. This stomach breathing, or diaphragmatic breathing, can help you relax and maintain calmness in today's study experience.

Breathing Protocol

Please remember the rule: you should do nothing to increase your sense of discomfort while you are practicing the breathing. To start breathing with your stomach, or diaphragm, you should rest in a comfortable position with your head centered, supported and in the midline of your body; your eyes are closed, with smooth eyelids; and smooth forehead; your mouth is relaxed: with lips apart, teeth apart, and tongue relaxed; there's no throat movement; your shoulders are sloped and even; elbows bent; your hands will be in a curled, relaxed position, not touching one another; knees are apart; and feet are pointing away from one another at a 45-90 degree angle. Then, place your right hand just below your rib cage on top of your stomach. Just exhale first to release air from your body—it should be a complete, relaxed release where there is no holding, controlling, or forcing of the release—it is like a balloon collapsing as you let your air go from your body. When you are ready to take your next breath of air in; let the stomach gently rise as if you are pushing your stomach up with the column of air coming in. After you take in a comfortable, normal breath, release your muscles and let the air go just as you did at first when you started the exercise…there is no controlled, gradual release, just let go all at once and have the air move naturally out of your body. Then, pause and rest for a few moments before you take air in again to

start another breath cycle. The rest period between breaths is the deepest point of your relaxation when everything is quiet and you relax before taking air in again. (Pause for 10 s) From the beginning of this training, you should breathe at a pace that makes you feel comfortable. (Pause for 5 s) You also want to breathe naturally and not too deeply in order to avoid over breathing or hyperventilation. If you were to feel light-headed or dizzy, the chances are you are taking in too much air with each breath…take a little less air in on your next breath and the breaths that follow. (Pause 10 s) Most people find that counting to 3 while air is coming into your lungs may set a natural, relaxed pace. Once the air is released, the rest period is typically the time it takes to count from 1 to 3. So, a starting pace for you can be counted as "air in-2-3; release-2-3; and rest-2-3" (Repeat this phrasing 2 times). Repeat this breathing pattern for several minutes to establish a comfortable, relaxed rhythm to your breathing (Pause for 5 s). Let your stomach rise as air enters, then let the stomach fall as you release the air, and let everything rest until taking in your next breath of air (Pause for 10 s). Your breathing rate will likely be somewhere between 3-7 breaths per minute as you practice diaphragmatic breathing. Let your breathing be slow and relaxed as your stomach moves up and down. Please use this diaphragmatic breathing method throughout your remaining time in the laboratory.

2. Control Group

Control Rationale

We are very interested in understanding your responses to the study procedures. Since we all have our own ways of responding to what happens to us, we are interested in following your responses carefully. The purpose of our project is to better understand the ways in which individuals such as yourself respond to the application of the laboratory procedures.

Control Protocol

First of all it is important to remember the rule that you should do nothing to increase your sense of discomfort. Sit up in the chair in an upright posture with your shoulders back and your head resting quietly. Take a few moments to notice your surroundings and let yourself get comfortable and settle in. We would like for you to sit quietly during the procedure and let your attention be directed to the activities going on around you. You should be observing yourself and your environment as you undergo the laboratory experience. Please remain aware of your surroundings and what is happening at any given moment. Take a few minutes now to let yourself be aware of what is happening. We will want you to continue to let yourself be aware of what is happening throughout your remaining time in the laboratory.

Participants in each condition were given an opportunity to practice the procedure, ask questions if desired, and then demonstrate the appropriate breathing pattern or rest control. Following the training instructions, the researcher explained the 10-min virtual reality experience in the same manner for all participants:

> You are to view a video of ocean swells from a boat at sea. You are to look straight ahead for the duration of the experiment. Every minute, you are to rate your seasickness level by verbally responding when prompted with a rating between 1-4 (1 = no symptoms, 2 = initial symptoms, 3 = mild nausea, 4 = moderate nausea). If a level of 4 is achieved, before the end of the video, the experiment will be terminated and you will still receive full credit for participation.

Upon exposure to the 10-min sea motion virtual reality experience, a laboratory assistant in the room obtained nausea ratings every minute. As indicated earlier, all participants' immediately following exposure to the virtual reality experience were given the $MSAQ_{post}$ along with a realism questionnaire. At the end of the trial, the participants were instructed to rest quietly so that a 5-min post baseline physiological assessment could be obtained. They were then given the perceived virtual reality realism questionnaire to complete.

Results

In order to ensure no differences existed between the two experimental conditions, independent *t* test analyses were conducted on all baseline data. No significant differences were found between the average age of participants in the diaphragmatic breathing condition ($\mu = 19$ years) and the control condition ($\mu = 18.6$ years), $t(58) = 1.07$, $p = .29$. Also, no significant differences were found between the average MSSQ scores of the diaphragmatic breathing condition ($\mu = 25.8$) and the control condition ($\mu = 22.9$), $t(53) = 1.06$, $p = .30$. In addition, no significant differences were found for self-efficacy scores at baseline, $t(58) = .13$, $p = .90$. The average self-efficacy scores of participants in the diaphragmatic breathing condition were found to be $\mu = 4.5$ and the average participants scores in the control condition were $\mu = 4.5$. Participants in both

conditions were asked to rate the realism of the experience following exposure, and results indicated that there was no significant difference between the diaphragmatic breathing condition ($\mu = 4.7$) and the control ($\mu = 5.2$) condition with respect to the perceived realism of the virtual reality experience $t(58) = 1.9$, $p = .06$.

The physiological data were also examined for potential baseline differences. For participants' breathing rate, we found the diaphragmatic breathing condition ($\mu = 14.9$ respirations per minute) and the control condition ($\mu = 13.8$ respirations per minute) did not significantly differ, $t(53) = 1.04$, $p = .30$. No significant differences were found between the diaphragmatic breathing condition ($\mu = 72.4$ HR, $\mu = 6.9$ heart rate variability) and the control condition ($\mu = 75.8$ HR, $\mu = 6.8$ heart rate variability) for average heart rates or high frequency heart rate variability, $t(53) = 1.17$, $p = .25$ and $t(53) = .54$, $p = .59$ respectively. We also examined the physiological data for normality using Q–Q plots and found that all the variables were normally distributed. Based on these data, it was concluded that there were no differences between the two conditions at baseline for any measured variable.

Since no differences were found at baseline, the a priori hypotheses were examined by using focused contrasts for both the physiological data and the self-report motion sickness ratings (Rosenthal and Rosnow 1985). We first assessed the breathing rates and heart rate variability. A significant difference in breathing rate was found between the diaphragmatic breathing condition and the attention control group. Also, a significant difference in high-frequency heart rate variability, as measured by respiratory sinus arrhythmia, was found between the diaphragmatic breathing condition and the control condition during the virtual reality experience. We also confirmed the a priori hypothesis that the diaphragmatic breathing condition would report a lower motion sickness rating than the control condition on the $MSAQ_{post}$ and the average self-ratings of motion sickness. See Table 1 for complete results.

We then explored the relationships between the average breathing rates for participants in each condition and motion sickness ratings over time. We first plotted, for each condition, the self-reported motion sickness ratings over time during the virtual reality experience (Fig. 1). The graph also illustrates that the diaphragmatic breathing condition reported fewer negative motion sickness symptoms than the control condition. We then plotted the mean respiration rates for the virtual reality experience for each condition over time (Fig. 2). The graphs suggested that spikes in self-reported motion sickness ratings might be related to increases in average breathing rates.

In order to detect if a linear relationship exists between symptoms of increased parasympathetic nervous system tone and the self-reported motion sickness ratings during the virtual reality experience, we examined the correlations between respiration rate, respiratory sinus arrhythmia, and self-reported sickness ratings by condition (Table 2). For the diaphragmatic breathing condition, a significant positive correlation was found between participants' respirations per minute and motion sickness ratings. There were also negative relationships between respiratory sinus arrhythmia, breathing rate and self-reported sickness level.

Lastly, we examined the motion sickness results of the participants who were able to maintain an average of at least seven breaths or less during the virtual reality experience. On the self-reported motion sickness ratings, two participants reported no symptoms, while the third reported only initial symptoms of motion sickness during the last 3 min. The $MSAQ_{post}$ data for these three participants suggested they achieved the most significant protection from developing negative motion sickness symptoms with an average $MSAQ_{post}$ score of, 1.77 out of a possible 9. These results supported the expected positive relationship between a slow respiration rate and lower motion sickness ratings. Overall, the present findings suggest the potency of controlled diaphragmatic breathing for reducing motion sickness symptoms.

Table 1 High-frequency respiratory sinus arrhythmia (RSA_H)

Measure	Control condition	DB condition	*p* value	Mean difference
Respiration rate	16.21 ± 2.77	11.38 ± 3.49	<.001	4.84
RSA_H	6.38 ± .86	7.46 ± 1.05	<.001	1.08
SS	1.78 ± .63	1.37 ± .44	.005	0.41
$MSAQ^{a}_{post}$	2.85 ± 1.72	2.1 ± .91	.043	0.75

Self-report sickness ratings (SS). Diaphragmatic breathing (DB). All measures collected during the virtual reality experience. Average respiration rate (in breaths per minute), average respiratory sinus arrhythmia values, average self-report motion sickness ratings (on 1–4 scale), and average $MSAQ_{post}$ scores for all participants. Mean differences reported as absolute values

[a] Asked to answer the questionnaire referencing their symptoms during the experience

Discussion

We examined the effects of diaphragmatic breathing training on activation of the parasympathetic nervous system as indexed by increased heart rate variability and subsequent prevention of motion sickness symptoms. Results demonstrated that the diaphragmatic breathing protocol increased parasympathetic nervous system tone, slowed respiration rate, and decreased development of motion sickness symptoms as compared to the control condition. The findings were consistent with our hypotheses that the diaphragmatic breathing protocol could

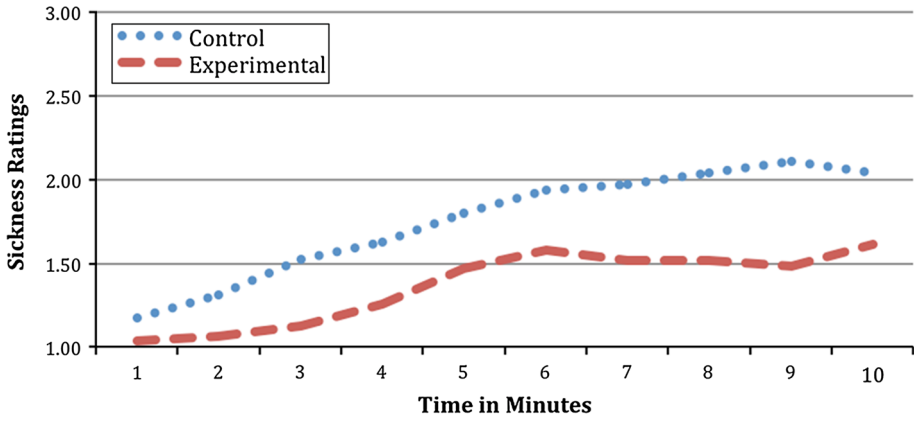

Fig. 1 Average sickness ratings for the diaphragmatic breathing condition (experimental) and control condition (attention) during the virtual reality experience. The possible values for sickness range from 1 to 4

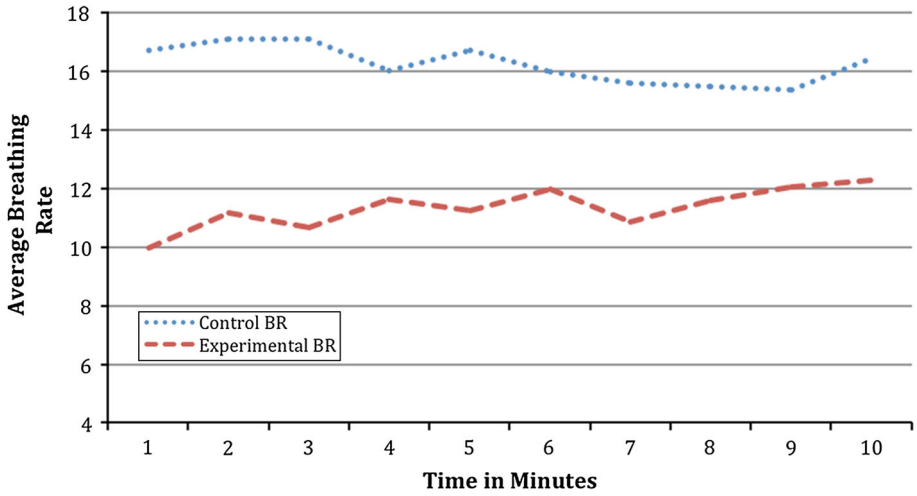

Fig. 2 Average breathing rates (BR) for each condition during the virtual reality experience over time

Table 2 All correlations were calculated with n = 48

Control condition			DB condition		
Measure	RSA_H	SS	Measure	RSA_H	SS
RR	.02	−.74**	RR	−.85**	.74**
RSA_H	–	−.14	RSA_H	–	−.89**
SS	–	–	SS	–	–

Respiration rate (RR). High-frequency respiratory sinus arrhythmia (RSA_H). Self-report sickness ratings (SS). Diaphragmatic breathing (DB). Table presents the Pearson's r correlations between the measures of physiology and motion sickness during the motion sickness inducing virtual reality experience

** $p < 0.01$ (two-tailed)

effectively reduce symptoms of motion sickness. While the current data were interpreted to support primarily the role of parasympathetic activity for controlling motion sickness symptoms, it is also possible that the mechanism of action involves reducing sympathetic nervous system tone.

As previously shown, breathing training can be used to ameliorate the development of motion sickness symptoms (Jerath et al. 2006; Joseph et al. 2005; Sang et al. 2003; Jokerst et al. 1999). The combined effect of diaphragmatic breathing mechanics and slowed respirations per minute indicates that these may be effective strategies for significantly increasing parasympathetic tone and protecting against motion sickness during exposure to motion sickness inducing stimuli. Interestingly, we did not separate the role of breathing mechanics and the role of breathing rate in this study; future studies would be well served to build experimental designs that would focus on this issue. Finally, in the current study we did not uniformly obtain the low respiration rates suggested by Lehrer et al. (2010a, b) that may be necessary for maximizing parasympathetic tone. With the three participants that were at or fewer than seven breaths a minute, their results suggest that slow diaphragmatic breathing offers significant protection from developing motion sickness symptoms. Overall, however, we obtained significant reductions in all recorded motion sickness symptoms using a standardized pre-recorded breathing training protocol.

We also examined the relationship between breathing rates and motion sickness symptoms. A significant positive

correlation indicates that an increased respiratory rate was associated with more motion sickness symptoms. If this relationship is confirmed in future research, treatment strategies for motion sickness could focus on evaluating specific breathing rates and their effectiveness as a preventative strategy. It will be important to identify if the breathing rate of 3–7 BPM is actually the most effective breathing range for the prevention of symptoms.

While the results supported our hypothesis that there would be significantly lower motion sickness ratings for the diaphragmatic breathing condition, it is important to recognize that, similar to previous research, the diaphragmatic breathing protocol did not prevent the onset of all motion sickness symptoms as measured by the self-rating of motion sickness and the MSAQ (Sang et al. 2003; Jokerst et al. 1999). There were, however, significant differences between the respiration rate, heart rate variability, $MSAQ_{post}$ scores, and self-reported sickness ratings between conditions. Despite the interventions inability to fully protect against motion sickness, we believe that the current protocol, incorporating a specific breathing rate and mechanics, warrants further investigation due to its ability to increase parasympathetic nervous system tone.

The positive correlation between breathing rate and self-reported sickness level in the diaphragmatic breathing condition indicates that achieving the optimal breathing rate of 3–7 respirations per minute may yield greater protection from motion sickness as compared to those breathing at higher rates (Cottin et al. 2008; Kulur et al. 2009). Results also suggest that participants may need to undergo more in depth training on respiration control before their exposure to a motion sickness inducing environment. Perhaps with more practice time, participants could achieve higher parasympathetic nervous system tone, increase their ability to maintain the desired respirations per minute, and further control the development of motion sickness symptoms.

The training intervention should focus on teaching participants to maintain diaphragmatic mechanics and slowed breathing rate for extended periods of time. Potentially, this could increase the protective effects of the protocol when participants are in the virtual reality experience. Also, the use of a breathing intervention that consistently establishes participants' average respiration rate between 3 and 7 breaths per minute should be explored because the maximum benefits of increased parasympathetic nervous system tone may rely on achieving a breathing rate in this target range. The potential benefits of slowed diaphragmatic breathing on parasympathetic nervous system tone may ultimately help reduce the need for medicinal treatments of motion sickness. These present findings support the further exploration of self-regulatory strategies for the management of motion sickness symptoms.

References

Berntson, G. G., Bigger, J. T., Eckberg, D. L., Grossman, P., Kaufmann, P. G., Malik, M., et al. (1997). Heart rate variability: Origins, methods, and interpretive caveats. *Psychophysiology, 34*(6), 623–648.

Bowins, B. (2010). Motion sickness: A negative reinforcement model. *Brain Research Bulletin, 81*(1), 7–11.

Carlson, C. R., Bertrand, P. M., Ehrlich, A. D., Maxwell, A. W., & Burton, R. G. (2000). Physical self-regulation training for the management of temporomandibular disorders. *Journal of Orofacial Pain, 15*(1), 47–55.

Cottin, F., Médigue, C., & Papelier, Y. (2008). Effect of heavy exercise on spectral baroreflex sensitivity, heart rate, and blood pressure variability in well-trained humans. *American Journal of Physiology-Heart and Circulatory Physiology, 295*(3), H1150–H1155.

Donchin, Y., Feld, J. M., & Porges, S. W. (1985). Respiratory sinus arrhythmia during recovery from isoflurane—nitrous oxide anesthesia. *Anesthesia and Analgesia, 64*(8), 811–815.

Eckberg, D. L. (1983). Human sinus arrhythmia as an index of vagal cardiac outflow. *Journal of Applied Physiology, 54*(4), 961–966.

Faul, F., Erdfelder, E., Buchner, A., & Lang, A. G. (2009). Statistical power analyses using G* Power 3.1: Tests for correlation and regression analyses. *Behavior Research Methods, 41*(4), 1149–1160.

Gianaros, P. J., Muth, E. R., Mordkoff, J. T., Levine, M. E., & Stern, R. M. (2001). A questionnaire for the assessment of the multiple dimensions of motion sickness. *Aviation, Space and Environmental Medicine, 72*(2), 115.

Gianaros, P. J., Quigley, K. S., Muth, E. R., Levine, M. E., Vasko, R. C., Jr., & Stern, R. M. (2003). Relationship between temporal changes in cardiac parasympathetic activity and motion sickness severity. *Psychophysiology, 40*(1), 39–44.

Golding, J. F. (2006). Predicting individual differences in motion sickness susceptibility by questionnaire. *Personality and Individual Differences, 41*(2), 237–248.

Grossman, P. (1983). Respiration, stress, and cardiovascular function. *Psychophysiology, 20*(3), 284–300.

Grossman, P., Karemaker, J., & Wieling, W. (1991). Prediction of tonic parasympathetic cardiac control using respiratory sinus arrhythmia: The need for respiratory control. *Psychophysiology, 28*(2), 201–216.

Grossman, P., & Svebak, S. (1987). Respiratory sinus arrhythmia as an index of parasympathetic cardiac control during active coping. *Psychophysiology, 24*(2), 228–235.

Hamdan, M. H., Joglar, J. A., Page, R. L., Zagrodzky, J. D., Sheehan, C. J., & Wasmund, S. L. (1999). Baroreflex gain predicts blood pressure recovery during simulated ventricular tachycardia in humans. *Circulation, 100*(4), 381–386.

Heer, M., & Paloski, W. H. (2006). Space motion sickness: Incidence, etiology, and countermeasures. *Autonomic Neuroscience, 129*(1), 77–79.

Hu, S., Grant, W. F., Stern, R. M., & Koch, K. L. (1991). Motion sickness severity and physiological correlates during repeated exposures to a rotating optokinetic drum. *Aviation, Space, and Environmental Medicine, 62*, 308–314.

Jerath, R., Edry, J. W., Barnes, V. A., & Jerath, V. (2006). Physiology of long pranayamic breathing: Neural respiratory elements may provide a mechanism that explains how slow deep breathing shifts the autonomic nervous system. *Medical Hypotheses, 67*(3), 566–571.

Jokerst, M. D., Gatto, M., Fazio, R., Stern, R. M., & Koch, K. L. (1999). Slow deep breathing prevents the development of tachygastria and symptoms of motion sickness. *Aviation, Space and Environmental Medicine, 70*(12), 1189–1192.

Joseph, C. N., Porta, C., Casucci, G., Casiraghi, N., Maffeis, M., Rossi, M., et al. (2005). Slow breathing improves arterial baroreflex sensitivity and decreases blood pressure in essential hypertension. *Hypertension, 46*(4), 714–718.

Kulur, A. B., Haleagrahara, N., Adhikary, P., & Jeganathan, P. S. (2009). Effect of diaphragmatic breathing on heart rate variability in ischemic heart disease with diabetes. *Arquivos Brasileiros de Cardiologia, 92*(6), 457–463.

Lehrer, P., Karavidas, M. K., Lu, S. E., Coyle, S. M., Oikawa, L. O., Macor, M., et al. (2010a). Voluntarily produced increases in heart rate variability modulate autonomic effects of endotoxin induced systemic inflammation: An exploratory study. *Applied Psychophysiology and Biofeedback, 35*(4), 303–315.

Lehrer, P., Karavidas, M., Lu, S. E., Vaschillo, E., Vaschillo, B., & Cheng, A. (2010b). Cardiac data increase association between self-report and both expert ratings of task load and task performance in flight simulator tasks: An exploratory study. *International Journal of Psychophysiology, 76*(2), 80–87.

Lien, H. C., Sun, W. M., Chen, Y. H., Kim, H., Hasler, W., & Owyang, C. (2003). Effects of ginger on motion sickness and gastric slow-wave dysrhythmias induced by circular vection. *American Journal of Physiology-Gastrointestinal and Liver Physiology, 284*(3), G481–G489.

McCabe, P. M., Yongue, B. G., Ackles, P. K., & Porges, S. W. (1985). Changes in heart period, heart-period variability, and a spectral analysis estimate of respiratory sinus arrhythmia in response to pharmacological manipulations of the baroreceptor reflex in cats. *Psychophysiology, 22*(2), 195–203.

Pagani, M., Lombardi, F., Guzzetti, S., Rimoldi, O., Furlan, R., Pizzinelli, P., et al. (1986). Power spectral analysis of heart rate and arterial pressure variabilities as a marker of sympatho-vagal interaction in man and conscious dog. *Circulation Research, 59*(2), 178–193.

Paule, M. G., Chelonis, J. J., Blake, D. J., & Dornhoffer, J. L. (2004). Effects of drug countermeasures for space motion sickness on working memory in humans. *Neurotoxicology and Teratology, 26*(6), 825–837.

Pyykkö, I., Padoan, S., Schalen, L., Lyttkens, L., Magnusson, M., & Henriksson, N. G. (1985). The effects of TTS-scopolamine, dimenhydrinate, lidocaine, and tocainide on motion sickness, vertigo, and nystagmus. *Aviation, Space and Environmental Medicine, 56*(8), 777.

Rosenthal, R., & Rosnow, R. L. (1985). *Contrast analysis: Focused comparisons in the analysis of variance*. Cambridge: Cambridge University Press.

Sang, F. D., Billar, J. P., Golding, J. F., & Gresty, M. A. (2003). Behavioral methods of alleviating motion sickness: Effectiveness of controlled breathing and a music audiotape. *Journal of Travel Medicine, 10*(2), 108–111.

Sherman, C. R. (2002). Motion sickness: Review of causes and preventive strategies. *Journal of travel medicine, 9*(5), 251–256.

Stoffregen, T. A., Yoshida, K., Villard, S., Scibora, L., & Bardy, B. G. (2010). Stance width influences postural stability and motion sickness. *Ecological Psychology, 22*(3), 169–191.

Uijtdehaage, S. H., Stern, R. M., & Koch, K. L. (1992). Effects of eating on vection-induced motion sickness, cardiac vagal tone, and gastric myoelectric activity. *Psychophysiology, 29*(2), 193–201.

Walther, L. E. (2005). Procedures for restoring vestibular disorders. *GMS Current Topics in- Otorhinolaryngology, Head and Neck Surgery*, *4*.

Watcha, M. F., & White, P. F. (1992). Postoperative nausea and vomiting: Its etiology, treatment, and prevention. *Anesthesiology, 77*(1), 162–184.

Wood, C. D., Stewart, J. J., Wood, M. J., Manno, J. E., Manno, B. R., & Mims, M. E. (1990). Therapeutic effects of antimotion sickness medications on the secondary symptoms of motion sickness. *Aviation, Space and Environmental Medicine, 61*(2), 157–161.

ŽEmaitytė, D., Varoneckas, G., & Sokolov, E. (1984a). Heart rhythm control during sleep. *Psychophysiology, 21*(3), 279–289.

ŽEmaitytė, D., Varoneckas, G., & Sokolov, E. (1984b). Heart rhythm control during sleep in ischemic heart disease. *Psychophysiology, 21*(3), 290–298.