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Evaluating binaural beats as a therapeutic tool for intervening visually-induced motion sickness in virtual reality environments

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ABSTRACT

Background: Visually-induced motion sickness (VISM) is an emerging problem in the application of virtual reality (VR) technology. Binaural beats are proven to be effective in reducing anxiety levels and enhancing pain management in VR environments. They may have the potential to be a remedy for symptoms of visually-induced motion sickness.

Objective: To investigate whether binaural beats can effectively ease the symptoms of VIMS.

Methods: Motion sickness susceptible individuals (n=35) were assigned to wear VR headsets and watch a 15-min VR video to evoke VIMS. Whenever motion sickness was self-reported by subjects, they were randomized into three groups receiving three types of intervention methods: Subjects in the experimental group listened to binaural beats; The control group was treated with beats of the same frequency at two soundtracks. And the blank group recovered without any sound played in the earphones. Subjects filled in the Simulator Sickness Questionnaires (SSQ) at three stages—before watching the VR video (baseline), during the watching experience (induction), and after watching (recovery). To increase the credibility, their physiological data were collected by a Biofeedback device during the whole process.

Results: Participants' subjective SSQ scores were analyzed, which did not reveal any significant difference between recovery and induction ($p>0.05$). The physiological data were following the result obtained from analyzing SSQ scores.

Conclusion: The binaural beats did not show a significant effect of alleviating VISM.

Keywords: Visually-induced motion sickness (VISM), virtual reality (VR), binaural beats.

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INTRODUCTION

As virtual reality technology develops, visually-induced motion sickness becomes a problem that urgently needs to be addressed. The VR viewers are subject to visually-induced motion sickness (VIMS), a digital version of motion sickness. Visually-induced motion sickness occurs when exposed to dynamic visual content such as Virtual Reality applications.[1] Typical symptoms of an acute visually induced motion sickness include pallor, cold sweat, dizziness, disorientation, fatigue and nausea.[2]

For the promotion of VR technology, it is essential to prevent VIMS from bothering users. Therefore, researchers are seeking viable and convenient methods to reduce the occurrence of VIMS. Some scientists have attempted to study the impact of music on the perception of motion sickness. According to Sang et al, music audiotape provided significant protection against motion sickness.[3] Moreover, an experiment by Keshavarz points out that pleasant music is an effective method to mitigate VIMS.[2] Although these researches collectively indicate that "pleasant music" is a potential countermeasure of the VIMS in VR environments, how to objectively or accurately quantify every user's pleasantness is still debatable. In other words, the conclusion that only perceived pleasant music can reduce VIMS is too ambiguous and lacks statistical significance.

It reminds the research of another type of claimed therapeutic tool—binaural beats. As per a piece of scientific literature, the binaural beats are a prospective remedy of VIMS incurred by VR scenes.[4] In this study, the effectiveness of binaural beats in treating visually-induced motion sickness in VR environments will be examined.

For many years, the mechanism of motion sickness is still arguable. The most prominent explanation is called sensory conflict theory—which states that motion sickness is elicited by sensory conflicts. If one of the sensations from vision, the vestibular system, or proprioception is inconsistent with the internal model of expected signals, conflicts between senses and the nervous system will arise.[5]

This theory explains how VIMS arises; the visual input contradicts the sensation from our body.

As we know that, external motion stimuli will be received by eyes, semicircular canals, and gravireceptors. And then, these receptors will evaluate external stimuli and send signals to the brain. The comparator in the brainstem is responsible for the comparison between signals and our brain's internal model.[6] If the mismatch between the signals exceeds the threshold, our neural centers will mediate signs of motion sickness.

The pathogenesis of VIMS involves the communication between the peripheral vestibular apparatus, ocular system, postural muscles, brainstem, cerebellum and cortex.[7] Related structures and their functions are listed in Table 1.

Table 1. Vital structures in the neural pathway responsible for motion sickness

Location	Structures	Function
Inner ear	Semicircular canals, Otolith organs, Vestibular nerve	They detect the head motion, acceleration and gravitational forces of the body[7]
Brainstem	Vestibular nuclei	Vestibular and visual afferent signals combine in the vestibular nuclei[8]
	Medulla oblongata, vomiting center, chemoreceptor trigger zone	These regions are linked to VIMS symptoms—vomiting and nausea.

Based on the sensory conflict theory, the occurrence of visually-induced motion sickness can be well explained at the neurological level: the absence of vestibular signal is incompatible with the presence of visual signals, leading to confusion and physiological responses. To be straightforward, VISM arises when your eyes tell you are moving while your muscles and inner ear say no.[9] This conflict makes your brain confused, thus mediating signs like nausea and vomiting. The mechanism behind this is still unclear, but M Treisman proposed an evolutionary hypothesis that suggests motion sickness to be an accidental byproduct of the emesis system being to rid the individual of ingested neurotoxins.[10]

There is evidence showing that the lower-frequency motion (<1Hz) is more nauseogenic than the higher-frequency one.[11,12] Motion sickness is provoked by low-frequency motion peaks at that of around 0.2 Hz, which are common in transportation in ships, coaches and aircraft.[13] Surprisingly, there are a huge number of reports revealing that people might experience motion sickness-like symptoms attributed to wind turbine infrasonic acoustic emissions within the range of 0.2-0.8Hz.[14] It might not be just a coincidence—there is a possibility that the mismatch between low-frequency motion and other signals is associated with the underlying cause of motion sickness. If the sensory conflict theory holds water, when the low-frequency visual input from the VR apparatus matches with low-frequency acoustic sound, perception of motion sickness should not arise. In other words, if combining low-frequency motion and low-frequency sounds can reduce VIMS, then it's a piece of evidence supporting the sensory conflict theory.

Given that infrasonic wave is harmful to the human body, the binaural beats serve as a good alternative. Binaural beats generate when sine waves with different frequencies are heard by neighboring ears respectively. It seems that the sound locates inside the head and produces the "wobbling and pulsating" effects. Unlike monoaural beats—beats with composite frequencies to one ear or both ears simultaneously—binaural beats are deduced to be demodulated by the medial superior olivary nuclei in the central nervous system.[15,16] As a result, the brain detects the frequency difference instead of two independent sound waves. Binaural beats can affect mood and reduce trait anxiety, anxiety in a specific situation.[17,18]

Previous research suggests that heart rate may be a useful indicator of small changes in the degree of sickness, which resulted from the stimulation in the sympathetic nervous system.[19] What's more, it is generally acknowledged that skin conductance is a valid measure of motion sickness, with a strong positive correlation with the degree of motion sickness.[20,21]

Objective of the study

In this study, the primary and direct objective is to examine if binaural beats can alleviate visually-induced motion sickness. The secondary objective is to verify the sensory conflict theory. If it is substantiated that binaural beats can mitigate visually-induced motion sickness, the sensory conflict theory is largely supported. We hypothesize that binaural beats cannot significantly reduce the severity of visually-induced motion sickness.

Novelty and importance of the study

There has been plenty of research concerning the therapy of motion sickness, but the emergence of VR technology has made it necessary to explore visually-induced motion sickness which few of the researchers have fully explored. Also, none of the published pieces of literature has examined the impact of binaural beats, an increasingly prevailing psychotherapy tool. In this essay, the writer innovates to examine the effect of binaural beats on the intervention of VIMS. This would be meaningful to the future development of virtual reality.

MATERIALS & METHODS

Stimuli and participants

A total of 35 students from Grade 7, who are motion sickness susceptible were selected as subjects in this experiment. All the subjects had a normal or corrected-to-normal vision, and none of them had a history of gastrointestinal, cardiovascular, or vestibular disorders. Before the experiment, they were informed of the procedure and potential risks and voluntarily signed an experimental protocol. Participants were allowed to abort the experiment at any time when they felt unbearable, and they kept conscious during the process. All the procedures strictly conformed to the IB experimental safety protocol.

The stimulus consisted of a 15-min VR video showing an adventure tour under the sea. The chosen video was 15-minute-long, given that the pilot experiment revealed that a 15-minute-long video was appropriate to evoke motion sickness without triggering severe discomfort. Participants were seated in a chair, wearing a VR headset. During the VR watching session, the participants were requested to minimize their head movement. Otherwise, their head movements would cause unnecessary vestibular input.

The binaural beats were self-designed in software called Audacity. In the control and experimental group, there was pink noise (35dB). There was no difference in beat frequencies of the two sound channels in the control group, both were 100 Hz. Whereas, for the experimental group, the beat frequency in the left sound channel (100 Hz) differed 0.5 Hz from that in the right channel (100.5 Hz). In the blank group, subjects wore noise-reduction headphones without sound playing to avoid disturbance.

Measurement of visually-induced motion sickness

As the most predominant measurement of motion sickness, the simulator sickness questionnaire (appendix 1) provides a straightforward and valid index of the overall simulator sickness severity.[22] See the translated version and a brief explanation of SSQ in supplementary materials 1. During the experiment sessions, each subject filled in three SSQ questionnaires to subjectively rate the level of VIMS at three stages-after relaxation (listening to music), after induction, and after recovery. Filling in three simulator sickness questionnaires was denoted as filling in the pre-SSQ test, mid-SSQ test and post-SSQ test.

Physiological responses

Although SSQ scores can provide a straightforward index of VISM severity, they are sorely based on subjective sensation and can be more convincing if supported by objective data. Virtual Reality environments can induce physiological changes in the sympathetic and parasympathetic nervous systems, and changes include variances in electrodermal, cardiac activities and breathing rate.[23-25] The cutaneous parameters are all regulated by the parasympathetic nervous system and sympathetic nervous system. They are indicators of cold sweating, increased pressure, fatigue, or other symptoms arising from motion sickness. Therefore, the physiological data were collected as an alternative or supplementary assessment of VISM.

Psychological data were recorded using a commercially available Biofeedback sensor (NeXus-4, © Mind Media B.V., Netherlands) connected to a system called BioTrace+. It traced the parameters of autonomic nervous system activity for measuring sympathetic arousal. The skin conductance (SC) /electrodermal data were measured with 2 electrodes placed on the middle phalanx of the left-index finger and left ring finger. The skin temperature (ST) was measured using a sensor attached to the left middle finger. Another PhotoPlethysmoGraphy sensor on the left thumb collected the blood volume pulse (BVP) and heart rate variability (HRV). The respiration sensor was placed around the abdomen just below the rib cage to detect respiration rate (breaths per minute, rpm).

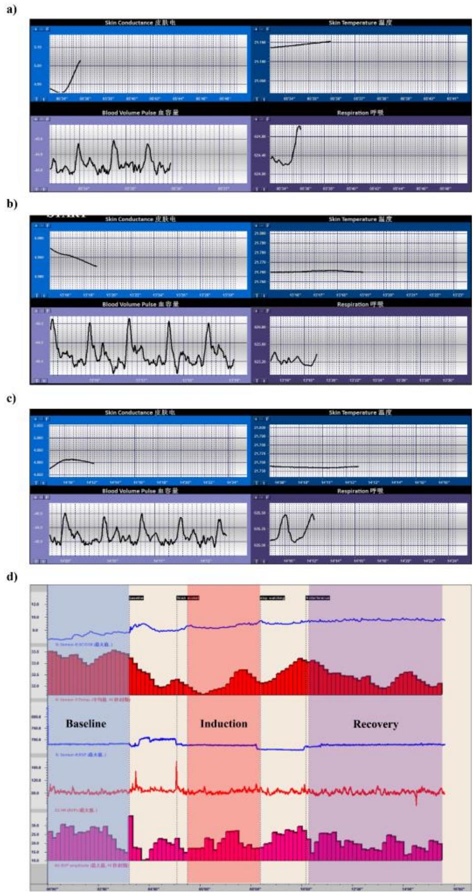

Figure 1. **Biofeedback sensor and BioTrace+ psychological data system**: *the parameters of autonomic nervous system activity for measuring sympathetic arousal were observed. a) without earphone b) with earphone c) final apparence d) resultant data.*

All the sensors were attached under the standard laboratory protocol and the User Manual for the BioTrace+ Software.[26] Throughout the experiment, participants wore the Biofeedback device. Critical points were marked by the experimenter as instructed by the screen created in advance. The details about the screens and instructions can be seen in the next section.

Procedure

Before the formal experiment, there was a pilot and feasibility study where 5 male and 5 female students (aged from 16 to 17 years old) were picked to test their sensitivity to binaural beats. Among them, all the female students could detect the 0.5 Hz difference in two soundtracks, and 80 percent of male students detected the 0.5 Hz difference. 60 percent of them reported that they distinguished a 0.2 Hz frequency difference. As a result, the 0.5 Hz frequency difference is chosen for the formal experiment to make sure subjects could sense the frequency difference. Subjects were randomly assigned into either the experimental group, control group, or blank group. The detailed procedure is listed in Figures 2 and 3.

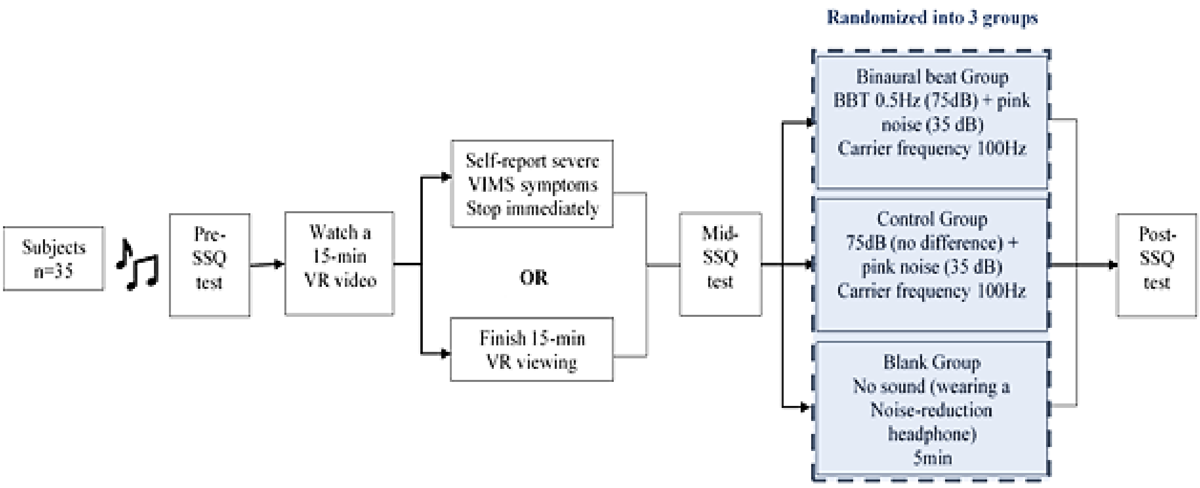

Figure 2. *The sad figure is the representing flow chart and experimental procedure of the research*

1) Participants listened to relaxing music for 3-4 min and their physiological data during this period were collected as baseline data for later comparisons.

2) After relaxing, participants were assigned a pre-SSQ test, assessing the level of motion sickness before being induced.

3) Then the experimenter helped participants to wear the VR headset to view the 15-min VR video. The viewing process stopped either when severe motion sickness was self-reported or when the video culminated.

4) A mid-SSQ test was given when the viewing ended, for checking the severity of VIMS induced by the video.

5) Subsequently, depending on the randomized experimental groups, participants were either exposed to binaural beats, beats with no difference between the left and right soundtracks, or no sound (control group). The duration of recovery lasted for 5 minutes. The volume of sounds was kept constant.

6) The last step was filling in the post-SSQ test to assess motion sickness after recovery.

Note a between-subjects design was chosen over a within-subjects design, preventing adaptation or habituation effects. Additionally, the between-subject design ensured that participants were not aware of the purpose of the study while viewing the video.

Figure 3. (a) VR Shinecon Virtual Reality Headset parameter configuration. (b) One of the subjects wearing a VR headset. (c) The Biofeedback devices are worn by a subject. (d) One of the subjects wore the earphone during the recovery.

RESULTS

SSQ scores

Using the method proposed by Kennedy et al,[22] subjects filled in three SSQ scales to subjectively measure their VIMS levels at different stages-at baseline, after induction and after recovery. The scores at three stages were denoted as Pre-SSQ, Mid-SSQ and Post-SSQ scores respectively. There are 31 effective questionnaires in total. See Appendix 2 for the raw data and calculation method.

The individual scatter plots were produced by using GraphPad Prism 6.0 (GraphPad Inc., La Jolla, California), and they show each subject's SSQ scores. Female and male groups are separately considered because they differ copiously in the susceptibilities to VIMS.[27] The black lines represent the mean scores of each group.

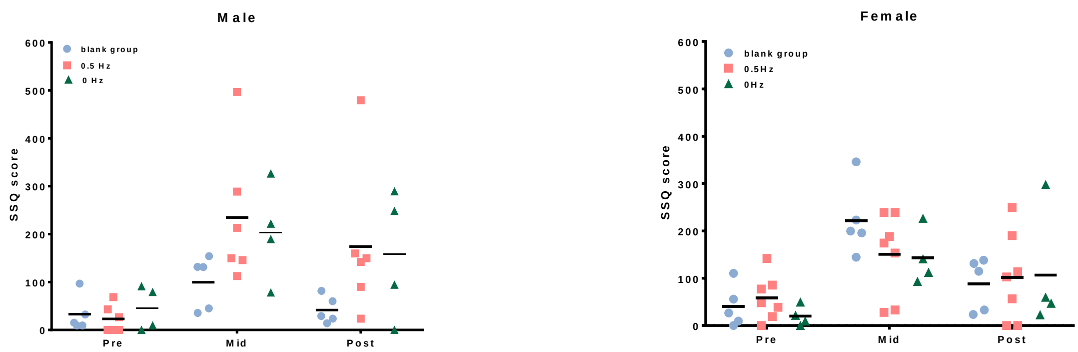

Figure 4. Individual SSQ scores: *The figure shows the VIMS levels at different stages during, before and after the induction in both male and female subjects*

The processed SSQ scores are listed in Table 2-3. There is a significant increase in Mid-SSQ scores compared to Pre-SSQ scores, meaning that watching the VR video did successfully induce VIMS. Also, the post-SSQ scores have a lower mean value than that of Mid-SSQ scores. It indicates motion sickness was mitigated to some extent, in all three groups. What's more, it can be easily deduced that the susceptibility of visually-induced motion sickness varies between individuals and genders.

Table 2. Female Group SSQ scores

	No intervention			0.5 Hz			0 Hz		
	mean	SD	N	mean	SD	N	mean	SD	N
Pre-SSQ	40.44	44.40	5	58.66	47.49	7	20.11	21.42	4
Mid-SSQ	221.72	75.06	5	150.59	87.97	7	143.05	58.70	4
Post-SSQ	88.09	55.41	5	101.75	93.59	7	106.75	128.19	4

Table 3. Male Group SSQ scores

	No intervention			0.5Hz			0 Hz		
	mean	SD	N	mean	SD	N	mean	SD	N
Pre-SSQ	32.66	37.04	5	23.02	28.53	6	44.98	46.84	4
Mid-SSQ	99.47	54.99	5	234.46	142.87	6	203.84	102.25	4
Post-SSQ	41.64	28.27	5	169.57	159.25	6	158.01	134.69	4

Physiological data

Among all the 35 subjects, 31 were subjectively perceived to have motion sickness. Their physiological data obtained before the introduction of the VR video serve as a basis for comparison with data collected during induction and recovery to assess the effect of different intervention methods.

Table 4. shows the mean values of the subject's psychological data at two stages-baseline and recovery. In the table below, the notation BL represents baseline, and RC stands for recovery.

Table 4. Paired Samples Statistics

Parameters		Mean	N	S. D.	S. E. M.
Skin conductance	BL	4.55	31	2.60	0.47
	RC	5.90	31	2.95	0.53
Skin temperature	BL	30.26	31	5.06	0.91
	RC	30.50	31	5.04	0.91
Respiration rate	BL	649.37	31	30.77	5.53
	RC	651.27	31	28.55	5.13
Heart rate	BL	89.85	31	12.39	2.22
	RC	93.47	31	13.08	2.35
Blood volume pulse	BL	22.74	31	12.66	2.27
	RC	19.61	31	15.25	2.74

Data analysis

Before entering the analysis part, it is necessary to clarify the research question and the hypothesis derived from it. To answer the question "Can binaural beats be effective to treat visually-induced motion sickness", the comparison between the level of VIMS before watching and after recovery is crucial. Besides, the comparison between the experimental group and the other two groups should also be included. If both of the two conditions are met, then the null hypothesis that "binaural beats are not effective at alleviating VIMS" is rejected:

1) After a 5-min treatment of binaural beats, the subjects' VIMS symptoms are significantly mitigated;
2) The effect of binaural beats treatment should vary significantly from that of the control group and blank group.

A t-test can compare the means of two groups, determining whether a treatment is effective or not. All the paired sample t-tests were completed in an integrated development environment for R, named RStudio.[28]

SSQ scores

The difference between Pre-SSQ (baseline) scores and Mid-SSQ (induction) scores is proven to be significant ($p<0.05$), as shown in Table 5-6. It reveals that the VR video had successfully evoked the symptoms of VIMS.

Table 5. Female SSQ Paired Sample T-test

Parameters	Mean	S. D.	S. E. M.	t	df	p-value
Pre - Mid	-127.60	85.42	21.35	-5.98	15	**<0.001**

Table 6. Male SSQ Paired Sample T-test

Parameters	Mean	S. D.	S. E. M.	t	df	p-value
Pre - Mid	-149.21	120.39	31.08	-4.80	14	**<0.001**

The next step is to verify whether the two conditions are met. The severity of motion sickness right after induction is quantified by the difference between the Mid-SSQ score and the Pre-SSQ score (Mid-Pre).

Table 7. Female SSQ Paired Sample Statistics

Parameters		Mean	N	S. D.	S. E. M.
No sound	**Post-Pre**	47.65	5	53.30	23.84
	Mid-Pre	181.29	5	42.91	19.19
0 Hz	**Post-Pre**	43.09	7	113.14	42.76
	Mid-Pre	91.93	7	104.52	39.50
0.5 Hz	**Post-Pre**	86.64	4	131.23	65.62
	Mid-Pre	122.94	4	66.13	33.07

Table 8. Male SSQ Paired Sample Statistics

Parameters		Mean	N	S. D.	S. E. M.
No sound	**Post-Pre**	8.98	5	37.35	16.71
	Mid-Pre	66.81	5	79.51	35.56
0 Hz	**Post-Pre**	150.99	6	142.02	57.98
	Mid-Pre	211.43	6	130.72	53.37
0.5 Hz	**Post-Pre**	113.04	4	129.21	64.61
	Mid-Pre	158.86	4	107.45	53.73

The level of motion sickness after recovery is quantified by the difference between the Post-SSQ and Pre-SSQ scores (Post-Pre). The SSQ paired sample statistics for the two genders are listed in Table 7 and Table 8.

The difference between male and female groups is obvious but there is no evidence showing which group is more vulnerable to visually-induce motion sickness. Paired t-tests were used to evaluate the significance of the difference between Post-Pre and Mid-Pre within all three groups. The results in Table 9 and Table 10 indicate that the null hypothesis cannot be rejected ($p>0.05$), which means the treatment of binaural beats did not show any effectiveness at alleviating VIMS. What's more, none of the three intervention methods exhibited the ability to effectively alleviate VIMS ($p>0.05$).

Table 9. Female SSQ Paired Sample T-test

Parameters	Group	Mean	S. D.	S. E. M.	t	df	p-value
(Post-Pre)-(Mid-Pre)	**blank**	-133.64	93.85	41.97	-3.18	4	**0.033**
	control	-48.83	69.61	26.31	-1.86	6	**0.113**
	binaural	-36.30	72.25	36.13	-1.01	3	**0.389**

Table 10. Male SSQ Paired Sample T-test

Parameters	Group	Mean	S. D.	S. E. M.	t	df	p-value
(Post-Pre)-(Mid-Pre)	**blank**	-57.83	59.07	26.42	-2.19	4	**0.094**
	control	-60.45	68.29	27.88	-2.17	5	**0.082**
	binaural	-45.83	99.91	49.95	-0.92	3	**0.427**

Physiological data

A paired sample t-test was used to determine which physiological data can be used to measure the level of VIMS. It has been proven that watching the VR video had successfully induced VIMS in the subjects. As a result, the parameter that varied significantly can objectively reflect the severity of visually-induced motion sickness. By comparing the differences in five physiological data at two stages (at baseline and induction), it is found that only heart rate varied significantly ($p<0.05$). When motion sickness intensifies, the subjects' heart rates decreased. In the following analysis, the heart rate will be used as a valid measure of subjects' motion sickness severity. The more severe the VIMS are, the more negative the heart rate difference (HR2–HR1) will be.

Table 11. Paired Samples T-test for Different Physiological Parameters

Parameters	Mean	S. D.	S. E. M.	t	df
SC2–SC1	-1.35	1.16	0.21	-6.43	30
ST2–ST1	-0.24	2.91	0.52	-0.45	30
RR2–RR1	-1.90	16.09	2.89	-0.66	30
HR2–HR1	-3.63	8.70	1.56	-2.32	30
BVP2–BVP1	3.13	13.01	2.34	1.34	30

HR2 denotes the mean heart rate at induction and HR1 denotes the mean heart rate at baseline. And the others can be deduced in the same manner.

Here are two self-defined concepts to be introduced: Subtract the mean heart rate at baseline from the mean heart rate at induction to obtain HR-minus. Subtract the mean heart rate at baseline from the mean heart rate at recovery to obtain HRminus2. The difference between HRminus2 and HRminus was used to see whether the level of VIMS at recovery differed significantly from that at induction. If the difference is significant enough, then it means the intervention was effective. The mean heart rate at baseline was subtracted because it would minimize the interference which arose from the individual difference in susceptibilities to motion sickness (not all the subjects got zero in the pre-SSQ test). Paired sample statistics for HRminus and HRminus2 are shown in Table 12.

Therefore, three independent paired sample t-tests were conducted. The results in Table 13 show that the differences between HRminus2 and HRminus within all the three groups are not significant enough ($p>0.05$). Therefore, the null hypothesis cannot be rejected, and this result is consistent with that obtained from SSQ scores.

Table 12. Paired Heart Rate Samples Statistics

Group	Type	Mean	N	S. D.	S. E. M.
No sound	**HRminus2**	4.89	11	12.17	3.67
	HRminus	-0.98	11	7.22	2.18
0 Hz	**HRminus2**	5.51	8	5.69	2.01
	HRminus	-0.59	8	13.12	4.64
0.5Hz	**HRminus2**	1.21	12	6.38	1.84
	HRminus	-0.19	12	3.37	0.97

Table 13. Paired Heart Rate Samples T-test

Parameters		Mean	S. D.	S. E. M.	t	df	p-value
HRminus2 - HRminus	**blank**	5.87	16.19	4.88	1.20	10	0.257
	control	4.92	17.01	6.02	0.82	7	0.440
	binaural	1.40	4.67	1.35	1.04	11	0.320

DISCUSSION

In summary, the results of SSQ scores and physiological data fit together to indicate that there is no strong evidence rejecting the null hypothesis, which means the subjects' overall severity of visually-induced motion sickness was not significantly reduced by the treatment of binaural beats after the exposure to a VR video. Some participants even reported intensified perception of VIMS after listening to 0.5 Hz binaural beats.

The possible explanations for these results include: 1) The sensory conflict theory does not stand; 2) The binaural beats failed to cause enhance EEG power,[29] therefore is unable to influence the perception of motion sickness; 3) 0.5 Hz is not an appropriate value because people are most VIMS-sensitive for sounds at frequencies near 0.2 Hz.[30]

In this experiment, variables like age, gender, head movement and mood were strictly controlled or considered to ensure validity and reliability. Also, some possible interference factors were excluded. The measuring equipment is highly accurate and precise. The sample size is large enough, and all the data are well organized and analyzed to draw a valid conclusion. Other factors that may influence the reliability of the results include the lack of a strict double-blind trial or actual clinic trial and the fact that subjects might have talked with each other about the objective of the experiment.

A between-subjects design was chosen over a within-subjects design. Its major drawback was that there was a significant difference in individuals' susceptibility to visually induced motion sickness. But the researcher had attempted to reduce it by subtracting the heart rate or pre-SSQ score at baseline when for the calculation. Among possible contaminates, the gender effect was selected to be balanced and analyzed, while others—like whether the participant frequently watches VR or 3D video games-were not identified. It is highly recommended for future researchers to analyze these aspects. The diet and the time of the day might have influenced the parasympathetic system activities. And that might be why not all of the physiological parameters can be a valid indicator of VIMS severity.

There might be some possible improvements in future experiments. For example, future researchers can choose a more appropriate recovery time and frequency difference (closer to 0.2 Hz). Probably, 5-min was too short for subjects to recover. Furthermore, a within-subjects design might offset the individual differences in VIMS sensitivity if the researcher treated every subject with three intervention methods. If one subject's motion sickness is significantly reduced after exposure to binaural beats than the control groups, the null hypothesis can be rejected. To avoid adaptation or habituation, the interval between each trail must be long enough. However, the experimental procedure was restricted by limited money and time.

Last but not least important, while tracing the heart rate variance of subjects, the researcher astonishingly found that five students had abnormally low heart rate variance levels, which indicated that they might have been bothered by depressive emotion. The results were reported to their teachers, lest they needed psychological assistance from the school or other agents.

CONCLUSION

The study aimed at investigating the impact of binaural beats on the mitigation of visually-induced motion sickness in VR environments. A group of motion sickness susceptible individuals (n=35), aged 13, were selected to watch a 15-min VR video. When the visually-induced motion sickness was evoked, they were treated with three intervention methods—binaural beats, normal beats and no sound treatment. Subjects' VIMS levels were evaluated by combining subjective SSQ scores with objective physiological data (heart rate).

By analyzing the changes in SSQ scores and heart rates, the results show that the null hypothesis cannot be rejected ($p>0.05$). In other words, no evidence supports that binaural beats can effectively mitigate visually-induced motion sickness, both in male and female groups. What's more, none of the three interventions was proven to be effective in reducing VIMS triggered by watching a VR video. The validity of sensory conflict theory is still arguable since the compelling evidence to support or completely contradict this theory is absent in this study.

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