Very Real VR

Jamie Voros[1†], Zachary Yoder[2†], and Alessandro Roncone[3*]

[1]Ann and H. J. Smead Aerospace Engineering Sciences, University of Colorado, Boulder, Colorado, USA

[2]Paul M. Rady Department of Mechanical Engineering, University of Colorado Boulder, Boulder, Colorado, USA

[3]HIRO Laboratory, Department of Computer Science, University of Colorado Boulder, USA

[*]Alessandro Roncone. Email: alessandro.roncone@colorado.edu

[†]These authors contributed equally to this work.

1 Introduction and Background

Virtual reality (VR) devices seek to immerse users into a digital environment to a degree which has been previously unattainable through traditional interfaces. In order to accomplish this feat, VR devices typically take the form of a wearable headset which displays a visual environment that entirely encompasses the user's field of view. VR has found applications in medicine [1], communication and entertainment. Recently, VR has become most used in simulation and video game applications [2].

However, VR users often experience unwanted side effects due to the immersive nature of the virtual environment [3]. Because virtual reality headsets only provide visual input, the user may experience side effects such as motion sickness or may express that the nature of the visual environment is unconvincing or does not feel real. The brain depends on cues from many sensory systems to feel real. One such system is the vestibular system, which communicates feelings of balancs (?). Here, we propose electrical stimulation of the vestibular system to mitigate the negative effects of the VR experience and create a more believable and immersive environment.

Galvanic Vestibular Stimulation (GVS) is a non-invasive, easy to administer method of stimulating the vestibular system. It involves providing electrical stimulation to mastoids (bones behind the ears), in doing this GVS stimulates the afferent neurons carrying signals from the inner ear organs to the brain. However, relatively few formal research studies have been carried out on the specific effects of GVS. Previous studies have largely focused on different applications of applying white noise to the vestibular system [4][5][6][7][8].

GVS has been shown as a method of more specific stimulation of the vestibular system [9], which

may cause the user to experience a sensation motion. [10] used GVS input in conjunction with a visual yaw-motion, and demonstrated that GVS could be used to create VR experiences that results in significantly lower cybersickness scores and a significantly more immersive environment than a no-GVS baseline [10]. This same technique for pitch and roll sensations has not yet been investigated.

To our knowledge, this is a first attempt to create more believable pitch and roll motions by combining a VR visual environment with GVS. We display a simple ocean wave environment to the user, where the user experiences a boat that is rocking in the waves. We ask the user to provide survey feedback [11][12][13] when the environment is displayed with and without GVS, in both the pitch and roll orientations. The subject will participate in a minigame with the task of throwing a ball into a basket. We will record the number of successful ball throws. We present the findings of the study and discuss the potential impact combining GVS with VR has on the larger virtual reality field.

2 Methods

In a 3×2 experimental design, we planned to test the efficacy of GVS as a means of improving the VR experience with two different VR conditions and 3 difference GVS conditions.

GVS was either targeted (design to illicit sensation of motion that matched up to the movements in the visual VR environment), white noise or not administered (none).

The VR environment either featured sinusoidal pitch tilt or sinusoidal roll tilt.

2.1 VR Environment and HMD

The virtual reality headset device we used was an HTC Vive HMD. The VR environment was made up of oscillating ocean waves, where the subject's position in the virtual environment was constrained to a floating raft. The raft, and consequently the user, was subject to both changes in vertical height and changes in tilt. Whether the subject experienced pitch or roll changes depended on their orientation within the environment. A picture of the virtual reality environment can be seen in Figure 1.

2.2 GVS

We used a Soterix Medical device to provide GVS. We used the white noise profile and the sinusoidal profile. We used the sinusodial profile as our targeted GVS profile. The sinusoidal profile was set up as the same frequency with which the virtual environment in the HMD was moving.

The white noise profile was administered at 1mA to all subjects. The sinusodial (targeted) profile was administered at 0.8mA (at peaks).

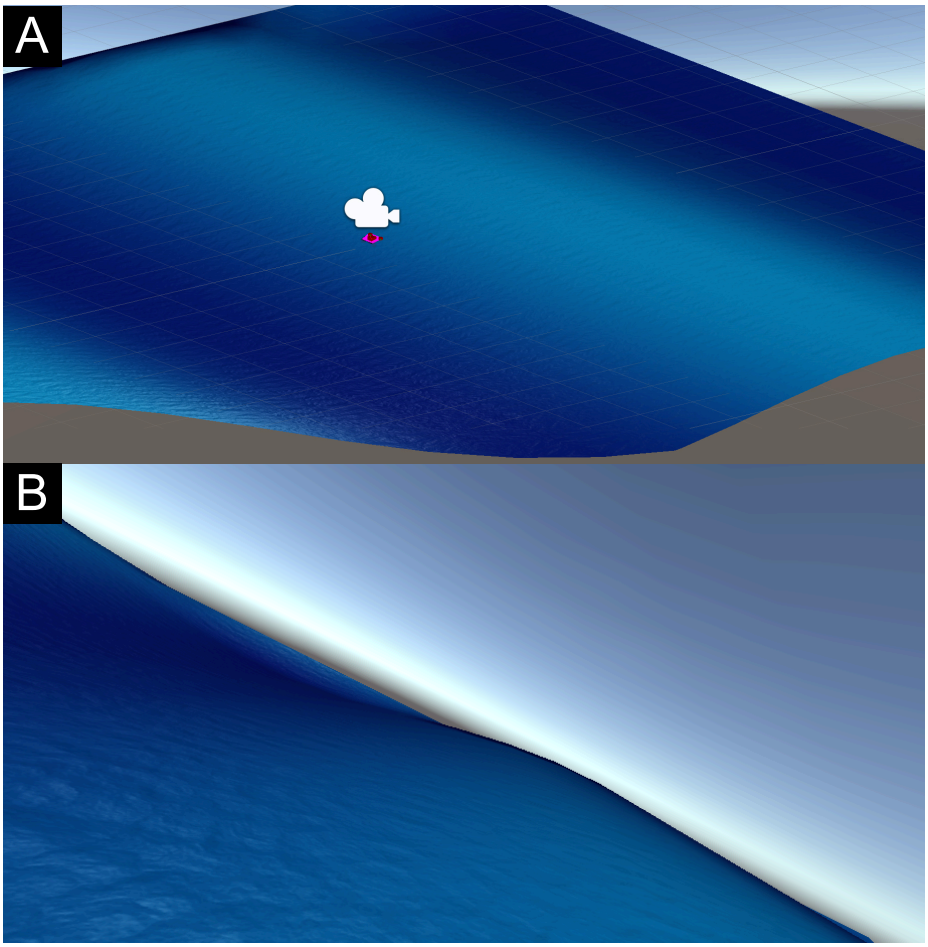

Figure 1: Virtual reality environment used in this work. (A) Overview of the virtual reality environment. The location of the subject in the virtual environment is denoted by the camera icon. (B) The environment displayed to the subject. In this case, the roll orientation is being displayed.

2.3 Procedures

All procedures were approved by the University of Colorado-Boulder Institutional Review Board and all subjects provided written informed consent. Subjects were screened for motion sickness susceptibility via the Motion Sickness Susceptibility Questionnaire (MSSQ) [14]. If a subject had an MSSQ score over the 90th percentile, they would have been removed. No subjects were screened out via the MSSQ.

After screening, subjects donned the GVS device [Sotreix Medical], the device remained donned for the duration of the experiment. To don the device, subjects first cleaned behind their nears with *Nuprep* gel. Subjects then donned a headband housing two plastic cups which were placed flush against the skin over the mastoids. *SignaGel* was inserted into the plastic cups, electrodes were placed into the cups and plugged into the Soterix Medical device. We ensured that the electrode connection to the subject had sufficiently low resistance (as indicated by the connection bars on the

Soterix Medical device).

Subjects then experienced the 6 experimental conditions in a randomized order. Each experimental condition consisted of donning the VR headset, watching the VR environment for 30 seconds, removing the headset and then completing the two questionnaires (SUS and KSSQ).

3 Results and Analysis

We had $n = 7$ subjects complete testing (3F, ages 22-29 mean 24.7 years). All subjects completed all experimental conditions.

We had two dependant variables, Kennedy Simulator Sickness Questionnaire (KSSQ) score and Slater-Usoh-Steed Questionnaire (SUS) score.

SUS scores was statistically significantly improved with the presence of GVS (both the white noise and targeted conditions). We were unable to detect a change in KSSQ with this experimental design.

3.1 SUS Score

We first ran a Shapiro-Wilk test for normality on each of the six groups of data that we collected, none were significant ($\alpha = 0.05$). We then tested for potential outliers via a Hampel filter. The filter gave us a range of $[-9.9, 38.9]$, between which all of our data points fell.

Running a repeated measure analysis of variance (RMANOVA) indicated that there the VR condition likely did not impact SUS scores (RMANOVA,$F = 0.905, df = 6, p = 0.378$) but that GVS condition may (RMANOVA, $F = 3.548, df = 6, p = 0.061$). The interaction did warrant further investigation (RMANOVA, $F = 0.64, df = 12, p = 0.544$). We therefore ran statistical tests on the differences in SUS scores between GVS conditions.

Since we were most interested in the impact that GVS has on the no stimulation (null) condition, we ran two paired t-tests on targeted GVS vs none and white noise GVS vs none. Targeted GVS showed a statistically significant improvement over the null condition (2-tailed paired t-test, $t = 3.04, df = 13, p = 0.009, CohensD = 0.81$) and had a large effect size ($CohensD = 0.81$). White noise GVS also showed an improvement over the no noise condition (1-tailed paired t-test, $t = 2.12, df = 13, p = 0.0267, CohensD = 0.57$) but had a more moderate effect size ($CohensD = 0.56$). Significant differences are shown graphically in Figure 2.

3.2 KSSQ Score

Similarly, we first ran a Shaprio-Wilk test for normality, none were significant at $\alpha = 0.05$. We then tested for potential outlienrs via the Hampel filter. The Hampel filter identified two potential outliers. We still ran an RMANOVA but kept in mind that the F-score (and thus p-value) would likely be inflated due to the two potentially anomalous data points.

There did not appear to be any significant changes in KSSQ score due to GVS (RMANOVA, $F = 0.52, df = 6, p = 0.606$) or VR (RMANOVA, $F = 0.47, df = 6, p = 0.520$). There may be an

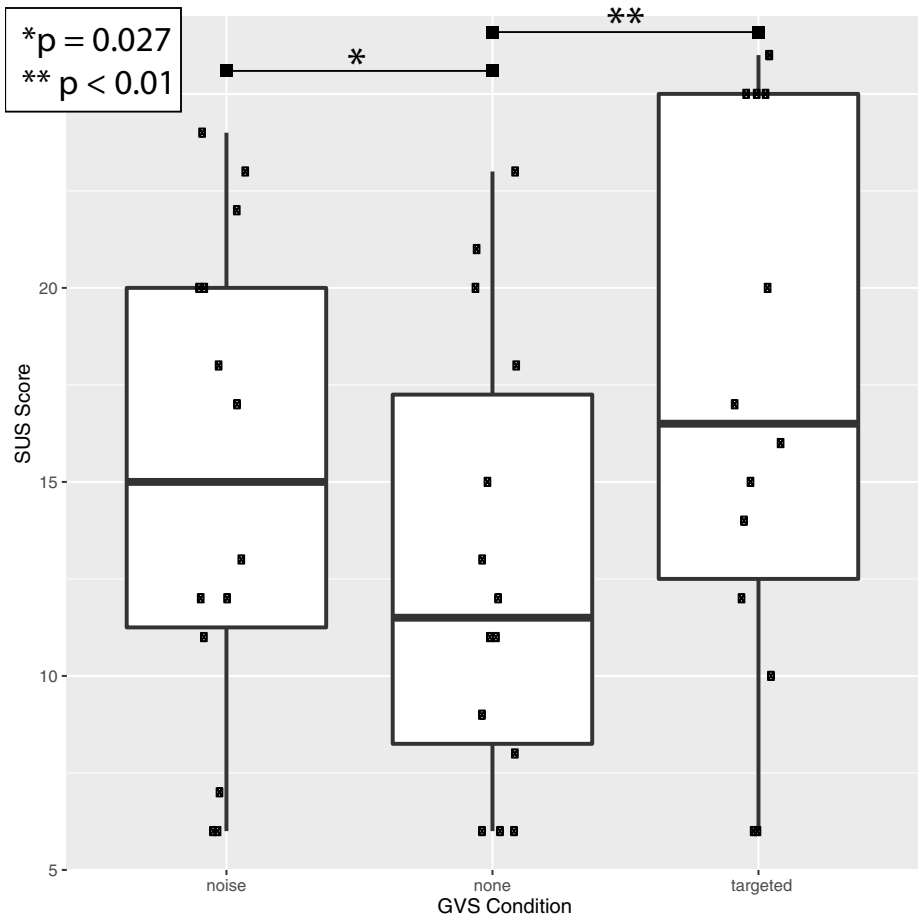

Figure 2: Boxplot to show differences in SUS score across the three difference GVS conditions. Stars indicate differences between groups as per the t-test protocol described above.

interaction effect (both GVS and VR), (RMANOVA, $F = 2.40, df = 12, p = 0.132$). Although the $p > 0.1$, recall that the two potential outliers may be inflating the p-value.

Examining a boxplot (see Figure 3) of each KSSQ scores divide by GVS and VR condition showed extremely similar means across all groups. We, therefore, decided not to run further statistical tests because we highly doubt that any would reach significance after post-hoc corrections. We note that due to our small study size ($n = 7$), we are not able to draw any conclusions from our data. We likely have high β error and it would not be appropriate to accept the null hypothesis because of this. Further, a previous study [15] showed white noise GVS to reduce sickness in VR.

4 Discussion

We present data supporting that hypothesis that GVS can improve the VR experience as measured by an established questionnaire [13]. Despite small our study size was ($n = 7$), we were still able to find a significant ($p < 0.01$) difference between experimental groups and demonstrate a large effect

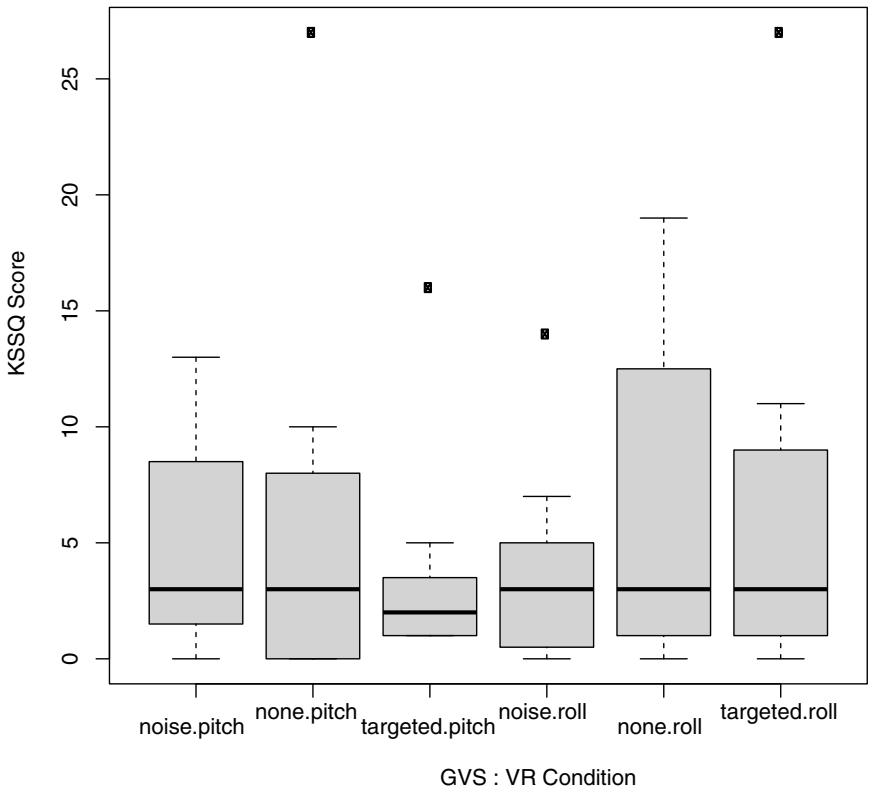

Figure 3: Boxplot to show KSSQ score across the groups, split by both GVS condition and VR condition. We note that the means appear similar

size ($CohensD = 0.81$). Our large effect size indicates that GVS has potential to vastly improve experiences in VR when the stimulation is targeted (when it matches up to the visual motion inside the HMD). To our knowledge, our study is the first study to examine the impact of targeted GVS in pitch and roll tilt, with just one prior study examining the use of GVS for yaw motions [10]. We were also able to show some limited improvement with the use of white noise, however we the effect size was much smaller and p-value much higher. We also note that we did not make post-hoc corrections, which would have nullified the significant finding that SUS scores in the white noise GVS condition were different from SUS scores in the no stimulation condition. This could be remedied by additional data collection.

We believe that we were unable to detect any changes in KSSQ score with our experimental design because of the realtively short time our subjects spent in VR. Although cybersickness is well documented [3][9][10][11], it is possible that our subjects were not in the virtual environment long enough to experience it. Additionally, since our study did not aim to intentionally make anyone feel unwell, we screened out subjects that we thought were most likely to experience cybersickness

(via the MSSQ, assuming that motion sickness susceptibility and cybersickness susceptibility are similar). Another possible reason that we were not able to replicate the results of the Weech et al. [15] study is because our subject pool was too small as compared the the effect size.

5 Conclusion

To our knowledge, we are the first use targeted GVS in conjunction with VR in roll and pitch tilt. We are excited to present statistically significant results indicating that targeted GVS improves the VR experience during passive roll and pitch motions. Further, the effect is not only significant, but the effect size is also considered large ($CohensD = 0.81$).

The next steps would be enhancing the visual VR environment and creating a GVS device capable to administering targeted GVS in response to subject's control inputs.

Acknowledgments

We would like to thank both the CS Department for hosting this class and the Bioastronautics Laboratory at The University of Colorado Boulder for allowing use of equipment and laboratory space.

References

[1] L. Ke, S. George, S. Thomas, D. Je, and M. Crotty, "Virtual reality for stroke rehabilitation (Review) SUMMARY OF FINDINGS FOR THE MAIN COMPARISON," *Virtual Reality for stroke rehabilitation (Review)*, vol. 80, no. 2, pp. 57–62, 2015, ISSN: 03678318. DOI: 10.1002/14651858.CD008349.pub4.www.cochranelibrary.com.

[2] M. Zyda, "From visual simulation to virtual reality to games," *Computer*, vol. 38, no. 9, pp. 25–32, 2005, ISSN: 00189162. DOI: 10.1109/MC.2005.297.

[3] J. Munafo, M. Diedrick, and T. A. Stoffregen, "The virtual reality head-mounted display Oculus Rift induces motion sickness and is sexist in its effects," en, *Experimental Brain Research*, vol. 235, no. 3, pp. 889–901, Mar. 2017, ISSN: 0014-4819, 1432-1106. DOI: 10.1007/s00221-016-4846-7. [Online]. Available: http://link.springer.com/10.1007/s00221-016-4846-7 (visited on 09/09/2020).

[4] F. Moss, L. M. Ward, and W. G. Sannita, "Stochastic resonance and sensory information processing: A tutorial and review of application.," *Clinical Neurophysiology*, vol. 115, pp. 267–281, 2004. DOI: 10.1016/j.clinph.2003.09.014.

[5] F. Zeng, Q. Fu, and R. Morse, "Human Hearing Enhanced by Noise," *Brain Research*, vol. 869, no. 1-2, pp. 251–255, 2000. DOI: 10.1016/s0006-8993(00)02475-6.

[6] E. Lugo, R. Doti, and J. Faubert, "Ubiquitous Crossmodal Stochastic Resonance in Humans: Auditory Noise Facilitates Tactile, Visual and Proprioceptive Sensations," en, *PLoS ONE*, vol. 3, no. 8, L. B. Vosshall, Ed., e2860, Aug. 2008, ISSN: 1932-6203. DOI: 10.1371/journal.pone.0002860. [Online]. Available: http://dx.plos.org/10.1371/journal.pone.0002860 (visited on 06/21/2018).

[7] J. L. Voros, "Cross Modal Stochastic Resonance in Perceptual Thresholds with Galvanic Vestibular Stimulation," PhD thesis, The University of Colorado, Boulder, May 2020.

[8] R. C. Galvan-Garza, T. K. Clark, A. P. Mulavara, and C. M. Oman, "Exhibition of stochastic resonance in vestibular tilt motion perception," eng, *Brain Stimulation*, vol. 11, no. 4, pp. 716–722, Aug. 2018, ISSN: 1876-4754. DOI: 10.1016/j.brs.2018.03.017.

[9] M. J. Cevette, J. Stepanek, D. Cocco, A. M. Galea, G. N. Pradhan, L. S. Wagner, S. R. Oakley, B. E. Smith, D. A. Zapala, and K. H. Brookler, "Oculo-Vestibular Recoupling Using Galvanic Vestibular Stimulation to Mitigate Simulator Sickness," en, *Aviation, Space, and Environmental Medicine*, vol. 83, no. 6, pp. 549–555, Jun. 2012, ISSN: 00956562. DOI: 10.3357/ASEM.3239.2012. [Online]. Available: http://openurl.ingenta.com/content/xref?genre=article&issn=0095-6562&volume=83&issue=6&spage=549 (visited on 09/18/2020).

[10] M. Sra, A. Jain, and P. Maes, "Adding Proprioceptive Feedback to Virtual Reality Experiences Using Galvanic Vestibular Stimulation," en, in *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems - CHI '19*, Glasgow, Scotland Uk: ACM Press, 2019, pp. 1–14, ISBN: 978-1-4503-5970-2. DOI: 10.1145/3290605.3300905. [Online]. Available: http://dl.acm.org/citation.cfm?doid=3290605.3300905 (visited on 09/09/2020).

[11] R. S. Kennedy, N. E. Lane, K. S. Berbaum, and M. G. Lilienthal, "Simulator Sickness Questionnaire: An Enhanced Method for Quantifying Simulator Sickness," en, *The International Journal of Aviation Psychology*, vol. 3, no. 3, pp. 203–220, Jul. 1993, ISSN: 1050-8414, 1532-7108. DOI: 10.1207/s15327108ijap0303_3. [Online]. Available: http://www.tandfonline.com/doi/abs/10.1207/s15327108ijap0303_3 (visited on 10/02/2020).

[12] W. IJsselsteijn, Y. De Kort, and K. Poels, *The game experience questionnaire*. 2013.

[13] M. Slater, M. Usoh, and A. Steed, "Depth of Presence in Virtual Environments," en, *Presence: Teleoperators and Virtual Environments*, vol. 3, no. 2, pp. 130–144, Jan. 1994, ISSN: 1054-7460. DOI: 10.1162/pres.1994.3.2.130. [Online]. Available: https://www.mitpressjournals.org/doi/abs/10.1162/pres.1994.3.2.130 (visited on 10/02/2020).

[14] J. F. Golding, "Motion sickness susceptibility questionnaire revised and its relationship to other forms of sickness," en, *Brain Research Bulletin*, vol. 47, no. 5, pp. 507–516, Nov. 1998, ISSN: 03619230. DOI: 10.1016/S0361-9230(98)00091-4. [Online]. Available: https://linkinghub.elsevier.com/retrieve/pii/S0361923098000914 (visited on 12/02/2020).

[15] S. Weech, T. Wall, and M. Barnett-Cowan, "Reduction of cybersickness during and immediately following noisy galvanic vestibular stimulation," en, *Experimental Brain Research*, vol. 238, no. 2, pp. 427–437, Feb. 2020, ISSN: 0014-4819, 1432-1106. DOI: 10.1007/s00221-019-

05718-5. [Online]. Available: http://link.springer.com/10.1007/s00221-019-05718-5 (visited on 12/02/2020).