Look at the Horizon: Evaluation of a Software Solution Against Cyber Sickness in Virtual Reality Applications

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Keywords: Cyber Sickness, Virtual Reality, Mixed Methods, Software Layer, Evaluation Study.

Abstract: Cyber sickness (CS), a symptom that occurs in 30-80% of users when using virtual environments, is still considered an obstacle to the spread of virtual reality (VR). The aim of this study is to investigate whether symptoms of CS can be minimised by software adaptation. A prototype of a layer based on the "Seetroën Glasses" was used for this purpose. 80 students participated in the study with virtual roller coaster rides. The results show that the group with the layer was able to increase its performance and that the layer was able to delay the exit of the participants for about 2 laps. The layer does not provide immunity to CS, but it does delay the onset of symptoms. The study shows that the virtual test environment is suitable for investigating CS and that the prototype of the layer may be promising for reducing symptoms of CS.

1 INTRODUCTION

Immersive interfaces such as simulators or virtual environments enable impressive interactions and compelling user experiences, but they carry the risk of severely compromising subjective well-being (Chang et al. 2021; Mayor et al. 2021). The problem is known by many names, e.g., simulator sickness or cyber sickness (Dennison/Krum 2019), and it is an open debate whether these refer to the same or closely related aspects of motion sickness (see David/Nesbitt/Naivaikko 2014; Gavgani et al. 2018; Zupanic 1993). Modern simulation systems such as the use of virtual reality (VR) can also trigger the above-mentioned complaints. However, as long as these negative effects in the use of virtual reality cannot be reliably avoided, they will continue to be a major obstacle to the growth of the VR medium.

Cyber sickness is a condition that can occur during or after exposure to virtual environments. Symptoms include headaches, eye strain, nausea or even vomiting in extreme cases (LaViola 2000). It is estimated that some degree of cyber sickness occurs in about 30% to 80% of all users (cf. Rebenitsch/Owen 2016).

Cyber sickness is therefore considered a major obstacle to the spread of the medium of virtual reality (VR). Although the phenomenon has been known for a long time under the names of simulator sickness or motion sickness and is attributed to conflicts between the visual and vestibular systems (Stanney/Kennedy/Drexler 1997), there is still no generally recognised solution for the prevention of the disease that is suitable for everyday use (Saredakis et al. 2020; Yildirim 2020).

2 RELATED WORKS

A large body of research on cyber sickness aims at a better understanding of the symptoms of the disease and the factors of its cause (see for an overview Duzmanska 2018 and Rebenitsch/Owen 2016). According to the theory of "sensory mismatch", the most likely cause of cyber sickness is a mismatch between visual stimuli and the corresponding vestibular or proprioceptive feedback (see Gavgani et

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Harth, J., Zimmer, C. and Zupanic, M.
Look at the Horizon: Evaluation of a Software Solution Against Cyber Sickness in Virtual Reality Applications.
DOI: 10.5220/0012049900003541
In *Proceedings of the 12th International Conference on Data Science, Technology and Applications (DATA 2023)*, pages 13-21
ISBN: 978-989-758-664-4; ISSN: 2184-285X

al. 2018). In addition, other factors can also contribute to the occurrence of motion sickness. These factors can be divided into hardware-dependent categories (e.g., tracking problems or input/output delays, refresh rate of displays, as well as screen tearing) or content-related categories (such as the visual representation of the direction of motion or the presence of linear or angular accelerations).

In addition, the processing of perceptions varies between people. Field dependence describes the tendency to which the perception of one's own body position in space is influenced by contextual information (Witkin et al. 1954). Individuals with higher levels of field dependence rely more heavily on external cues (e.g., reference frames, background objects), while field-independent individuals rely more heavily on internal cues (e.g., vestibular, proprioceptive) to perceive body position. Field independence is more common in men and associated with lower susceptibility to motion sickness (Bendall et al. 2016). Field dependence can affect the perception of vection (illusory self-motion) in virtual space when a visual frame is missing and the vertical of the earth is not clearly displayed (Keshararz et al. 2016).

An innovative and promising solution against the occurrence of motion sickness while travelling by car or train has been presented by the car manufacturer Citroën. The so-called "Seetroën Glasses" (Figure 1) add a variable horizon to the peripheral field of vision of the wearer. According to the manufacturer, this leads to a peripheral and stable focus of the surroundings, which suppresses the symptoms of motion sickness (cf. Picot/Wright 2016). The manufacturer of the glasses advertises a success rate of 95 %. In addition, the Seetroën glasses are said to take effect in only 10-12 minutes even if motion sickness is present and could even be taken off again afterwards (cf. Citroën 2020). Unfortunately, we could not find any independent research or evidence for the effectiveness of these glasses.

Figure 1: Seetroën Glasses (cf. Citroën 2020).

The aim of this study was to investigate whether and to what extent discomfort in the use of virtual applications can be minimized by a software-based adaptation from the motion sickness domain.

3 METHODS

Both the layer and the application were created from scratch in the Unity Engine for this study. For the conception of the virtual layer, we adapted the principle of the "Seetroën glasses" (Figure 1) of the car manufacturer Citroën. In principle, the layer should also be easy to use in any VR application. To test the effect of the layer, we therefore created an application that can induce cyber sickness in the first place.

For this purpose, a prototype was developed together with the University of Applied Sciences Düsseldorf, which provides the user with peripheral fixed points in the head-mounted display (HMD) in the style of the "Seetroën Glasses" (see Figures 2, 3).

The application was realised in the Unity engine and shows the following features:

- Roller coaster ride with a duration of 70 seconds per lap,
- Activation / deactivation of endless rides,
- Activation / deactivation of VR layer,
- Additional offset for layer (0-1),
- Options for the virtual distance of the layer to the user's POV (2m, 1m, 50cm, 30cm, 20cm, 10 cm).

The test environment of the study consists of a virtual roller coaster ride that goes through a looping and several steep curves and slopes. The aim of the design of the roller coaster was to create a suitable environment that can lead to cyber sickness. Overhead rides as well as tight curves while travelling fast are considered good conditions for generating the symptoms under investigation (Islam et al. 2020).

The Hardware Setup for the study consisted of a capable VR computer (AMD Ryzen 5600, GeForce RTX 3080, 32 GB RAM) and a suitable VR Headset (Valve Index).

By means of a virtual visual layer, which is modelled on these glasses, the visual-vestibular conflicts of the users should be eliminated. The main research question was to what extent the principles of the anti-motion sickness glasses "Seetroën Glasses" by the car manufacturer Citroën can be transferred to the use of VR headsets and to what extent the layer can help against the symptoms of cyber sickness.

Figure 2: Rollercoaster with activated layer.

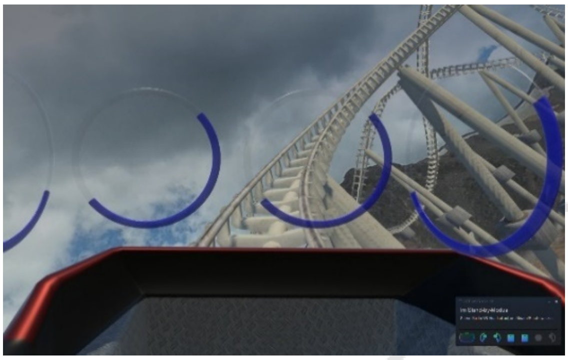

Figure 3: Dynamic adaptation of the layer to the virtual horizon.

3.1 Participants

Eighty students (49 female, 31 male) with an average age of 23.51 ± 5.89 years (minimum 18, maximum 45 years) participated in the study and were randomly assigned to one of the two groups: control or layer. The extent of field dependence was measured with three visual perception subtests by summing the individual raw scores and classifying them as norm scores (c.f., LPS-2; Kreuzpointner/Lukesch/Horn 2013). The average norm score for performance in the LPS-2 Visual Perception was 101.50 ± 14.73 (minimum 74, maximum 139).

Table 1: Quasi experimental design with perception style and viewing conditions.

	Intervention with layer	Control without layer
Field dependence low	N=20 (11 f., 9 m.)	N=21 (10 f., 11 m.)
Field dependence high	N=20 (15 f., 5 m.)	N=19 (13 f., 6 m.)

After median dichotomization of performance in the LPS-2 Visual Perception, participants with a score below the median of 100 were classified as field dependent, and participants with a score above 100 were classified as field independent. Considering the perceptual style and the viewing conditions, the results of the participants are grouped in a quasi-experimental design (see Table 1.). Female (f.) and male (m.) participants are evenly distributed across the four groups.

The participants' experience with motion stimulation was also asked. About one third of the sample (N=25, 31.3 %) said they had never ridden a roller coaster or only once, 25 % (N=20) up to ten times and most participants (N=35, 43.8 %) more than ten times. When asked how often they played computer games, half (N=42, 52.5 %) said they never played, followed by at least once a month (N=19, 23.8 %), at least once a week (N=15, 18.8 %) and daily (N=4, 5 %). Only 4 participants (5 %) use VR at least once a month. The rating of the subjective sensitivity to motion on a scale of 0-10 resulted in an average value of 4.18 ± 2.34 (minimum 0, maximum 9) for the sample. The distribution is right skewed (skewness = .736) and flattened (kurtosis = -.493), with many small values. The participants thus tend to describe themselves as insensitive to motion (Figure 4).

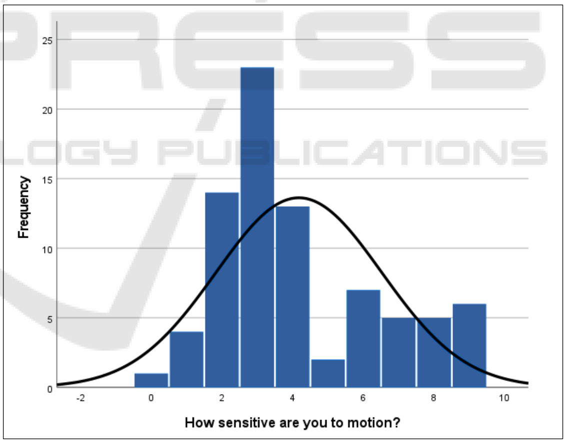

Figure 4: Ratings of subjective sensitivity to motion (N=80).

3.2 Materials and Procedures

In a mixed methods approach, we conducted a quasi-experimental study with a questionnaire survey, static ataxia tests and a subsequent evaluation by qualitative interviews. While the questionnaires establish objectifiable coherence between the level of cyber sickness and the different prototypes, the interviews primarily served as a subjective assessment and articulation of the experiences from the subjects' point of view. Conditions for participation were a minimum age of 18 years and the exclusion of serious illnesses (e.g., epilepsy, serious cardiovascular diseases, diseases of the hearing organ), a pacemaker or other implanted medical devices as well as acute or chronic mental illnesses.

The study received a positive vote from the Ethics Committee of Witten/Herdecke University (S-142/2021). In addition, the subjects had the option of discontinuing their participation in the study at any time, which is pointed out to them in a consent form. Furthermore, the study complies with the Code of Conduct on the Ethical Use of Virtual Reality in Research (cf. Madary/Metzinger 2016).

The Cyber Sickness Questionnaire (CSQ) was developed based on the Simulator Sickness Questionnaire (cf. Kennedy 1993; Bimberg et al. 2020) and the Virtual Reality Sickness Questionnaire (cf. Kim 2018; Sevinc/Berkman 2020). It serves as a quantifiable survey form and consists of a total of 24 items, with six demographic items (age, gender, previous VR experience) and nine items on symptoms of cyber sickness, e.g., nausea, headaches, dizziness. The CSQ is presented to the test subjects before and after the roller coaster ride to enable a pre/post comparison.

The static ataxia tests were also conducted in a pre/post design to measure possible balance disorders (disequilibrium; cf. Litleskare 2021) of the subjects that could be caused by the roller coaster ride. In the static ataxia tests, a body posture is to be maintained for a certain duration (30 seconds), first with open and then with closed eyes. The performance in the tests SPLEO (stand on preferred leg eyes open) and SPLEC (stand on preferred leg eyes closed) as well as SNPEO (stand on non-preferred leg eyes open) and SNPEC (stand on non-preferred leg eyes closed) is recorded before and after the roller coaster ride.

The perceptual style field dependence was recorded with the three subtests of the performance test system (LPS-2; Kreuzpointner/Lukesch/Horn 2013) for visual perception: Subtest 6: mental rotation, Subtest 7: area count and Subtest 8: line pattern (see Table 2). In total, the performance test system 2 contains eleven subtests in the four factors crystalline intelligence, fluid intelligence, visual perception, and cognitive speed. The good to very good internal consistency of the three subtests is $\alpha = .86$ (subtest 7), $\alpha = .90$ (subtest 8) and $\alpha = .93$ (subtest 6).

In addition, we applied the Fast Motion Scale (FMS) during the subject's immersion. The procedure is as follows: Acquisition of a self-measured, subjective measure of cyber sickness, which is continuously queried by the study leader during the immersion (McHugh et al. 2019). In the FMS, the subject is asked to verbally communicate the measure of cyber sickness, e.g., on a scale of 0-20 (Keshavarz/Hecht 2011) or 1-10 (Bock/Oman 1982). From this, a running chart or graph of the subject's subjective well-being can be created. This can identify sections of an application or process that cause increased levels of cyber sickness (McHugh et al. 2019). In our approach, the current well-being of the test subjects was recorded after each lap on a scale of 0-10.

Total duration time for every single participant in the study was about one hour.

4 RESULTS

The results of the study include both the basic technical creation and programming of the virtual layer in virtual reality inspired by the Seetroën glasses as well as the test application itself and the evaluation of the prototype in a randomised control trial.

The creation of the prototype based on the "Seetroën Glasses" could be carried out successfully. In VR, a layer could be activated over the visible image in the options menu. In this way, the test subjects could be divided into two groups: while the control group rode the roller coaster without a layer, the experimental group saw the layer to be tested in their field of vision.

4.1 Cyber Sickness Questionnaire (CSQ)

The test-theoretical examination of the questionnaire is carried out with item analyses in which the mean value, standard deviation and discriminatory power of all items are calculated. According to Lienert/Raatz (1994), the coefficient of selectivity is the correlation of the item response with the sum value of the scale and is the characteristic value for the extent to which the differentiation of the persons by the item corresponds with that by the scale.

After the intervention, the items 1 (Do you suffer from nausea?), 4 (Do you suffer from dizziness when your eyes are closed?) and 7 (Does your head feel heavy or full?) have the highest agreement in the post-CSQ, with mean values of $M = 2.20$, 1.73 and 1.73 respectively. The discriminatory power of the items in the post-CSQ is in no case below the critical value of .20, and many are in a good to very good range (r .60).

To test the scale of the CSQ, the reliability is calculated according to Cronbach's Alpha. This model of internal consistency is based on the average inter-item correlation. Characteristic values of the CSQ scales are the scale mean (M), standard deviations (SD) and the homogeneity coefficients (α). As expected, the higher agreement is found in the Post-CSQ_sum scale (1.57 ± 0.40) vs. the Pre-CSQ-sum (1.13 ± 0.22). Both scales show a high internal consistency, which can be rated as satisfactory to good (α > .700).

Statistical testing of differences in the CSQ scales between the study groups (control vs. intervention, field-independent vs. field-dependent, quasi-experimental design) revealed no significant differences.

Table 2: Descriptive statistics (mean, standard deviation) for the Post-CSQ_sum scale in the study groups (N = 80 participants).

	Intervention with layer	Control without layer
Field dependence low	1.54 ± 0.35	1.61 ± 0.39
Field dependence high	1.54 ± 0.33	1.58 ± 0.53

4.2 Ataxia Tests

The ataxia tests, as well as the CSQ, were performed before and after the roller coaster for a maximum of 30 seconds. The performance of the participants in the two tests SOPLEC (stand on preferred leg eyes closed) and SONPLEC (stand on non-preferred leg eyes closed) is documented in table 3.

Table 3: Descriptive statistics for performance in the ataxia tests (N = 80 participants).

Ataxia Tests	M	SD
Pre_SOPLEC_sum	13.99	8.97
Post_SOPLEC_sum	13.07	9.19
Pre_SONPLEC_sum	13.46	8.81
Post_SONPLEC_sum	13.31	8.12

Statistical testing revealed a significant difference. While in the control group the performance in the ataxia test SOPLEC was significantly less favorable after the roller coaster ride than in the pre-test, the group with the layer was able to increase its performance (F = 4.55, p = .036).

4.3 Fast Motion Scale

The Fast Motion Scale (FMS) is an assessment of the subjective measure of cyber sickness during the immersion, in this case during the 15 laps of the roller coaster ride. Participants had the option to end the immersion early, so only the first two laps were completed by all. Overall, the FMS shows a large spread of values (response scale 1 - 10). The average number of laps is 9.20 ± 4.78 (minimum 2, maximum 15).

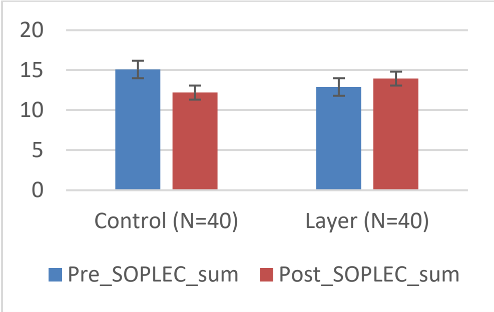

Figure 5: Error bars for performance in the pre and post SOPLEC ataxia test before and after the intervention (N=80).

Table 4: Descriptive statistics for FMS items in 15 laps (N = 80).

Fast Motion Scale (FMS)	M	SD
FMS_1	1.83	2.11
FMS_2	2.63	2.53
FMS_3	3.29	2.53
FMS_4	3.54	2.44
FMS_5	3.67	2.51
FMS_6	3.76	2.50
FMS_7	3.70	2.41
FMS_8	4.07	2.66
FMS_9	4.09	2.71
FMS_10	3.81	2.67
FMS_11	3.66	2.76
FMS_12	3.07	2.16
FMS_13	3.25	2.27
FMS_14	3.41	2.37
FMS_15	3.19	2.28

The rapid reduction of the sample is evident in the survival function (Figure 5) of the Kaplan-Meier analysis, while the 1-survival function (see Figure 6) illustrates the growth of cyber sickness over time described in the literature.

The first third of dropouts are up to lap 5 (N=26, 32.5 %), the middle third up to almost the last lap (N=28, 35 %) and only one third of participants (N = 26, 32.5 %) complete the intervention with all 15 laps.

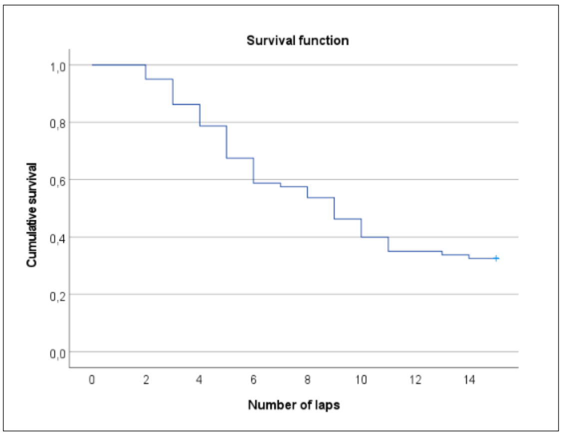

Figure 6: Survival function for the number of laps in the roller coaster ride (N=80).

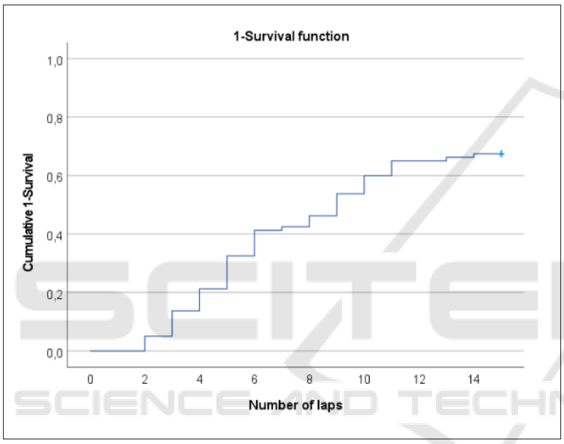

Figure 7: 1-Survival function for the onset of cyber sickness in the roller coaster ride (N=80).

These three groups differ significantly not only in the number of laps, but also in gender, subjective sensitivity to exercise and in the Cyber Sickness Questionnaire (post-CSQ) after the intervention. There are significantly more females (N = 20) than males (N = 6) in the early dropout group (Chi-Square = 6.73, p = .035), who have significantly less experience with computer games (Chi-Square = 17.24, p < .001) and describe their subjective sensitivity to exercise at a higher level (Mann-Whitney-U = 211, p = .018). In the Post_CSQ, the highest expression in comparison is found in item 1 (Do you suffer from nausea?) with 2.62 ± 0.64 (Kruskal-Wallis-H = 26.21, p = .001) for this group.

In the middle group with a dropout between the 5th - 15th lap, on the other hand, a different symptom profile emerges. Here, the highest expression in the Post_CSQ is item 2 (Do you suffer from headaches?) with 1.64 ± 0.73 (Kruskal-Wallis-H = 10.82, p = .004) and item 6 (Does your head feel heavy or full?) with 1.96 ± 0.64 (Kruskal-Wallis-H = 13.49, p = .001). The sum of the CSQ after the intervention shows clear differences between the three groups (Kruskal-Wallis-H = 21.72, p < .001).

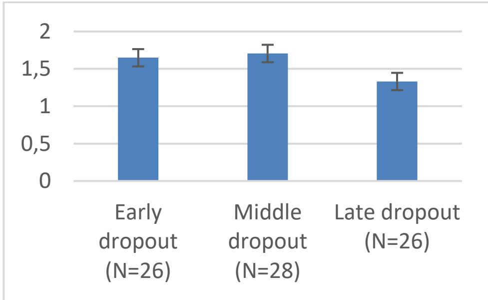

Figure 8: Results in the Cyber Sickness Questionnaire (CSQ) after the intervention (N=80).

To better understand these effects statistically, we formed an FMS score from the sum of the individual FMS values divided by the number of laps ridden (transformation to scale). The FMS score is on average 3.95 ± 1.90 (minimum 0, maximum 8) and differentiates significantly between the control and layer groups (Mann-Whitney: U = 566, p = .021), with less favorable average values for the control (4.37 ± 1.98) compared to the layer (3.52 ± 1.75).

The difference between the genders is even more marked (Mann-Whitney: U = 487, p = .007), with higher scores for females (4.38 ± 2.06) than for males (3.27 ± 1.39). There is no difference in field dependence.

5 CONCLUSIONS

Overall, the application is a very suitable test environment for the emergence of cyber sickness. Figures 5 and 6 clearly show how the onset of cyber sickness steadily increases over time (or over the duration of the roller coaster ride) and how more and more test subjects abandon the ride. In addition, a clear three-way division of the test subjects can be made in our sample: while a third of the subjects already quit by lap five, another third manages to ride until lap 10 before quitting. The last third seems to have no difficulty in spending the entire time in VR. A more detailed analysis shows that the sensitive group consists mainly of female participants who have little experience with computer games.

This finding is consistent with the state of the research (see Curry 2019), but not only Saredakis et al. (2020) summarize that more research is needed to better identify and understand the prevalence of cyber sickness due to gender differences or other individual factors regarding immersive technology (Harth et al. 2018). Currently, the discrepancies identified appear to be best explained by a complex combination of various individual factors and uncontrolled experimental variables (Grassini/Laumann 2020).

The main question of this study was whether the activation of the layer makes a difference in the occurrence of cyber sickness. However, this technical evaluation turned out to be more difficult than expected. The results of our study seem to be determined by at least two limitations in their informative value:

The transferability of our results to a generalization is limited by the underlying sample. Firstly, it consists of a rather young sample, and secondly, it is very different in terms of previous experience with digital games and virtual reality experiences. Here, an experimental design would be advisable for a follow-up study that is oriented towards both the separation of genders and the separation of computer game experience.

The methodologically determined limitation concerns the generous offer of a possible exit at any time during the experiment. With this, we generated ethically valuable, but less meaningful data. This is because it can be assumed that the test persons terminated the experiment before the actual occurrence of severe cyber sickness. In the case of the sensitive subjects, this probably happened even earlier. In a further series of experiments, we would therefore not offer a self-chosen exit (proactively) at any time, but rather wait for the individual wish to quit. Therefore, a more rigid procedure, which was not considered mainly for ethical reasons, would probably have led to significantly higher numbers of laps, higher scores in the FMS and more significant differences in the post-CSQ.

Nevertheless, a clear tendency for the effect of the layer can be seen with the data we collected. Thus, our results are in line with the literature regarding technical solutions against cyber sickness (cf. Pico/Wright 2016). A direct comparison of the exit times between the two experimental groups with/without the layer shows that the layer can delay the exit of the test persons by about 2 laps (see Figure 8). Although the layer does not provide immunity, it does delay the onset of cyber sickness.

In light of our findings, it is possible that the layer could also be utilized in other virtual reality environments, extending its applicability beyond the roller coaster test scenarios. Further research would

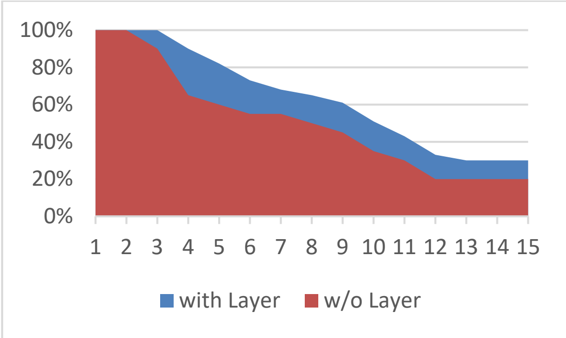

Figure 9: Comparison of the cumulative exit points during 15 rounds of rollercoaster (with layer = blue; without layer = red; N=80).

be required to investigate the efficacy of the layer in different settings and to determine whether its positive effects on reducing cyber sickness symptoms remain consistent across a wider range of applications.

Another aspect to consider is user acceptance of the layer. Although our study did not specifically focus on evaluating user satisfaction, it is crucial to explore whether users perceive the layer as a helpful and acceptable solution in their virtual reality experiences. Investigating the optimal transparency levels for the layer and examining how it could be adjusted to accommodate individual preferences and needs would provide valuable insights for enhancing user experience.

The layer may prove particularly useful during the initial training phases of virtual reality applications, akin to how astronauts undergo training to mitigate the effects of motion sickness. By using the layer to cushion the impact of cyber sickness during early exposure to virtual environments, users may be able to gradually acclimate to the VR experience, eventually reducing their reliance on the layer. This approach would position the layer as a temporary solution for easing the transition into VR usage, rather than a permanent fixture.

In conclusion, our study presents a promising first step in exploring the potential of the layer as a means of reducing cyber sickness symptoms. While it does not provide complete immunity to cyber sickness, it delays the onset of symptoms and may offer valuable benefits for users, particularly during the initial stages of virtual reality exposure. Further research is needed to refine the layer's application, assess user acceptance, and evaluate its efficacy in a broader range of virtual environments.

ACKNOWLEDGEMENTS

We would like to thank the Internal Research Grant of the Faculty of Health at Witten/Herdecke University for funding this study.

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