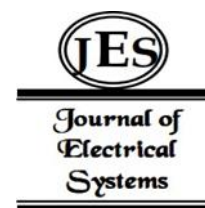


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Virtual Reality Sickness and its Impact on the Effectiveness of Virtual Reality Training



Abstract: - Today's fully immersive VR systems are struggling with the phenomenon of so-called "VR sickness". VR sickness represents a subtype of cybersickness that has been induced specifically by VR technology such as the CAVE or HMD headset. The essence of current VR systems is to allow an individual to move in a virtual space, with little or no real movement. Movement in the virtual environment is achieved by relatively small body movements, but mostly through teleportation from place to place, or by using buttons and analogy joysticks on the controller. Thus, it can be assumed that the primary agent of the state of nausea here is not motion, but the illusion of motion.

The individual symptoms of VR sickness can manifest in a person in the form of fatigue, blurred vision, headache, upset stomach and rapid breathing, which may escalate in the final stages to severe nausea, disorientation or vertigo and vomiting. The dominant symptom here is disorientation and motor problems, which may be followed by feelings of nausea, upset stomach or vomiting, and only lastly by symptoms associated with visual or ocular disturbance.

Again, there are factors associated with the overarching categories of "sickness", which for the sake of generality will be summarised for now as: healthy and biological predispositions, VR technology used, time and experience.

A popular methodology for measuring and recording cybersickness is in the form of the so-called "Simulator sickness questionnaire". A form for recording subjective statements from subjects who have undergone a VR experience, and from whose responses an SSQ score is calculated indicating the severity of cybersickness.

However, previous studies and measurements on the topic of cybersickness and VR sickness have revealed other manifestations that can be objectively measured and the progression of VR sickness in an individual can be recorded in real time, such as heart rate, cortisol, pupil dilation or electrodermal activity.

The presented paper presents the actual research design and the basic measurement results for two ready-made applications designed for an industrial enterprise, where in the case of the first application conventional training occurs, but in the case of the second application, an environment for the occurrence of VR sickness is created in its introduction by accelerated movement of a forklift and the effect of the given on the error rate is observed. At the same time, the aspects and objective characteristics that influence the occurrence of virtual sickness are monitored using standardized tools. The aim is to obtain data for effective prevention of these aspects in the virtual reality environment.

This paper presents the research carried out and the measurement results.

Keywords: Industry, training, virtual reality, virtual sickness.

I. INTRODUCTION

The barriers between the digital and real worlds are becoming thinner almost every day. Whether it's overcoming distances, access to information and online resources, or means of communication and social networks. The drive to digitise all possible means and services and to adapt reality as faithfully as possible in digital form is virtually ubiquitous. The real and virtual worlds are becoming inseparable from each other, and the consequences in one of them follow us into the other. One of the fast-growing new technologies today that is bringing the two worlds closer than ever before is so-called virtual reality.

In its current form, VR represents a tool for unique possibilities of interaction with the virtual world, and an extension of the possibilities of information technology. It is used for visualization of models or virtual tours. It also finds application in education, training and training of people of different professional backgrounds. VR technology serves both professional, creative and entertainment purposes. Nowadays, virtual reality technologies are facing the risk of a phenomenon also known as "VR sickness", a subcategory of motion sickness/kinetosis that has been specifically evoked in humans through virtual reality. The terminology of this topic is not always clear. Especially between the terms "VR sickness" and "Cybersickness". Motion sickness, also known by names such as "Kinetosis",

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"Travel sickness" or "Motion sickness", occurs in an individual during a conflict of the senses. When movement registered by the eyes is inconsistent with actual movement or movement registered by the vestibular system, muscles and joints of the body. This conflict of senses is described in the "Sensory mismatch theory", which is currently considered the most likely explanation for motion sickness [1] [2] [3]. A typical example of motion sickness is the case when the occupants of a moving vehicle excessively fix their attention and gaze on a phone, book, map, etc. Visual motion information is not registered by the person who is actually in motion, and this motion is registered by the senses of others. A conflict of senses is created. [4] In VR sickness it is the opposite. VR sickness and motion sickness demonstrate similar symptoms. However, one of their differences is that in VR, motion is visually registered, but no motion is actually performed. Again, there is a conflict of the senses. [5] Symptoms of motion sickness include fatigue, difficulty concentrating to confusion, headache, dizziness, sweating, rapid breathing, upset stomach to vomiting. [1]

Cybersickness can be expressed as a subset of motion sickness, and a superset of VR sickness and simulator sickness. It can also include other technologies such as screens or monitors that can evoke a state similar to motion sickness. [6] Cybersickness, as a type of motion sickness, is also sometimes referred to as visually induced motion sickness (VIMS) [7] and thus shares many, but not all, of its characteristics. It differs primarily in that the state of motion sickness is not due to the presence of actual motion (motion), but to the illusion of spontaneous motion that is not actually being performed (vection).[8] Typical symptoms of cybersickness consist for the most part of a feeling of nausea, disorientation postural instability or vertigo, confusion, headache or eye pain, and blurred vision. [8] [5] [1]

Simulator sickness is thus categorized as a subset of motion sickness and cybersickness, and a superset of VR sickness. Simulator sickness can occur in individuals after a certain amount of time or activities in different kinds of simulators. Simulator sickness falls into its own category, research on which has been mostly tied to flight simulators. Depending on the technological design and authenticity of the simulator, real motion (motion) can occur in the device as well as the illusion of it (vection) at the same time. [9] Similar to motion sickness and cybersickness, there are inherited symptoms such as fatigue, general or stomach upset, headache or eye pain, concentration problems, blurred vision, dizziness or vertigo, and rapid breathing. [8] [9] [5] [3]

Previous measurements, surveys, analyses, and meta-analyses conducted by educational, scientific, and private institutions have attempted to find individual variables and factors that figure into the issue of cybersickness and VR sickness. The factors are indeed many and consist of individual, technological, and other components. [9], [10] VR sickness is caused by many factors, both from the perspective of the person and the VR headset itself. The severity and susceptibility to VR sickness is determined by the physical predispositions of the individual such as their age, gender, susceptibility to kinetosis. Technical parameters and technologies used in VR HMDs such as FOV, Depth of Field, IPD, refresh rate, latency, control method as well as the principle of stereoscopic imaging are also figured. The design of the VR environment, rest frame, motion control within 6DOF play a role in VR sickness in terms of the possibilities that the VR environment provides. A strong factor playing a role in the susceptibility or severity of VR sickness in an individual appears to be resistance/adaptation to kinetosis or previous experience with VR environments.

Currently, practices already exist for measuring and mitigating VR sickness, whether these are preventative measures of the VR system itself, or recommendations on how to regulate VR technology and the experience it provides. In addition to the general symptoms associated with nausea and confusion, VR sickness manifests in objectively measurable ways in the form of increased heart rate, elevated cortisol levels, dilated pupils, and changes in an individual's electrodermal activity. The SSQ questionnaire and its equivalents are currently used for subjective measurement of VR sickness. However, other supplementary information from questionnaires such as the NASA TLX or SUS can also be used to measure VR sickness. The various factors listed above can be used as guidelines to reduce the impact and frequency of VR sickness. However, if VR sickness has already occurred, there is the possibility of treating it by returning the individual to the real world and waiting for it to subside. Ideally, hydrate the body with water or, better, tea with ginger, and indulge in quiet rest and fresh air. In more acute cases, VR sickness can be treated in a similar way to kinetosis in the form of administering travel sickness pills such as Kinedryl, H1-antihistamine or Scopolamine. [4] [11]

II. METHODOLOGY

A VR application for an industrial environment was created in the Unity development environment. Specifically, this is an automotive application. Specifically, the application simulates the environment of a production floor in which the subject acts as a production operator and driver of a low lift battery truck.

The VR measurement itself consists of two separate measurements on two versions of the application. The measurement in the first version of the application includes only the assembly part, where the subject is placed in the production operator's position. Here the subject is guided through the assembly process with the help of audiovisual instructions. In the second, modified version of the application, the subject is initially placed in a low-lift trolley, which travels with the subject around the production floor before the actual assembly begins at the workstation. The subject has no control over the animated machine and can therefore only look around and let the trolley drift around the virtual hall until it is transported to the assembly station.

The hall itself in the modified version of the application is augmented with additional objects, workstations, and obstacles in the way. The hall is conceived in a rectangular shape, with a track for the transport equipment near the outer edge of the hall, forming a closed circuit. Production equipment, workstations, and staging areas are located in the middle of the hall and along the walls.

In the modified version of the application, the subject is placed in a low-lift truck before the assembly begins and is uncontrollably wheeled down the hall. During the ride, the subject meets several nooks and crannies in the hall. The situation here takes on a messy scenario in the hall, where the rover needs to avoid obstacles in the aisle as it makes its rounds. The path through the hall is therefore chaotic and disorganised. There is a need for avoiding obstacles in the path and finding alternative routes to get through blocked or restricted sections. The chaotic state of the hall and the disorganised ride is deliberate. Turns, chaotic environments, changes in speed, unexpected movements and stops over which the subject has no control are there to induce VR sickness. Eventually, after navigating and zigzagging around the assembly hall, the subject is brought in front of their station where they are now expected to complete the same assembly task on the part in the role of a production operator.

Assembly is the basic part of the application that both versions have in common. As part of assembly, the user is expected to assemble the car door panel/board component. Assembly is divided into several steps. The steps have a defined order and therefore completion of the previous step is required before proceeding to the next step. Each of the steps is accompanied by audio instructions and a spatial indicator (arrow) on how to complete the step. Some of the tasks require subjects to turn and interact with more distant locations and objects. Some steps require more precision than others, or the use of both hands at once.

It is expected that confusion over the procedure may arise in the user due to inattention, or a persistent feeling of nausea caused by VR sickness. For this reason, a red button is present on the workstation table at each step. When pressed, the button plays audio instructions for completing the current step. The number of times this button is pressed is recorded on the adjacent right monitor of the simulated workstation. The number of these needs for instruction repetition is one of the variables monitored in the measurement, indicating the possible impact of VR sickness on instruction clarity.

The differences between the behaviour, performance, and physical state of a user without the presence of VR sickness, with a user whose VR sickness was evoked by an uncontrolled walk down the hall, are recorded and compared as part of the measurement.

The measurements themselves were carried out at several different locations.

The individual participants were contacted and then personally visited together with the necessary equipment. The portability of the VR HMD Meta Quest 2 allowed for such a flexible way to conduct measurements and adapt to many different conditions.

After familiarizing themselves with all the details of the upcoming measurement, the subject completed an entry questionnaire.

Once the entry questionnaire was completed and the HMD Meta Quest 2 was prepared, the necessary GSR sensors were attached to the subject's body, and aligned with the CAPTIV software, simultaneously running on a nearby laptop. All necessary peripherals and means of recording the measurement process were ensured to be functional. VR measurements were performed on physically able subjects, at room temperature, indoors, in a large enough space, standing up. Subjects were fitted with a VR headset, and were given brief instructions on the controls, and time to adjust to the control and feel of VR. Recording was then started, and one version of the app was launched. The order of which version of the app played first or second was purely random. While the application was running,

the subject was monitored, and individual measurements and relevant information were recorded. Once all steps within a given application were completed, the entire measurement process was repeated once more with the second version of the application. After completing all steps even within the second application, the subject was taken off the VR headset and measurement sensors, and were asked to complete the NASA TLX and SSQ questionnaire. Throughout the measurement process, subjects were monitored, and given the necessary time to become familiar with the VR environment. Alternatively, they were also given the necessary time to rest/recover from any VR sickness. In case of emergencies, subjects were assisted during these situations. Once all necessary data was collected, the measurement was completed. The data were then analyzed, evaluated, compared and interpreted using several methodologies.

Data analysis and interpretation were performed in the CAPTIV software environment, tracking individual VR records, and other ancillary software. Factors encountered during each measurement that may have contributed to the final values were taken into account. For the resulting data, it was compared whether or not it agreed with previous studies.

III. RESULTS

A total of 32 subjects participated in the VR sickness measurement. Efforts were made to find and involve subjects who would provide, as far as possible, the most balanced ground and combination of characteristics figuring in VR sickness, such as gender, age, susceptibility to kinetosis, etc. All 32 subjects are almost equal in gender distribution consisting of 17 males and 15 females. This almost equal distribution may help for a more accurate analysis of the effects of VR sickness on individuals, depending on their gender.

Subjects were divided into four age categories. The first age category represents individuals under the age of 25. The second category includes individuals aged 25 to 39 years. The third category is individuals aged 40 to 65 years. The last category is individuals over the age of 65. A total of 9 individuals under 25 years of age, 9 individuals between the ages of 25 and 39, 13 individuals between the ages of 40 and 65, and one individual with an age greater than 65 were counted.

Subjects were only able to divide themselves into the three lowest categories of average daily time spent on video games, although the entry questionnaire had up to six categories. The three occupied categories are average daily time spent on video games less than 1 hour with a total of 22 subjects. The 1 to 3 hours category with 8 subjects. And lastly, a category of 4 to 6 hours, containing only 2 subjects. The remaining categories of 7 to 9, 10 to 12, and more than 12 hours remained vacant.

Previous experience with VR plays an important role in the measurement, and therefore subjects were also divided according to whether they had previous experience with the technology. Of the 32 subjects, a supermajority with 17 subjects reported that they had. The remaining 15 subjects indicated that they had no experience with VR so far. The last significant variable in the entry questionnaire was a question on the subjects' susceptibility to kinetosis. A total of 12 subjects indicated here that they were susceptible to kinetosis, and the remaining 20 subjects indicated that they were not.

Data from the NASA TLX questionnaires were processed in box plots as a set of all the factors of the questionnaire as well as an individual view of each factor. Most subjects did not experience excessive mental strain during the measurement, with only a minority (about a quarter) of subjects indicating values greater than moderate. For physical strain, the range of values was from 0 to 40. The 25 percentile lies at 0, and the 75 percentile has a value of 17.5. The 50 percentile (median) is at 5, and the mean value is at almost 8.6. Thus, physical strain represented the lowest-rated factor on the NASA TLX questionnaire. The subjects, both in their responses and their behavior during the measurement, showed no noticeable signs of physical exertion or fatigue. Values for the feeling of time burden ranged from 0 to 50, with one outlier of 80. The 25 percentile is at 0, and the 75 percentile is at 25. The median value here is 10, and the mean value lies at 15.15. Time burden represented the second lowest-rated factor by the subjects. No time pressure was placed on the subjects in the measurement, and thus the ratings were not influenced by anything other than subjective perceptions of time. The subjects' performance quality scores range from 45 to 100. The 25 percentile has a value of 76.25, while the 75 percentile reaches a maximum value of 100. The median is at a fairly high value of 90, and the mean is not far off at nearly 87. Thus, three-quarters of the subjects are very satisfied with their performance, and the remaining quarter report relatively high to moderate values. For effort, the values range from 0 to 70, with the exception of one outlier of 100. The 25 percentile has a value of 10, and the 75 percentile here has a value of 45. The median has a value of 27.5, and the mean has a value of approximately 28.4. Overall, subjects reported that they did not have to expend significant effort to complete the

tasks within the measure, or in coping with the effects of VR sickness. However, there were a few subjects who reported very low to zero values, as well as subjects above the 75 percentile for whom the effort expended was at a moderate or higher level. Frustration ranges from a value of 0 to a value of 80, and thus forms the widest spread of values of all the other factors. There is also the widest zone between the 25 and 75 percentile (IQR), with values ranging from 0 to 48.75. The median has a value of 15, and the mean has a value of 24.2. The majority of subjects here reported mild to moderate frustration during measurement, while a minority reported greater than moderate values, up to noticeably high values. Subjects often expressed frustration over the long waiting time before the audio instructions or the VR sickness-inducing hall ride would end, and they would be able to start working. Subjects also continued to frequently get frustrated over poor hand-object collision boxes.

Data from the SSQs are analysed and interpreted in three sections. The first section focuses on the overall value of TS. The second section focuses on how the different SSQ sub-values (N, O, D), figured during the measurement, and how they affected the subjects. The third section looks at the individual symptoms of the SSQ questionnaire, specifically their severity and frequency. Most subjects exceeded the cutoff for finding the symptoms to be bad. Only a handful of subjects reported SSQ values less than 5, and a portion of the subjects ranged in significantly higher values not only 2.75 times, but up to 5 times the cutoff value of 20. Thus, it can be concluded that according to the data provided by the subjects, most of the subjects' TS values were more than severe for the symptoms of cybersickness. Driving an uncontrollable low-lift truck through the hall for 80 seconds was enough for subjects to rate their feelings this seriously. Despite the apparent severity of cybersickness from both the data and the subjects' physical reactions, VR sickness did not pose a significant barrier to completing the assembly task or affect the subjects' performance. In almost all cases, the symptoms resolved within a few tens of seconds after the ride ended, and the reassured subject resumed the assembly task. Thus, the response was strong but short-lived. However, some subjects reported headaches or migraines within a few days of measurement. These subjects were of older ages and were prone to kinetosis. This phenomenon was not observed in other categories.

The measured mean values of the subjects were considered in the analysis within several categories. Significant differences emerged for subjects based on their gender, age, time with video games, VR experience, and susceptibility to kinetosis. For gender, it was found that females achieved higher TS scores, and therefore stronger effects of cybersickness, compared to males. By age category, the most susceptible age group was individuals aged 25 to 39. This is followed by individuals aged 40 to 65, followed very closely by individuals under the age of 25. Subjects over 65 showed the least indication of cybersickness compared to the other age categories. The results indicate that young adults and middle-aged individuals are the most susceptible group to cybersickness. The results are misleading, but this phenomenon is not unexpected, as the views of previous studies to date have been mixed. Older individuals are sometimes cited as being more susceptible to cybersickness because of impaired motor skills, and younger individuals because they are not yet sufficiently developed. A categorisation based on time spent playing video games presents clear results, with individuals who spend on average more time playing video games being less prone to cybersickness. For prior VR experience, individuals who had already used VR reported higher TS values on average compared to those who had not used VR before. In this case, it is important to note the subjective nature of the SSQ questionnaire scores that may have contributed to this counterintuitive conclusion. Finally, subjects prone to kinetosis showed TS values almost twice as high. Thus, confirming the correlation between motion sickness and VR sickness.

Comparison of the individual SSQ subcomponents provides a picture of how induced VR sickness affected subjects during the measurement, and which component played the largest role. (N) Nausea has an overall range of values from 0 to 57.24, and having 2 outliers of 76.32 and 95.4. The 25 percentile has a value of 9, and the 75 percentile has a value of 35.75. The median is located at a value of 19.08, and the mean having a value of 27.12. Subjects showed no noticeable signs of gastroenterological discomfort, visible drooling, or markedly increased sweating during the measurement in many cases. Subjects commented most on a general feeling of nausea. (O) oculomotor values range from 0 to 37.9, with no outliers. The 25 percentile has a value of 7.58, and the 75 percentile has a value of 37.9. The median value is 22.74, and the mean value is 25.34. Subjects on the SSQ frequently reported oculomotor-related symptoms such as general discomfort, strained eyes, or difficulty focusing. However, subjects did not visibly exhibit significant vision-related problems during or after the measurements, despite the fact that some had severe dioptries. The low values may also be explained by the fact that this subsample uses the standard smallest multiplier to calculate the result of 7.58. (D) disorientation takes values from 0 to 111.36, having two outliers of 167.0 and 208.8. The 25 percentile is at 13.92, and the 75 percentile at 69.6. The median value is 27.84,

and the mean value is 49.59. From the comments of the subjects and the physical reactions of some of them during the measurements, it was found that the most frequent complaints of the subjects were dizziness, feeling of instability, vertigo and nausea. Whether judged by median, mean value, total range or IQR only, or the highest value reported, in all cases the disorientation subscale (D) is the highest. Thus, it can be concluded that disorientation was the biggest problem for the subjects in the SSQ.

The measurement progress of each subject was recorded by TEA CAPTIV T-SENS GSR sensors communicating with the CAPTIV software. At the same time, however, a recording was also made in the Meta Quest 2 VR headset, allowing tracking of what the subject was seeing and doing at a given measurement point. By temporally aligning these two recordings and monitoring them simultaneously, it is possible to track the subjects' reactions to different situations during the measurement. The graphs of most subjects take the form of a fluctuating but steady increase. Most subjects ended up with values higher than at the beginning of the measurement. On average, the subjects' minimum and maximum measured μS values increased by a factor of 2.5 during the roughly 10-minute measurement period. However, the subjects' responses were variable, and showed in some cases a difference of only 1.3 times higher, but also up to 6 times higher. Subjects often started at a low value and gradually, as time increased, their values increased. After completing the first application, the subject's VR headset was momentarily removed from their head to switch applications. During this time, when the subject is once again perceiving the real world around them, a decline in values can be observed on most graphs (usually around the middle of the graph). Men showed higher mean μS values during the measurements compared to women. This phenomenon may be attributed to physical differences between men and women. Similar to the measured TS values in the SSQ, the age category also shows significant differences in the measured μS values, with the age category 25 to 39 years again emerging as dominant. The age category under 25 years is second, followed by the category 40 to 65 years and then subjects over 65 years. Longer average daily time spent on video games clearly helps to mitigate the effects of VR sickness. Subjects with prior VR experience scored higher than those who had not previously had the honor. Lastly, subjects susceptible to kinetosis achieved higher values compared to those not susceptible.

An analysis of the subjects' times for each application concluded that the average time to complete a standard application was 3 minutes and 55 seconds. While the average net time to complete the modified application for inducing VR sickness was 3 minutes and 38 seconds. This phenomenon can be explained by the fact that the order of the applications was not always the same, and that the chosen order was not evenly balanced. For 19 subjects, the standard application was first, and for 13 subjects, the modified application was first. Thus, more subjects had slower times on the standard application due to their previous inexperience with the process, and thus performed better on the second attempt on the modified application. Inducing VR sickness was not sufficient to prevent subjects and their newly acquired experience from achieving better times than the previous trial.

In absolutely all cases, the variant of the application that was performed by the subject first was slower compared to the second application. This phenomenon is attributed to the fact that the assembly process of both applications is completely identical. Therefore, the subject has gained experience with the controls, and is already familiar enough with the whole process to achieve better times.

Thus, it cannot be clearly concluded that VR sickness was a significant barrier to task completion during the measurement period, or that it was a large factor in creating a significant difference in application completion time. Regardless of whether VR sickness was induced at the beginning or in the middle of a subject's measurement. Thus, prior experience with the process greatly outweighed the VR sickness factor in the question of which application would be completed faster.

In total, 30 of the 32 subjects completed the measurements with higher μS (Microsiemens) values than when they started. Most subjects showed a steady increase in μS values measured with the GSR sensors as measurement time increased. The steadily increasing values during the measurements answer the question why it is recommended to limit the time spent in VR to smaller periods (about 30-45 minutes), considering that the average measurement time per subject was only 10 minutes and 6 seconds, and was sufficient to achieve noticeable differences in the measured values.

Subjects without kinetosis susceptibility achieved slower times on average compared to those with kinetosis susceptibility. As mentioned, the response to kinetosis was strong but short-lived. All subjects were always given an initial audio briefing after the ride before the start of the montage, which was sufficient for subjects to recover from VR sickness. However, this phenomenon deserved more attention. Upon closer study of the data, it was found that the category of subjects not prone to kinetosis was more numerous, and also had more subjects who had no

previous VR experience. Thus, many subjects were found to have high individual times, ranging sometimes above 5 minutes to 8 and a half minutes per application, where each contributed their bit to these higher average values. On the other hand, the kinetosis-prone category had more subjects who had experienced VR before, and none of the subjects exceeded the 5 minutes per application threshold. Thus, it is suggested that kinetosis susceptibility did not carry a strong weight in the time differences, as opposed to other of the subjects' characteristics.

The button for repeating the audio instructions was pressed 10 times during the entire measurement process for all subjects. Such a low number compared to the number of subjects (32) is explained by the fact that the apps were sufficiently illustrative in their instruction and visual cues, for such a drastic reduction in the need for cues. Of these 10 presses, the button was pressed 7 times in the standard app, and 3 times in the modified app. Again, it can be hypothesized here that this phenomenon is due to more subjects starting with the standard app as their first app.

From observation of the measurement records, and the readings from the GSR sensors, it was evident that VR sickness caused observable arousal in most subjects during its duration. This fact was also frequently confirmed by the subjects' unsolicited comments both during and after the ride. However, this arousal quickly subsided after the VR sickness-inducing ride ended. After the completion of the ride, the subjects' measurements stabilized again. However, in most cases, the values remained in a higher average range than before exposure to VR sickness. Here, it can be assumed that the state of heightened attention or agitation from the previous exposure to VR sickness, combined with the effect of the time spent in VR described in the previous section, is still maintained in the subject. Ultimately, however, this did not prevent subjects from successfully completing both applications.

Presentations of other significant increases and decreases in values, were detected in cases where the audio briefing had been completed, and the subject was now left to do as they were asked. Subjects could then be either confused and searched around the workstation for exactly what to do, or became frustrated at their failed attempts to grasp or reach the object. After completing a step, there was a moment of respite for the subject and also a visible drop in values. However, this phenomenon was not a condition for all subjects or for all of their assembly tasks.

Experienced or calm subjects did not experience noticeable frustration during the assembly process, and did not show many sharp increases in values, other than the beginning of the VR sickness-inducing ride down the hall. Subjects were not stressed or confused, and thus their course of values was smoother, and no similar sharp increases in values or "spikes" were noted.

IV. CONCLUSIONS

In order to find a solution to the VR sickness phenomenon, we are supported by previous findings from previous studies as well as the data obtained from the measurements performed in this paper. The measurement helped not only to confirm previous claims or not, but also to provide a ground to think about possible ways to address the issue of VR sickness.

The individual propositions focus on affirming and considering simultaneously existing methods, data, and practices. They also continue to consider theoretically possible starting points for VR sickness and current VR systems. Ways to prevent and reduce the impact of VR sickness are already being used, currently feasible, but also theoretically possible ways that are not yet feasible due to the limitations of current technology or understanding of VR sickness. It must be added that, within the scope of this paper, no feasibility study or attempts to implement the mentioned theoretical solutions are carried out. However, should a solution to this problem be found due to new technologies or knowledge, it is theorised that this would further contribute to a way of mitigating the incidence or severity of VR sickness.

The measurements showed that subjects who are not prone to kinetosis have almost twice as low TS values and a lower and smoother waveform of μS values measured by the GSR sensors.

The user can begin to adapt to movement in VR by using a teleportation method of repositioning and rotating in the virtual environment using the analog stick on the controller/peripheral. Later on, once the user gets used to it, they can switch to smooth movement using the analog stick on the controller and rotating using their whole body.

Further, the feeling of nausea can be additionally mitigated by having individuals operate the VR while seated instead of standing.

Last but not least, there is also the possibility to start acclimating to the virtual world through applications that do not require the user to move through space. These are applications such as classic assembly workplace simulators, cabin flight simulators, driving simulators, cooking in the kitchen, and many other similar applications of an educational or entertainment nature where the user is restricted to moving only within a small space most of the time.

The measurements examined the impact of VR sickness on people who played video games more frequently or who already had VR experience. In both cases, the TS values on the SSQ were lower for these individuals. Continued both categories had faster times. The average μS values measured by the GSR sensors were lower only for those who play video games more frequently. Subjects knew approximately how the program worked and kept calm. However, subjects with VR experience recorded higher values. It can be assumed that this phenomenon is related to nervousness and frustration over the triviality of the task from experienced subjects. Or also the nervousness of experienced subjects, taking the measurement as a competitive challenge, and striving for the best time/performance.

Findings from previous studies suggest that the inclusion of multiple human senses in virtual environments not only aids immersion, but also mitigates the sensory conflict that contributes to the potential increase in VR sickness. Thus, if we consider that multisensory stimulation helps with sensory conflict, we need to achieve as much immersion of the user in the VR world as possible, by stimulating as many of their senses as possible and bringing them fully into the virtual reality.

Currently, VR HMD systems have a visual and audio component, but haptic response and the sensation of touch and interaction with virtual objects is still neglected.

In this realm, we already find the possibility of VR peripherals in the form of gloves that have haptic response. One is thus able to feel touch when interacting with virtual objects thanks to the gloves. There are also suits/vests enabling the same. This peripheral device is mounted on the torso of a person and can also register and simulate the touch or impact of virtual objects with the user's chest, abdomen, hips, or back. The use of multiple technologies to allow for additional depth of immersion and separation from the real world could be made easier by these technologies. It could help with conflict of the senses, which would now be more attuned/dominant to the VR world than ever before, instead of their constant awareness of the real world.

Generally speaking, VR activities should be conducted in an adequate, sufficiently spacious and empty environment, with a supply of fresh air at a favourable room temperature.

The VR setup should be provided with a sufficiently large space, at least 2x2 metres or more in size, to provide clear space for undisturbed movement at least from a stationary position. However, it is recommended that the largest space available be as large as possible to allow safe movement up to walking in the space. This space should be free of obstacles, dropped objects, and other objects that could be struck, bumped, tripped over or stepped on.

The space should not be stuffy or dusty to ensure healthy breathing conditions. Further, the space should be sufficiently illuminated by natural or artificial light for proper functioning of the VR sensors.

Another ingenious solution may be the presence of a fan. A fan blowing air towards the user in VR can provide many benefits. Fresh air intake and cooling properties that will help with sweating, which can occur at an increased rate in VR activities compared to typical computer activities. However, the air flowing from the fan also has an orientation property, namely that it gives the user a sensory awareness of where they are relative to the fan airflow in the real world at all times.

It is recommended to ensure sufficient hydration and nutrition of the body before starting VR activities. A dehydrated or hungry person may be irritable or tired and therefore more vulnerable to VR sickness.

A person should be familiar with the general limits of the average VR user, and then become aware of and assess their own limits. Adhere to the general rule of thirty to forty-five minutes of recommended VR use, before returning to reality, and adequate rest for the body and comparison of the senses. Then, depending on your current state, adjust your time and activities in the VR environment, especially in situations where there is a risk of VR sickness. It is also advisable to use VR in a seated position if the user is unable to use VR standing up for one or more reasons. The same applies with the style of control, navigation and movement in VR. Thus, start on teleportation method of moving and snap turning. After getting used to this style of movement in VR, the user can begin to adapt to full body rotation and smooth movement using the analog joystick.

If one has a history of kinetosis, it is advisable to be cautious when using VR, and possibly be prepared to exit VR quickly in the event of VR sickness. It would continue to be advisable to keep freely available travel sickness pills such as Kinedryl, H1-antihistamine or Scopolamine on hand for any VR sickness treatment needs. Ginger/ginger tea may also be an alternative. However, take care that the effects may vary from person to person.

The most effective current ways of mitigating VR sickness appear to be high resistance to kinetosis or gradual adaptation of the individual to kinetosis or the VR environment itself. The goal here is habituation to sensory conflict, and movement in the VR environment, or causing kinetosis. This can be done by exposing oneself to

kinetosis or directly to virtual reality. Training one's senses also with the help of playing video games, seems to be highly beneficial to increase resistance to VR sickness.

It is necessary to provide sufficiently powerful HW for VR HMDs. Therefore, a tethered HMD connected to a sufficiently powerful computer is preferred. Continue to ensure optimization of software and applications. This is to ensure the lowest latency/response time and sufficiently high frame rate and FPS, preferably 144 Hz and FPS and above, to ensure a stable and smooth image leading to better user immersion.

Software or individual applications should have full motion and interaction capabilities regardless of whether the individual is seated or standing. Offer all-axis (6DOF) viewing and movement capabilities, albeit limited to the realism of the situation. Offer options for movement around the VR space that are more friendly to the individual. Ability to navigate the VR world by moving and turning using fluid body movement. As well as offering the ability to teleport and rotate using analogue sticks or buttons on peripheral devices.

When designing VR experiences, one should limit the user's sudden limited control over their own movement, unsolicited abrupt movements or moving the user around the VR world. The user's movement through the VR world should feel as natural as possible, and not allow more freedom of movement than the user is specifically capable of. It is further recommended that the VR scene always include a rest frame for the eyes, by which the user can determine the relative motion of moving surrounding objects to some static object. From a design point of view, this can be achieved in such a way that the VR scene always contains some static object in sight serving as said rest frame. One can also use the inclusion of a virtual nose or other static image built into the user interface itself, serving a similar purpose.

It is recommended that customization of control and content occurs on the part of the individual according to their own preferences and physical predispositions/limitations.

Continued attention to adequately spaced time periods in VR, interspersed with pauses to return to the real world. Allow the individual time to recover, rest and rehydrate if necessary. A person who is dehydrated, hungry, stressed/irritated, or prone to kinetosis should limit their VR experience to shorter periods of time and not expose themselves to situations/applications that are prone to induce VR sickness.

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