Investigating Motion Sickness Techniques for Immersive Virtual Environments

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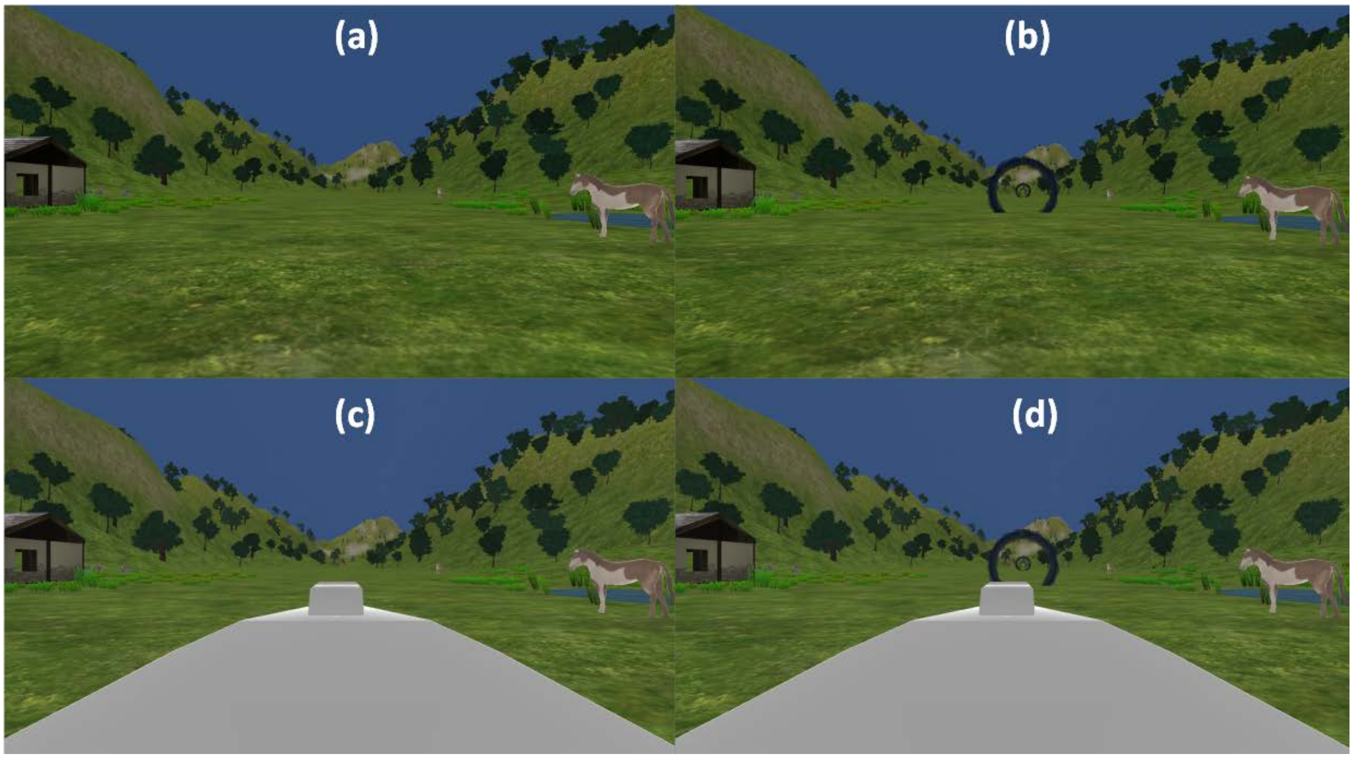

Figure 1: Visual methods examined for investigating motion sickness (a) none, (b) visual path (VP), (c) frame of reference (FoR), (d) frame of reference and visual path together (FoR, VP)

ABSTRACT

Motion sickness is one of important issues in immersive virtual environments. In some cases it may last for hours after participation in the virtual experience. Reducing the amount of motion sickness in healthcare applications is of great importance. This paper is examining how motion sickness can be reduced in immersive virtual environments. Two visual methods were designed to assess how they could help to alleviate motion sickness. The first method is the presence of a frame of reference (in form of a cockpit and a radial) and the second method is the visible path (in form of waypoints in the virtual environment). Four testing groups were formed: two for each individual method, one combining both methods and one control group. Each group consisted of 15 healthy subjects. Results show that there is a pattern in the data favouring visual path as a better method against motion sickness compared to the frame of reference.

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CCS CONCEPTS

• **Computing methodologies** → Computer graphics; Graphics systems and interfaces; Virtual reality; Perception.

KEYWORDS

Virtual reality, motion sickness, perception, immersive environments

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1 INTRODUCTION

Immersive virtual reality (VR) is nowadays booming in the creative industries and healthcare applications even if it has been known for quite some time that some users suffer from motion sickness [1] (also referred to as simulation sickness [7] or visually induced motion sickness (VIMS) [2]). Symptoms of motion sickness include nausea, stomach awareness and many more [28] and it may last for hours after participation in the virtual environment. Even if there are a lot of commercial VR applications, mainly in the gaming and education industry, the requirements for acceptable motion sickness are lower compared to other application domains. For instance, in healthcare applications (i.e. rehabilitation, ambient assisted living, behavior monitoring systems, etc) it is absolutely important to eliminate (or minimise) motion sickness. The effects of VR and related technologies for healthcare have been previously documented [10], [34]. A recent study found evidence suggesting that VR improves post intervention knowledge and skills outcomes of health professionals when compared with traditional methods [4].

There are three competing theories about why motion sickness occurs. The mostly discussed one is the conflict cue theory [22]. The other two include the postural instability [22], [12] and the poison theory [22]. Former states that problem is caused by conflicting information coming from different senses (usually conflict between visual and vestibular systems). Several techniques to combat the issue were proposed and investigated. Some of them are: visual frame of reference (like a grid [6], [8] or a virtual nose [5]), effects of different fields of view (FoV) [35], modifying movement either by applying different walking speeds [24], [16] or changing stairs to act like a ramp [16], [17], using pharmaceutics like antihistamines [38], adaptation/habituation [25], stimulating vestibular system [20], using portals to teleport users [29], mental distraction [13], laying down [15], [14], taking breaks [26] and user in control of the camera/movement in virtual environment [30], [7], [37], [19].

This paper investigates whether two different visual techniques can reduce motion sickness in immersive virtual environments. To try to understand better some of the reasons that affect motion sickness, an exploratory VR experience was only examined and interaction was not taken into consideration. The first method that was examined is called frame of reference (in form of a cockpit and a radial) and the second one a visible path (in form of waypoints in the virtual environment). The two methods chosen are the most popular ones for computer games and they are also easy and inexpensive to implement. To assess them, four testing groups were formed: two for each individual method, one combining both methods and one control group (see Figure 1). Each group consisted of 15 healthy subjects. Results indicate that there is a pattern in the data favouring visual path as a better method against motion sickness compared to the frame of reference.

The rest of the paper is structured as follows. Section 2 presents a brief background about motion sickness and then important factors that affect it. Section 3 explains the design of the chosen scenarios whereas section 4 the most important parts of the implementation. Section 5 describes the methodology followed for the experiment. Sections 6 and 7 present the qualitative and quantitative results of this experimental study. Finally, section 8 presents our conclusions and future work.

2 UNDERSTANDING MOTION SICKNESS

There are several approaches used to describe the feeling of discomfort and various symptoms associated with exposure to a VR simulation. Most frequently used terms are motion sickness [1], simulator sickness [36], simulation sickness [7], visually induced motion sickness (VIMS) [2], cybersickness [22] or VR sickness [33]. These terms are often used interchangeably, however some of them have different connotations and some terms are not limited to use only with conjunction with virtual reality. There are many symptoms associated with the motion sickness: nausea, disorientation, tiredness, headaches, sweating, eye-strain [28], difficulty focusing, salivation increasing, difficulty concentrating, blurred vision, dizziness, vertigo, stomach awareness and burping [27]. This section describes various methods which can be employed to alleviate motion sickness.

2.1 Frame of reference

Frame of reference, is a very popular method employed to help with motion sickness, means to add a visual frame of reference (a rest frame) to the image. It helps to reduce the sensory conflict between visual and vestibular sensations. In 2011, the effects of different types of rest frames were researched [8]. They used both: the well-known simulator sickness questionnaire (SSQ) [31] and neuro-feedback based on Electroencephalography (EEG), to measure motion sickness with and without rest frame conditions. Both SSQ and EEG scores were reduced significantly with rest frame present. In 2013 a study used roller coaster simulation [6] both with and without rest frame to demonstrate whether rest frames reduced motion sickness. A total of 22 participants were exposed to simulation and their EEG was measured. A grid of two horizontal and two vertical white lines was used as a rest frame. Based on SSQ analysis, rest frame proved to reduce motion sickness. Furthermore in 2015, a virtual nose [5] was introduced as a new way of reducing motion sickness. A model of human nose was placed in the center of view in simulation for the Oculus Rift head-mounted display (HMD). Evaluation results with 41 subjects concluded that this method is an inexpensive mean for reducing motion sickness.

2.2 Visible path

Visible path method is understood as simply placing waypoints along the predefined path in the virtual environment. Thanks to the visible waypoints, users should anticipate movement in VR. This is different from the situation when user is in control of the movement. Users in control are able to anticipate the movement and this could be the reason why being in control weakens motion sickness. Visible path method separates control and anticipation. Users are positioned in a passive seated experiment and can only anticipate the movement by observing waypoints marking the path, but they are not in control of the movement.

2.3 Field of view

The field-of-view (FOV) also seems to have an effect according to a previous study [35]. A group of researchers in Netherlands exposed participants to simulation for 50 minutes and tested two kinds of FOV - internal and external. External being screen size and distance from it and internal being angle of camera in-game. They concluded that more motion sickness occurred when those different FOVs were congruent, when internal and external FOVs were in agreement.

2.4 Speed

The issue of movement in virtual environments is tightly coupled with the theory of sensory conflict. The user is seeing the movement in the simulation even if their body does not move in real-space. There have been studies to help understand what is the best way to move in virtual environment to cause as little motion sickness as possible. In 2001, 96 Chinese males participated in an experiment to find out what speeds are suitable for simulation tours in virtual environments [24]. Eight different speeds were evaluated, each on 12 participants. Nausea ratings were recorded using SSQ. The results were that longer the exposure (ranging between 5 to 30 minutes) the higher nausea ratings and that the nausea increased with speeds 3 m/s to 10 m/s, the 10 m/s having the highest nausea, then stabilizing.

2.5 Locomotion

In terms of locomotion, a study [16] examined a simple condition - whether the way of mapping between moving in virtual environment and joystick control influence motion sickness. Three different navigational mappings were tested: constant speed, direct mapping to speed and smoothed constant speed. Twenty participants were recruited for this experiment and SSQ was used to measure motion sickness. The results were inconclusive for the mappings in general, however there was a tendency in the data in favoring speed mapping over other two mappings. Experiments on using virtual ramp instead of stairs were performed in both [16] and [17] first with 22 students latter with 34 students. It was proven that virtual ramp reduces motion sickness in comparison with the stairs.

Another way can be to use portals to teleport users [29] instead of actual movement. This approach can also be used to reorient them or to work in harmony with limitations of physical space. In the study authors argue that real walking has advantage of increasing presence and reducing mental load. Few approaches can be used to allow free walking in virtual environments and taking real world limitations into account at the same time. For example simulating a 360 degrees turn while user does only 180 degree turn. The novel approach is to show the user they are nearing the edge of workspace boundary and allowing them to open portal they can work through to reorient and re-position them. This approach does not cause additional motion sickness.

2.6 Habituation - Adaptation

At least three studies conclude that adaptation to VR experience is a proven way to reduce severity of motion sickness. Many developers of VR promote best practices on VR development and experiences. One of the points being mentioned often is that VR users are amongst the worst participants for experiments. One of the reason behind is that they have been habituated to motion sickness. They spend a lot of time in VR experiments which are only prototypes and early versions. These projects lack required polish and developers experiment with different approaches before settling on the one, which is going to make it to the final product. By being constantly exposed to these imperfect conditions VR developers adapt and experience less motion sickness. In another study researchers exposed 19 subjects to a game Wipeout using HMD for five days [18]. Simple 4 point malaise scale was used to rate severity of nausea. Proportion of users who did not report symptoms of nausea increased steadily with each day of exposure. Researchers concluded that habituation occurred.

Moreover, it was experimentally shown that longer exposure to simulation produces more motion sickness [25]. The effects of repeated exposures concluding that adaptation occurs almost every time were also evaluated based on SSQ questionnaire to measure motion sickness. For the duration exposure four categories were used: 0 to 1 hour, 1 to 2 hours, 2 to 3 hours and 3 or more hours. For the repeated exposure 7 sessions were recorded. Both duration of exposure and repeated exposure showed being linearly related to motion sickness outcomes. Moreover, a study from 2008 immersed 70 people on 10 occasions [23]. Several objective measures were used before and after the exposure as well as subjective measure using Pensacola Simulator Sickness questionnaire. Over the period of ten sessions overall mean symptom score decreased for the group of participants with an exception of one participant who reported increased symptoms. Guidelines for alleviation of motion sickness [26] also states that adaptation is one of the strongest and most potent fixes for motion sickness.

2.7 Cognitive load

It is common sense that taking breaks can also help to reduce motion sickness and can be linked to experience [26]. Taking a break you can refresh the mind and helps us to become more relaxed. Taking a break separates exposure to shorter and more comfortable sessions [25]. Even though motion sickness symptoms might eventually add up so longer pause might be required. Shorter and more frequent sessions might also help with adaptation. A study investigated whether having mind occupied with audio letter memorising task [13] can reduce severity of motion sickness. They evaluated sixteen subjects and concluded that mental distraction can reduce motion sickness by 19%. To measure motion sickness they used 11-point misery scale (MISC). They also used the motion sickness susceptibility questionnaire (MSSQ) to rate subjects' susceptibility to motion sickness before the experiment. Only susceptible subjects who experienced motion sickness before were included in the study.

2.8 Posture

A study that deal with posture [15] compared seated position with supine (lying down) position. Subjects were exposed to horizontal and vertical motion. The former proved to be twice as nauseogenic as latter. Another interesting finding was the revelation of time needed to achieve moderate nausea. It differed for various scenarios, ranging from 9 to 27 minutes. They used MSSQ to evaluate susceptibility to motion sickness. The result is that least nauseogenic is supine position together with horizontal movement, then seated position with vertical motion, followed by supine position and vertical motion. Most nauseogenic is seated position together with horizontal motion. A more recent study [14] argues that protective postures such as supine position might be incompatible with task performance. This study investigates motion sickness susceptibility and references a lot of relevant studies. It looks into motion sickness and mentions several aspects, including women being more susceptible to motion sickness than men, the term 'Mal de debarquement', ('sea legs') [7], as the sensation of unsteadiness when sailor returns to land and also states that age has an effect. Individuals with high levels of aerobic fitness appear to be more susceptible to motion sickness. Several sources on habituation being an effective measure against motion sickness.

2.9 User in control

Many studies exist for having user in control of the camera/movement in virtual environment. A characteristic example is a study from 2008 [30] which states that higher levels of symptoms were reported in passive viewing compared to active control over movement in the virtual environment. This might be relevant especially for VR experience designers (not necessarily VR game designers, were having players in control is common due to the nature of games - experience is driven by the player). An early paper from 1995 [7] discusses difference between passenger and operator. The concept is that latter on can anticipate movements leading to lesser motion sickness. Two studies focused especially on user in control. The first study [37] that tried to investigate whether real world difference of passengers being less prone to motion sickness works in virtual reality too. They exposed pairs of participants to simulation. One of them was in control of the movement, second played only passive role. Passengers showed greater motion sickness. Another study [19] used SSQ to measure the difference between the two and concluded that complete control reduced severity of motion sickness.

2.10 Other

Conflict cue theory arises from differences between visual stimulus and inner ear sensations. Researchers at the University of Iowa investigated whether stimulating vestibular system [20] can help with motion sickness. They argued that adding vestibular stimulation might lead to more realistic driver behavior in driving simulators. Galvanic vestibular stimulation (GVS) was used on 19 participants. Nausea rates were evaluated using SSQ. Among other things, GVS was concluded to be successful in reducing motion sickness. In 2015, a study suggested that pharmaceutics could be used to alleviate symptoms of motion sickness [38]. There are at least nine different kinds of drugs used against motion sickness (i.e. antihistamines).

3 SCENE DESIGN

As mentioned in the introduction, the experiments were set to investigate only two of the sickness alleviation methods. These two methods were designed for immersive virtual environments and the goal was to make them as general as possible so that they can be applied to a number of different application domains. The design was focused only on an exploratory experience and interaction was not taken into consideration.

Borrowing story flow from the storytelling concept, experience starts with a prologue. It is there to grab attention, to make user 'buy into' the experience. In case of this experiment it is the initial area with a small farm house, cows, horses, little pond, bushes and a butterfly. Initial waiting time is part of the scene for the viewer to get used to the VR experience, to have a chance to look around and enjoy the first scene (see Figure 2). It is the only scene in this experience in which the viewer's position is fixed and only scene without viewer's movement. Nevertheless, head-tracking is active and users can look around, move and lean their heads.

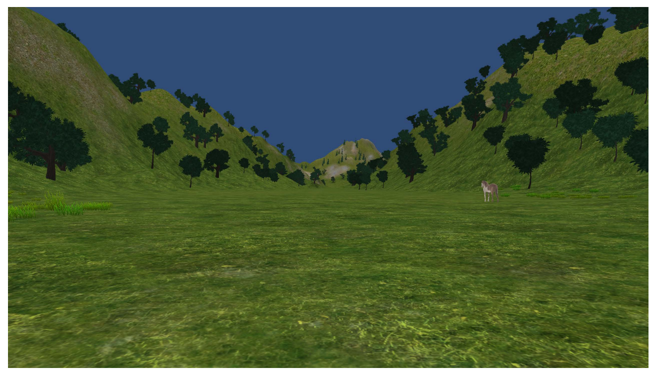

Figure 2: Initial view of the VR scene

When countdown runs out vehicle starts to move. Viewer is being transported in a straight line through a valley. Right at the beginning a horse runs along the vehicle for few seconds. There is no acceleration. It is a very calm ride without any distractions. To promote calmness, there are leafy trees around. This is a part of experience to make participants to get used to moving in the virtual environment, without having any surprises. Even though viewer moves, it is less exciting than initial scene but this part is limited to 1 minute.

What follows is a 30 second long climb up the hill. It is still fairly comfortable without rapid changes in direction or speed. It builds up an anticipation. There are also bumps on the terrain and environment changes a bit. Terrain gets rocky and there are conifer trees instead of deciduous trees. After 90 seconds into the experience the viewer is at the top of the hill where the rest of the scene can be observed. Slowly, vehicle points downward and rapid descend begins. This is the first part of the experience which might cause any significant discomfort. Some participants might be afraid of heights, causing them to experience vertigo at the top of the hill. When the descend starts, some might experience a level of motion sickness. It is the first point in the experience with fast acceleration. It is worth mentioning, that even though there is an acceleration, this part of path is fairly straight line without any turns or tilting involved. This is also an important part of the experience. It sets the tone to the rest of the scene - a roller coaster-like movement through the environment. This part takes only 10 seconds, but the feeling is very strong.

Figure 3: Descending in the VR scene

After descending down from the top of the hill there is a first turn (see Figure 3). Track tilts to the side as well, hugging the slope of the hill. There are no rapid changes in the speed of the vehicle. Again, only one part of the motion is introduced - there is only tilting in this part, without acceleration. It takes another 30 seconds to curve right and then start climbing again. This is the part when both tilting and acceleration are present. Until now, they were always separate. There is a steep climb up the hill, followed by a rapid descend into the rocky valley. As expected this part caused a level of discomfort during the development and should be responsible for causing some level of discomfort to participants too.

To make it feel like a more realistic experience, there is a calmer part which does not include any acceleration. In particular, 185 seconds after the start vehicle slows down and evens up the tilt. What follows are two very steep hills with slow climb up and very fast plunge down. It takes 20 seconds to climb each hill. There is a short straight path between the hills for viewer to catch a breath. During the development an interesting aspect of these steep hills emerged. Moreover, there were no clouds in the sky, just blue sky. And as the vehicle points straight up, viewer looses any reference points about their motion and it feels like nothing is happening (unless if they look down). This contrasts with rapid descend downhill and feels like there is more acceleration than really is. In this part there is no tilting and the path is straight.

In 250 seconds into the experiment, there is a long right turn along the wall of the castle, followed by a part with a lot of tilting to both sides. First tilting happens in the time span of 7 seconds. What follows is a right turn making track point towards the castle. 280 seconds after the beginning, there is a second tilting part lasting 20 seconds. Both tilting parts involve only tilting without significant acceleration or changes in direction of the track. Experiment ends after 305 seconds by the vehicle riding into a gate of the castle and the camera fading out to black.

4 IMPLEMENTATION

Unity 3D game engine was used for implementation, scripts were written in programming language C#. Unity scene was developed on a desktop computer with Intel i5 processor Nvidia GeForce 1060 GTX graphics card. Development was done on Oculus Rift DK2 and an experiment was conducted with Oculus Rift CV1. Both of the methods implemented and tested (frame of reference and visible path) are controlled by toggling their rendering on and off, meaning an element is shown on the screen or not. As the participants only experience single variant of methods against motion sickness it is not needed to implement any transitions or effects during the activation or deactivation of the method.

A simple terrain was designed in Unity and texture used had a natural look to approximate realism of the scene. Textures were applied by using editor feature to paint texture on a terrain with a brush. Texturing was also used to fabricate shadows in the forest of trees. Spots of darker texture was painted under each tree to make it seem like the tree is connected with the ground. Another use for textures was to replace detail meshes on terrain, such as rocks and bushes. Few different textures were used to give terrain different look in various parts of the scene.

The virtual camera was placed inside a cockpit with transparent hood. User sits inside and observes the scene. The waypoint design was inspired by the training rings used in games, where player has to complete an objective by flying through predefined path. By having waypoints as separate rings or gates, user immediately understands that the nearest one is the next intermediate destination. There is a faint color tint applied if waypoint applies a higher speed to the vehicle. Inside the ring of a waypoint there is an effect of shrinking torus. This was implemented to grab attention and make users focus on the waypoint.

Figure 4: Illustration of the path using waypoints

A rail system was designed to transport any object (i.e. vehicle) through the environment using waypoints objects marking the path (see Figure 4). It can move any object in the scene smoothly and therefore may be used for simple animations. In this paper, it was used for virtual representations of animals to move naturally in the scene (i.e. the butterfly flying around and for the running horse at the very beginning of the scene). Vehicle has a constant speed of movement but there are two ways how it rotates on each timeframe. First one, refers to the rotation towards the next waypoint, i.e. the tip of the vehicle rotates to face the next waypoint. Second is vehicle leaning from side to side according to the tilt of the track.

This is done by looking at the tilt of the next waypoint. Linear interpolation was applied to rotate the vehicle on the track towards the next point smoothly.

5 METHODOLOGY

A total of 60 healthy participants took part in the experiment, split into 4 focus groups. These 4 groups correspond to the 2 methods against motion sickness, whose effects are being evaluated. Participants were assigned to their respective group using a random number generation approach. First group experiences the VR scene with both methods being active. The second and third group have only one method active. Last group has both methods disabled. This configuration is used to check how individual methods perform and whether their combination gives better results in contrast to only one active method. There were only 3 distinct age groups. Most of the participants were students and young adults between 18 and 25 years (first group). The second group was in the range 26-33 years old and had 22 participants. In the last group, there were only 3 older participants (33 and above).

Figure 5: Participants experience

Participants were instructed to put on the HMD and sit comfortable (see Figure 5). The application was set to show a menu screen (menu options are visible on the LCD screen). Inside VR there was a small area with relaxing green leaves texture and menu options were not visible. This allowed experimenter to switch settings of the methods against motion sickness without participant knowing which setting was used. After that, participants were asked whether they could visualise the scene properly. If needed experimenter helped participant to adjust straps and HMD to fit it comfortably. Then a testing scene was launched. There was a fixed 15 seconds interval set at the beginning of the scene. User was asked again whether they could observe the scene properly. After that participants were instructed to just watch the scene and to look around until experiment is over. The experiment was designed to last for 5 minutes.

Written feedback was collected after the experiment. For the qualitative part, a single sheet of A4 paper was provided where participants provided feedback. After participants finished writing down, experimenter read through the feedback form, asked for clarifications or put additional questions related to the feedback given. The discussion after the experiment was very beneficial, because often participants would only write down few things even though they had a rich experience and many things to contribute to the feedback, but for some reason did not share it at first. During the discussion participants were prompted to provide their feedback. Moreover, subjective feedback from participants was collected via the 'Simulator Sickness' questionnaire [27], the well known 'Presence' questionnaire [3], and the 'NASA Task Load Index (NASA-TLX)' questionnaire [32].

6 FEEDBACK

Collected user feedback can be summarised into: (a) embodiment and immersion, (b) body movement, (c) graphics, (d) sound and (e) first-time experience.

6.1 Embodiment and immersion

Two participants shared that they would welcome a virtual body parts to be part of the experience: "It would be nice to see some parts of my virtual body like hands, legs,..." "I was missing hand/body." Without virtual body a sense of immersion and presence was probably affected to a degree. This indicates that embodiment in VR could have an effect in motion sickness. Also, participants reported forgetting about the real world: "I had to remind myself from time to time that I am actually sitting on the office chair in the lab not flying above the surface somewhere in the countryside." A design of the head-mounted display can play a role in immersion too: "In the beginning I was not able to be fully concentrated on the virtual reality because I could see a piece of a real world from the bottom of the glasses, but a bit later I was completely concentrated on the VR."

6.2 Body movement

Another effect of the study was involuntary body movement of the participants. It was occurring especially during the part when the track was tilting from side to side. Participants were sitting on their chair and tilting their heads, sometimes with their torso too. Interestingly, some of them were tilting the head to counter the tilting of the virtual camera in order keep their horizon and some of them tilted their head accordingly to the tilt of the track. A participant said: "Twist caused my head to tilt." Various body parts were mentioned, sometimes participants were moving voluntary to balance themselves. A lot of them had a tendency of leaning back while going uphill and leaning forward when riding down. In some cases, they were even reacting to the virtual world in a real reactions in a real world (like going to the right or left, sitting differently on the chair or even going closer or further away). Some characteristic feedback: "When movement twisted from left to right I tried to balance it with moving my torso." "I felt need to move my shoulders slightly to balance vision rotations." "My head was shaking and I was trying to stabilize with my legs to not to fall."

6.3 Graphics

However, a lot of the feedback was related to the visuals of the virtual scene. Video-games nowadays have reached photo-realistic graphics and from the feedback it is obvious that they have expected better graphics overall. Participants would welcome more details in the environment. Some parts of the landscape were a bit bare. Mostly because of the performance concerns. Apart from grass moving in the wind and few animal animations there was not much happening in the virtual scene. The appearance of the virtual terrain was frequently mentioned. Finally, there was contradictory feedback in terms of the object in the scene. A typical example is: "Rocks looks realistic, but grass not" and "Rocks are way too far from reality" which shows the diversity.

6.4 Sound

Ten participants requested to have sound, music or other audio effects in the experiment. The various sources of sound or audio effects mentioned include: Sound of trees, sound of wind when going fast, ambient sounds, wind running through leaves, birds, sound of vehicle and horse running, birds, additional sounds of the movement (rustling), sounds of nature, sound of rails, water, animals sounds in the distance, scroop of cart, sound around gates, sound of wind on a top of mountain, surround sound (3D audio corresponding to the images) and insect noises. Another point was to include music to the study: "Music was missing, like a movie soundtrack or instrumental" by simulating Doppler effect [11] in the scene.

6.5 First-time experience

Several participants reported that the VR HMD (Oculus Rift) was comfortable to wear and operate. Some noted that display quality is poor but nevertheless the experience felt real enough. They indicated that VR is still too technical for early adopters and the hardware technology should become more effective in terms of usage. Overall, they rated it as a positive experience. Among them, seven participants tried VR for the first time and six were amazed with the experience. Recorded feedback from a first-time VR user: "When I looked into virtual reality through the device for the very first time I was amazed how it looks like and how smoothly and naturally it reacts to movements of my head. I was in completely different world".

7 QUESTIONNAIRE ANALYSIS

7.1 Simulation Sickness

The primary goal of the experiment was to assess the effectiveness of the two selected methods for reducing motion sickness. As mentioned earlier, to measure participant's severity of motion sickness standardized SSQ was used. SSQ is widely accepted [31] because it can provide a way of measuring a list of symptoms caused. The SSQ total score was calculated based on [27] and participants were randomly assigned to 4 groups. Results from all groups with methods involved in the prevention of simulation sickness ('FoR', 'FoR, VP' and 'VP') show that they had an effect compared to the 'none' group. Summary of important values for each testing group (mean and median values of SSQ score and the standard deviation) are illustrated in Table 1.

Table 1: Mean, median and std. for each method (SSQ)

Method	Mean	Median	STD
FoR	33.72	18.22	27.455
FoR,VP	23.23	16.22	20.894
none	31.65	28.7	24.68
VP	25.51	22.22	12.881

Participants in groups with cockpit ('FoR' and 'FoR, VP') reported they could survey the environment more completely (mean 5.87 and 6.00) compared to the participants without the cockpit (mean 5.33 and 5.73). Examining objects from multiple viewpoints was easiest for the 'FoR' group (cockpit only) with the mean value of 4.53. Group with visible path reported mean of 3.87. An interesting point found was that higher computer usage was positively correlated with the lower SSQ scores (see Figure 6). It is clear, that there are too few participants with low computer usage to draw any concrete conclusions.

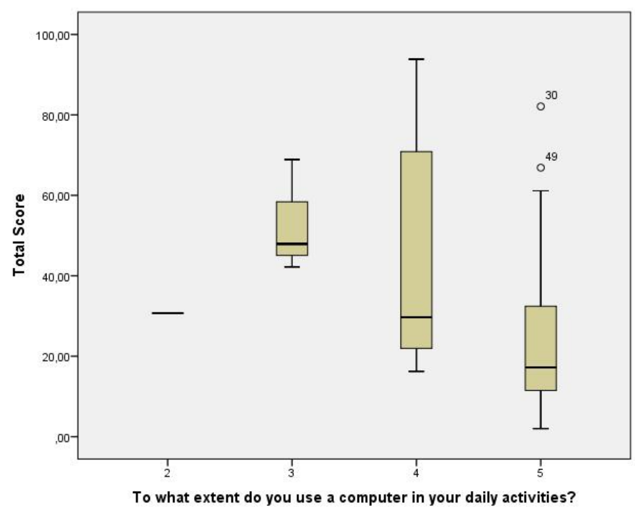

Figure 6: Relationship between computer usage and motion sickness

Analysis of the SSQ scores showed no significant difference between the different groups (FoR, VP, FoR and VP, none). Gender did not play any significant difference to testing groups. The time of doing the experiment (morning, afternoon) was also examined but again no significant correlations were found. However, the mean values show that frame of reference has little to no effect and visual path does seem to lower the SSQ score.

7.2 Presence in VR

In terms of presence, the majority of the participants did not have any previous experience with VR. However, was little difference between the groups and how quickly they adjusted to the VR experience. Since this was mainly a passive experience in VR, this outcome was expected. The mechanism which controlled movement through the environment was also examined since it is an important aspect of presence. A relationship between frame of reference method and how much participants considered movement natural in the virtual reality environment was found as shown in Figure 7. Movement was extremely artificial for group 'none'. On average movement was "moderately compelling" (4 on the scale) for participants in groups involving frame of reference ('FoR' and 'FoR, VP'). Results of group 'VP' are between control ('none') and frame of reference groups. On average, movement felt more artificial than natural for all participants (potential improvement for the future).

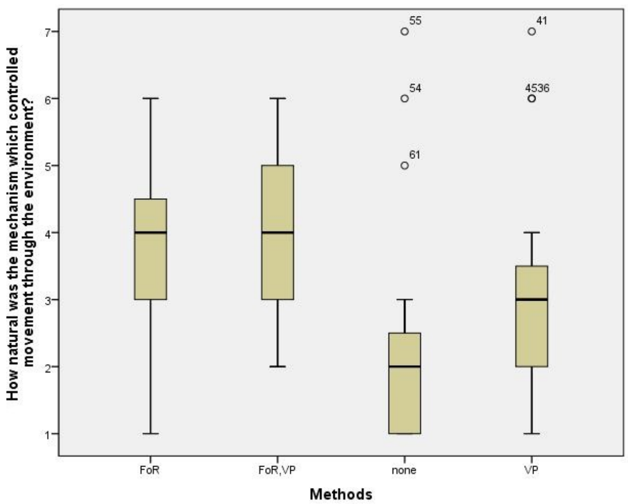

Figure 7: Mechanism of movement in different visual paradigms

As far as navigation inside the virtual environment is concerned there was little difference for the participants in each group. Similarly, there were no significant differences between the groups in terms of how quickly they adjusted to the VR experience. Moreover, examining objects from multiple viewpoints was easiest for the 'FoR' group (cockpit only) with the mean value of 4.53. Group with visible path reported mean of 3.87.

7.3 Cognitive Load

NASA-TLX is associated to the total amount of mental effort being used in the working memory. Overall, TLX score was low on average which correlates with the fact that this was an experiment with passive only user involvement. The TLX score was slightly different between tested groups. Group 'none' had the highest score with 35.22, closely followed by group 'FoR' with 35.16. This could be interpreted as frame of reference having no effect on TLX. Visible path has slightly lower score 32.5. Interestingly, when both methods are employed (group 'FoR, VP') the overall TLX score is only 23.55. It seems that on their own methods have little to no effect, however when combined they reduce task load index.

Finally, data analysis reveal relationship between TLX and SSQ scores (see Figure 8). Higher TLX value correspond to the higher values of SSQ total scores. This could be potentially explained

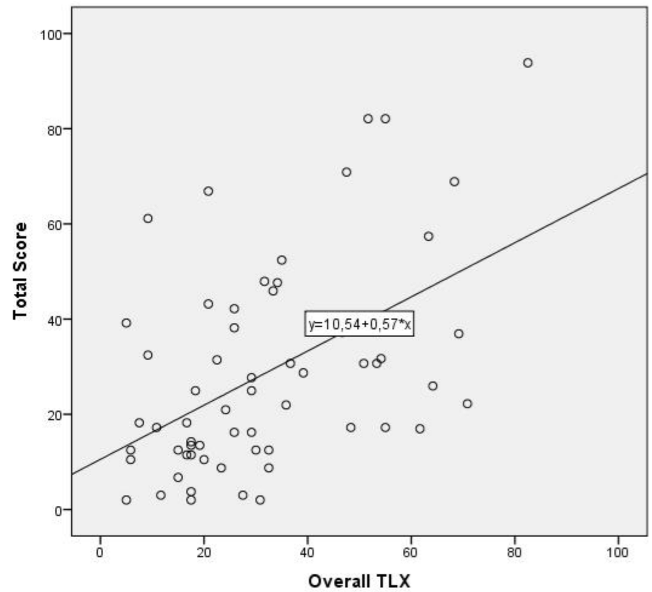

Figure 8: Relationship between TLX and SSQ

because higher level of discomfort and stressful (demanding and frustrating) experiences go together. More research could be done in the future to pinpoint the exact cause.

8 CONCLUSIONS AND FUTURE WORK

This paper presented a comparative study for examining motion sickness in immersive VR. The main purpose of the study was to evaluate whether two selected methods help to alleviate motion sickness including: frame of reference (FoR) and visible path (VP). Frame of reference method means to add a visual frame of reference (a rest frame) in the view. Visible path should help users to predict the movement by placing visible waypoints along the track. Four testing groups were formed, each consisting of 15 participants. There was one group for each method (groups 'FoR' and 'VP'), one combining both methods (group 'FoR', 'VP') and one control group (group 'none'). Experimental results indicated a pattern in the analysis. In particular, the best way to reduce motion sickness was found to be the combination of FoR and VP. Comparing alone the FoR and VP, the latter was also found to be better (but with no significance). These findings suggest that future developers could easily develop VR applications using FoR and VP to offer better experiences.

The findings of this study, can be used for a variety of applications. In the future, we plan to use them for two different VR projects. The first one, is an entertaining and educational tool that aims in teaching folk dances using immersive VR [21]. The targeted audience is very wide and motion sickness plays an important factor in making the technology adaptable. The second application, is focused on the healthcare domain and more specifically on functional neurological disorders. The goal is to evaluate VR as a potential therapeutic tool for treatment purposes. A model for generating head and eye movements during gaze shifts of virtual characters will be used to examine social stress [9] in VR. In this scenario, the target audience is patients which suffer from functional neurological disorders and motion sickness could have catastrophic results.

Finally, more sickness alleviation methods will be designed and evaluated. Specifically, two more methods will be assessed including: 'speed' and 'locomotion'. These two methods are also reasonably easy and fast to implement but to have a more general conclusion the participation sample should be considerably bigger. In terms of data collection procedures, neuro-feedback and bio-feedback will be gathered together with questionnaires. This will allow us to investigate deeper the effects of motion sickness in immersive VR environments.

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