On the Effect of the Vertical Axis Alignment on Cybersickness and Game Experience in a Supine Posture

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***Abstract*—Cybersickness is still an inevitable adverse effect when using VR systems, resulting in different levels of discomfort, and potentially breaking the immersive experience. To date, few studies have focused on exploring VR experience in the supine posture. Recent research indicated that simple adoption of VR game initially designed for a seated posture (by rotating 90 degrees) could lead to more severe cybersickness, even to experienced users. Following the insights from previous literature and the widely-accepted sensory conflict theory, we proposed an assumption that might explain such a phenomenon. The hypothesis is that when the perceived virtual coordinate system contradicts the received real-world coordinate through our vestibular system, the conflict appears, which can lead to a sense of discomfort. Hence, the primary goal of the study is to evaluate whether such conflict has an impact on cybersickness. Furthermore, we explored methods of mitigating this conflict through different game designs so as to improve the experience for the supine posture. The final results show that the design that aligned with the real vertical axis is effective in mitigating cybersickness, especially for games that present an acceleration sensation.**

***Index Terms*—Virtual Reality, Cybersickness, Immersive Interaction**

I. Introduction

The vision of virtual reality (VR) has existed for more than fifty years [11]. Fred Brooks defined VR as an engaging experience in which users are effectively immersed in an interactive virtual world [6]. Even though the technology has improved immensely with more advanced head-mounted displays (HMD) with wider tracking capabilities, a comfortable experience has not been fully ensured yet. In 1993, Kenney et al. reported that more than ninety percent of VR users in their studies experienced discomfort during exposure [20]. Thanks to the development of new technology, hardware-induced discomfort is now mostly avoided. The pressure then has been passed onto content developers and user experience designers. Generally, the widespread adoption of VR is still threatened by the side effects during exposure to the virtual environment [1]. Visually-induced motion sickness, simulator sickness, and cybersickness have been used interchangeably in the literature to describe such adverse effects. Given that this work revolves around the specifics of Virtual Reality Sickness, we use the term cybersickness to refer to this concept from this point onward.

Cybersickness can occur during a Virtual Reality (VR) experience, leading to unpleasant symptoms such as nausea, dizziness and headaches [8]. Such anomalies are unwanted as they tend to hinder the user experience significantly and in the worst-case scenario, lead users to abandon or avoid the VR experience altogether. Currently, our understanding of cybersickness is far from complete, hindering the development of a cure. In order to unlock the full potential of VR, there is a need to obtain an extensive understanding of its side-effect.

Typically, the user often plays either standing or seated when experiencing VR. However, it can be necessary to confine individuals to the supine posture when it comes to studying human-brain phenomena with VR settings, such as monitoring participant brain activities using fMRI [22]. Moreover, a supine pose is expected to be more relaxing for VR experience at home or on a bed in rehabilitation institutions [29]. While there has been much effort made to study the different factors on cybersickness in seated, standing, and walking conditions, there is limited contribution to study such

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side-effects when a user plays in a lying-down posture. Given the huge potential application of VR in clinical treatment like anxiety [36], and the nature of such treatment in a supine posture, this paper argues that it is also essential to understand the influence of cybersickness in such posture given these serious applications.

A recent study conducted by Marengo et al. used a 3D Pac-Man style game to compare the effect of different cybersickness mitigating factors for both supine and seated postures [23]. Results indicate that even experienced VR users, who were thought to be less vulnerable to cybersickness [14] [16], still experienced discomfort in the lying-down posture. In contrast, they reported no such feelings when seated. The paper concluded that the incongruity between the lying-down posture and moving around the virtual world in a straight standing position, might be to blame. In light of this, we propose and formulate a possible explanation into a kind of sensory conflict; that is, the discrepancy between inputs of the vestibular and visual system could lead to cybersickness (further details are provided in the following sections). In other words, this paper contributes to the following three points: 1) Investigate whether specific game design without the identified conflict could mitigate cybersickness. 2) Investigate whether a VR game design without acceleration could mitigate cybersickness 3) Investigate whether the game designs mentioned above are more adapted to the lying down posture concerning the VR game experience. The main research questions are:

- Do individuals feel less sick if they perceive to be "lying-down" in the virtual world, while also physically lying-down?
- Would subjects prefer experiencing VR in such a design mentioned above?

II. Related Work

A. Theories explaining Cybersickness

In previous studies, different conflicting theories have been discussed to explain the cause of cybersickness, including sensory conflict theory [25], postural instability theory [30], and poison theory [34]. Yet, as of the time of writing, there is still no definite explanation to this phenomenon [27].

The *Sensory Conflict Theory*, also known as the visual-vestibular conflict theory, happens when visual cues conflict with the ones from vestibular and proprioceptive senses [26]. Vision plays an important but not exclusive role in self-motion perception [3]. Scientists have proved that neurons in vestibular nuclei simultaneously respond to inputs from both retina and vestibular, which allows inferences concerning visual-vestibular interaction [10]. The combined messages provide an indication of the observed speed and the direction of the moving visual world, which creates a sensation of self-movement [12]. When the vestibular and visual stimuli are not coherent, a conflict situation arises leading to physiological discomfort. In 1991, Thomas A. Stoffregen proposed an alternative hypothesis named *Postural Instability Theory*. Unlike the sensory conflict theory, postural instability theory states that individuals feel discomfort when they cannot control their postural stability or have not yet adapted themselves to maintain it [30]. Likewise, the theory is not an one-for-all standard. Other studies have conflicting results indicating that postural instability is not a requisite for cybersickness [9]. A less predominant explanation is the *Poison Theory* postulated by Michel Treisman [34]. His hypothesis is based on the Sensory Conflict Theory, where he defines that the sensory system regulates the body's movement and estimates it's location in space, which in turn is vulnerable to slight changes. However, this theory has raised some skepticism within the community as it is difficult to test the veracity of such hypothesis [27].

Until now, the Sensory Conflict Theory is still the most widely accepted. The reason being that empirical studies have indicated that cybersickness is related to sensory conflicts rather than the other subsidiary hypotheses [8] [24]. Hence, the arguments in this paper are under the premise of the Sensory Conflict Theory.

B. Mismatches

One of the most essential implications of the sensory conflict theory is that changes in movements (i.e. magnitude or direction of acceleration) could lead to mismatch between senses. Combining previous findings [32], three kinds of mismatch can arise, the third one is formulated on our assumption:

- The visual stimuli do not match the natural stimuli of our daily life.
- Only the visual system receives the stimuli, while the vestibular system continues to sense the surrounding physical world naturally, which can lead to a sensory conflict. Simply, there is no real-world acceleration that could be sensed by vestibular organs, meanwhile, the eyes perceive visual acceleration.
- The visual and the vestibular sensors receive information from orthogonal coordinate systems. The vertical axis sensed by the otolith organs (or real-world gravity) is perpendicular to the visually sensed one. This mismatch happens in the supine posture (Fig. 1)

Following the sensory conflict theory and mismatches, constant speed is not expected to induce cybersickness while changes in speed would [2]. Naturally, this would lead to an assumption that the biggest conflict for VR involves accelerations, both translational and rotational. Combining the notion that vestibular sensors provide information of linear acceleration and angular rotation of the head in space and are unable to encode constant velocity motion [32], we conclude that acceleration is one dominant factor.

C. The posture factor

Posture is one of the most frequently studied factors of cybersickness. Generally, the seated posture was proved to be less sickness-inducing than the standing one since it allows for more stable postural control [8]. Comparatively, the significance of the supine pose has been neglected. Such a posture is mostly utilized in neuroscience studies using fMRI

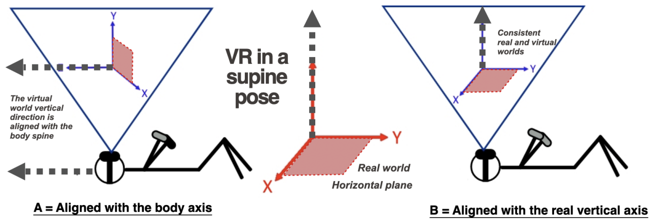


Fig. 1: Virtual vertical axis orientation factor: A. Aligned with the body axis design and B.Aligned with the real vertical axis design. The red axis are the real world axes and the blue ones inside the triangle are the axes of the virtual world.

[5] [28] to investigate human brain activities during virtual navigation tasks. It is also important for studying motion sickness in micro-gravity environment since experiencing VR in the supine posture could present some similarity with this sensory context [7]. The head orientation is the marked difference between seated and lying-down posture. Previous neuroscience studies indicated that even though the vestibular and proprioceptive systems are not or at least not fully activated during VR exposure, the directional information (e.g., head orientation) provided by the vestibular system is always active and present [33]. The disparity between visual cues indicating the upward direction in the virtual environment and idiothetic cues indicating that the user is in fact lying down physically in the real world may result in more severe cybersickness [23] [33]. Hence, the VR experience of navigation in the supine posture is worth exploring.

III. Experimental Design

Fig. 1 showcases the perceived visual coordinate systems relative to the real world. The real-world coordinate system with its highlighted horizontal plane is visible in the middle. The coordinate system inside each triangular field of view is the virtual coordinate system that the user perceived visually in VR. Design **A** in Fig. 1 represents the original virtual world orientation according to Marengo et al's work [23], while design **B** shows the new design proposed within this paper. The objective is to reduce the disparity between head orientation in real-world and visual head orientation in virtual world so as to reduce cybersickness. To standardize the terms, we use *Aligned with the body axis design* for design A, and *Aligned with the real vertical axis design* for design B.

In the body axis design on the left, even though people might perceive the vertical axis aligned with the body, it is hypothesized that the vestibular system still adjusts itself to perceive the real-world vertical direction as it keeps sensing the gravity, which conflicts with the virtual coordinate system that people perceived visually. For this reason we introduce the second conflict-free design for which the real and virtual coordinate systems are aligned.

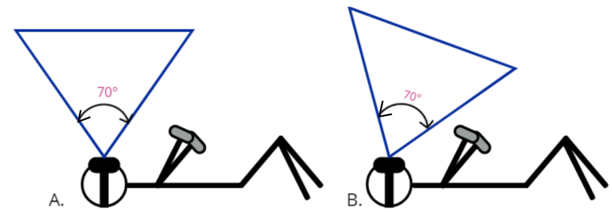


Fig. 2: The field of view was rotated 20 degrees around the pitch axis to ensure a better view of the bedroom scene

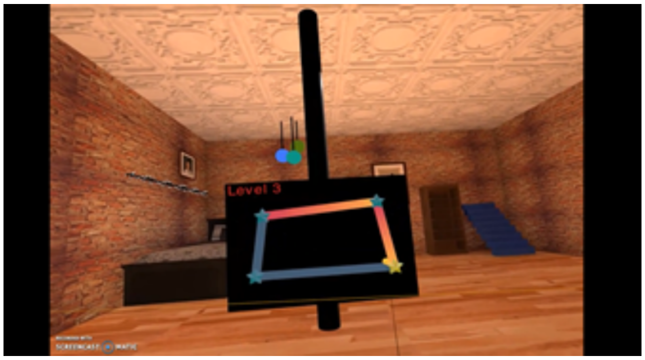
A. Experimental design

The design of this experiment is a 2 by 2 factorial design with both *virtual vertical axis orientation* and *game type* as the within-subject factors. Each factor has two different levels. We define the first level of virtual vertical axis orientation factor as as the ***Aligned with the body axis*** short as Body Axis and the second level as the ***Aligned with the real vertical axis***, short as real Vertical Axis. Note that, the axis orientation difference refer to the ones in the virtual world. In all conditions, participants play in a **supine posture**. As aforementioned, Fig. 1 presents a visual illustration of the two defined postures above. Similarly, the two levels of game type are defined as ***Static Game (SG)*** and ***Dynamic Game (DG)***. Details of the game designs are presented in the following section. For simplicity, we named the four conditions as: **Dynamic Vertical (DV)** for Dynamic + Real vertical Axis design combinations, **Dynamic Body(DB)** for Dynamic + Body Axis design combinations, **Static Vertical (SV)** for Static + Real Vertical Axis design combinations, and **Static Body (SB)** for Static + Body Axis design combinations.

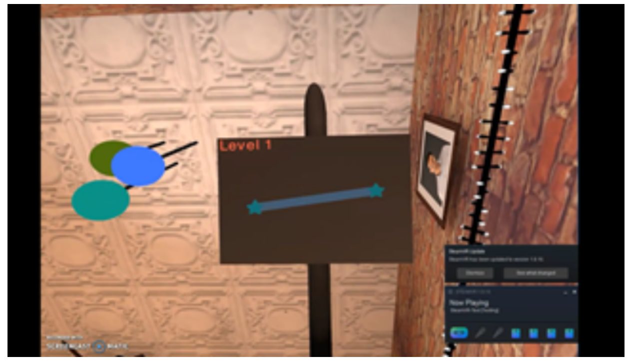
For evaluation purposes, we investigate the influence of the factors as mentioned above on eight dependent variables: 1) Simulator Sickness Questionnaire(SSQ) [20] total score 2) SSQ-Nausea score 3) SSQ-Oculomotor score 4) SSQ-Disorientation score 5) Game Experience Questionnaire [15] (GEQ) total score 6) GEQ-Negative score. 7) GEQ-Positive score 8) GEQ-Flow score.

B. Participants

All the participants are recruited through flyers and intranet of a local research institute. The targeted subjects were requested to obey the following rules: 1) No ingestion of alcoholic, motion-sickness medicine or similar substances up to 12h before the experiment, and 2) The last ingested meal must be at least two hours before the sessions. A total of 30 participants(7 female) aged between 18 to 27 were participated in this experiment. Among which, seven of them reported never experienced VR applications or games before, while the others reported to have a few VR experience. None of them are experienced users. The study was approved by the ethic committee examination.



(a) Static game in the body axis condition, the task is to connect the stars with the controller on the puzzle board in the virtual bedroom.



(b) Static game in the real vertical axis condition, the task is to solve the same star connection puzzle on the board hanging on the pillar.

Fig. 3: The static games with different virtual vertical axis orientation

C. Design,apparatus and stimuli

a) Game design: The virtual environment(VE) was designed as an enclosed bedroom-like space with decorations and furniture. The four game variants share the same virtual environment, where the main variations are the posture and game mechanism. It is also important to keep in mind that all variants are viewed in the first-person perspective in the VE. Decorations on walls and ceiling indicate the direction of the "simulated gravity". Since a previous study proved that the angle of the perceived horizontal plane changes depending solely on the angle of the upper body [17], hence, it was decided to slightly tilt the field of view at a 20 degree angle (see Fig. 2) to ensure that the individual was not constrained to viewing the ceiling in both DV and SV conditions. This modification was further tested on a pilot study with 6 subjects, in which none of them noticed the slight angle change.

The task of the static game is to connect all the stars without going back through the same path (see Fig. 3a and Fig. 3b). The game was made purposefully simple and straightforward as to mitigate the influence of skill of the different participants. When the game starts a laser pointer appears from the controller, this allows participants to trace a path towards each star while holding down the trigger button. The puzzle can be reset by pressing a button on the controller. Upon completion of a level, particles appear from the stars and fall naturally based on simulated virtual gravity. These particles serve to reinforce the direction of the virtual gravity and vertical axis orientation. The whole game consists of 10 different levels with increased difficulty. Each subsequent level loads automatically without interference from the experimenter. The last level was purposely made impossible to complete to ensure the same length of playing time for all individual participants.

In the dynamic game (see Fig. 4a and Fig. 4b), players must control their avatars and avoid getting hit by the incoming falling stars in red and collecting blue stars. Due to the size constraints, avatar movement is limited to the lateral axes only. This movement was achieved by using the force detection feature of the Valve Index controllers. For simplicity, the magnitude of the force cannot influence the magnitude of acceleration. Based on the pilot study, the maximum avatar movement speed is set to 5 $\mathrm{m\,s^{-1}}$, with an acceleration of $200\mathrm{m\,s^{-2}}$.

b) Apparatus: The head-mounted display used in this study is the *HTC Vive Pro Eye* (HTC 2019). The headset includes a dual OLED screen, a combined resolution of 2880 * 3200 pixels, a 110- degree field of view and a refresh rate of 90 Hz. Participants provide user inputs via two Vive index controllers. We take advantage of the force sensors inside the controller to achieve the lateral movement.

D. Subjective Measures

a) Simulator Sickness Questionnaire: Simulator Sickness Questionnaire(SSQ) is still an authoritative measurement of cybersickness [20]. It consists of 16 questions that evaluate the physiological status of participants. Using SSQ in VR research still faces challenges such as the non-uniform discretization of subscores, the military reference population of samples, its subjective nature, and missing baseline scores [4]. Even though it is disputable [37] [1], we maintained the use of pre-posture SSQ in this study, as suggested in Bimberg et al.'s paper [4]. The reasons are three folds: 1) Unlike Kenney's study, our sample size is not big enough to be treated as a population that could be further used as the baseline; 2) Currently, there is no optimal way to solicit information about subject's physiological status before an experiment, and 3) Our experiment is performed in across two different sessions occurring on two different days; thus we cannot ensure that the participant will have the same condition for both days. As mentioned above, the SSQ scores are collected as SSQ Total Score(SSQ-TS) and subscores as SSQ Nausea (SSQ-N), SSQ Disorientation (SSQ-D), and SSQ Oculomotor(SSQ-O).

b) Game Experience Questionnaire: To our knowledge, VR game experience in supine posture has not been discussed yet. To answer the second research question, we intended to measure game experience to make better estimation of the quality of different designs. Since we didn't find any standard VR game experience questionnaire in previous studies, we kept

(a) Dynamic game in the body axis condition, the task is to control yourself with controllers moving either to the left or right to collect blue stars and avoid red stars

(b) Dynamic game in the real vertical axis condition, the task is to control yourself with controllers moving either to the left or right to collect blue stars and avoid red stars.

Fig. 4: The dynamic games with different virtual vertical axis orientation

the relevant questions in the Gaming Experience Questionnaire [15] and modified the items to make them more adaptive to our experiment. The items in this questionnaire can be classified into four different components : Competence, Flow, Negative Affect and Positive Affect. The sum of each item score represents the general satisfaction. The negative affect items score are multiplied with -1.

E. Procedure

The experiment takes place over the course of two different sessions of around 45 minutes each. Each session is conducted on two different days (with a minimum interval of 1 day and maximum up to 3 days). For each session, a participant plays both of the games (i.e. one static and dynamic version) with the same virtual vertical axis design, a mandatory 5-minutes break in-between is required. Participants always started with the static game. Considering that the dynamic game with visual acceleration will theoretically induce more severe cybersickness than without, it was decided that participants always start with the static one. To ensure an equal balance between the posture variations and to mitigate an "order"-bias, half of the participants started with the SV condition while the remaining half started with the SB condition. (see Fig. 5).

The experiment was conducted in a noise-free room with a yoga mat and a pillow in the centre (for participant comfort). After signing the consent form, participants are given a short introduction of the study in question, the general procedure of the experiment and how to play each game. Once explanations are concluded, participants are asked to fill a demographics questionnaire along with the pre-SSQ to gather information of their current state as a baseline reference. Participants were then assisted to put on the HTC VR headset and lie down on the yoga mat. Each Valve Index controller are then given to participants and the button positions were emphasised. After the eye calibration phase, subjects are exposed to the virtual environment for 10 seconds without the game (The familiarisation phase) and played the static game for 3 minutes. The familiarisation phase serves to help participants understand the

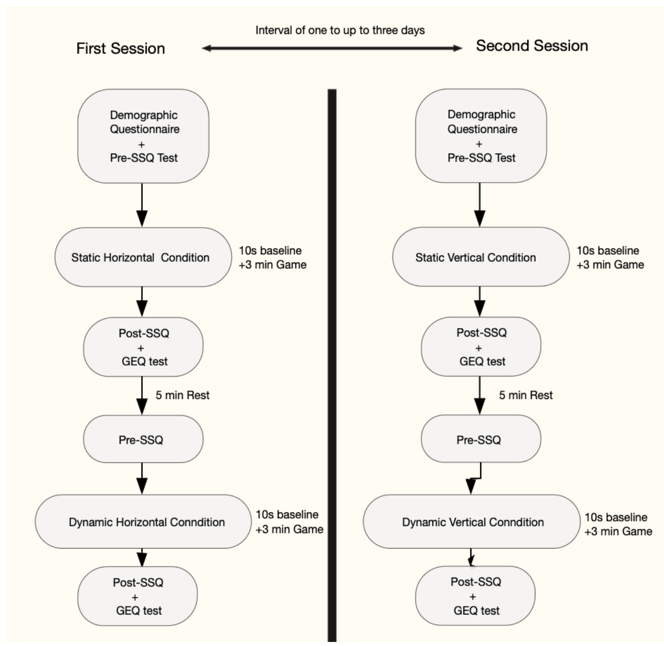


Fig. 5: The diagram showcases two sessions of the experiment with an interval of minimum one day between them. Each session consists of two sub-sessions with the static game first

virtual gravity direction. To achieve such purpose, particle cues were added in the virtual scene to reinforce the direction of the "simulated gravity". Upon completion of the 3-minute game, participants are asked to fill in the post-exposure SSQ. After a short break, the experiment continues with the dynamic game in a similar fashion to the previous. It is worth mentioning that all participants are told to minimize their head movement during the experiment.

IV. Results

SSQ Scores: Table. I shows both the mean and standard deviation of all all participant SSQ scores. To test the normality of the data, a Shapiro-Wilk test was performed. All the p values are below 0.05, which means the data significantly deviate from a normal distribution. For all the four conditions a standard Wilcoxon Signed-Rank Test was performed comparing the difference between the SSQ scores before and after the game. For the SB condition, no significant differences were found for the SSQ-TS(p = 0.060), SSQ-N(p=0.307) and SSQ-O(p=0.204). However, a significant difference was observed for the SSQ-D with a p value of 0.01. For the SV condition, a significant difference between the pre- and post-SSQ scores were found in SSQ-TS(p=0.005), SSQ-O(p= 0.008) and SSQ-D(0.02). However, no significant difference was found for SSQ-N(0.169). While, the DV condition presented significant differences for all the SSQ scores (SSQ-TS(p = 0.008), SSQ-N(p=0.018), SSQ-O(p=0.010) and SSQ-D(p=0.035)). Similar results were also observed for the DB condition, where SSQ-TS(p = 0.000), SSQ-N(p=0.001), SSQ-O(p=0.000) and SSQ-D(p=0.000).

SSQ by factor: The difference between the post and pre-SSQ are subsequently calculated as SSQ for comparison between different level of a factor. Again, since the difference data was not normally distributed, Wilcoxon Signed-Rank Tests were conducted. Statistic results show a significant difference between the Dv an DB condition(SSQ-TS(p = 0.007), SSQ-N(p=0.021), SSQ-O(p=0.021) , no difference was found in SSQ-D (p=0.057). No significant difference was found in any of the SSQ scores between the SV and SB condition(SSQ-TS(p = 0.559), SSQ-N(p=0.685), SSQ-O(p=0.927) and SSQ-D (p=0.430). Significant difference was found with respect to game type in body axis design(SSQ-TS(p = 0.008), but not in virtual vertical axis design (SSQ-TS(p = 0.433).

Combing all data together, each factor has 60 samples. Generally, we did not found significant effect of posture or game type on SSQ-TS (p-posture = 0.200, p-gametype = 0.150).

TABLE I: The Mean and Standard Deviation in parenthesis of the obtained SSQ Scores. Bold values highlight the significant difference between pre- and post- scores

Different[a] Conditions	SSQ score-absolute			
	SSQ-TS	*SSQ-N*	*SSQ-O*	*SSQ-D*
SB-pre	21.4(21.4)	17.8(20.8)	20.0(18.1)	**17.2(22.1)**
SB-post	29.5(24.1)	21.0(21.8)	24.5(20.4)	**34.4(30.5)**
SV-pre	**19.8(20.5)**	18.1(19.3)	**16.9(19.8)**	**16.2(24.5)**
SV-post	**26.9(21.3)**	20.7(17.6)	**23.0(20.8)**	**27.8(27.4)**
DB-pre	**19.8(17.6)**	**16.2(17.7)**	**16.9(15.0)**	**19.0(21.8)**
DB-post	**37.6(28.1)**	**29.2(25.0)**	**30.9(23.9)**	**40.8(32.3)**
DV-pre	**25.9(22.7)**	**21.3(21.9)**	**22.5(20.5)**	**24.1(24.8)**
DV-post	**34.7(24.9)**	**27.7(20.9)**	**28.0(22.3)**	**37.1(35.4)**
Different Conditions	**SSQ score-relative**			
	SSQ-TS	*SSQ-N*	*SSQ-O*	*SSQ-D*
SB	8.1(31.9)	3.2(29.0)	4.54(25.6)	17.1(38.8)
SV	7.1(13.5)	2.5(12.2)	6.1(13.1)	11.6(25.1)
DB	17.8(18.4)	13.0(18.3)	13.9(16.9)	21.8(25.0)
DV	8.7(17.3)	6.3(12.1)	5.5(16.8)	13.0(31.4)

[a]SB = Static + Body Axis
[a]SV = Static + Real Vertical Axis
[a]DB = Dynamic + Body Axis
[a]DV = Dynamic + Real Vertical Axis

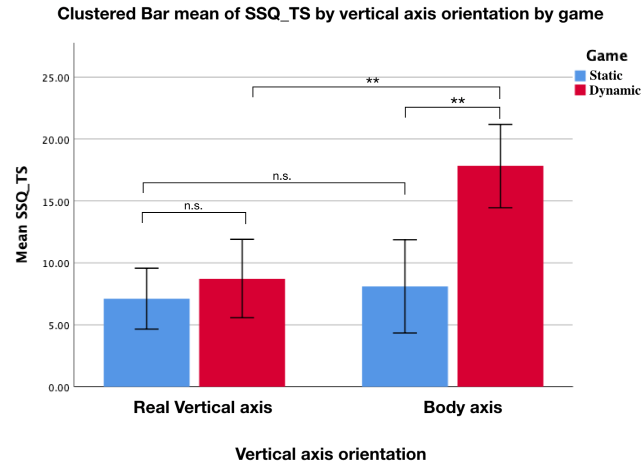


Fig. 6: ΔSSQ Total means of each condition .Error bars represent the standard deviation.

Game experience Score: The GEQ evaluates participant responses based on four player experience traits: Competence, Flow, Negative Affect, and Positive Affect. All components scores are summed; the Negative effect scores have been multiplied by -1 before the summation [15].

We did not found significant differences between the SV and SB conditions concerning the GEQ total scores and its sub-scores($p > 0.05$). Neither between the DV and DB conditions. In general, the different virtual vertical axis orientation have no remarkable influence on the game experience. Regarding the effect of game type on game experience, the results imply a significant difference between the static and dynamic ones. We found significant difference between DV and SV condition with respect to GEQ total score(p=0.007), negative score(p=0.008) and positive score(p=0.000). In addition, the statistics reported a significant difference between DB and SB condition with respect to GEQ total score(p=0.006), negative score(p=0.003) and positive score(p=0.000).

To investigate the relationship between cybersickness and game experience, we used Spearman's correlation analysis. Results indicated a negative correlation between SSQ-TS and GEQ total score in SV condition (p = 0.004). Additionally, negative correlations were found between SSQ-TS and GEQ positive scores in SV(p= 0.019), DB(p= 0.039), and DV condition(p=0.019). We didn't find significant correlation between flow and SSQ in all conditions ($p > 0.05$)

V. Discussion

Following Kenny's classification of severity of sickness based on central tendency [19], SSQ scores ranging from 5 to 10 indicate minimal cybersickness symptoms, while scores higher than 15 can indicate perceived and notable cybersickness. Overall, as expected, it was observed that the SV condition had a lower frequency of inducing cybersickness, whilst the DB condition had a higher frequency amongst the participants. Similar to previous studies [1] [13], a higher tendency was observed in games with accelerations, when compared to the condition without. As shown in Table. I, for SB, SV and DB conditions, the profile of cybersickness symptoms(SSQ sub-scores) was $D > O > N$, which differs from what have been reported in the previous studies [18] [1]. Since very few studies have been conducted in a supine posture, the exact cause of the slightly higher oculomotor score than nausea is unknown. It is interesting to have future studies exploring the profile of VR sickness symptoms when playing in different posture (e.g. seated-, standing- and supine-postures).

Since the translational and angular acceleration or deceleration are the main contributing factors of VR sickness. Hence, in this preliminary study, we evaluated static games without any translational or rotational movements to further prove this assumption for this particular posture. Comparing the two static games, we did not find any significant differences between the two conditions, even though the SV condition scores lower than the SB condition. More precisely, it means that the SV condition was still able to induce VR sickness with the exception of Nausea. Contrarily, results show that the SB condition did not induce cybersickness, with the exception of the Disorientation factor, which supports our assumption of the effect of aligning virtual vertical axis. Overall, the static games proved to show a low to none existing tendency of inducing VR sickness. Interestingly, during the pilots the games were tested with two experienced VR users who are quite susceptible to VR sickness. They reported being moderately sick during the baseline session in SB condition but not SV condition. Additionally, the sickness in SB condition decreased as they focused later on playing the game and reoccur when they completed a level and the particle started falling. Given the fact that the detailed VR susceptibility was not clear before formal experiment, for the future studies, it could be interesting to group the participants by their sensitivity to cybersickness and reevaluate participant responses with a larger sample size. However, considering that there is no solid method to measure such susceptibility, there is a pressing need to develop a robust standard approaches to assess individual cybersickness susceptibility.

Previous research stated that cybersickness tends to increases with the number of degrees of freedom (axes) [21]. Hence, we constrained the acceleration to one axis. The main purpose was to induce VR sickness gradually so as to eliminate other possible contributing factors. Significant differences indicate that both dynamic games induced sickness, where the mean scores of the DB condition was almost double that of DV condition. As predicted, a significant difference was also observed between the two conditions, confirming our previous assumption that the virtual vertical axis orientation is a contributing factor to cybersickness for the lying down posture. In general, we can observe a higher disorientation score while in body axis conditions than in real vertical axis conditions, further reinforcing our hypothesis on perceived virtual-real world axes conflict.

Similar to the game experience feedback from the post-exposure interview, the statistical results of the GEQ total score did not show any proof that one posture outperformed the other. Regarding the game type, people showed significantly more interest in static games than dynamic ones. However, the results are only applied to our specific designs. It is assertive to conclude that static games would provide a better experience than games with movements. Generally, our correlation analysis results agree with the findings by Somrak et al [31] and Mammen et al [35], where cybersickness and fun are negatively correlated. However, Unlike the results in their papers, we did not find any significant correlation between flow and cybersickness.

VI. Limitations

Overall, there are some limitations in this experimental design. First of all, the average pre-SSQ scores are higher than expected, especially for the DV condition. During the interview, some participants reported that they came in with a certain degree of fatigue. It is important and difficult to obtain detailed information without implication of the symptoms like fatigue, eye strain, headache before the experiment. Ideally, if we have a large number of samples, we could have excluded participant data with high pre-SSQ score and VR experience. Also, the experiment would be conducted on selected experienced VR users, who already have a basic understanding of their own susceptibilities to cybersickness. Secondly, the average time of being in acceleration or deceleration states was short, which could mask the difference between both static and dynamic game variations. Lastly, we mainly applied the subjective measurements, as a follow-up study, it would be interesting to use physiological measures as well.

VII. Conclusions and future work

In light of the sensory conflict theory, we proposed a new conflict that might potentially lead to cybersickness when users experience VR in a supine posture. In order to investigate our assumption, we implemented two kinds of VR games, one in which the virtual coordinate system is aligned with the real-world coordinate system. Another one in which the virtual vertical direction is perpendicular to the real-world one. Also, Leveraging the findings in previous studies that visual acceleration can escalate the sensory conflicts between visual and vestibular systems, we introduced the static and dynamic games to explore whether such a game design factor could mitigate cybersickness for a lying-down VR game experience. Results indicate that aligning the virtual and the real-world coordinate systems is effective in mitigating VR sickness in the supine posture, especially for games with acceleration. Additionally, games without acceleration or deceleration presented a less sickness-inducing experience for participants. Regarding the game experience, our results were in accordant with the previous findings that there is a negative correlation between the degree of cybersickness and a positive gaming experience. Moreover, even though using the pre-SSQ remains disputable, our experiment showcases the importance of collecting information about the subject's state of health before the experiment. Namely, there is a need to come up with an optimal examination of the precondition of health without implying participants of the possible sickness that they might experience in the follow-up experiment. To conclude, the findings could provide preliminary insights to design a VR experience suited for a supine posture, which could potentially be used for rehabilitation purposes or medical studies. In future studies, it would be interesting to explore different types of interactions and navigation methods to improve the game experience and mitigate cybersickness while taking the characteristics of such a special user pose into consideration.

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