Turn Your Head Half Round: VR Rotation Techniques for Situations With Physically Limited Turning Angle

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ABSTRACT

Rotational tracking enables Virtual Reality (VR) users to turn their head around freely 360° while looking around the environment. However, there are situations when physical head rotation is only possible for not more than a certain range, e. g., when the user sits in a bus or plane while she is wearing a VR headset. For these situations, rotation gains were introduced to decouple virtual and real rotations. We present two more techniques that allow 360° virtual turning in a physically limited space: *Dynamic Rotation Gains* and *Scrolling*. We conducted an experiment to compare those three rotation techniques and a baseline condition regarding VR sickness, spatial orientation, and usability. We found a significant underestimation of rotation angles for the dynamic rotation gains which might mean that this technique is more subtle than others. Furthermore, usability was higher and VR sickness lower for the dynamic rotation gains while scrolling caused the highest VR sickness. Finally, we conducted a confirmatory study to prove the applicability of dynamic rotation gains in an actual VR experience and got promising feedback.

CCS CONCEPTS

• **Computing methodologies → Virtual reality**; • **Human-centered computing → Virtual reality**.

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1 INTRODUCTION

Virtual Reality (VR) technology is becoming more widespread and accessible. In addition to diverse application domains, usage contexts such as location or time of day are also diversifying. VR applications are used at home, at the workplace, or in public. This entails certain challenges. For instance, there are situations where the user's turning angle is physically limited and therefore looking around freely in a 360° environment is not possible. This could happen, for example, when VR head-mounted displays (HMDs) are used in a bus or airplane (see Figure 1). Moreover, some users, e. g., people with disabilities, might not even be capable of turning their head 360° physically due to motor issues.

This motivates the need to develop interaction techniques which facilitate turning around 360° virtually to explore the virtual environment (VE) completely, even in situations when a 360° physical rotation is not possible. Such techniques need to decouple the one-to-one mapping between physical and virtual rotation.

A well known possibility to do that are *rotation gains* [18] which multiply the physical head rotation of the user with a factor or *gain*. This gain amplifies the physical rotation which results in a larger virtual rotation. To keep this manipulation imperceptable the applied rotation gain has to stay below the detection thresholds. This technique, however, has implications on spatial orientation or VR sickness. Moreover, rotation gains below the detection thresholds do not suffice for turning around 360°. Hence, alternative solutions are

Figure 1: A VR user is sitting in a bus and wears an HMD. In this situation, it is not possible to turn around 360° physically but at the most 180°.

necessary that cover the whole 360°. Solutions that are characterized by high usability, low VR sickness symptoms, and no impairment of spatial orientation.

In this paper, we introduce two rotation techniques for these situations: *Dynamic rotation gains* and *scrolling*. We compare these techniques with traditional static rotation gains and actual physical rotations in an experiment to assess VR sickness, spatial orientation, and usability. We furthermore conducted a confirmatory study to prove the applicability of dynamic rotation gains, the technique that showed the most potential in the experiment.

The remainder of this paper is structured as follows. Section 2 discusses related work. Section 3 presents the different rotation techniques in detail and Section 4 describes the experiment we conducted to compare those techniques. Section 5 discusses our findings and section 6 presents the confirmatory study. Section 7 concludes the paper.

2 RELATED WORK

Originally, Razzaque introduced three different kinds of amplified rotations: (1) rotations while a user is standing on a spot, (2) rotations while the user is turning, and (3) rotations while the user is walking [14]. Later, number (2) was defined as *rotation gain* $g_R := \frac{R_{virtual}}{R_{real}}$ by Steinicke et al. [18]. When a rotation gain g_R is applied to a real-world head rotation with angle α, the virtual camera is rotated by $\alpha \cdot g_R$ instead of α. They also estimated detection thresholds for rotation gains and other gains. It turned out that rotations can be scaled by gains between 0.67 and 1.24 without the user noticing the manipulation [18]. Other experiments found different thresholds, e. g., between 0.84 and 1.16 [1]. Jaekl et al. stated that an average gain of 1.26 felt most stable to their participants [5]. Peck et al. found that users are less aware of a rotation gain when using visual distractors [11]. Although, the range of the not noticeable gains is quite low in all experiments, this does not mean that stronger gains can not be applied. Some studies report that even high gains were not detected when the participants were not directly asked [8, 9]. This might suggest that the detection rate is lower if the attention of the participants is not actively drawn on the fact that they are manipulated. Furthermore, a few papers discuss that even obviously strong gains can be the better option in some situations [4, 11, 19].

Jay and Hubbold investigated rotation gains regarding their effect on VR sickness and performance [6]. They found that a gain of 2 was more efficient than a natural rotation and did not induce sickness. In another experiment, participants that were using a gain of 2 performed not worse than in a control condition [8].

Rotation gains that are changing dynamically during turning were implemented by Zhang and Kuhl [21]. It turned out that gains can be increased or decreased without users being able to discriminate between an increase and a decrease. Dynamic rotation gains were also used to implement a *Guided Head Rotation* which helps the user to keep her head in a comfortable pose [15]. Other work introduced a velocity-dependent dynamic amplification for curvature gains [10].

3 ROTATION TECHNIQUES

All of the proposed techniques are designed to enable 360° virtual rotation with a physical rotation range of only 180°. We decided for this physical range motivated by situations in public transport (see Figure 1). Of course, different situations might provide smaller or larger physical rotation ranges. Hence, the described techniques have to be adapted to those situations accordingly.

Static Gains

A common possibility to amplify a physical head rotation is to use a static rotation gain. This method multiplies the physical rotation with a factor which remains constant throughout the rotation and is independent of the head direction.

Since we want to investigate which technique is most suitable for reaching targets that are directly behind the user, we need to rotate 180° virtually. While seated, a physical head rotation of approximately 90° is possible. This means we

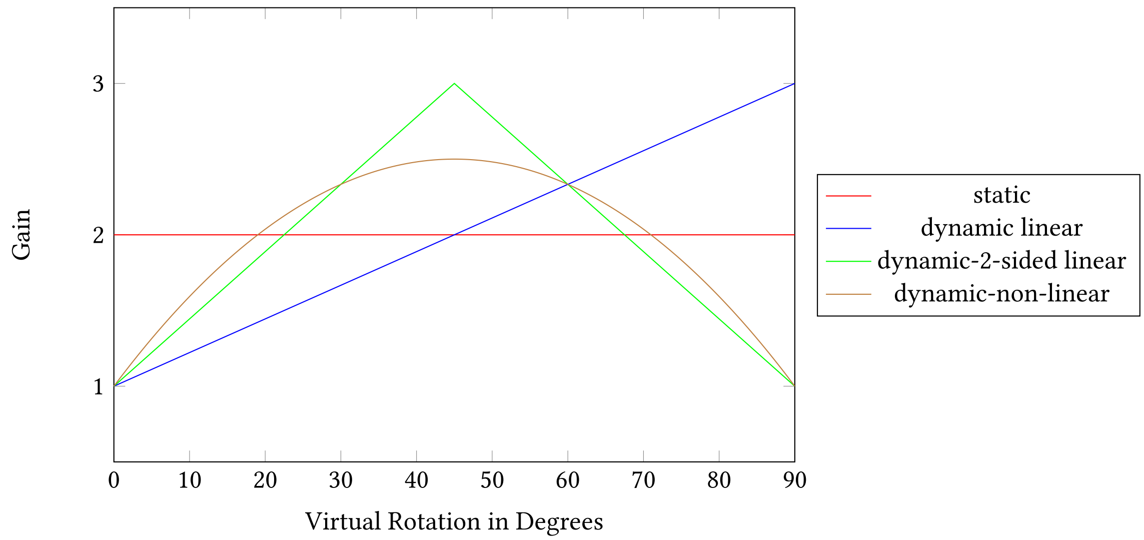


Figure 2: Applied rotation gains during a $90°$ virtual rotation. In all implementations, except static gains, the gain changes depending on the current head direction.

need to double this physical rotation to achieve the targeted 180° virtual rotation. Therefore, we chose a gain $g_R = 2$ for the experiment (see Figure 2), despite knowing that this is above the estimated thresholds [18].

Dynamic Gains

Such a high static gain, i. e., a high control/display (C/D) ratio, comes at a cost of accuracy [13, 20]. The user has to keep his or her head still and move carefully towards the target point.

Hence, instead of a static rotation gain, it might be advantageous to use a dynamic rotation gain. In contrast to the static gain, a dynamic gain is not constant but changes during rotation. Specifically, it would be possible to increase the gain up to a certain point during turning and, then, decrease it again when the user gets close to the target of her rotation. This way, rotation would have an ease-in and ease-out phase similar to techniques to enhance animation. A similar approach was already used for hand interactions in VR [3].

There are several possibilities to implement a dynamic gain. For example, the gain control could be speed-based as in the work of Frees et al. [3]. But then, the final rotation could be different for every user since people rotate with different velocities and it would not be guaranteed that the user is able to look behind herself. Because of this, we decided to couple the gain to the head direction of the user instead of the rotation velocity.

In a first naive implementation, we just increased the gain starting at 1 until the user directly looked at the target. This enabled a smoother entry into the amplification, targeting a positive effect for VR sickness. To achieve the same effect as with the static gain, the dynamic gain has to be 3 at the end of the rotation (see Figure 2). The gain may be calculated using the formula 1:

$$g_R = g_{min} * (1 - \frac{R_{virtual}}{R_{target}}) + g_{max} * \frac{R_{virtual}}{R_{target}} \quad (1)$$

g_{min} is the minimum gain of 1, g_{max} is the maximum gain of 3, $R_{virtual}$ is the virtual rotation and R_{target} the target rotation angle. Because the gain is very high when the user comes close to the target, we get a similar problem as with the static gain: The C/D ratio is very large and accuracy decreases.

In the second implementation, we decreased the gain again linearly after reaching half of the target rotation (see Figure 2). This way, the beginning as well as the ending is smooth and focusing the target is made easier. The gain may be calculated using formula 2:

$$g_R = g_{min} * |\frac{R_{virtual} - R_{half}}{R_{half}}| + g_{max} * (1 - |\frac{R_{virtual} - R_{half}}{R_{half}}|) \quad (2)$$

R_{half} is half of the target rotation angle. The maximum gain is weighted more, when the user gets closer to this threshold.

These first two implementation have a common disadvantage: The maximum gain in the first as well as in the second implementation is 3. Since the probability of motion sickness increases with a high gain, the goal of our third implementation was to decrease the maximum gain while the total amplification should stay the same. Therefore, the

(a) (b)

Figure 3: A participant is wearing the Oculus Rift HMD and a touch controller for input while she sits on a chair (a). The virtual bedroom that was used in the experiment (b).

increase of the gain must not be linear. Instead, we used a parable (see Figure 2). In the beginning of the rotation the gain is $g_R(0) = 1$ and in the end of the rotation it is $g_R(R_{target}) = 1$. At half of the target rotation angle the gain has to be $g_R(R_{half}) = g_{max}$. Using these three points we can put up quadratic equations for all targets to calculate the gains. To achieve the same total amplification as with the first two approaches the maximum gain of this implementation has to be $g_{max} = 2.5$. This is 0.5 less than with the other approaches. Hence, using this final implementation, the beginning as well as the ending is smooth, focusing the target is made easier, and the maximum gain is lower. Furthermore, we conducted an informal pilot study with 6 participants. They had one minute per technique (dynamic-linear vs dynamic-non-linear) for free exploration of a VE. All participants preferred the dynamic-non-linear approach.

So, we decided to use this approach in the main experiment (see Section 4).

Scrolling

In addition to static and dynamic gains, we implemented *Scrolling* which is a gain-independent rotation technique. The user turns around as usual without an amplification of the rotation. And after a certain threshold angle has passed, the virtual rotation will be continued automatically until the target is reached without physical head turns of the user.

For example, if the user wants to look at an object that is behind her at 180°, she starts turning around towards the target. When the threshold angle is reached, she can stop turning and the virtual camera is continuing the rotation. As long as the user's head is positioned behind the threshold angle, the virtual rotation is carried out. The virtual rotation stops as soon as the user is turning back her head below the threshold angle.

Hence, a threshold angle of 90° means that the user can turn freely without amplification in the range from −90° to 90°. The virtual rotation would start automatically when the user turns her head more than 90° or less than −90° and stop when she turns back into the range from −90° to 90°. If the user continues physical rotation after the virtual rotation started, it has no effect on the angular velocity.

We did some initial tests with a threshold of 90° but discarded that value since it can be very uncomfortable to hold a head rotation of 90° for some time when your body is still oriented straight forward on a chair. Instead, we chose a threshold angle of 60° which is more suitable in the long run.

4 EXPERIMENT

In this experiment, we compared the three rotation techniques static gains, dynamic gains, scrolling and a baseline condition; the goal was to assess VR sickness, spatial orientation, and usability.

Participants

32 participants (12 female and 20 male, age on average $M = 26$ years, $SD = 8.87$) completed the experiment. The participants were students, who obtained class credits, or professionals at the local department of computer science. One participant was left handed and the rest were right handed. All of our participants had normal or corrected-to-normal vision. 24 participants had used HMDs before. Their average experience with HMDs was $M = 2.97$ ($SD = 1.43$, in a range of 1 = no experience to 5 = much experience). Most of them had some experience with 3D computer games and they usually played 4.75 hours per week on average.

Materials

The experiment took place in a 10m × 6m laboratory room. We instructed the participants to wear an Oculus Rift HMD (see Figure 3 (a)), which provides a resolution of 1080 × 1200 pixels per eye with an approximately 110° diagonal field of view and a refresh rate of 90 hz. Positional tracking was done by two cameras which were delivered with the Oculus Rift. The participants were seated on a swivel chair or stationary chair (depending on the condition) in the center of the tracking area. A touch controller served as an input device via which the participants provided responses during the experiment. For rendering, system control, and logging we used an Intel computer with 3.4 GHz Core i7 processor, 16 GB of main memory and two Nvidia Geforce GTX 780 Ti graphics cards. The virtual environment was rendered using the Unity3D engine 2017.2 and showed an architectural visualization of a square bedroom (see Figure 3 (b)).

The participants were seated on a chair in the center of this virtual room so that they look at the wall opposite the bed. In the center of the participant's view is a small circle which serves as pointer and input method (see Figure 4 (a)). To interact with an object, the user just has to look at this object for two seconds in which the circle fills up. There are two types of objects the user can interact with: the *center element* and the targets. The center element is a pink cube that is located in the center of the user's field of view when a trial is started. The targets are 7 pink spheres which are located around the user at angles of 90°, 120°, 150°, 180° as well as −90°, −120°, and −150° (see Figure 4 (b)). Interacting with the center element starts and finishes a trial.

Methods

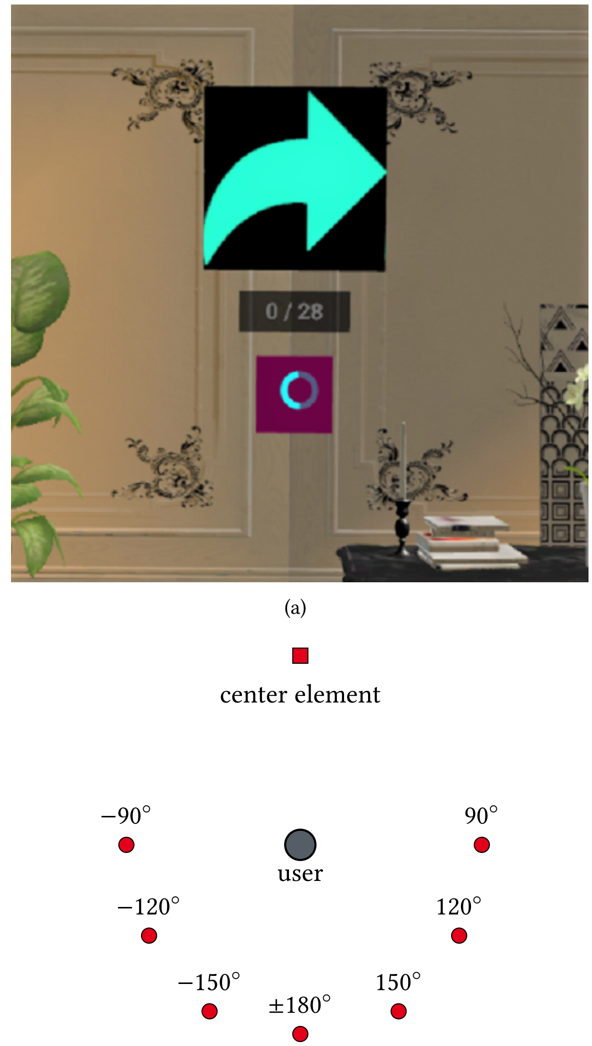
We tested the 4 conditions shown in table 1 in a within-subject design. The order of the conditions was balanced using the latin square method. For each condition, each of the 7 targets was repeated 4 times. This means there were $7 \times 4 = 28$ trials per condition which were randomized and $28 \times 4 = 112$ trials in total per participant. Participants completed 3 training trials before each condition.

Condition 1:	Baseline condition
Condition 2:	Dynamic gain
Condition 3:	Scrolling
Condition 4:	Static gain

Table 1: The four conditions of the experiment.

In the baseline condition, the participants are seated on a swivel chair and the physical rotation is not amplified. The other conditions are described in section 3. During those conditions, the participants were seated on a stationary chair, so that they can only move their head but not the whole body.

Interaction Task. At the start of one trial a target was positioned somewhere behind the participant. Moreover, an arrow was shown above the center element that indicated the direction at which the target could be found (see Figure 4



(a)

(b)

Figure 4: The participant's pointer interacts with the center element and the arrow that indicates the direction to the target appears (a). The arrangement of the seven targets and the center element around the participant (b).

(a)). Participants were asked to turn in the specified direction until the target was in their field of view. This turn was manipulated depending on the condition. Participants did not turn their body but only the head (except in the baseline condition). After reaching the target, participants had to hover their cursor on it for two seconds. Upon completion of the trial, the scene changed to a grey environment and the participants had to fullfill a pointing task, which was also used in similar studies to investigate spatial orientation [12]. In this new environment, the amplification of the rotation was disabled. This means, that movements of the participant

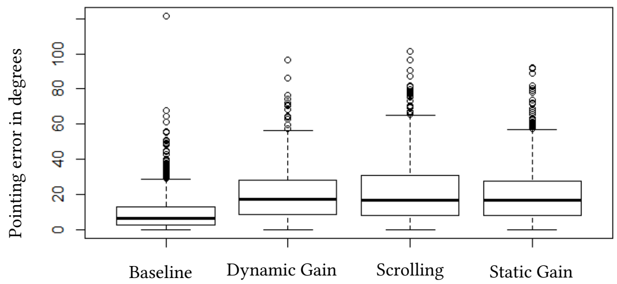


Figure 5: Results of the pointing task: The absolute error in degrees (y-axis) is shown for all four conditions (x axis). Overshoot and undershoot errors are merged.

were transferred one-to-one to the virtual world. Participants had to return and point to the virtual position of the starting/center element, i. e., to the position where the trial was started, using the touch controller with a ray extending from the controller. The yaw difference between the pointing direction and the actual position of the center element was saved. If the turn of the participant is estimated greater than it actually is, this is called an *overshoot* and, if it is estimated smaller, an *undershoot.* Because the rotation modifications were disabled when the scene changed, it is not possible to hit the center element by simply pointing physically forwards. Therefore, it is not sufficient to remember only the executed physical rotation but the participant has to perceive the VE during the amplified rotation to become aware of their spatial orientation. After the participant confirmed the pointing direction, the virtual bedroom is displayed again rotated around a random value to avoid a habituation to the orientation of the room.

Experiment Procedure. Before the experiment, all participants filled out an informed consent form and received detailed instructions on how to perform the experimental task. Furthermore, they filled out a demographic questionnaire. The Oculus Rift was calibrated individually according to the needs of the participant. After each condition, the participants had to rate the worsening of their well-being on an eleven point likert-scale (0: as before the condition, 10: much worse). It was made clear that this question targets only on the pure worsening that occurred during the last condition. This means that a participant had to answer "0" (no change) when she does not feel worse than before the condition even if she feels sick already. A similar approach was used in another experiment successfully [2]. We used this method to

Technique	Undershoots	Overshoots
Baseline	**350**	**546**
Dynamic Gain	**596**	**300**
Scrolling	439	457
Static Gain	**519**	**377**

Table 2: Number of over- and undershoots separated by rotation technique (significant differences are marked as bold).

measure VR sickness instead of the Simulator Sickness Questionnaire (SSQ) [7] since the participants would not have enough time between the conditions to recover their sickness level to its origin. Furthermore, the participants filled out the System Usability Scale (SUS) questionnaire after each condition.

At the end of the experiment, the participants are asked to give a subjective estimation about their preferred technique. The four techniques had to be ranked from bad to good.

Results

Spatial Orientation. Figure 5 shows the overall results of the pointing task. A Shapiro-Wilk test revealed that the data is not normally distributed Hence, we analyzed the results with a Friedman test at the 5% significance level. We found a significant effect of the rotation technique on the total pointing error ($p < .0001$). A post-hoc Wilcoxon signed-rank test found out that the pointing error was significantly lower in the baseline condition than in the other conditions ($p < .0001$). The pointing error in the other conditions did not differ significantly.

Then, we analyzed the pointing error in each condition separately for overshoots and undershoots using Wilcoxon-Mann-Whitney tests. Table 2 shows the number of under- and overshoots for each technique. In the baseline condition, overshoots occurred significantly more often than undershoots ($p < .0001$). On the other hand, undershoots occurred significantly more often than overshoots when dynamic or static gains were used ($p < .0001$). Figure 6 shows the average undershoot and overshoot errors for each technique. We found that the overshoot error was significantly larger than the undershoot error in the baseline condition ($p < .0001$) and for the scrolling technique ($p = .005$). For the dynamic gain, the undershoot error was significantly larger than the overshoot error ($p < .0001$).

To compare over- and undershoots between the different techniques, we analyzed the data with a Kruskal-Wallis test at the 5% significance level. We found a significant effect of the rotation technique on the overshoot error ($p < .0001$). A post-hoc test using Mann-Whitney tests showed significant differences between the baseline condition and all other conditions ($p < .0001$). It also showed that the overshoot error

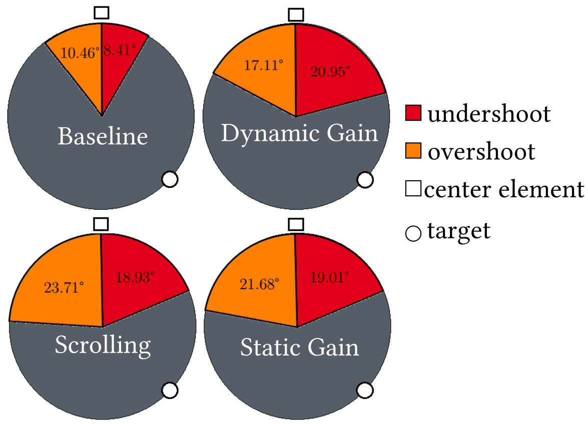


Figure 6: Average overshoot and undershoot errors per condition. The participant is located in the center of the circle and looks at the target (white circle) while she is pointing to the center element (white square). Undershoot is marked in red and overshoot is marked in orange. For better clarity, all parts are scaled up.

for dynamic gains is significantly lower than for scrolling ($p < .0001$) and static gains ($p = .001$). We could not found any significant differences between scrolling and static gains.

Furthermore, we found a significant effect of the rotation technique on the undershoot error ($p = .012$). The undershoot error in the baseline condition is significantly lower than in all other conditions ($p < .0001$). For dynamic gains, we found a significantly larger undershoot error than for scrolling ($p = .004$) and static gains ($p = .009$). We could not found any significant differences between scrolling static gains.

Finally, we anaylzed the influence of the target position, i. e., the size of the angle between center element and target, on the pointing error. For this, we merged overshoot and undershoot error. We found a significant difference between the different target distances using a Friedman test ($p < .0001$). Using regression analysis, we could show a significant linear correlation between target distance and pointing error ($p < .0001$). Larger distances produce larger errors (see Figure 7).

VR Sickness. Figure 8 shows the results of the question about the participants' well-being. A Shapiro-Wilk test revealed that the data is not normally distributed. Hence, we analyzed the results with a Friedman test at the 5% significance level. We found a significant effect of the rotation technique on the well-being ($p = .0005$). A post-hoc Wilcoxon signed-rank test found that the worsening in the baseline condition is significantly lower than for scrolling ($p = .001$) and static gains ($p = .006$). Also, the worsening for dynamic gains is significantly lower than for scrolling ($p = .0008$) and static

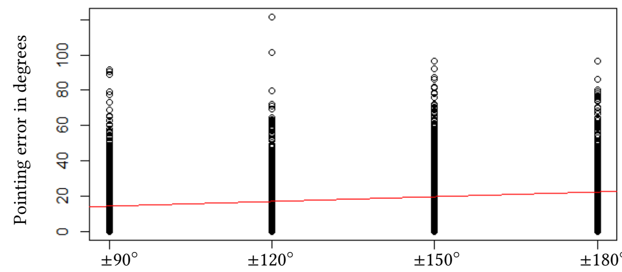


Figure 7: Linear correlation between target and pointing error.

gains ($p = .004$). We could not find any significant differences between the baseline condition and dynamic gains ($p = .387$) as well as between scrolling and static gains ($p = .134$).

Usability. Figure 9 shows the results of the SUS questionnaire. Scrolling got the lowest rating with an average score of 69.7 ($SD = 16.12$). Static gains received an average score of 77.3 ($SD = 14.92$). The baseline condition and the dynamic gains achieved the highest scores with an average of 83.2 ($SD = 14.37$) and 85.2 ($SD = 13.28$), respectively. A Shapiro-Wilk test revealed that the data is not normally distributed. Hence, we analyzed the results with a Friedman test at the 5% significance level. We found a significant effect of the rotation technique on usability ($p < .0001$). A post-hoc Wilcoxon signed-rank test found that the scores of the baseline condition are significantly higher than for scrolling ($p = .007$) and the scores for dynamic gains are significantly higher than for scrolling ($p = .0001$) and for static gains ($p = .016$). We could not find a significant difference between scrolling and static gains ($p = .657$) as well as between the baseline condition and dynamic gains ($p = .657$)

When asked for sorting the techniques according to their preferences, the participants voted dynamic gains best (17 votes), followed by the baseline condition (9 votes), scrolling (4 votes), and static gains (2 votes).

5 DISCUSSION

In the pointing task, none of the techniques could compete with the baseline condition. However, in the results, we observed some interesting aspects regarding the spatial orientation using dynamic gains. For dynamic gains, the undershoot error was larger and occured more often than the overshoot error. Furthermore, the overshoot error for dynamic gains was smaller than with static gains or scrolling while the undershoot error was larger for dynamic gains than with static gains or scrolling. This means, participants tended to estimate the rotation smaller than it was, which is an indicator that the amplification of the physical rotation was quite subtle. This was not the case for static gains and scrolling.

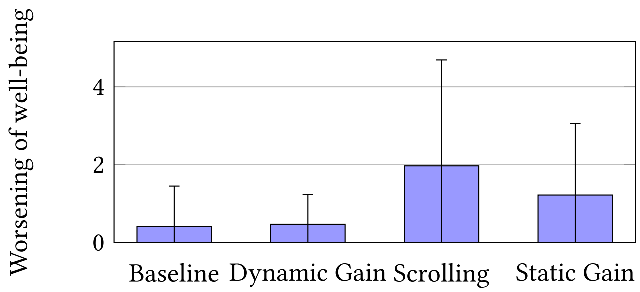


Figure 8: Worsening of the participants’ well-being after using each technique.

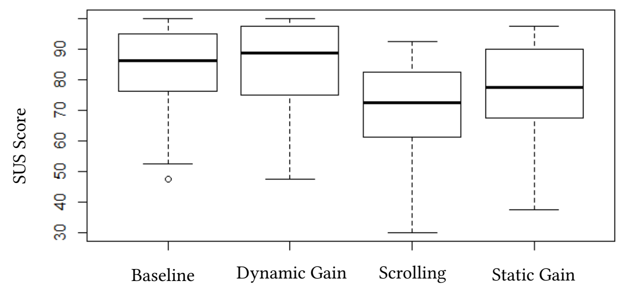


Figure 9: SUS scores of the different rotation techniques.

Regarding VR sickness, scrolling turned out to be the worst technique while dynamic gains performed as good as the baseline condition.

Analyzing the SUS usability questionnaire, dynamic gains and the baseline condition offered best usability. Dynamic gains were even preferred over the baseline technique which appears to be surprising but might be attributed to the manner of the question: Participants judged the best experience, and dynamic gains have some advantages over the baseline technique like reduced turning effort.

In summary, dynamic gains scored in most of the criteria and, therefore, might be a good alternative to natural physical rotation.

6 CONFIRMATORY STUDY

To verify the applicability of the approach that performed best, i. e., the dynamic gains, we performed a brief confirmatory study and gathered qualitative feedback in a narrative VR experience.

Materials and Methods

The same setup as described in Section 4 was used. We also used the same VE as in the experiment but instead of the seven targets virtual humans were placed in the room around the user. These virtual humans told the fairy tale *The Princess and the Pea*. They did this alternately: Each human spoke some sentences and then another one continued until the complete tale was told. The spoken sentences were generated beforehand using an online text-to-speech tool. During playback in the VR experience the lips of the virtual humans were synchronized with the spoken words using the Oculus Lipsync plugin. The sound source was set to the position of the currently speaking human to create a spatial impression.

The participants had the task to listen to the tale and to face always the human who is currently speaking. Hence, they had to turn around when the speaker changed, according to the origin of the sound. During these turns, dynamic rotation gains were applied. This way, we could enable the user to turn around in a 360° virtual environment during the whole experience while the user only had to use a 180° range in the physical world. The participants did not know about the rotation gains before and during the study.

After the tale was told the participants had to fill out some questionnaires including the SSQ, the Slater-Usoh-Steed presence questionnaire [16, 17], a demographic questionnaire and a custom questionnaire.

Participants

In total, 14 participants (5 female and 9 male, ages $18-26$, $M = 21.5$) completed the confirmatory study. The participants were students or members of the local department of informatics. All participants had normal or corrected-to-normal vision. Four participants wore glasses during the experiment. No participant reported a disorder of equilibrium. No vision disorders have been reported by the participants. Nine participants had participated in an experiment involving HMDs before. The experience of the participants with 3D stereoscopic displays (cinema, games etc.) in a range of 1 (no experience) to 5 (much experience) was $M = 3.64$ ($SD = 0.93$). Most of them had experiences with 3D computer games ($M = 3.36$, $SD = 1.65$, in a range of 1 = no experience to 5 = much experience) and they usually played 6.8 hours per week on average ($SD = 13.19$). The body height of the participants varied between $1.57 - 1.97$m ($M = 1.77$m, $SD = .09$m). The total time per participant, including pre-questionnaires, instructions, study, post-questionnaires, and debriefing, was 20 minutes. Participants wore the HMD for approximately 10 minutes.

Results

After the tale, we asked the participants if they noticed that there was an acceleration during the rotation. Only four participants noticed this. However, when asked if this acceleration disturbed them, all participants denied. Only one participant stated that this acceleration disctracted him from listening to the speakers and that he was briefly confused. After we explained the used rotation technique to the participants, eleven participants said that they did not notice anything and that it felt very smooth to them. For example, one participant said: "It worked so well, it felt like naturally turning your head in real life". On the other hand, one participant stated that he felt sick because of the fast rotations while another one said that it was comfortable after a short acclimation.

These results indicate that most of the participants did not notice the rotation gain, and most of them were actually surprised that the rotations were manipulated.

We measured a mean SSQ-score of 13.62 ($SD = 19.71$) before the experiment, and a mean SSQ-score of 16.83 ($SD = 25.69$) after the experiment. The mean score for the sense of feeling present in the VE was 2.14 ($SD = 1.46$) on a five-point likert scale.

7 CONCLUSION

In this paper, we introduced a new technique based on dynamic rotation gains for rotating around in a VE when in a situation where only a limited physical turning angle is available. This technique turned out to perform similar as natural rotation regarding criteria like spatial orientation, usability, and VR sickness, and better than other techniques like static gains or scrolling. This was evaluated in an experiment with 32 participants. Additionally, we proved in a confirmatory study that the technique is appropriate for use in actual VR experiences.

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