Inducing Unintentional Positional Drift (UPD) in Virtual Reality via Physical Rotations and the Illusion of Leaning

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Abstract

In Virtual Reality (VR) users often turn their bodies during experiences. Virtual navigation techniques use body rotations and virtual forward translations to simulate movement. Despite being designed for stationary use, these techniques can cause Unintentional Positional Drift (UPD), impacting user safety and VR experiences. We carried out a human-participant study, approved by our university ethics board, involving 20 participants performing repetitive rotation tasks. Our study focused on intentionally inducing UPD via physical rotations by adding an offset to the VR camera's roll angle, creating a visual illusion of "leaning" or "banking." Our results show that camera roll offsets induced UPD along participants initial left-right axis under specific conditions. Additionally, rotation magnitude and forward translation flow affected UPD, while no significant effects were found due to rotation direction.

Index Terms: Virtual Reality, Unintentional Positional Drift, Rotation Gain, Rotation Movement, Leaning.

1 Introduction

During Virtual Reality (VR) experiences, users often rotate their bodies for interaction and navigation. A significant challenge is enabling users to navigate IVEs larger than their physical workspace. Researchers have proposed several alternative navigation techniques that use virtual rotations and forward translation to create the illusion of movement without physical displacement. Techniques like walking-in-place (WIP) and arm swinging mimic natural walking facilitate virtual movement while providing the sense of presence in the virtual environment. However, recent work has shown that VR users using stationary techniques can still unintentionally move in their physical workspace, a phenomenon known as Unintentional Positional Drift (UPD) [2]. This can be problematic, as users may come close to physical boundaries or obstacles without noticing while making common movements such as rotations. Rotations typically begin with head movements followed by upper body rotations and limb displacement and can lead to positional drift [1].

In this paper, we take a novel approach to intentionally induce UPD via physical rotations as a means of repositioning users. This could be of interest to minimize UPD or reposition users away from physical boundaries or obstacles. We manipulate the angle of camera roll of users by adding a constant offset to produce the illusion of "leaning" or "banking," a common phenomenon when turning. We hypothesize that this would lead to overleaning during rotations more than usual. Additionally, we focus on the effects of rotation magnitude and direction and virtual forward translation on UPD. We conducted a human-participant study to investigate the effects of camera roll offsets, rotation magnitude and direction, and virtual forward translation on UPD. Our research is guided by the following hypotheses:

- **H1** The direction of the camera roll offset can determine the direction of drift.
- **H2** The larger the camera roll offset, the larger the drift among users.
- **H3** The larger the rotational magnitude, the larger the drift among users.
- **H4** Rotation direction can determine the direction of drift.
- **H5** User's drift more along the forward axis due to virtual forward translation.

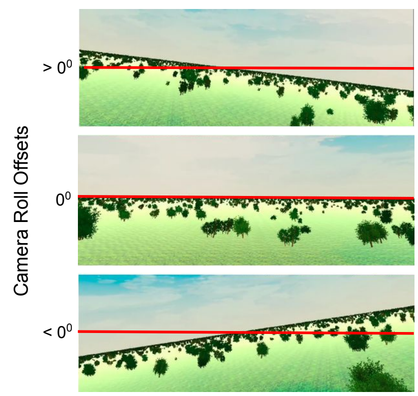

Figure 1: In-VR screenshots of a user viewing forward towards the horizon of the virtual experience with three camera roll offset conditions (from top to bottom): $> 0°$, $0°$, $< 0°$. The red line is a reference of the horizon without an offset.

2 Experiment

2.1 Participants

We recruited 20 participants from our university community, 14 male, 5 female and 1 non-binary, ages between 18 and 44, $M = 25.7$, $SD = 6.1$. The study protocol was approved by the institutional review board (IRB) of our university under protocol number: $SBE - 17 - 13446$.

2.2 Materials Required

Participants used the Meta Quest 3 and the controllers in a physical space of $5m \times 4m$, so that they could drift without interruption. The rendering was done directly on the HMD and developed using Unity Engine version $2022.3.44f1$.

2.3 Rotation Task and UPD Measurement

Users had to perform a sequence of physical rotations. At the beginning of each condition, a user interface (UI) would present instructions on the amount and direction of rotation. Then, participants had to press the trigger button on the controller. This action would remove the instructions UI, which would cue them to begin rotating as instructed, and their pose (position and orientation), would be

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saved *(initial trial pose)*. After completing the rotation, the screen automatically turned black, cueing them to stop rotating. Participants then would re-position their feet to face forward and prepare for the next trial. Once ready, they press the grip button to end the current trial and begin the next, as the instructions UI would reappear. At this moment, the *drift after rotation* is measured by comparing their current pose with the *initial trial pose* recorded before the rotation. Before starting the next rotation, the *initial trial pose* is updated with their current pose. After completing six rotations to complete the current condition, six drifts would be recorded per condition.

2.4 Study Design and Procedure

The study would be a within-subjects design with the following four independent variables and levels:

1. Camera Roll Offset (5 levels): $-10°$, $-5°$, $0°$, $5°$, $10°$
2. Magnitude of Rotation (2 levels): $90°$ and $180°$ rotations.
3. Direction of Rotation (2 levels): Clockwise (right) and counter-clockwise (left) rotations.
4. Virtual Forward Translation (2 levels): With and without virtual forward translation.

Upon arrival, participants read a brief description of the study procedure and provided their consent. Before donning the HMD, participants would complete the Simulator Sickness Questionnaire (SSQ) to assess their sickness levels prior to the experiment.

Each participant would experience the baseline conditions first, followed by the camera offset conditions, and ended the experiment with the baseline conditions again. For each condition, they perform the rotation task six times. Baseline conditions would have $0°$ camera roll offset, while camera offset conditions would have greater than or lower than $0°$ camera roll offset. Breaks would be administered after they performed the six conditions, to reduce fatigue and sickness. They would be instructed to keep the HMD on and close their eyes for at least one minute. During this time, participants would answer the Fast Motion Sickness Scale (FMS) questionnaire to record their sickness levels. The conditions were randomized. Upon completing all rotations, participants removed the HMD and completed the SSQ, FMS, and demographic questionnaires. Finally, the whole experiment took less than 60 minutes and participants were compensated.

3 Results

We analyzed the responses with repeated-measures analyses of variance (RM-ANOVAs) and Tukey multiple comparisons with Bonferroni correction at the 5% significance level. Analysis and plots were prepared using R version 2024.04.2.

Simulator Sickness Check: We did not find any significant effects on participants' SSQ scores, $M = 38.7$, $SD = 91.14$, nor FMS scores, $M = 1.66$, $SD = 2.42$.

3.1 Camera Roll Offset on UPD

We found a significant effect of the camera roll offset on user drift along the left-right axis, $F(1.97, 33.45) = 7.72$, $\boldsymbol{p = 0.002}$, $\eta_p^2 = 0.32$, see Figure 2. No significant effects were found on the forward axis. Pairwise comparisons showed significant differences between $-5°$ and $5°$, and $-5°$ and $10°$. Participants drifted left for $-5°$ and right for $5°$ offsets, supporting **H1**. However, this behavior was not observed for $-10°$ and $10°$ offsets, not supporting **H2**.

3.2 Effects of Rotation Magnitude, Direction, and Virtual Forward Translation on UPD

We found significant effects of rotation magnitude on users' drift. After a rotation, main effects were observed along the left-right axis, $F(1,17) = 4.46$, $\boldsymbol{p = 0.049}$, $\eta_p^2 = 0.21$, with $90° > 180°$, and along the forward axis, $F(1,17) = 4.51$, $\boldsymbol{p = 0.048}$, $\eta_p^2 = 0.20$, with

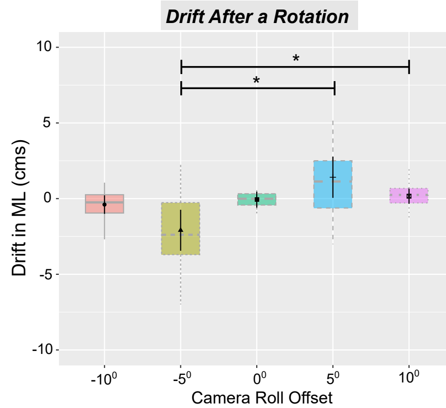

Figure 2: Boxplot of Drift along ML axis due to Camera Roll Offset after a Rotation. The vertical error bars indicate the standard error. The horizontal bars and asterisks indicate statistical significance ($*$ $p<0.05$).

$90° < 180°$. This result does not support our hypothesis **H3**, indicating that larger rotation magnitudes may not lead to greater drift.

We did not find any significant main effects due to the direction of rotation on users' drift, which disagrees with our hypothesis **H4**.

We found significant effects of virtual forward translation on users' drift. After a rotation in the forward axis, $F(1,17) = 15.19$, $\boldsymbol{p = 0.001}$, $\eta_p^2 = 0.47$ where users drifted more without virtual forward translation compared to with it. This disagrees with our hypothesis **H5**. No effects were found on drift along the left-right axis.

4 Conclusion

In this paper, we presented a VR experiment (N= 20) investigating the effects of adding offsets to the roll angle of the virtual camera to induce UPD through physical rotations. Specifically, we examined camera roll offsets of $0°$, $-10°$, $-5°$, $5°$ and $10°$. We tested these offsets with two levels of rotation magnitude ($90°$, $180°$), direction (clockwise, counter-clockwise), and virtual forward translation (with, without). Participants' UPD was measured during a repetitive rotation task. Our findings indicate that the camera roll offset manipulations of $-5°$ and $5°$ significantly increased the drift of the participant towards the offset direction. However, this effect was not observed with larger offsets of $-10°$ and $10°$. This suggests that rolling the virtual camera can induce UPD towards the direction of the roll, but there may be a threshold beyond which the effect diminishes. Furthermore, participants drifted more on their left-right axis when rotating $90°$ and on their forward axis when rotating $180°$. Regarding virtual forward translation, participants' drift along the forward axis was reduced when it was present. These findings provide insights into VR users' drift behavior during physical rotations and offer a novel approach to induce UPD.

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