Combining Redirection with Common Game Elements

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Abstract: This study explores how integrating common game elements with redirection techniques influence user perception and whether they can be adjusted to induce higher gains and more movement. We tested four game elements: user interface spawning position, spawning of collectibles, interactions with non-player characters, and interactions with enemies. These elements were combined with rotational gains. Additionally, we examined the effects of terrains in combination with translational gains, as well as a new redirection technique inspired by slipping. Our findings indicate that combining game elements with rotational gains led to increased movement, providing greater opportunities for redirection while masking the manipulation. With proper adjustments, this approach can remain unobtrusive to the user experience. However, special terrains resulted in a similar detection of manipulation for both, the slipping method and the translational gains. This work paves the way for future research on integrating these game elements with rotational and translational gains.

1 INTRODUCTION

Virtual reality (VR) games is becoming increasingly popular, with VR game revenue expected to reach $3.2 billion in 2024[1]. Natural walking where the player's movement is mapped 1:1 to the virtual environment (VE), consistently emerges as the best locomotion technique to navigate VEs as shown by Usoh et al. (1999). However, this technique requires the physical space to match the size of the virtual world, which is often not the case. Therefore, redirection techniques have been developed to steer the user's path towards navigable areas in the physical space. (Suma et al., 2012) looked into creating a taxonomy for these techniques. Among the criteria used to classify them were subtle or overt. Subtle ones are not perceived by the user, while overt techniques are noticed by the user and might lead to a break in presence. Subtle techniques are often favored for that reason. Redirected Walking (RDW) is a subtle technique, allowing the manipulation of the mapping between movements in the physical and virtual worlds. This is used to steer the user away from boundaries based on various gains, which were formally defined in the work of (Steinicke et al., 2010). Among these gains, rotational gains scale the rotation of the physical world when mapped to the virtual camera. On the other hand, translational gains allow for scaling the distance traveled, either slowing down or speeding up the user's movement. Other types of gain has also been presented, pushing for newer ideas e.g, bending gains that lead the user to walk on a curve in the real space, as presented by (Langbehn et al., 2017), and redirection during non-forward steps, as developed by (Cho et al., 2021).

Mismatches between the mapping of physical movements and their virtual counterparts are limited by thresholds where users begin to notice the differences. Extensive research has been conducted to determine these thresholds: (Steinicke et al., 2010; Williams and Peck, 2019; Kruse et al., 2018). While these thresholds are influenced by various factors such as user characteristics, adaptation over time, the features of the head-mounted display, and the type of environment, they still restrict the possibility of unlimited walking in infinitely large virtual spaces. To address this, researchers have attempted to combine gains with specific aspects of the environment to induce movement, allowing for greater alterations in the mapping (higher thresholds) or masking the manipulations. The elements incorporated to achieve these goals are often referred to as distractors, which are features that capture the user's attention, forcing movement or reducing their ability to notice the manipulations. This was initially explored by (Peck

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et al., 2009), where different types of distractors were tested highlighting that when integrated into the VE context were better perceived by users.

In this work, we explore the combination of the most common game elements with rotational and translational gains. The goal of this combination is both to mask the mismatch that occurs and to encourage more user movement, enabling the application of redirection techniques. After an analysis of popular games, we identified five aspects that can be used for redirection: user interface (UI) elements spawned during the gameplay, spawning of collectibles, interactions with non-playing characters (NPCs) and enemies, and terrains. An illustration of the modifications to these elements is shown in Figure 1. The first four mentioned elements UI, collectibles, NPC, and enemy interactions, were combined with rotational gains, while terrains were paired with translational gains. We examined how applying rotational gains during interactions influence the redirection perception—either by forcing the user to walk around an NPC to engage with it or during fighting enemies. For collectible objects, we explored how dropping them away from the user in optimized locations might encourage more user rotation. For the UI, we investigated how spawning it at a different angle from the user, rather than directly in front, could impact the user's experience.

The concept of terrain effects originates from real-world. (Leicht and Crowther, 2007) demonstrated that walking on dry beach sand reduces speed and increases the number of steps compared to walking on concrete or grass. Ice further complicates locomotion by introducing slipping. Most translational gain experiments have focused on virtual standard terrains that do not impede movement in physical space. To address this gap, we propose two approaches: inducing slipping at the end of a walk and applying continuous slowing gains during walking. Utilizing terrains where users naturally walk slower or experience slipping could enhance the effectiveness and realism of redirection techniques.

This work presents the user studies conducted to evaluate perceptions of these modifications and assess whether these elements can effectively mask the manipulation. The remainder of this paper is structured as follows: First, we will present related work on gain threshold determination and the use of distractors in redirection methods. This will be followed by a description of the VEs developed for the study and the study procedure. Finally, we will present the results from the user studies, followed by a brief conclusion.

[1]VR Game Revenues Report, accessed on 14.01.2024

2 BACKGROUND

(Steinicke et al., 2010) showed that rotations can be sped up by 49% or slowed down by 20% without the player noticing, and translational movements can be up-scaled by 26% and down-scaled by 14% without be noticed by the user. A study by (Kim et al., 2022) analyzed how the size of a room impacts the thresholds for translational gains. They found that translational gains are more noticeable in smaller rooms than in larger ones. (Kruse et al., 2018) investigated the impact of showing the user's feet and the number of visual cues in the space on sensitivity to translational gains. Additionally, (Williams and Peck, 2019) explored thresholds in relation to user characteristics, such as gender, and hardware characteristics, such as field of view (FOV).

Peck et al. worked with distractors in several studies by combining them with resets, which are fail-safe mechanisms used when a collision is imminent, requiring the user to stop navigation and reorient themselves. First, (Peck et al., 2009) demonstrated that the more integrated a distractor is with the overall context of the VE, the more it is liked by users and the less noticeable the reorientation becomes. (Chen and Fuchs, 2017) followed up by presenting S2C with resets based on interactive distractors. In this setup, a dragon appears and needs to be shot while the gain is applied, rotating the user to the center. Similarly, (Cools and Simeone, 2019) investigated the interactivity between distractors and their effects on user performance and behavior. They tested three continuous reorientation-based resets and one based on discrete reorientation. The work showed that using distractors led to less breaks in presence and was preferred by users. Another study by (Sra et al., 2018) introduced the concept of coupling game elements that typically cause intentional blindness reduction with redirection. These aspects were shown to enhance presence, reduce dizziness, and improve the unnoticeability of the reorientation.

Other researchers investigated new thresholds when distractors are combined with other elements, rather than solely studying their effects on user experience and perception, as seen in the previous section. (Schmelter et al., 2021) combined discrete rotation jumps with common actions performed in games, and identified the extent of rotation that can be applied while remaining unnoticed. (Williams and Peck, 2019) examined the effects of a deer walking in front of the user and determined the associated thresholds. (Lutfallah et al., 2024) explored how the established thresholds for translational gains could be pushed when combined with a shooting task while walking.

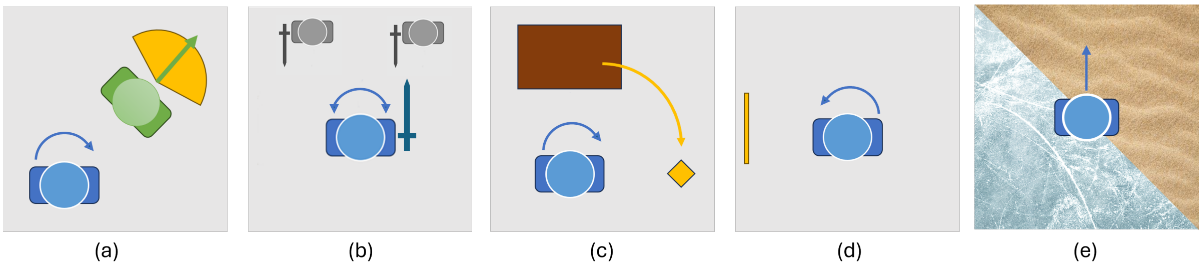

Figure 1: Illustrations of the different game elements combined with either rotational or translational gains. Images (a) to (d) show the user experiencing rotational gains, while image (e) demonstrates the user experiencing translational gains. In (a), the user must walk to the yellow area to interact with the non-player character. In (b), the user interacts with enemies. In (c), the user rotates to collect an item. In (d), the user interacts with a menu spanning to their left, also forcing rotation. Image (e) highlights the user walking straight, where the terrain may either slow the user down (sand) or cause slipping (ice).

3 PROPOSED TECHNIQUES AND IMPLEMENTATION

We investigate five different game elements, each including one modification or combination, except for terrain, where two possibilities emerged: either slowing terrains or slippery terrains. We decided to divide the experiments into two user studies to keep them short and avoid overwhelming the participants. The user studies were divided based on the type of gain applied. Thus, the two terrain aspects were tested in one user study which will be labeled as translational modification study (TMS), while the other four elements combined with rotational gains were tested in a separate user study that will be referred to as rotation modification study (RMS).

The two environments were built using the Unity 3D game engine. As a foundation for the games, OpenRDW by (Li et al., 2021) was used, which provided implementations of rotational and translational gains. The HTC VIVE Focus 3 was used as head-mounted display (HMD), offering a display resolution of 2448p x 2448p per eye and a refresh rate of 90Hz. The game run on a PC with an Intel Core i9-12900KF processor and an Nvidia GeForce RTX 3080Ti graphics card, and was streamed to the HMD.

3.1 Virtual Environment for TMS

In this study, we investigated the effect of terrain in combination with translational gains. Our aim was to explore how different terrain types, which challenge walking ability in real-world environments, might influence user experience in a virtual setting when combined with redirection. For this purpose, we build two virtual environments of for each of the two terrains: the first had shallow water that typically slows the user, and another simulating ice, where slipping is a factor. The goal was for users to experience the same redirection with both modified terrain (ice or water) and normal terrain. Based on this, the design choice was to create a long, rectangular VE where the user walks straight toward a checkpoint indicated by a glowing sphere. The walkable area is 15×3 meters, bordered by walls. On the forward path, the user experiences one type of terrain, and on the return path, the other terrain; for example, the user might walk through water, experiencing a slowing effect, and on the way back, walks on normal ground experiencing the same slowing gain. The different terrains are shown in Figure 2. An avatar representing the user's body, taken from the FinalIK asset, was shown and adjusted to match the user's dimensions, enhancing bodily self-immersion. Additionally, corresponding footstep sounds were added to simulate steps on either water or ice.

In the water scene, a texture is applied to the walls and floor such that they resemble an outside pool, and also a layer of water, with a height of $0.4m$, is applied above the floor level. In the ice scene that was used to test the slipping mechanism, we had two types of grounds: the normal one as well as the one where an ice texture was applied. The slipping mechanism is triggered whenever the user's speed falls below a certain threshold. The user's position gradually shifts in the direction of movement, with the push effect fading over time. This is achieved using Unity's Lerp function, with a decay factor controlling the diminishing effect of the slip. The threshold for triggering the slipping, as well as the various slipping values tested, were empirically determined based on a preliminary small user study.

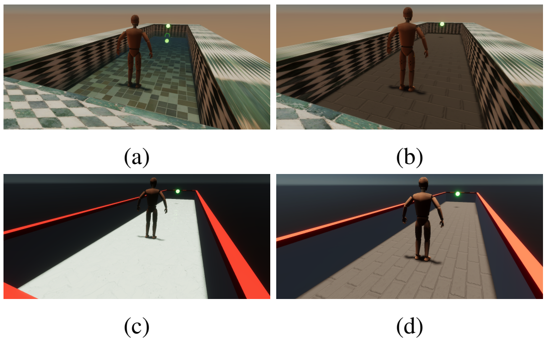

Figure 2: The virtual environment depicted shows the user walking on water terrain in (a), ice terrain in (c), and normal pavement on the return path in (b) and (d).

3.2 Virtual Environment for RMS

In this study, rotational gains were combined with four game elements. The game is set in a dungeon composed of three adjacent rooms, each measuring $4m \times 4m$. In each room, one element (except the user interface) was utilized. Figure 3 shows screenshots of the rooms containing the game elements, along with a screenshot of the inventory UI. Background music was played throughout the game to enhance player immersion and mask external noises not related to the game. The sound was non-spatial, meaning it did not originate from a specific location in the dungeon. The four rooms did not fit within the physical space, which had dimensions of 10×6 meters. However, interacting with each element in the room led to a continuous reorientation until a 90° rotation between the physical space and the VE was reached. This was followed by an additional 90° continuous reorientation when the participant interacted with the door, resulting in a total reorientation of 180° in each room. This ensured that the second room always fits within the available physical space. Additionally, 2:1 resets following the implementation in the OpenRDW library were allowed in case the system failed to reorient the user properly.

The interaction with the UI was repeated three times, as the player had to collect three keys in each room. The keys were picked up by hovering over them and pressing a button, which caused them to disappear and be added to the inventory. When all keys in a room were collected, the inventory could be opened by pressing the trigger button on the left controller. The inventory then appeared at a 90° offset to the left of the player's current facing direction. It displayed three pictures of the keys, which also served as buttons that the player could hover over and press the trigger button to activate a key. The inventory would then close, and a green sphere would appear on the right side of the door, encouraging the player to turn and look at it, signaling successful key usage. The player repeated this process three times until the door opened. In this work, the UI referred to an inventory list however this can be generalized to any UI needed in a game such as a menu or map.

The second element investigated was the spawning of collectables that would force the user to rotate rather than spawning directly in front of the player. For this, a chest was used where the player had to hold their hands over it and press the trigger button on the right controller. The key then spawned above the chest with a force applied to it, propelling it approximately $1.5m$ in a certain direction. To pick up the key, the player had to walk and rotate. This process was repeated three times to obtain the three keys, with the first and third keys flying to the left and the second key flying to the right.

The third element tested was NPC interaction. The goal was to force the user to walk around the NPC, represented by a person, to initiate a conversation. The NPCs were placed in the opposite direction from which the player entered the room, compelling rotation. Interaction was possible only when the player stood in front of the NPC, marked by a white circle on the floor. When the player stepped into the circle, it turned green, indicating correct positioning. Pressing the trigger button on the right controller then caused the NPC to drop a key.

Fighting with a sword while applying rotational gains was also examined. The player fought three skeletons using a sword. The sword was placed in the middle of the room, surrounded by the skeletons. This required the player to rotate to fight the skeletons, which did not move toward the player before the sword was picked up. To pick up the sword, the player had to move their hand close to it and then press and hold the trigger button on the right controller. If the sword touched a skeleton, the skeleton disappeared and dropped a key.

For all the game elements tested, the rotational gain values were the same and were applied only when the user was interacting with the proposed element. As a result, walking between the rooms was free from redirection. Additionally, whenever a reorientation of 90° happened for a specific element the rotational gains were set to 0. A rotational gain value lower than the one proposed by (Steinicke et al., 2010) was used because a preliminary user study showed that users tend to notice redirection more in smaller rooms with a high number of object, consistent with the work of (Kim et al., 2022). Therefore, gains of 31% and -12% were applied, depending on whether the rotation was accelerated in the direction of head movement or in the opposite direction.

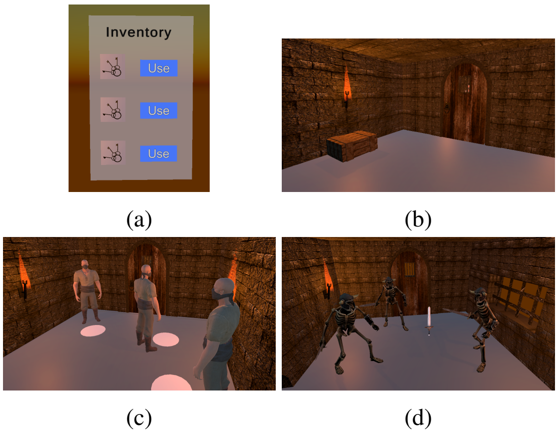

Figure 3: Screenshots from the virtual environment showing different rooms and their respective game elements. In (a), the inventory UI is displayed, where the user can select keys to open the door. In (b), the chest that spawns the key is shown. In (c) and (d), non-player characters (NPCs) are displayed with the interaction circle in front of them, and in (d), the enemy skeletons and the sword are visible.

4 USER STUDY

For both user studies, participants were recruited from the university staff and students. All participants had normal or corrected-to-normal vision. The RMS included 19 participants (16 identified as male while 3 as female), while the TMS had 22 participants (14 identifed as male, 7 as female and 1 selected "Other" option). Some participants took part in both studies, since the studies were conducted a month apart. The mean age of participants was 24.58 ± 2.16 years for the RMS and 23.5 ± 2.94 years for the TMS.

The procedure followed by users was similar for both experiments. First, participants signed a consent form. Then, they completed a demographics questionnaire, which asked about their age, gender, and prior VR and gaming experience, followed by the Simulator Sickness Questionnaire (SSQ). Participants were given instructions on how to complete the tasks and interact with the elements they would encounter. In both experiments, participants completed an introductory scene to familiarize themselves with the gameplay mechanics and interactions. In the TMS, the introductory scene allowed participants to walk, while in the RMS, they were shown a room with the four elements and were required to interact with each element. In both introductory scenes, no gains were applied. After completing the tasks in each study, participants filled out the SSQ again and answered several customized questions.

For both studies, counterbalancing of experiments was employed. For the TMS study, half of the participants started with the ice experiment and the other half started with the water experiment. Additionally, half of the participants experienced the normal pavement terrain first, followed by the special terrain. This was done to prevent any bias from the order of the experiments. We tested multiple gains to determine if different levels of redirection would affect user perception. This procedure was the same for both the water and ice scenes. In the water scene, we adjusted the slowing translational gain, while in the ice scene, we modified the slipperiness. The participants were also informed that a speed manipulation would be applied during the walk, with the manipulation changing after every second checkpoint. There are five slowing translational gains that the player is exposed to in the water scene: 1, 0.9, 0.8, 0.7, 0.6. Every second checkpoint, the user needs to select one of the terrains to answer the question "On which terrain did you feel slower?". To answer this question, the user is informed that the answer will appear as text on both hands, and they will need to press the corresponding buttons on the controller. This approach follows the Two-Alternative Forced Choice (2AFC) method used in previous works as the ones of Steinicke et al. (2010). For the ice scene, the perception is tested across different slipperiness levels, ranging from no slip (NS), low slip (LS), medium slip (MS), high slip (HS), to very high slip (VHS). Every second checkpoint, the user need to select one of the two terrains to answer the question "On which terrain did you feel less slippery?". Again, the answers were selected by pressing a corresponding button.

For the RMS, participants played two rounds of the game, with each round consisting of the same three rooms presented in a different but counterbalanced order. Participants had to collect three keys in each room and use them to progress to the next one. In the chest room, participants spawned the three keys from the chest and collected them. In another room, they collected three keys from three bandits, and in the third room, they had to kill three skeletons, each of which dropped a key.

5 RESULTS AND DISCUSSION

For the TMS and RMS, the mean difference in pre- and post-SSQ questionnaires was 0.51 ± 22.98 and 14.34 ± 18.41, respectively. Two participants had a difference greater than 40 for RMS, specifically 59.8 and 52.36, while one participant showed a difference of 56.2 for TMS. This suggests that the RMS induced more cybersickness than the TMS, and this difference was statistically significant based on a Mann-Whitney

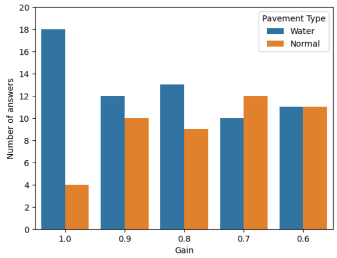

Figure 4: The number of responses indicating that the manipulation felt stronger for each corresponding gain, comparing the water and the normal pavement conditions.

U test. It should be noted that participants spent a longer time in VR during the RMS experiment.. However, since none of the participants reported feeling symptoms or mentioned that this hindered the experiment, all participants were included in the results.

5.1 Results for the TMS

In this study, the goal was to determine whether participants would perceive the manipulation more on normal pavement or on water and ice pavement. To investigate this, a 2AFC question was asked when the same manipulation was applied to both pavements.

For the water experiment, 58.1% of participants reported that they felt the slowing effect more strongly when walking in shallow water. A binomial test with $k = 0.5$ was conducted to assess whether participants genuinely perceived a difference. The result ($p > 0.05$) suggests that the null hypothesis—that the answers were given randomly—cannot be rejected. Further investigations were conducted to examine the correlation between the gain applied and the participants' perception. The distribution of responses that the terrain with water had more slowing compared to the gain applied is shown in Figure 4. For the initial condition where no gain was applied, 81% of participants reported that the manipulation felt stronger on the water terrain. This suggests that participants expect to move more slowly in water, even when no manipulation is present. The percentage of responses indicating that the manipulation was stronger in water decreased as the gain increased, but remained equal to or above 50%.

In the ice experiment, 50.9% of participants reported feeling the manipulation more on the normal terrain than on the ice terrain. We further investigated participants' perception across different slipperiness levels, ranging from NS to VHS (see Figure 5). The distribution of responses was nearly equal, suggesting that participants were answering randomly. This observation was further supported by the binomial test, where we obtained $p > 0.05$ for all conditions.

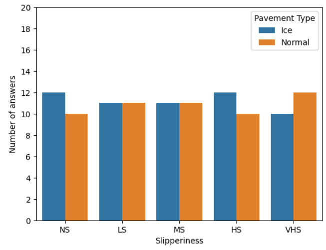

Figure 5: The number of responses indicating that the manipulation felt stronger for each corresponding slipperiness, comparing the ice and the normal pavement conditions.

Additionally, both experiments were rated as highly immersive on a scale of 0 (low immersion) to 5 (very immersive). The water experiment was rated at 4.09 ± 0.86, and the ice experiment at 4.18 ± 0.85. Based on the Shapiro-Wilk test, the distributions were not normal; therefore they were compared using the Wilcoxon test, which revealed no statistically significant difference. Furthermore, participants rated whether they felt more immersed when walking on the normal terrain versus the ice, as well as between water and normal terrain. A score of 0 indicated greater immersion in the normal terrain, while 5 indicated greater immersion in the special terrain. The respective scores were 3.4 ± 1.1 for the ice scene and 3.23 ± 1.0 for the water scene, showing that in both cases, participants felt more immersed when walking on the special terrains. Finally, participants rated whether they felt the water and ice masked the manipulation, compared to the normal pavement, on a scale from 0 to 5. The water and ice scenes received a score of 3.27 ± 1.1 and 3.4 ± 1.1, respectively.

5.2 Results for the RMS

For the **user interface** part, 8 questions were asked to investigate the user perception of the rotational gain and the modification of the UI's spawn position. A total of 42.11% of participants reported having difficulty finding the inventory after opening it by answering "Yes." Responses to ordinal questions (0 = Do not agree, 5 = Agree) indicated that the inventory's use was not very intuitive for all participants ($\mu = 3.53 \pm 0.88$), that the 90° offset of the inventory disrupted the game flow ($\mu = 3.16 \pm 1.14$), and that the offset was also considered annoying ($\mu = 3.37 \pm 1.13$). Participants were further asked what degree of offset would be appropriate to avoid disrupting the game flow or causing annoyance, and an average value of $47.03 \pm 17.81°$ was reported. To determine whether participants noticed the rotational gains, a similar approach to (Suma et al., 2011) was used, where decoy questions were included alongside those directly referencing the modification. In response to the relevant question about rotational gains, 36.84% of participants reported noticing this manipulation. The decoy questions, "Did the room get bigger or smaller while using the inventory?" and "Did it feel like you were getting bigger or smaller while using the inventory?" were both answered "No" by all 19 participants, indicating no guessing occurred.

For **close combat**, ordinal questions (0 = Do not agree, 5 = Agree) indicated that participants felt highly immersed during the fight ($\mu = 3.84 \pm 1.42$), but the fight itself did not feel very realistic ($\mu = 2.34 \pm 2.23$). This was mainly due to the simplistic mechanic where merely touching the enemy resulted in death, without a health system that would allow the user to die if attacked. Only 15.79% of participants felt that their rotations were sped up or slowed down during the fight. The decoy question, "Did you feel like you were getting smaller or bigger while fighting the skeletons?" was answered "Yes" by only 5.26% of participants, indicating no guessing occurred. Additionally, 21.05% of participants felt like the world was rotating around them.

For the **chest interaction**, two decoy questions were asked. "Did you feel like your forward movement was sped up or slowed down while picking up the keys?" was answered "Yes" by 5.26% of participants, and "Did objects (keys or chest) on the floor move by themselves?" was answered "Yes" by 10.53%. The rotational gains were noticed by 31.58% of participants based on the corresponding question. Participants also answered ordinal questions regarding the chest interaction. When asked to rate the ease of spotting the keys, where 1 meant "Easy" and 5 meant "Hard," the score was 2.11 ± 0.72. Regarding whether the keys flew too far from the chest, thus interrupting the game flow (1 = Do not agree, 5 = Agree), the score was 2.53 ± 0.99. For the question of whether participants would have preferred the keys to be dropped directly in front of them (1 = Agree, 5 = Do not agree), a score of 3.32 ± 1.45 was recorded.

For the **NPC interaction**, the decoy question, "Did it feel like your forward movement was sped up or slowed down while walking in the room with the bandits?" was answered with "Yes" by only 5.26% of participants, and 36.84% of participants noticed the rotational gain. The question on whether NPCs not facing the user was disruptive scored 1.79 ± 0.95 (0 = not disruptive, 5 = very disruptive). The question, "Usually in games, NPCs like the bandits can be interacted with from any side. Do you think that the current implementation is better?" was answered "Yes" by 57.9%, "No" by 10.53%, and "It does not matter" by 31.57%.

5.3 Discussion

Regarding the game elements combined with rotational gains, all of them led to less than 50% noticing the manipulation applied. Fighting with the enemies resulted in better masking of the manipulation, with 15.79% noticing it, while for the other elements, the rate ranged between 31% and 37%. This supports the hypothesis that the more engaged a user is, the less likely they are to detect the manipulation. For specific elements, the UI results indicate that the chosen shift of 90° was too large, with almost half of the participants having troubles to locate. However, even with such a large spawning angle shift from the user's front, the negative impact was relatively low. Knowing that the user had to select objects three times, it can be assumed that if the user only had to perform the selection once, discomfort could be reduced. For the key drop out of the chest, most participants stated that the key's propulsion from the chest was still easy to spot, and the flow disruption was rated neutrally, indicating that the modification was acceptable. The NPC interaction modification was rated as the least disruptive (1.79), and the majority of participants (57.9%) affirmed that they preferred having the limited interaction area over being able to interact with NPCs from the other side. This suggests that this element could be used to induce rotation, with NPCs being dynamically placed in the space depending on the reorientation needed.

The results from the terrain modification experiment show that the type of terrain did not significantly affect the detection of manipulation for either the translational gain or the slipperiness effect, except in the base case of translational gains, where 80% of participants stated that the gain felt higher on the water terrain. This was reflected by approximately 50% consistently rating the special terrain as having more manipulation. This finding contradicts our initial hypothesis that participants, expecting to move more slowly, would perceive less manipulation. Several factors could explain this, such as the absence of haptics. Despite that, the terrains were beneficial in terms of immersion, as participants rated the special terrains as more immersive than the normal ones.

5.4 Limitation

Several limitations may have affected the results of the two user studies. First, the participants were primarily male students, which could have biased the results. Regarding the rotational gain-based study, only a single value for rotation was tested to keep the experiment short. However, testing multiple values for rotational gains, as well as different angles for UI shifts and distances for key drops from the chest, would have helped identify optimal values. Nonetheless, this work primarily aims to pave the way for future element-specific user studies. In the slipperiness experiment, the slip effect was calculated using Unity's lerping function rather than a physics-based method, which could be improved. Additionally, in both the water and ice terrain experiments, haptic feedback could be incorporated to enhance immersion. Furthermore, full-body tracking was not used to track participants' feet and sync the sound of footsteps, potentially causing a discrepancy between the timing of steps and the triggered sound.

6 CONCLUSION

This work provides valuable insights into how game elements can be integrated with rotational and translational gains to improve VR navigation while reducing the noticeability of manipulations. The study shows that game elements like NPC interactions and enemy combat can effectively mask rotational gains. However, terrain manipulations (especially ice and water) require further refinement, as users detected the same level of manipulation as on normal pavement. Overall, this work contributes to enhancing natural walking in VR, but further research is needed to determine the optimal values for UI position changes and collectible drop distances to minimize discomfort. Additionally, more exploration of terrains is necessary, as users rated positively for immersion.

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