Diving Head-First into Virtual Reality—Evaluating HMD Control Schemes for VR Games

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ABSTRACT
Virtual reality games are on the cusp of mainstream acceptance and introduce a new input channel in the form of the head mounted display. Head tracking input can be mapped to several functions in the game world such as camera view, targeting and avatar movement direction. However, the role of head tracking in control schemes for virtual reality games is often overlooked. We evaluate how player performance and experience is affected by HMD control schemes in the first-person PC game *Team Fortress 2*. The "coupled" control scheme (in which both the mouse and HMD control camera view, targeting and movement direction) had the highest performance scores of the VR control schemes. Nonetheless, the schemes with the lowest performance scores gave the best player experience in terms of self-reported immersion and player preferences. This research refocuses attention on HMDs and provides empirical findings that can guide designers when integrating head tracking input into control schemes.

Categories and Subject Descriptors
H.5.2 [**User Interfaces**]: Evaluation/methodology, Input devices and strategies, Interaction styles; K.8.0 [**Personal computing**]: General—*Games*.

General Terms
Design; Human Factors.

Keywords
Virtual reality; Head mounted display; Games; Control scheme; Game interaction; First-person shooter; Immersion.

1. INTRODUCTION
A control scheme maps game inputs to actions in the game world and therefore has a key impact on user experience. Whereas control schemes for desktop 3D games have been developed over time, a control paradigm for virtual reality (VR) games has not yet solidified.

A promising approach to discovering the best controls for VR games is to focus on the head-mounted display (HMD), the input device common to all VR games. But how should we integrate head tracking input into a game's control scheme? This input can be mapped to several in-game functions such as panning the camera view, specifying movement direction and selecting targets. These options can be implemented in isolation or in combination, creating a myriad of possible control schemes. To date, little is known about which strategy offers players the better gaming experience.

This study evaluates 3 VR control schemes. We have 3 main research questions:

1. Which control scheme provides the most control (as measured by player performance)?
2. Which gives players the best experience (in terms of self-reported immersion and intuitiveness of controls)?
3. Does the effectiveness of a control scheme depend on the task context?

Figure 1. The Oculus Rift head-mounted display in use.

2. RELATED WORK
2.1 Head Tracking as VR Game Input
Given the interactive nature of games, control schemes are a central issue affecting player experience [3]. Several studies have explored interaction techniques for games that use head or face tracking. However, these studies do not directly compare strategies for utilizing head-tracking input, but instead compare player performance and experience in games with and without

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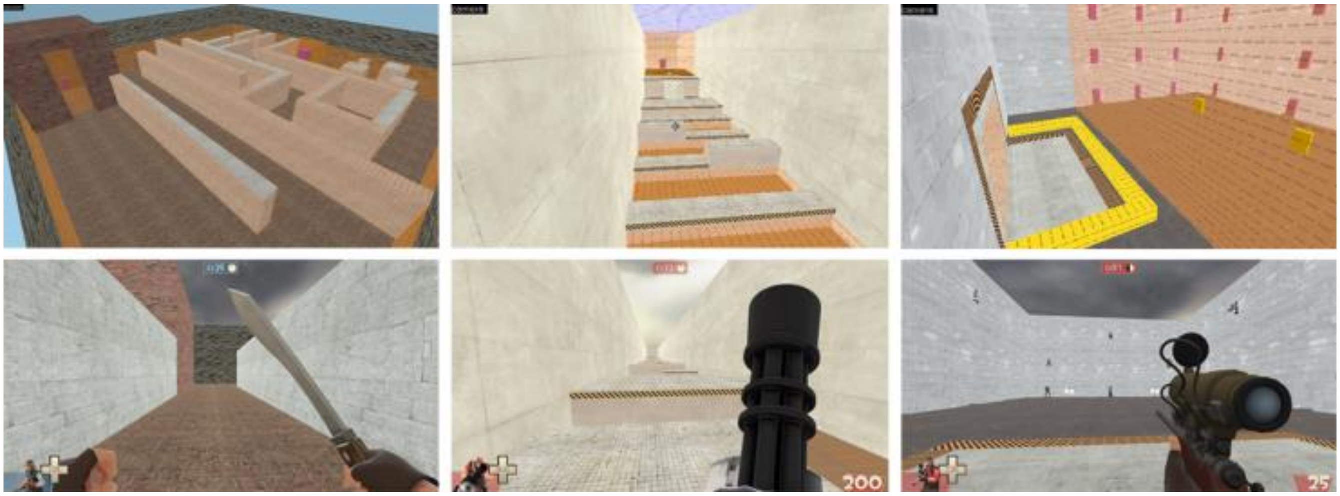

Figure 2. Perspective and first person view of the maps for each task: travel map (left); jumping map (center); targeting map (right)

Head-tracking. Head-tracking input enhances immersion, but hampers player performance [4, 12, 15, 17]. The VR systems in these studies all used the same (decoupled) control scheme in which head tracking controlled camera view, with a secondary input device controlling targeting and movement direction.

2.2 VR Games and Player Experience

Player experience is commonly characterized using the concept of immersion. The sources of immersion are often linked to the intuitiveness of the controls, sensory immersion, engrossing story and challenging game mechanics [7]. Various VR systems have been compared to non-VR game systems, to prove that VR games are more "immersive" than desktop 3D games [6, 12, 16]. However, until interaction techniques for VR games are directly compared we cannot know which is the most immersive within the VR medium.

Head-tracking in Virtual Environments

Ruddle et al. [11] and Bowman et al. [1, 8] found that using head tracking to control movement direction (or "gaze-directed" travel) was mose effective than other schemes. Lampton et al. [5] found that using head tracking to control the camera view was the most effective input for target selection. Pausch et al. [10] had similar results in their study that compared head-mounted display and joystick as input devices for locating targets in a virtual world.

3. VR GAMING SYSTEM

3.1 Hardware

Our study required a standard PC gaming setup that would be familiar to gamers and not introduce an extra layer of novelty. For PC gaming, the standard input devices are keyboard and mouse. To this standard gaming system we added an Oculus Rift Development Kit 1 [9]—a HMD designed for VR gaming that tracks head rotation on x, y and z axes.

3.2 Software

We used *Team Fortress 2* (*TF2*) [14], a first-person shooter by Valve Software as our testing environment for the study.

3.2.1 Task-based Game Maps

We built 3 custom *TF2* game maps with the *Hammer* map editor that is included in Valve Software's *Source* software developer kit [13]. These maps provided the 3 task-based testing environments for the experiment. The tasks tested were: targeting (in which players aim and shoot at targets); travel (in which the player maneuvers through a maze while avoiding walls); and jumping (in which the player jumps from platform to platform). See Figure 2 for a view of each of the maps.

3.2.2 Control Schemes

TF2 comes with 8 pre-defined VR control schemes. We identified 3 for inclusion in the experiment (see Figure 3). The 3 schemes are as follows:

- **Coupled control scheme** (called scheme 0 in *TF2*): HMD and/or mouse input controls both the camera view and the avatar's movement direction. The targeting reticule is fixed in the middle of the screen. Therefore the HMD is an additional channel of input and an alternative to mouse input.
- **Decoupled control scheme** (called scheme 1 in *TF2*): The mouse controls direction of movement, but the HMD takes over control of the camera view. The targeting reticule is fixed in the center of the camera view. The player can look around freely without affecting movement direction.
- **Head-directed control scheme** (called scheme 3 in *TF2*): The HMD controls movement direction and camera view, while the mouse controls targeting. The player can move the reticule independent of the movement direction, but if the player drags the reticule to the edge of the screen the camera view pans in that direction.

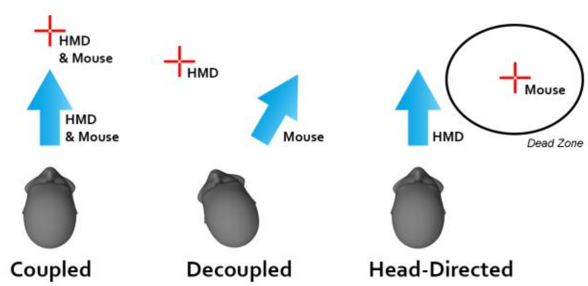

Figure 3: *TF2* VR control schemes. The head represents the player avatar, the arrow represents movement direction and the crosshairs represents the targeting reticule

- **Non-VR control scheme**: This scheme is the standard "mouselook" control scheme used in most first person PC games, in which the mouse is used to control camera view, targeting and avatar direction. The participants used a monitor instead of the Oculus Rift as their display.

4. EXPERIMENT

4.1 Participants

Participants were recruited through social media and word-of-mouth. We chose participants who were self-identified gamers, both to ensure that controlling the character with mouse and keyboard controls would not interfere with their experience of the control schemes, and so that our sample would more accurately represent the target audience for VR games. Participants were asked to rate their skill in playing 3D games on a scale of 1 to 5, with 5 being high. The average skill level of participants who completed the study was 4.2. None of the participants had played a VR game before.

From the original sample of 13, 11 participants completed the experiment. Two participants dropped out of the study because of simulator sickness. The remaining sample was composed of 10 males and 1 female.

4.2 Study Design

The study followed a 4 x 3 within-subjects design. The two independent variables were control scheme (4 levels—3 VR and 1 non-VR control scheme) and task (3 levels—the targeting, jumping and travel tasks). Therefore, the experiment consisted of 12 within-subject conditions. Two dependent variables (time and errors) tested performance on the jumping and travel tasks, while the dependent variable for the targeting task was the number of "kills".

4.3 Experimental Procedure

To begin, participants were fitted with the Oculus Rift and given 5 to 10 minutes to become familiar with the HMD and the virtual environment. As this was a within-subjects design, each participant completed all tasks for all control schemes (for a total of 12 trials). Performance measures (time, errors and "kills") were recorded in-game for each task. Each participant played all 3 tasks with the first control scheme and then completed the *Immersive Experiences Questionnaire* (IEQ) by Jennet et al. [2] to measure player immersion. To reduce the length of the test, our questionnaire only included a subset of 11 questions taken from the original 30-question set that measured the various sources of immersion. Of the questions chosen, 2 measured control as a source of immersion, 2 measured cognitive involvement, 3 measured challenge, 2 measured emotional involvement, 1 measured real world dissociation. A follow up single question measure of immersion ("How immersed did you feel?") was asked at the end of the IEQ. The participants were also asked to rate how much simulator sickness they felt with the control scheme and what they liked best and least about the control scheme. The same process was followed for the other 3 control schemes. The control schemes and tasks were counterbalanced to prevent order effects.

At the end of the test session, participants filled out a questionnaire in which they ranked the three VR control schemes in order of preference. A test session lasted approximately 45 minutes.

5. RESULTS

5.1 Player Performance Results

The non-VR scheme resulted in the highest performance for all tasks except the travel task's time measure. Of the VR control schemes, the coupled scheme resulted in the best performance scores for both the jumping and travel tasks and the head-directed control scheme resulted in the best performance scores for the targeting task. See Figure 4 and Figure 5.

A two-way repeated measures MANOVA was conducted for the jumping and travel tasks. Results indicated that control scheme had a marginally significant main effect on time and errors, $F(6, 58) = 2.027$, $p = .076$, $\eta_p^2 = .173$. Interaction between task and control scheme was marginally significant $F(6, 58) = 2.027$, $p = .080$, $\eta_p^2 = .172$.

To follow up the MANOVA, we conducted univariate two-way repeated measures ANOVAs to test the main effect of control scheme on each dependent variable. There was significant main effect of control scheme on both errors ($F(3,30) = 3.279$, $p = .034$, $\eta_p^2 = .247$) and time ($F(3,30) = 3.563$, $p = .026$, $\eta_p^2 = .263$).

Tukey's HSD comparisons indicated significant ($p < .05$) differences between: the non-VR < decoupled; non-VR < head-directed; coupled < decoupled; and coupled < head-directed control schemes for both the time and errors dependent variables.

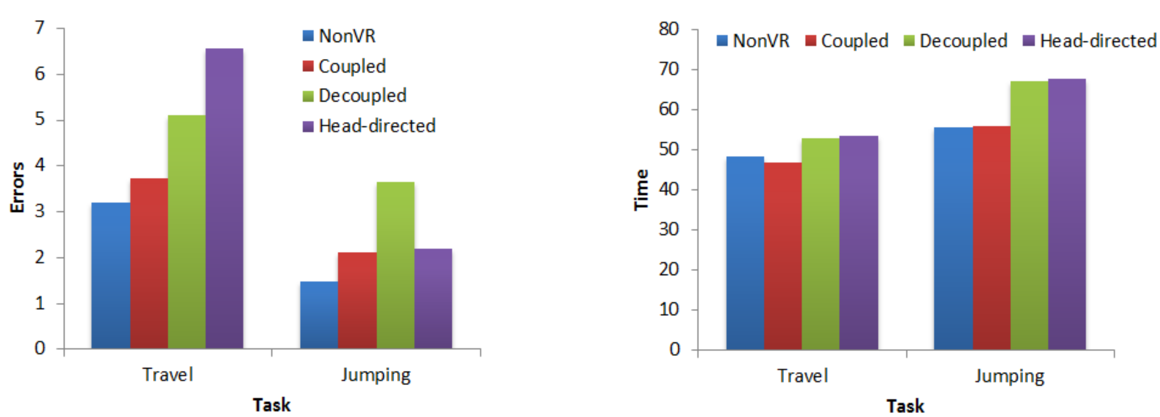

Figure 4. Column graphs showing means for errors (left) and time (right) by task and control scheme. Note that lower values indicate better performance.

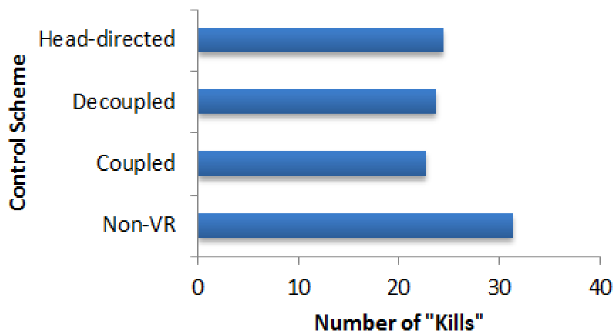

Figure 5. Bar graph showing means for "kills" by control scheme. Note that higher values indicate better performance.

A one-way repeated measures ANOVA was also used to test the main effect of control scheme on "kills" for the targeting task. The results of the ANOVA were marginally significant $F(3,30) = 2.529$, $p = .076$, $\eta_p^2 = .202$. However, there were no significant pairwise comparisons for the "kills" measure.

5.2 Player Immersion Results

The participant's answers for the questionnaire were summed and a mean score for questions relating to each control scheme was obtained. A Friedman's nonparametric test found significant differences ($\chi^2(3) = 15.029$, $p = 0.002$) between the scores for each scheme. A follow up question: "How immersed did you feel?" provided a single measure of immersion with which to verify the results of the questionnaire. The decoupled and the head-directed schemes had the highest immersion scores (see Table 1). Friedman's nonparametric test found marginally significant differences ($\chi^2(3) = 6.942$, $p = 0.74$) between the scores.

Table 1: Friedman's mean ranks and mean scores for the single measure of immersion for each control scheme. Higher scores mean more self-reported immersion.

Control Scheme	Mean Rank	Mean Score
Non-VR	1.82	30.00
Coupled	2.41	33.00
Decoupled	2.73	37.00
Head-directed	3.05	37.00

5.3 Control Scheme Rankings

Of the VR control schemes, the head-directed control scheme was the most preferred, followed closely by the decoupled control scheme (see Table 2).

Table 2: Frequency table for control scheme rankings

Scheme	Ranked 1st	Ranked 2nd	Ranked 3rd
Coupled	0 (0%)	3 (27.3%)	8 (72.7%)
Decoupled	5 (45.5%)	4 (36.4%)	2 (18.2%)
Head-directed	6 (54.5%)	4 (36.4%)	1 (9.1%)

6. DISCUSSION

Prior research has shown that players find VR games more immersive and enjoyable than non-VR games, but stop short of comparing VR control schemes. Our results confirm that HMD control schemes have a significant effect on player performance and experience and should be an important consideration when designing VR games.

We found that performance and immersion scores were inversely related—a pattern found in several other usability studies [12, 16, 17], albeit our study is the first to show this in the context of comparing VR schemes for gaming.

Integrating HMD input into a control scheme has been proven to decrease performance scores, a finding echoes by other work [4, 12, 15, 17]. In our study, only the coupled scheme came close to matching the non-VR scheme in terms of performance. Reasons for the coupled scheme's high performance scores might be its simplicity and similarity to the non-VR scheme. Both the coupled and non-VR schemes control the movement direction, camera view and targeting all with a single input device (HMD or mouse). In contrast, the other schemes increase complexity by mapping the mouse and the HMD to different functions.

We did find that performance results were task-dependent (a finding consistent with other VR research [1, 5]). The control schemes resulted in relatively uniform performance for the travel and jumping tasks (where the coupled control scheme was the most effective), but the targeting task results don't follow the same pattern. Rather, all VR schemes performed similarly for the targeting tasks. Observation of participants during the targeting task showed that 8 of the 11 participants used the HMD and mouse in the same manner for all VR control schemes: first "looking at" the target, then using the mouse to make fine adjustments.

Interestingly, even though the VR schemes reduced performance, players preferred them over the non-VR scheme—which suggests that players prefer the control schemes that offer immersion over those that offer control. The most cited reason for preferring a control scheme was that it felt "natural". One participant said: "It felt more natural moving your vision with your eyes and the aimer with your hand" (for the head-directed scheme). One participant stated that they "could continue to use the mouse and keyboard to navigate but could also look around as well" (for the decoupled scheme). The control schemes with the highest rankings did not frustrate users despite the lack of control they offered in relation to the coupled (and least preferred) scheme.

7. CONCLUSION

The results of this study highlight the challenges that game designers face in creating the first generation of VR games. To make the most of this novel medium, game designers must take advantage of its strengths while avoiding its limitations. VR games with head-tracking input offer a new modality that can both positively increase the participants' sense of immersion and negatively affect performance. The performance measures suggest that of the VR schemes, the coupled scheme gave players the most control, but player felt most immersed while using the decoupled and head-directed schemes. Overall, players preferred the more immersive decoupled and head-directed schemes over the easy-to-use coupled scheme.

Research into VR control schemes can provide guidance to the pioneers of VR game design. This study represents a first step toward that goal. Future directions could include testing more VR control schemes using a larger group of participants.

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