

# Does Adding Physical Realism to Virtual Reality Training Reduce Time Compression?

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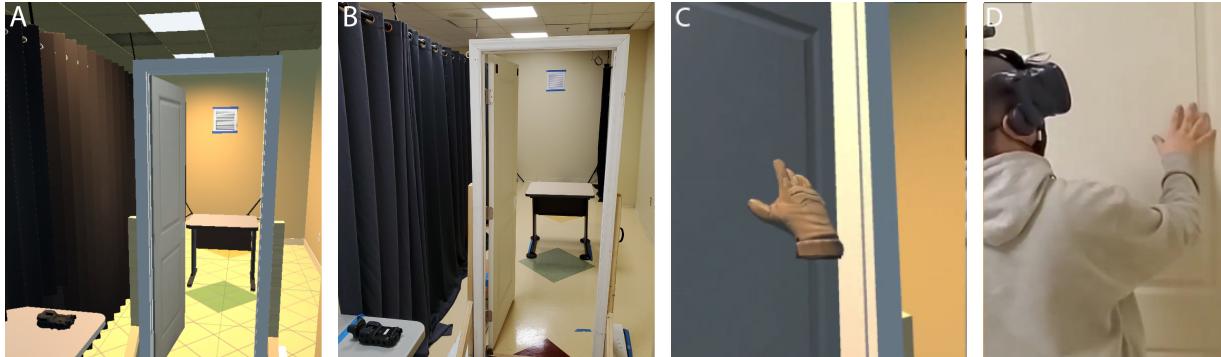


Figure 1: Hazmat training virtual and real environments. The virtual environment was modeled as a precise copy of the real one. In the high physical realism VR condition, the user picks up a real gas monitor prop (B, lower left.) which is tracked and registered to the virtual counterpart (A, lower left). The tracked hands are mapped to virtual hands, and the user pushes a real tracked door (D) which animates its virtual counterpart (C).

## ABSTRACT

Virtual reality (VR) is known to cause a “time compression” effect, where the time spent in VR feels to pass faster than the effective elapsed time. Our goal with this research is to investigate if the physical realism of a Virtual Reality experience reduces the time compression effect on a gas monitoring training task that requires precise time estimation. We used physical props and passive haptics in VR task with high physical realism and compared it to an equivalent standard VR task with only virtual objects. We also used an identical real-world task as a baseline time estimation task. Each scenario includes the user picking up a device, opening a door, navigating a corridor with obstacles, performing five short time estimations, and estimating the total time from task start to end. No significant effects were found comparing the estimate differences between the high and low physical realism conditions. We discuss implications of the results and limitations of the study, and discuss how future work may better address this important question for virtual reality training.

**Index Terms:** Human-centered computing—Time-perception—Virtual Reality; Human-centered computing—Human computer interaction (HCI)—Interaction devices—Haptic devices.

## 1 INTRODUCTION

Hazardous material (HAZMAT) technicians respond to emergencies where their perception of time is essential to the success of the operation. One example scenario is the identification of gas leaks. In order to correctly identify a potential gas leak, HAZMAT technicians must

hold a monitoring tool close to a potential source for a sufficient amount of time. Failing to hold the monitoring tool long enough could lead to undetected leaks that can have severe and potentially deadly consequences. At the same time, emergency calls that result in severe gas leaks are not common<sup>1</sup>, which causes HAZMAT technicians to gain little practical experience real emergency situations. Traditional training using classroom instruction and real life simulation exercises may not be as effective as VR-based training, where the user can have real-time visual feedback about a potentially missed leak occurrence.

However, VR causes a well known *time compression* effect, where the perception of time by a user in VR is perceived as shorter than the actual elapsed time [11, 15]. In other words, much like watching a movie or playing a video game, VR can make time feel as passing faster for the user. So, in situations where measuring time is essential to the learning of a task, as is the case with gas monitoring, such a time compression effect could lead to negative results. For example, users might learn in VR that what they perceive as being a sufficient amount of time to detect a gas leak (say, 30s) is actually a shorter amount of time (say, 25s). This could lead to a failed execution of the task in a real-life situation.

Thus, our goal with this study was to quantify time estimation under different conditions in VR, as compared to a real-world equivalent task [9].

Next, we discuss relevant VR literature on training, physical props and passive haptics, and time perception and estimation.

### 1.1 VR Training

Different from other forms of computer interfaces, VR translates detailed human body motion directly into the virtual environment and creates a highly realistic experience. Coupled with the ever-increasing quality of computer graphics, VR is capable of simulating

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<sup>1</sup>The average number of methane gas leaks in the US per year between 2010 and 2020 was approximately 230 [3], which is high for its environmental and safety impacts, but rare enough that most first responders rarely respond to emergency calls involving leaks

life-like experiences. Virtual reality-based training is getting increasingly popular in fields where re-creating specific scenarios is costly, risky, or inconvenient, such as in minimally invasive medical procedures [1], the military [13], and public safety [5].

In learning theory, error exposure training involves the use of someone's mistakes during training to provide performance feedback to the learner as part of the educational experience [14]. In fact, learning from errors has been shown to be more effective than learning with one's successes [7]. In the case of gas monitoring tasks where invisible but deadly gases need to be detected, if a HAZMAT technician in training fails to monitor certain areas for a sufficient amount of time, they have committed an error. A VR gas monitoring training tool can offer error exposure training by visually showing the location of invisible gasses that were missed by the trainee. Figure 2 is an example of a commercially available gas-monitoring training tool's after-action review showing where gas concentrations and reading thoroughness.

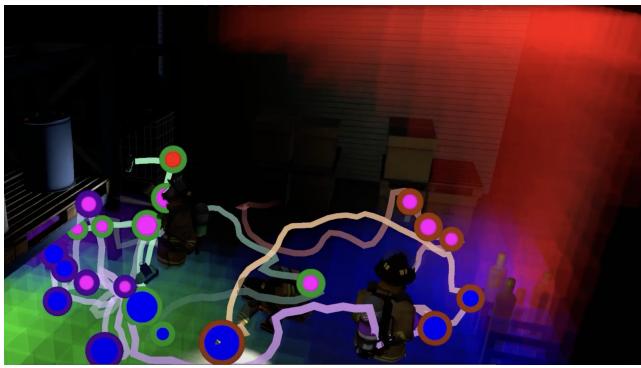


Figure 2: After action review of a gas monitoring training session, with a visualization of invisible gases (red and green volumes), and the monitor's path, monitored locations, and thoroughness of the readings. Screen grab courtesy of NextGen Iteractions [12].

## 1.2 Physical props and passive haptics

Typical VR equipment consists of a head-mounted display (HMD) and two controllers, which represent the user's head and hands. The controllers are capable of tracking the position and orientation of the user's hand, however, they have a fixed form factor. The user is able to interact with virtual objects and devices with their controllers, represented by virtual hands, but they can not feel the form and weight of these props. The nonexistent feeling of touch reduces immersion, can cause breaks in presence, and limits the experience to the audio and visual channels only. This issue exists as long as standard VR controllers are used. *Physical props* in VR are real tracked objects that are registered to a digital twin displayed through the HMD [4]. As long as the user's hands can be tracked, the user can interact with the physical props through visualizing the prop's identical digital representation in the virtual environment along with the tactile feeling of holding and manipulating the physical object. The user is able to feel the texture, form, weight, and heat of these props, which addresses the limitations of virtual props and standard VR controllers.

Physical props are a type of *passive haptics* [8]. Passive haptics offer great realism to VR experiences by adding accurate somatosensory feedback to the user. Additionally to smaller props to represent handheld devices, passive haptics are also useful to represent larger structures, such as walls and furniture in virtual environments. Previous research demonstrated that using passive haptics in VR training applications produces a positive training outcome [6].

## 1.3 Time perception in virtual reality

The perception of time is a subjective judgment that relates to perception, attention, and memory [10]. Previous research found that VR causes a time compression effect, where users perceive time as running faster when in a VR simulation [11, 15]. However, there is some evidence that suggests no difference between perceived time in the real world and VR [2], particularly during short time estimates in the order of 2-5 seconds.

We hypothesize that differences in the perception of time between VR and the real world may be related to the realism of the experience. We suggest that increasing the physical realism of VR to approach that of the real world could lead to a better matching of the perceived time in VR to that of the real counterpart.

Because gas monitoring tasks require precise time estimation, it is important that VR training for such ability approach the real world with respect to time estimation as much as possible. Thus, we investigated whether a VR training environment with high physical realism can cause time judgments to be closer to those of the real world.

## 2 TESTING ENVIRONMENT

The experiment was conducted in a university lab with a section curtained off during the period in which the study was executed. Figure 3 shows an overview of the virtual environment built for the study. The application was written in Unity and consisted of a hallway with a door through which the participant had to walk to take five gas leak measurements before returning to the origin (see Section 3.5).



Figure 3: An overview of the virtual task environment. In the high physical realism condition, real desks matching the position of the virtual ones were placed in the experiment laboratory. In the standard VR condition (low physical realism), all real props were removed. The real world condition was performed without the HMD and had all elements of the high physical realism VR condition.

The testing environment used in the experiment consisted of three setups, which were used as the experimental conditions. The conditions were the real world, which served as a baseline control, VR with high physical realism, and VR with low physical realism.

**Real world.** In this setup, the user removed their HMD and completed the task with all the physical props. The gas monitoring device tracking was still used to indicate the start and end of holding the device up to the vent (see Section 3.5).

**VR with high physical realism.** In the VR with high physical realism setup, there was a physical copy of all virtual environment objects, providing passive haptics. As Figure 1 shows, the user picks

up a real gas monitor, pushes a real door, and walks around real desks.

**VR with low physical realism.** In this setup, all physical props were removed, and the user interacted with the VR controller to pickup and hold a virtual gas monitor.

### 3 EXPERIMENT

Aiming at analyzing the effect that VR physical realism has on time perception, we conducted a repeated-measures experiment with 16 volunteers, all of whom were university students. The goal of the experiment was to evaluate the how each each VR condition (high physical realism vs. standard VR) compared to time estimation in the real world.

#### 3.1 Location

The experiment was held in an isolated laboratory with minimized distractions. We created an artificial corridor by placing a wall of curtains parallel to a wall. This wall of curtain blocked visual distractions from the participant and reduced the size of the area we had to replicate in the virtual environment, leaving less room for errors.

#### 3.2 Participants

A total of 16 individuals took part in this study, recruited through convenience sampling. Two participants did not provide their socio-demographic information. Of the 14 participants who reported socio-demographic information, 8 (57%) were male and 6 (43%) were female, with an average age of  $M = 20 \pm 2.83$  years. When questioned about their familiarity with VR equipment, 6 (43%) stated they were slightly familiar, 3 (21%) moderately familiar, and 3 (21%) not familiar at all. 8 individuals disclosed using corrective lenses for vision. 10 participants identified as right-handed, 3 as left-handed, and 1 as ambidextrous. When questioned about symptoms of dizziness, 7 (50%) said "sometimes", 6 (43%) said "never", and 1 (7%) said "about half the time."

#### 3.3 Apparatus

The experiment was conducted over a Unity application. The hardware was an HTC Vive Pro with a wireless transmitter, HTC Vive trackers (pucks) to track the gas monitoring device and the door in the high physical realism conditions. For the VR with high physical realism condition a Leap Motion hand tracker mounted on the HTC Vive (Figure 4). HTC Vive controllers provided tracking for the hands during the standard VR condition performance.

The physical props that provided passive haptics in the high physicality VR (and real world) condition were a 3D printed gas monitoring tool outfitted with inner weights to match the weight and center of gravity of a real device, a functional standalone door, and one small and one large desk for participants to maneuver between vents. Additionally, 5 vent images that matched the VR vent textures were printed in durable material.

#### 3.4 Design and data collection

Each participant repeated the same set of tasks 3 times. The first condition was always the real world to collect baseline time estimations. Then participants performed either the standard VR condition or the high physical realism VR condition. Finally, the remaining condition was performed. All participants started with the real world condition, but order for the VR conditions was counterbalanced to reduce potential order effects. Here, the independent variable was the condition performed by the participant.

Our goal was to make the participant interact with the props around them and get a feeling of the current level of physical realism, the participant would then go through a series of time estimation tests while we collected data.



Figure 4: The HMD that was used in the study with the wireless transmitter and the Leap Motion hand tracker.

#### 3.5 Procedure

The participant walked into a small designated area marked on the ground (Figure 5). In this area, the participant is provided the necessary equipment for that condition, such as the VR headset, controllers, and other tracking devices. If the condition is physical, a hand tracking system is activated to display their hands through the VR headset. The participant is reminded of the procedure before each condition and also told they will be asked to guess the total time they spent during the condition.

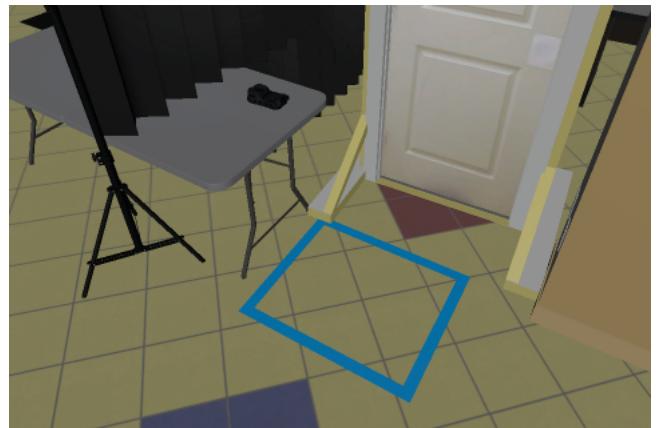


Figure 5: The participants started all tasks standing inside the blue square (which was also marked in the real world) and facing the door.

After each condition, the next one was prepared by having the experimenter facilitate the swapping of physical props for virtual ones and vice versa. For better tracking of the VR conditions, the black curtains were drawn after the participant wore the HMD, so they would not notice this change.

With the experimenter's signal, the participant began by picking up the gas monitoring tool from the desk next to them (with or without physical props depending on the condition). The participant then opened the standalone door and walked through it. The participant walked up to the vent labeled "1", and brought the gas monitoring tool close to it. A signal was sounded at which time they were instructed to begin counting/estimating, in whole seconds, the time that passed until a second signal was heard. Unknown to the participant, the duration between the two signals varied between

25 and 35 seconds, randomly selected by the computer. After the second signal sounded, the participant verbally told the experimenter their estimation in seconds, and the researcher recorded that number. The participant repeated the time estimation process 4 more times in the order of the label of the vents (see Figure 6. After the participant finished the time estimations, they return back to the starting position and verbally tell the researcher their rough estimate on the total time they spent during the condition. The computer recorded the actual time that passed between each of the 5 pairs of signals, and the total time the participant spends during each condition trial, starting upon crossing the door at the into the room and ending upon crossing the door back.

After each condition, the participant sat down and rested for 5 minutes.



Figure 6: The order of vents to check from 2 to 5. Vent 1 can be seen in Figure 1B.

### 3.6 Data Analysis

Data were collected during the experiment in terms of the participants' time estimation accuracy, and after the experiment as demographic data. From each participant, we collected 6 data points (5 vents and 1 total time) in each of the 3 conditions, totaling 240 data points that represent the participants' time estimation accuracy. We analyzed this data in a number of ways to see if physical props had an effect on the participants' perceptions of time.

## 4 RESULTS

In this study, we calculated the ratio of time between actual elapsed time and time estimation under different conditions and vents. The mean accuracy (where 1 is perfect accuracy) for participants when considering only condition (real world, high physical realism VR, and standard VR) was  $M = 1.08 \pm 0.33$ ,  $M = 1.05 \pm 0.36$ , and  $M = 1.07 \pm 0.38$ , respectively. Table 1 shows the means and standard deviations of the accuracy over Condition and Vent.

A repeated measures ANOVA was conducted to investigate the effect of Condition and Vent on Accuracy. The results showed that the main effect of the Condition was not statistically significant,  $F(2, 28) = 0.594$ ,  $p = 0.559$ . This suggests that there was no significant difference in the accuracy between the different condition groups. The main effect of Vent was also not statistically significant,  $F(1, 98, 27.69) = 1.219$ ,  $p = 0.311$ . This suggests that there was no significant difference in the accuracy between the different Vent groups. The interaction effect of Condition and Vent was not statistically significant,  $F(2, 22, 31.12) = 1.472$ ,  $p = 0.245$ . This indicates that there was no significant interaction between the Condition and Vent groups on Accuracy.

Table 1: Mean and SD accuracy for vent time estimates per condition.

Condition	Vent	Mean Accuracy	SD Accuracy
High	1	1.099	0.378
High	2	1.097	0.474
High	3	1.04	0.369
High	4	1.004	0.32
High	5	1.022	0.293
Low	1	1.062	0.302
Low	2	1.155	0.627
Low	3	1.088	0.368
Low	4	1.042	0.271
Low	5	1.028	0.299
Real	1	1.13	0.41
Real	2	1.05	0.292
Real	3	1.094	0.361
Real	4	1.03	0.273
Real	5	1.101	0.35

In this study, we also measured the total estimated time between conditions. Similarly, we calculated the ratio of time between actual elapsed time and estimated time. The mean accuracy for participants when considering only the real world conditions was  $M = 1.42 \pm 0.76$ , for high physical realism VR it was  $M = 1.43 \pm 0.75$ , and for standard VR, it was  $M = 1.37 \pm 0.73$ . In the repeated measures ANOVA, the results found that the main effect of the Condition was not statistically significant, with  $F(1.32, 18.45) = 0.003$ ,  $p = 0.981$ . This suggests that there was no significant difference in the ratio retention between the different condition groups.

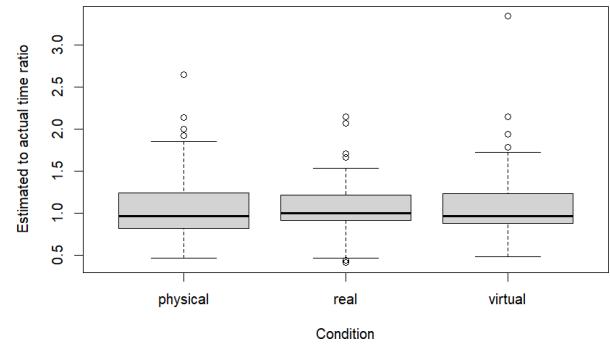


Figure 7: Time estimation accuracy for total time spent in the condition trial.

We took the average of the ratios of participants' estimated times to the actual times per condition, and used it as a score to compare with the real-world/base condition. Because we are comparing the ratios, a score of 1 means the participant has estimated the exact time while a score of above 1 means they have over estimated, and a score below 1 means they have under estimated. Figure 7 shows the accuracy scores grouped by the condition. We see that all three conditions are highly similar with their medians close to 1. We noted a considerable amount of outliers. Figure 8, shows that the virtual condition scores closer to the real-world condition.

## 5 DISCUSSION

Our study found that, although we did not observe significant effects, time compression was consistently present throughout the trials. The fact that similar time compression was found in both virtual reality and real-world conditions suggests that time compression occurs

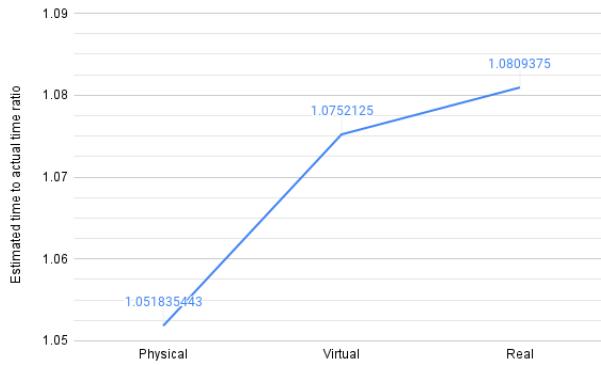


Figure 8: Time estimation accuracies

regardless of the environment in which the task is performed, for tasks such as counting time and retroactively estimating time spent in a longer task.

To the best of our knowledge, this study was the first to compare time estimation in different virtual reality conditions using a real-world estimate as a baseline. We did find that time compression occurred in all conditions, which suggests that the task itself may have had the strongest impact on time estimation, rather than the environment in which the task was performed. It's possible that humans naturally tend to overestimate time when performing conscious, methodical tasks such as counting time between two signals, and that any potential effects of the environment may have been obscured by the task's impact on time estimation.

Another possible explanation for the lack of observed effects is the use of a within-subject experimental design. Previous research has found a significant time estimation bias during repeated exposures, which suggests that between-subject experiments may be more appropriate for studying differences in time estimation between conditions [11]. Further research, involving more time and participants, is needed to verify these assumption.

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