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Conference Paper

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Publication date:
2020-09-30

Permanent link:
https://doi.org/10.3929/ethz-b-000443755

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Originally published in:
https://doi.org/10.1109/CW49994.2020.00026

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Designing Virtual Training Environments: Does Immersion increase Task Performance?

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***Abstract*—One of the main characteristics of virtual reality (VR) is immersion, which leads to comprehensive illusions of reality. Accordingly, VR is used in many applications like entertainment, marketing, and training. Especially in training applications, the effect of immersion on training success is still not entirely clear, since too much immersion may cause side effects such as users experiencing high mental demand whereas too little may disturb users' well-being. To further investigate the matter, we developed two virtual training environments, wherein users train a typical industrial assembly task either in low or high immersive VR. In a controlled pilot study, we additionally introduced a third condition, the control group, which justifies the necessity of the training. Immediately after the VR training session, each participant completed the corresponding real assembly task in which their performance was measured. Preliminary results from our pilot study show that participants trained in high immersive VR performed better, while negative side effects could not be detected.**

***Keywords*-Virtual Reality; Training Simulator; Immersion.**

I. Introduction

While Virtual Reality (VR) technology has been extensively developed and studied since the 1980s, it has only recently become affordable and accessible for a broad user group. An example for an affordable and accessible VR system is the HTC Vive Pro including a head-mounted display, two controllers and a tracking system, which allows users to navigate freely within confined spaces of up to 10×10 meters. The technological capabilities of VR systems are defined by the immersion they possess. Higher immersion provides a more extensive illusion of reality and is therefore supposed to make a user feel more present in a Virtual Environment (VE) [1], [2].

The ability to create a comprehensive illusion of reality makes VR a promising technology, especially for education and training purposes. Although VR training applications have existed for decades, there is still a controversy regarding their design and success, i.e. actual performance outcomes [3]. When creating a virtual training environment (VTE), numerous immersive features regarding hardware and software have to be considered. Although it may seem obvious that the highest immersion should always be favored in training applications, this also has its costs. First, from a developer's perspective, it would be preferred to use inexpensive hardware (e.g. the Google Cardboard) and simple VEs. Second, recent concerns have arisen that high immersion might generate cognitive overload and unnecessary distraction for the user, which would affect training success negatively [4], [5].

In the study presented in this paper, we respond to these concerns by developing two VTEs to train an industrial assembly task either with high immersion or low immersion. We conduct a pilot study, wherein each participant will be randomly assigned to receive either (A) low immersive training, (B) high immersive training or (C) no training. Immediately after the training, a corresponding real assembly task is performed to measure training success. The chosen use case is the assembly of Modular Support Systems (MSS), which are installed in commercial buildings to accommodate mechanical, electrical and plumbing components on ceilings or below floors. Besides an authentic setting, i.e. the assembly of MSS is regularly carried out by construction workers, the chosen task involves mostly memorization and transfer of acquired knowledge. Thus, the use case's extent and complexity represents a broad variety of assembly tasks that are currently relevant in industrial settings (e.g. factories or construction sites).

II. Related Work

VTEs have gained increasing popularity with diverse applications being developed and evaluated in contexts such as industrial assembly design [6] or paramedic procedures [7]. However, one of the main concerns of VTE research is the comparison to traditional methods (e.g. real training or other media). These research efforts concluded that training in VR is either: (i) better [8], (ii) worse [5], or (iii) insignificantly different and thus comparable to traditional methods [9].

Besides varying findings regarding the success of training in VR, the VTEs in prior research differ substantially regarding their immersive features (e.g. interaction via tracked hands [8], buttons [5], or tracked real objects [9]). We conclude that a deeper understanding of the concept of

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DOI 10.1109/CW49994.2020.00026

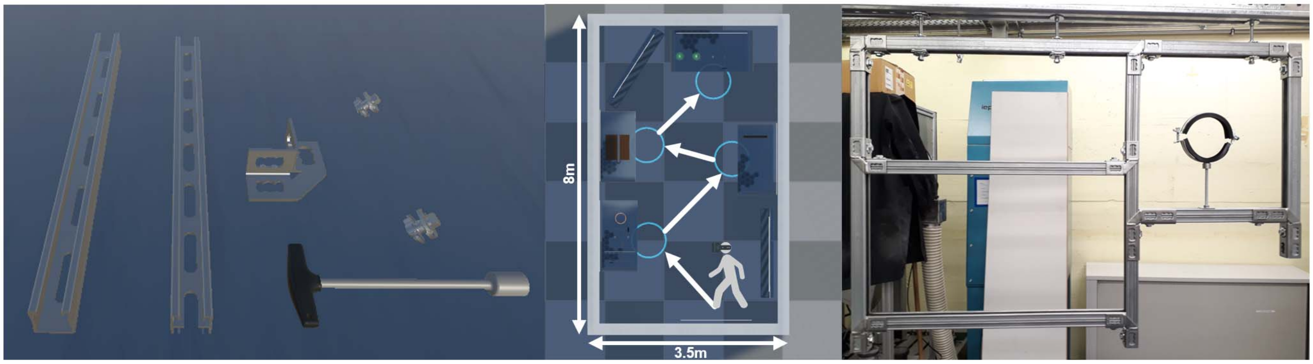

Figure 1: Pilot Study – from left to right: all component types necessary for a complete assembly, navigation of the high immersion VTE by real walking, and the complete assembly of the real evaluation task

immersion is needed to explain the discrepancy within prior research. Thus, the research goal of this study is to investigate whether the immersion influences users' training success in VTEs. Furthermore, the performance shall be rigorously assessed through a real task.

III. Use Case

The industrial task to be trained in VR is the assembly of a MSS, which consists of angular conjunctions, two different types of extruded profiles, and so-called push buttons, which connect and fix the other components. A push button is a load-bearing connector that facilitates the assembly. However, its working principle is supposedly not self-evident. The VTE representation of the push buttons, all other components, and the required tool to assemble the MSS are shown in the leftmost image in Figure 1. Additionally, the completely assembled real MSS is shown in the rightmost image of Figure 1.

For an assembly of the MSS, participants need to understand three distinct core concepts: (a) distinguishing the different types of rails, (b) identifying the rails' orientations on a 2D layout, and (c) understanding the working principle of push buttons. These three core concepts are all covered in the VTEs. To successfully assemble all components, participants need to memorize the content of the training and transfer the acquired knowledge to the real world task.

IV. Study Design

A. Technical Setup

We use an HTC Vive Pro VR system including its two handheld controllers and four connected tracking stations spanning a walkable area of 8×8 meters. Participants carry a gaming laptop in a backpack, which renders the VTE, allowing for a free walking experience within the tracking space. The VTEs are implemented in Unity3D due to its simple access to SteamVR.

Considering state of the art VR applications, the development of virtual content is much more expensive than the equipment. Furthermore, research should investigate on instructional features that could be supported by a system rather than comparing different technologies [10]. Therefore, we focus only on software-related immersive features and implement them according to Figure 3.

B. Study Procedure

The study procedure consists of five distinct phases, which are presented in Figure 2. In three phases, i.e. phase one, three, and five, we ask the participants to answer questionnaires to obtain subjective data on their well-being and their perception of the VTE. These questionnaires include common questions on demographics, simulator sickness, and task load.

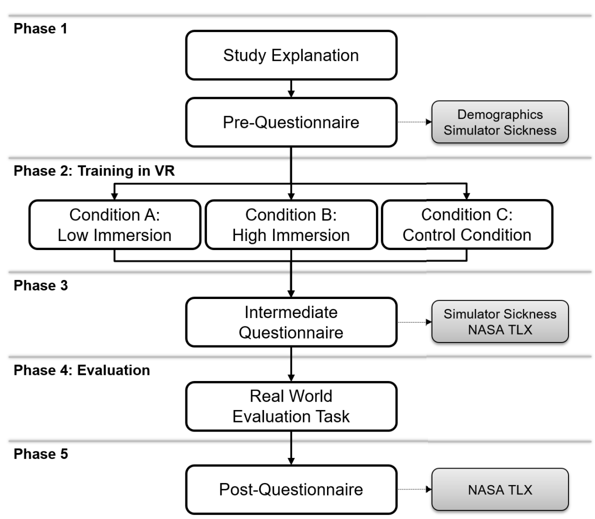

Figure 2: Study Procedure

In the phases two and four, the use case of the study is directly addressed, whereas phase two is conducted in VR, while phase four is done in a real environment. Phase two considers the training phase and is further divided into two

Table I: Questionnaire results with mean (M) and standard deviation (SD); Completion Rate in Percentage

Training Condition	**n**	**SSQ**		**TLX VR (Training) Session**		**TLX Evaluation Task**		**Completion Rate**
		Pre	Post	Mental Demand	Physical Demand	Mental Demand	Physical Demand	
Overall	30	24.3±22.9	24.1±23.8	34.6±19.2	17.3±20.8	62.3±22.1	47.0±24.9	13.3%
Low Immersion	10	23.1±17.4	26.1±18.1	34.0±21.7	07.0±09.5	65.0±15.1	39.0±18.5	10.0%
High Immersion	10	16.5±21.9	16.5±18.6	35.0±20.7	18.0±22.5	53.0±26.3	52.0±31.9	30.0%
No Training	10	33.3±27.6	29.6±32.6	35.0±17.8	27.0±24.1	69.0±22.4	50.0±23.1	00.0%

separate training conditions: 2a) Low Immersion Training and 2b) High Immersion Training. To detect a possibly occurring ceiling effect originating from the misjudgment of the evaluation task's difficulty, we introduce a third condition: 2c) the control group, which plays an unrelated VR game. In case the assembly task was too trivial, a training of any kind would be obsolete, since participants could just fulfil the task without any prior instructions. Accordingly, we aim to show the necessity of the training to grasp the core concepts of the installation using the control group. In the two particular training conditions 2a) and 2b), participants train how to completely assemble the MSS visualized on a given layout plan. Following this schematic layout step-by-step, they are guided through the different processes on how the individual components work, are connected and which tools are required. The conditions 2a) and 2b) are clearly distinguishable by their software-related immersion, as shown in Figure 3.

The mapping of participants' movements onto changes in the low immersion VTE is abstract: pressing buttons on the controllers is mapped to selecting objects, starting animations of virtual objects, or using a tool (depending on the current step of the training). In the high immersion VTE, the mapping of participants' movements onto changes in the VTE are natural: to move a specific object, participants grab that object using a controller and move it by physically performing the according motion. Furthermore, while the low immersion VTE is performed completely in a seated position, in the high immersion VTE, participants are required to navigate the VE by real walking (Figure 1, center). In the low immersion VTE, interactivity is low: participants have only a limited number of ways to influence the content of the VTE. Conversely, the high immersion VTE requires a unique type of interaction for almost every task that needs to be completed throughout the training. Acoustic feedback, haptic feedback and partial rendering of a participant's body, i.e. both hands, are only provided in the high immersion VTE, but not in the low immersion VTE. Acoustic feedback is provided through 15 audio clips that are played (e.g. when an object is dropped or when a tool is used to tighten a connection). Haptic feedback is provided through vibrotactile pulses exerted by the HTC Vive controllers. These pulses are exerted in situations in which vibrations are also perceived if the same action is performed in reality.

In phase four, the training success, i.e. memorization of training content and transfer of the acquired knowledge, is assessed by performing the task in a real environment. The study participants are asked to completely assemble the real MSS with the same components they were taught in the training phase. They are again provided with a 2D layout plan and are additionally put under a time limit of 15 minutes.

	Immersive Features	**Low Immersion VTE**	**High Immersion VTE**
Hardware	Field of View	110°, Dual AMOLED Screens	
	Frame Rate	90Hz	
	Image Quality	1440 x 1600 Pixels per Eye	
	Stereoscopy	✓	
	Tracking Level	6 DOF	
Software	Mapping	Abstract	Natural
	Interactivity	Low	High
	Acoustic Feedback	×	✓
	Haptic Feedback	×	Vibrotactile
	Virtual Body	×	Hands

Figure 3: Immersive Features of the VTEs

C. Participants

For the pilot study, 12 female and 18 male participants signed up, who were 23.6±3.1 years old (M±SD). These participants were randomly assigned to one of the three experimental conditions 2a-c). One participant per group had more than five hours of self-declared previous VR experience, while the other 27 participants had less than five hours of previous VR experience.

D. Data Acquisition

For the subjective measurements, we used standardized forms like the Simulator Sickness Questionnaire (SSQ) and the NASA Task Load Index (TLX). The SSQ items are rated on a 4-point scale and describe various simulator sickness symptoms. Based on this, the final score, ranging between 0 (not affected at all) and 235.62 (severely sick), is calculated. The TLX rates various aspects of task load (e.g. mental and physical demand) on a scale from 0 to 100. Since all these questionnaires yield subjective measures, a fourth measure is introduced, which aims to provide an objective description of the task performance in the real world evaluation task. For this pilot study, we limited the objective measure to an overall, binary completion rate.

V. Results and Discussion

The results of the pilot study for each condition, as well as overall are summarized in Table I.

According to the SSQ data, none of the participants experienced peculiar symptoms for simulator sickness and thus none was excluded. The absence of significant increases in participants' SSQ scores indicates that the participants felt comfortable using the VTEs and that they did not perceive simulator sickness.

On average, the self-reported physical demand in the high immersion VTE (TLX score 18.0) was 157.1% higher than in the low immersion VTE (TLX score 7.0) while mental demand was fairly similar. This was expected since the high immersion VTE has a higher interactivity and allows free walking while the content covered in both VTEs is identical. With an average of 53.0/100.0, the mental demand in the evaluation task was lowest for participants trained in the high immersion VTE. This indicates that participants being trained in the high immersion VTE were able to transfer their acquired knowledge more efficiently than the participants from conditions B and C. However, none of the observed differences in the TLX scores exhibited statistical significance in a one-tailed t-test.

A comparison of the completion rates shows that participants trained in the high immersion VTE were three times as likely to complete the assembly as participants trained in the low immersion VTE. Furthermore, the fact that none of the participants of the control group was able to complete the assembly indicates that the difficulty of the chosen use case was adequate for the intended purpose.

VI. Conclusion and Future Work

This research sheds light on the relationship between a VTE's immersion and the achieved training success. In the results of this pilot study (see Table I), we observe a corresponding tendency, which needs to be extended and further investigated. Especially the fact that participants trained in the high immersion VTE were three times more likely to completely assemble the MSS in the given time than participants trained in the low immersion VTE is a promising preliminary result. Identifying this relationship will result in the next major step for training in VR, since immersion would become a valid option to qualitatively estimate the effectiveness of a VTE. By further investigating the immersive features listed in Figure 3, a finer granulation shall be created and evaluated by different combinations of immersive features. Based on this, the optimal immersion should become identifiable, allowing for cost optimization and scalability on an industrial level. In the planned extension of this pilot study, we aim to increase the sample size and introduce additional objective and subjective measures such as eye gaze tracking, general motion trajectories, and also relevant user traits (e.g. personal innovativeness). Furthermore, we aim to create an adaptive VTE, which reacts to the user's physiological state. By upgrading the current system with physiological measurement devices such as an eye tracker or a body tracker, the training environment will be enabled to react for instance to users' stress and boredom levels by introducing new challenges and tasks, but will also be able to counteract simulator sickness.

Acknowledgment

This work was supported by a project financed by the Hilti Family Foundation in Schaan, Liechtenstein and RhySearch in Buchs SG, Switzerland. Additionally, the authors would like to thank Hilti AG for the fruitful collaboration and the equipment provided.

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