Training in Immersive Virtual Reality: A Short Review of Presumptions and the Contextual Interference Effect

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Abstract. The increase of shipped consumer immersive virtual reality (IVR) up to 6 million units in 2019 shows the increasing popularity of this medium. Invests of 8 billion dollars are anticipated in the next five years for the training sector. With the development the question arise, what effects and advantages can be expected using IVR in human training? This paper reviews three important areas, when it comes to the design of immersive virtual reality trainings: 1. cognitive load, 2. spatial imagination and the contextual interference effect.

Keywords: Immersive virtual reality training · Contextual interference effect · Training design

1 From Computer Based Training to Immersive Virtual Reality

Virtual, computer-based learning and training environments have been around for decades. Their manifestations range from text-based and image-based learning programmes [1], learning tools [2], simple video-based coaching (e.g. Lynda.com) to clinical trainings [3]. Based on the field of application the learning content should portray or enrich real-life experiences by using videos and animations. To achieve this goal, most computer-based and smartphone-based E-Learning programmes present 3D models on a screen in 2D (Desktop-VR). In this use case, the interaction is often limited to the use of a computer mouse with the room sensory and/or motor activity being excluded. The user-generated content is shared in online forums (e.g. Moodle) and users can communicate by using (Video-) chat and screen-sharing software (e.g. Skype, TeamViewer). Furthermore, the acquisition, practice, and testing of learning material can be promoted by doing multiple-choice tests, word completion tasks, matching tasks, etc. and can be supported by avatars (pedagogical agents). To promote the immersion into the virtual worlds, virtual reality headsets (iVR) present the

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information in 3D, enable stereoscopic vision and improve the opportunity to interact, hereby enriching the feeling of being present in the virtual world. The experience can be enhanced, by creating one's avatar to experience, create and communicate with others in a community without the requirement of being physically present in the same place. Similar to the real world, using iVR, several people can collaboratively create, share and save virtual objects, processes, and spaces online (e.g. Modbox). The processes of computer-based training and testing can be designed in a way to be more realistic and to better portray real-world tasks and situations. Next to the established techniques, this can be achieved by implementing motor-based interactions (e.g. construction and dismantling of a machine), adaptive and time-controlled processes (e.g. biochemical reactions in a cell) or the incorporation of 360-degree videos in simulations. The above-mentioned opportunities to promote the quality of interaction, communication, and creativity in virtual reality raise the question of efficacy. What are the benefits of immersive iVR compared to desktop-VR? Is the extra effort and expense justifiable by a similar or greater improvement in learning outcomes? The empirical evidence is wide-ranged and not conclusive. In the field of learning in virtual reality, there are important subject areas, that should be considered when designing iVR training: Cognitive Load, Spatial imagination and learning paradigm.

2 Cognitive Load, Spatial Imagination and Learning Paradigm

During learning with a multimedia environment, it is important to keep the cognitive load (CL) on a medium level, because a high degree of CL can interfere with the learning process [4]. Besides questionnaires [5], brainwave parameters (measured with electroencephalography, EEG) can be used as objective psychophysiological correlates for the measurement of CL [6]. The degree of CL is called the Cognitive Load Index (CLI). A high CLI is tantamount to a large amount of objective CL whereas low CLI is equivalent to a low amount of CL for the brain. High CLI can, for example, emerge as a result of diffusion when solving a problem and simultaneously be overstimulated by the high level of detail of 3D models on a 2D screen (e.g. computer or smartphone) [7]. In a study, Dan and Reiner [8] illustrated that in certain brain areas, CL measured objectively with CLI by EEG, is lower when learning in virtual worlds supported by avatars and focussed on the learning material by HMD-VR. When the same 3D content is presented in the virtual world on a 2D display, CLI is elevated. Makransky et al. [9] demonstrated negative effects on learning and the CLI, if the VR learning environment was not designed in a task- and/or user-centred design process. Therefore, the inclusion of the target group in the design of the virtual learning space seems to be an important factor relevant to the learning success and CL. In addition, spatial imagination is an important factor. Hulk [10] showed in his study, that independent of the spatial imagination abilities, learners needed more learning time when 2D-Learning-Tools used 3D-Animations. At the same time, students with lower spatial imagination abilities seem to benefit more from the presentation of the learning material in iVR [11]. Whether learners with high spatial imagination abilities also present with lower physiological stress parameters has yet to be studied. The aspects "CL" as well as "learners" abilities however are highly relevant for the application in the field of training. Furthermore, contemplating the influence of the opportunity to interact (designing controls and movements) in virtual reality, results on learning efficacy are mixed. Sugand et al. [12] observed large learning effects (i.e. faster processing time and reduced error rate) in medical training for surgeons. Likewise, Webster [13] observed higher learning success in user-centred designed training in iVR, compared to the control group (PowerPoint presentation). Children between the age of 6–8 for spatial matching tasks [14] as well as engineering students [15] benefited from using iVR, compared to control groups and/or other VR-Groups, the most. Additionally, elderly people seem to benefit from iVR in memory performance [16]. Conflicting to the above-listed studies, Phé et al. [17] did not observe any learning effects after VR-Training in novices and experienced physicians. Only people with no background in medicine showed improvements over time. Only Våpenstad et al. [18] and Makransky et al. [9] could find no effect through iVR. At this point the intended learning success needs to be defined and a learning paradigm must be suggested. Applying pedagogy to the design of VR training is not easy. Although the current empirical knowledge indicates a positive impact of iVR, studies with contrary results can also deliver useful indicators on how to design effective training in virtual reality. The majorities of VR-Training studies focus on the development, usability and the feeling of immersion and lesser on learning efficacy and a meaningful didactic conception. However, psychological learning research offers didactic principles that can be especially useful for improving the learning transfer of skill-learning. Studies that used didactic and psychological paradigms together with a user-centred design approach of the training, showed a positive effect of iVR on the learning success (e.g. [13]). Studies without this pedagogical and/or psychological approach where learning transfer was measured as an indicator of learning success but not the main focus in the design of the VR learning space, showed a negative effect of iVR on learning success (e.g. [9]). Therefore, the successful use of iVR as a training tool might be dependent on the proper training design based on empirical learning paradigms and with a user-centred approach. One of those learning paradigms is the contextual interference effect (CIE).

3 Context Interference Effect and IVR Training

The hypothesis states, that high contextual interference would impair the acquisition but enhance the retention and transfer of learning [19]. The CIE was first investigated by Battig [19] in the instance of learning word-pairings. The hypothesis was later adapted by Shea and Morgan [20] in motor learning, where the CIE has mainly been a subject of interest [21]. By reviewing the scientific literature about the CIE, it becomes evident, that the manipulation of practice schedules (blocked vs random practice) is the only source of interference used in the vast majority (if not all) of the studies. In the CIE studies, blocked practice as low degree of interference (learning the same task several times in a blocked order before moving on to the next task. E.g. AAA, BBB, CCC, etc.) is compared to random practice as high degree of interference (learning the different tasks in a random order. E.g. ACB, CBA, BAC, etc.). Using HMD-VR, the CIE-Paradigm can be much easier implemented in a virtual training environment compared to the real world. For example, in virtual reality, complex procedures can be practiced in a randomized order without constraints of the physical world. In contrast, learning in the real world can be constrained to the extent that randomized training is not always feasible. The promising impact of CIE relevant to the transfer of the learning content presents an additional interest in the paradigm for HMD-VR. A wide range of VR Training studies focuses on real-world tasks as e.g. manufacturing assembly (e.g. [22]), neurologic surgery (see [23]) and military training (e.g. [13]). Those VR training programmes are often created to promote the transfer of the learnt skills into the real world. By systematically implementing CIE in HMD-VR, there might be highly beneficial effects on the transfer of learning to the real world. The CIE has been studied in a wide range of areas as e.g. in sports (e.g. [24]), simple tracking tasks (e.g. [25]) and simple motor skill learning (e.g. [26]). Comparing those CIE areas of interest to the complex real-world tasks that present themselves to be good candidates to transfer the learning process into virtual reality, there appears to be a relevant gap. By reviewing the literature on CIE, only a handful of studies might be comparable to real-world tasks and therefore relevant information sources for the design of training courses and/or studies for HMD-VR. The identified studies are presented in Table 1. By analysing the identified studies, study-design principles for future CIE studies in VR should be identified.

Table 1. Identified CIE studies to address complex real-world tasks that present interesting similarities to the identified HMD-VR studies

Study	Skill that is learned in study	Number of tasks	Amount of task repetition
[27]	Training orthopedic surgical skills	5	5 × 5 (whole vs random vs blocked)
[28]	Troubleshooting skills	4	5 × 4 (blocked vs random)
[29]	Troubleshooting skills	4	12 × 4 (blocked vs random)
[30]	Stick and rudder flighting	13	10 × 13 (whole vs blocked vs sequenced)
[31]	Laparoscopic surgery skills	4	20 × 4

By analysing the different studies in Table 1, there seems to be a wide range of different training structures (e.g. the number of tasks and amount of repetitions of each task). Additional studies in the area of real-life tasks are needed to gather further information related to CIE and design of training with the focus on transfer success. In a meta-analysis, Brady [32] pointed out, that the practice schedule manipulation (blocked vs random practice) is the only source used to generate interference in the identified studies and that other sources of useful interferences need to be identified. Originally, Battig [19] argues that there might be several sources of interference within and external to the learning task. By reviewing the CIE literature, there still seems to be solely focus on practice schedule manipulation. Virtual reality studies could present themselves as helpful instruments to advance scientific knowledge on the CIE. Other sources of interference as e.g. lighting quality in a factory, background noises in the operating theatre, degree of scaffolding presented during learning a manufacturing assembly task, etc., could be easily designed and investigated. Conclusively, based on the gap in scientific knowledge about the CIE referred to complex real-life tasks and possible sources of interference on one side and the need of applying pedagogic/psychological learning paradigms in VR training on the other side, the exploration of those two research areas and their interaction, seems to be highly relevant for science and the industry.

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