Applications of Immersive VR in Nursing Education

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Abstract— Regulatory and financial restrictions put a burden on nursing education, thus educators struggle to provide adequate training. Low quality training put patients, practitioners and the devices they use at risk of harm or malfunction. In other fields, simulation-based training (SBT) has shown to be an effective tool. Immersive virtual reality (VR) provides a wide range of learning enhancing aspects. In this paper, we did a survey on the current state of immersive VR with head-mounted displays (HMD) in nursing education and its effects on learning. We searched relevant databases for predefined PICO terms. The results indicate that head-worn immersive VR helps in learning and increases student motivation. We believe that the low amount of identified publications points to a niche in the field and that further research into the effectiveness of HMD-based devices in education is necessary. Furthermore, we found that "VR" is used to relate to anything computer based. However, since it is now predominantly used to describe an immersive experience, a convergence of terminology is required. Future research should be based on bigger samples and more extensive statistical analysis to be able to prove the positive effects of VR in student motivation and learning outcomes.

Keywords— nursing, education, virtual reality, head-mounted display

I. Introduction

A lot of jobs require extensive training due to the high amount of responsibility they bring with them. Often, this means responsibility for the well-being of others. Several industries such as aviation, medicine, and military have implemented simulation-based training (SBT) as part of accumulating knowledge and skills, both in initial and continuing education. First introduced in 1940 with "Resusci-Anne", a mannequin doll for resuscitation exercises [1], simulations with several degrees of fidelity have spread to aviation (flight simulators, both screen based and high fidelity devices) and military (tactical training, live action with dummy ammunition), but also medical and healthcare, fields that require a more hands-on kind of skill acquisition (surgery task trainers, mannequins which simulate birth giving, software based simulations) [2].

In nursing, however, educators are struggling to find adequate teaching methods, partly due to an increase of safety requirements and stiffer financial constraints. Forced to counter an inability of nursing apprentices to focus on multiple tasks and "significant performance anxiety" due to lack of a regular contact with patients, SBT has been introduced in nursing. The aforementioned financial constraints make the use of expensive mannequins in nurse training unsustainable, requiring the adoption of more cost-effective solutions [3].

Virtual Reality (VR) seems to be a viable solution under the given constraints. With the advent of widely commercially available consumer-grade devices in 2013 [4] many of the areas identified earlier have turned in some way to use VR in their training programmes. In the context of our work we define VR as a fully immersive, 360 degree artificial environment, which is experienced through a head mounted display (HMD). The user may interact with this world with his voice, gaze, gestures, and / or so called tracked controllers that offer an array of different buttons. Environments that do not fit this description, such as monitor-based Second Life® are therefore excluded from this review. VR caters to a lot of learning approaches through its multi-sensory and kinaesthetic style of interaction [5].

II. Background and Objectives

A. Nursing shortage

With regard to Germany, the overall nursing personnel is projected to be missing 165,000 caregivers until 2020, all the while the amount of people in need of care will double to 4.5m until 2060. While in 2009 and 2010 there were 9,000 apprentices (11,000 respectively), only 6,500 people decided to start a (non-academic) career in nursing [6].

PriceWaterhouseCoopers (PWC), an economy research institute, estimated in a 2011 study that by 2030 the amount of missing caregivers in the German federal state of North-Rhine Westphalia will be as high as 36,000 in 2030, which is fifteen times as much as in 2011. Another 40,900 positions will be vacant in general healthcare, a tripling of the 13,900 in 2011 [7]. However, Ostwald et al. also note that this deficit can be counter with appropriate measures. These include cost-efficient healthcare system, standardisation of training and bringing back trained nurses who left their jobs due to bad work-life balance, since it will not be possible to fill the requirement numbers with nurses just starting out [7] .

Nursing educators point to several difficulties in teaching due to financial and timely issues, and in their Carnegie National Nursing Education study from 2009, Benner et al. state that nurses are undereducated for their demands in practice. In order to help design training more cost-efficient and effective in learning and memory retention, digital training solutions can be employed. They propose simulation based training (SBT) as a means of remediation [8], [9]. Stricter government regulations and lesser possibilities to do "hands on" training with patients is leading to fewer real-life training possibilities. There is a need for cost-effective training solutions, simulation based training and VR are among these [3].

B. Simulation Based Training

There is a range of evidence, showing that SBT improves learners' competence and their skills when compared to traditional teaching methods [2]. While simulation in itself is an invention from the 1920s, healthcare education has started to adopt simulation increasingly only in the past twenty years. Foronda et al. introduce computer- (screen) based simulation software vSim® amongst other emerging technology. Their research indicates positive effects of SBT on effectiveness of virtual simulation training for communication, teamwork, and other skills. Furthermore, they report studies hinting at positive experiences with both VR itself and its implementation [9]. In a 2016 review, Freina et al. present articles that consider VR as a simulation tool. Topics in the medical field include surgery training, dental procedures and general training in virtual hospitals as an assessment tool for technical-skill development [5]. However, Green et al. point out that the user of VR requires appropriate training and orientation before they can be expected to perform in the environment [10]. However, all tested VR systems are found to have construct validity and "are useful in determining those that require further training" [5].

C. Virtual Reality Technology

VR is based on the principles of immersion, interaction and user involvement. According to Freina et al., it can be differed between two kinds of VR: immersive-and non-immersive. The latter term describes a technology simulates a world that is usually interacted with by means of monitor and keyboard / mouse as in- and output devices. For this article, the authors focused on the first term, immersive virtual reality. The high(er) degree of immersion is achieved by the use of a VR Head-mounted Display (often known as VR headset, glasses, or goggles). Additionally, sound and smell can be employed. Most VR applications focus on two of the five senses, namely sight and hearing [11].

These goggles consist of a display with two lenses that is worn over the eyes. These lenses enable stereoscopic vision by gathering two separate, slightly different images from the display. The brain collects the information and processes them, thereby calculating distance properties using the parallax effect and thus place the objects at the correct distance, creating a sense of depth [12]. For high end applications, all of the required rendering calculations are running on the graphics card of the computer the HMD is connected to [12]. For lower-fidelity graphics, there are now devices that can do the graphical calculations on their own [13]or use smartphones as the processing unit.

In order to move around and interact with the virtual environment, HMD employ different technologies for tracking. Outside-in tracked systems have hardware that offer a technology similar to GPS, meaning that cameras follow the HMD and forward the (change in) position to the application. Inside-out systems, in contrast, use room tracking and a combination of sensors such as accelerometers and gyroscopes. These system scans the ambient room for visual features, such as a sudden dip in colour or contrast, i.e. at corners to span a coordinate system. The relative change in distance between these points, combined with inertia sensors is translated into a change of position in the virtual world [14].

The creation of applications usually employs a toolchain consisting of 3D tools such as Blender or Maya to create the environment and the objects within, a programming IDE like Visual Studio or Mono to program interactions, and a game development engine such as Unity3D or Unreal Engine to put these parts together and add VR capabilities through a vendor-delivered software development kit (SDK) [15].

Until now, HMD in education are still rarely used. This might be due to the fact, that in the past such devices were expensive and often induced nausea due to low resolution and framerate which causes a mismatch between the movement of the head and the corresponding change in the scene [5].

Existing literature shows a wealth of applications of immersive VR in different fields of education, such as medicine, military, and engineering [5], [16]–[19]. However, although in the nursing sector reviews show plenty of use of SBT, the applications are mainly restricted to non-immersive screen based training software [9], [10], [20], [21]. Reviews focusing on the use of immersive VR with head-mounted displays in nursing education are still missing.

D. Objectives

In order to fill the above mentioned gap we aim to give an overview over the different applications of head mounted displays in nursing education. The method section will give deeper insight on our approach for this review, based on the PRISMA protocol (version of 2015), a widely used evidence-based set of items for reporting in systematic reviews and meta-analyses [22]. The findings from the systematic review are presented in chapter III and discussed in chapter IV.

III. Methods

We used the following inclusion criteria for our review:

- Publication year >= 2013 (year of introduction of consumer-grade HMD)
- Publication language English or German
- At least one examined VR technology was a head mounted display (HMD)

Therefore we excluded all studies limited to screen based training software.

In order to compile a comprehensive collection of available literature, the following databases commonly used in medical, nursing or computer science have been searched for articles both in English and German:

- CINAHL
- PubMed
- Livivo
- EbscoHOST
- ScienceDirect
- Cochrane
- ACM Digital Library
- IEEE Xplore digital library

We adjusted our search strategy for each database requirements. The following search strategy was used for the PubMed database:

(virtual reality OR VR) AND (nursing OR care) AND (teaching OR learning OR education) NOT surgery NOT medical

(virtuelle Realität OR virtual reality OR VR) AND Pflege AND (Lehren OR Lernen OR Bildung) NOT OP NOT Operation NOT medizinisch

We decided to use the NOT terms to exclude studies which focused on medical doctors‘ teaching.

To evaluate the findings two independent reviewers screened the abstracts manually for the PICO items „Nursing education“ and „head mounted displays“. PICO is an acronym for "Patient or Problem", "Intervention", "Comparison" and "Outcome". It is a concept which is frequently used in clinical studies to help break down research questions into searchable keywords [23]. In a second step the corresponding full articles were manually screened for eligibility. After final selection we also screened for secondary sources in the lists of references of the included articles.

The obtained articles were finally listed in a table to present an overview of the results. Furthermore we categorized the articles by learning domains according to Bloom. The psychologist Dr. Benjamin Bloom and his team developed a framework in order to promote higher forms in education. As part of their work they identified three domains of learning: cognitive (knowledge), affective (attitude or self) and psychomotor (skills) [24]. Since the goal of this review is to give a descriptive overview there was no assessment of bias or evidence. To get an appreciation of the chosen methodology we checked if the described study included a comparison and/ or evaluation. A comparison was hereby defined as at least two different VR devices or at least two different user groups included in the study. An evaluation could be focus groups, questionnaires or interviews.

IV. RESULTS

With our search strategy we identified 1153 articles in total. Fig 1 shows the exact splits per database. 1041 articles were excluded for being duplicates or lack of connection with the PICO terms.

112 full texts were screened for eligibility, from which 109 were excluded because of not meeting the inclusion criteria. The screening for secondary sources revealed additional 7 articles. In total 10 articles were included in the review, all of them in English (see Fig. 1).

Five of the included articles can be assigned to the cognitive, three to the affective and one to the psychomotor learning domain. In one article the learning domain could not be specified because of lack of description. The assigned learning domains can be found in Table 1.

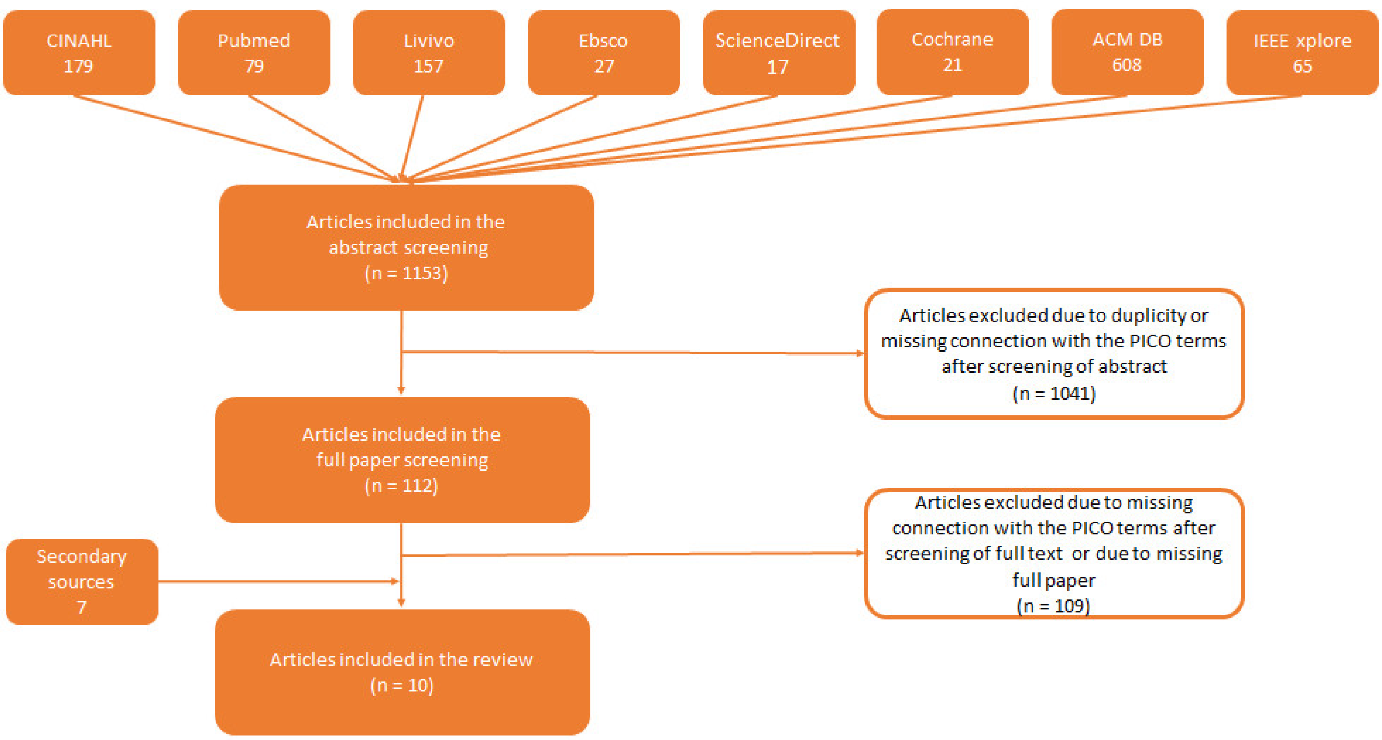

Figure 1 Review of literature

TABLE I. SYNOPTIC TABLE OF INCLUDED ARTICLES

Authors	Subject	Learning domain	VR Device(s)
Blome et al. 2017 [25]	first aid in VR	cognitive	HMD
Butt et al. 2018 [26]	Game-Based VR with Haptics for Skill Acquisition	psychomotor	HMD
Elliman et al. 2016 [3]	communication with virtual patients suffering from dementia	affective	HMD
Farra et al. 2016 [27]	Storyboard Development in neonatal care for VRS	cognitive	HMD
Farra et al. 2017 [28]	Training in the skill of decontamination	cognitive	HMD/ mouse+keyboard
Juanes et al. 2015 [29]	virtual environment for 3D-visualization of a hospital operating room	indefinite	HMD
Kleven et al. 2014 [30]	communication and interaction with patients in a virtual operating room	affective	HMD
Moro et al. 2017 [31]	learning anatomy in VR	cognitive	mobile-based/ desktop-based
Prasolova-Forland et al. 2017 [32]	Team communication and collaboration in a virtual university hospital	affective	HMD/ screen-based
Shewaga et al. 2015 [33]	Serious Game for Epidural preparation	cognitive	seated HMD/ room-scale HMD

The methodological evaluation resulted in 6 studies including comparison and 9 studies including an evaluation. Every article including a comparison also did an evaluation. Only one article didn't describe neither comparison nor evaluation.

V. Discussion

A. Included articles

1) Cognitive learning domain

In the cognitive domain, we found four articles. Blome et al. describe an application of VR to prepare students for first aid (VReanimate) [25]. They employ the HTC Vive HMD to immerse the user in a scenario, where a manikin requires a thorax massage. The pulse is simulated through the controllers' vibration motors. Haptic, auditive and visual feedback help the user to feel more present in the scene, and different environments, such as a forest or a military bunker increase stress levels to further increase realism. To present the tasks they use a non-verbal approach by e.g. using the visual of a headset as a self-reference instead of the usual text or speech. The authors interviewed the users to learn about their impression on different factors such as the material learned and how effective they felt the practicing with this specific approach was. Qualitative interviews indicated that the participants did not experience any difficulties in understanding the non-verbal signs [25].

In 2016 Farra et al. published an article presenting their development of a storyboard for VR simulation [27]. To make sure the content of their Oculus Rift-based simulation is correct, they met with specialists from that area who identified the necessary content. In this case, the learning objectives revolve around the evacuation of a hospital during e.g. natural disasters. The storyboard includes the objective, a scene (room, environmental sounds, and alerts), required actions, the innate challenges and a possible redirection of the user's attention if they missed critical steps, such as closing a door or going the wrong way. Based on the results of a qualitative pilot study, the authors refine the simulation but do not elaborate on their results [27].

In a follow up paper in 2017, Farra et al. compared the memory retention for the skills learned of students that used the Oculus Rift with one group that used mouse and keyboard and another group that learned with written instructions [28]. In total, 100 students completed the interventions and participated in focus groups afterwards. As results of the evaluation the authors cited subjective statements of the students saying that they enjoyed the VRS despite of technical issues and physical responses such as motion sickness [28]. A detailed comparison of the three groups and objective data was lacking.

Moro et al. developed an application to teach anatomical knowledge using virtual reality [31]. The goal of their study was to compare desktop-based and mobile-based devices based on student test scores, perceptions and adverse health effects experienced during use. 20 participants were randomly assigned to either the Oculus Rift (desktop-based) or the Gear VR (mobile-based). Statistical analyses didn't reveal any difference according to test scores whereas students using the Gear VR reported significantly more often nausea and blurred vision [31].

Shewaga et al. developed a serious game teaching an epidural preparation [33]. They focused on comparing two means of locomotion in VR using a standing form of virtual reality, where you actually move around the room (called room-scale VR) and a sitting form of VR, where you change your position in the artificial environment by "teleporting" (called seated VR) using a HTC Vive HMD. 40 participants participated in an experiment using a within-participants design, where each participant plays the serious game under both conditions. During the game their tasks were to read a patient record, wash their hands, wear a proper operating room clothing and gather the appropriate tools needed for the epidural procedure. Results were achieved by using multiple questionnaires and gameplay metric data indicating a significantly higher immersion using room-scale VR [33].

2) Affective learning domain

Three articles were sorted into the affective domain. Kleven et al. studied how VR can be used in a) training communication skills in anaesthesia and surgical nurses (n=12) and b) providing information for non-medical personnel (n=12) [30]. The participants of the first study (a) had to role-play in four different medical scenarios, while their teachers took the roles of patients and relatives. After the sessions, the participants rated different aspects of the experience in a questionnaire and an interview. While the results were mixed, they did show a high degree of immersion, but also various levels of motion sickness. Most of the participants said it was quicker to understand the software interface using VR and five of the participants preferred the HMD as a computer screen while the rest rated it equally to a standard monitor. The participants commented that VR is capable of helping understanding certain topics [30]. The results are limited to descriptive statistical analyses only. Associations or diversity were not analysed.

Continuing on that project, Prasolova-Førland et al. used the environment to train interdisciplinary communication for nurses and doctors [32]. Same as above, role playing scenarios were developed beforehand, including different medical cases (e.g. geriatrics, gynecological). The development of the scenarios was guided by learning outcomes the students were expected to reach, such as practical skills, understanding the importance of structured communication with the stakeholders (i.e. nurses, doctors, patients, relatives), and knowledge about the collaborative team process. All participants (n=18) did the two-phase experiment, where the first phase was doing the roleplay on a desktop system and the second phase was doing it with VR goggles. All results collected from screen capture, observing, group interviews and a questionnaire, with the exemption of the results regarding physical discomfort, are not distinguishing between the desktop and the VR phase. The participants claimed to have achieved the outcome for learning that structured communication is important to full extent. All other outcomes were completely or at least partly achieved, no participant stated that they did not achieve the learning outcomes at least partly. In this study as well, results were mixed but generally positive. However, patients reported various, but rather high degrees of physical discomfort due to the HMD [32]. Their results were also limited to descriptive statistical analyses only.

Elliman et al. implemented a virtual hospital ward and activities for students to develop communication skills with a focus on communicating with patients suffering from dementia [3]. The script was developed by an expert practitioner for dementia care to ensure a realistic conversation. After going through the simulation without a headset, the participants answered as questionnaire and then repeated the simulation three more times to record the participants' performance over time. As a next step, the users would re-do the experiment whilst wearing an HMD and then filled out a questionnaire to collect. Quantitative and qualitative data with respect to the level of immersion. Although the authors did not provide detailed results of the pilot study yet, they did note that the cable-free implementation on the Google Cardboard, a DIY-HMD made of cardboard and two lenses, is especially useful [3].

3) Psychomotor learning domain

Only one article can be assigned to the psychomotor domain. In their exploratory pilot study Butt et al. compared a traditional partial task trainer with a game-based virtual reality (Oculus Rift) to practice urinary catheterization [26]. Based on a brief demographic survey 20 participants were assigned to the two groups using a matched-pair design. Each participant had one hour to practice urinary catheterization as often as he wishes to and was filmed during this practice. Evaluation included a usability survey, time on task, number of procedures completed in an hour, analysis of conversations and behaviour as well as a follow-up skill demonstration. The VR system was rated better usable and more enjoyable while the participants also practised significantly longer and more often. However, the follow-up skill demonstration didn't show any differences between the two groups [26].

4) Unspecified learning domain

Juanes et al. focused on a description of the building of a virtual environment [29]. Due to lack of a clear description of their task we could not assign it to a learning domain. They built a virtual environment of a hospital operating room without specifying possible target groups or tasks. Using the Oculus Rift, training with different operating room devices and monitors is possible [29].

B. Limitations

Due to our goal to give a descriptive overview of applications, we do not have a clearly defined outcome in this review. Further, we did not assess bias nor evidence, as recommended by PRISMA. Based on our choice of databases and limitations in publication language, we might have missed relevant published research. Existing VR products without underlying scientific publications have also not been included.

C. Conclusions and Recommendations

The reviewed articles show that SBT and Virtual Reality have a positive effect on student motivation and learning, but to be able to investigate and prove the positive effects of virtual reality with regard to learning outcomes, studies with bigger samples and more extensive statistical analyses are necessary. Furthermore the investigated outcome shouldn't be limited to user experience and health related effects. Only four out of the 10 articles included in the review examined objectively (with a test or comparison of multiple iterations) or subjectively (self-report) if the aimed learning outcomes (if specified) were achieved by the participants. Furthermore, compared to the identified applications in both the affective and cognitive learning domains, there is little research on HMD-based psychomotor skill training in nursing. However, nursing is an area where a variety of technical skills is required. With additional hardware, such as tracked gloves for detailed input, immersive VR can be a helpful addition to the status quo. During our review, we learned that the term "Virtual Reality" covers a wide range of technologies. This can probably be explained due to the early existence of the term when compared to the launch of consumer-grade immersive VR head goggles. Now, with the term "VR" abundant in technology and media, we propose the use of a clear distinction between the immersive and the non-immersive virtual reality technologies. In the science community, Milgram's concept of a virtuality continuum is widely accepted. Here, monitor based (non-immersive) video displays belong into the first class of hybrid display environments. Immersive Virtual Reality goggles belong into class 5, meaning a completely graphic display of artificial environments. Hence, the term "monitor based simulation" should be used when the simulation is not immersive [34]. To tap the full potential of VR, like it is done in other fields already, one could employ not only more realistic in- and output devices such as gloves, but also sensors for temperature, auditive feedback, vibration and even employ the olfactory sense.

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