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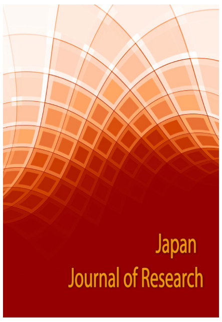

Immersive Virtual Reality to Learn How to Perform Lumbar Puncture

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Abstract

Introduction/Objectives: *Medical training necessitates the performance of potentially bloody procedures, requiring materials, adequate environments, and patients to familiarize trainee doctors with tools and surroundings. However, achieving this objective often proves challenging. Immersive virtual reality (VR) emerges as a promising tool to bridge the gap between theoretical knowledge and practical application in a realistic context. Here, we present the design of a virtual reality tool developed by Jaime I University of Castellón in collaboration with primary care of Department 21 of Orihuela, aimed at enhancing training opportunities for resident medical interns in a safe environment, as well as for medical students.*

Method: *A multidisciplinary team followed an interactive process to design and implement the tool. Through a "Focus Group," doctors, health experts, and computer developers from Jaime I University of Castellón developed the lumbar puncture learning tool.*

Results: *A prototype is in the validation phase as a training tool for performing lumbar puncture. It comprises a virtual training scenario where users must execute the lumbar puncture procedure.*

Conclusion: *VR presents a profitable and accessible alternative. A tool has been developed for lumbar puncture procedure training. The virtual environment created offers a safe and controlled space replicating the usual scenario for performing lumbar punctures, providing immediate feedback on technique and allowing students to adjust and correct their performance in real time.*

Introduction

Lumbar puncture (LP) is a medical procedure in which a thin, hollow needle is inserted into the lower part of the spine to remove a sample of cerebrospinal fluid (CSF). The needle is placed between two bones of the spine and introduced into the subarachnoid space. The CSF sample is then examined under a microscope to look for signs of infection, inflammation, or disease, such as central nervous system (CNS) conditions or neoplasms. Additionally, a lumbar puncture may be performed to measure or reduce CSF pressure around the spinal cord and brain, administer drugs (chemotherapy or anesthetic medications) directly into the CSF, or inject contrast dye for certain imaging tests.

Performing a lumbar puncture can be challenging for many doctors, especially in emergency situations, due to its complexity. Practice using mannequins requires significant setup time, equipment preparation, and post-practice cleanup. Moreover, access to mannequins may be limited, and their bulky size necessitates ample space for simulation. Virtual Reality (VR) presents an exceptional opportunity to simulate realistic situations in immersive and safe 3D environments. Numerous studies have demonstrated that VR can enhance technical skills and facilitate practical learning, thereby improving student engagement and motivation through personalized experiences and teamwork facilitation.

The use of VR as a training tool in the medical field has experienced continuous growth. For instance, in 1994, Bostrom introduced a virtual simulator with haptic feedback for lumbar puncture procedures, while in 2008, Kanumuri compared the effectiveness of VR and computer-enhanced videoscopic training devices for laparoscopic tasks. Studies, such as the one presented by Farber, have highlighted the effectiveness of virtual environments in emphasizing specific maneuvers like lumbar puncture, providing an authentic tactile and visual experience in needle insertion. Similarly, techniques with similar characteristics, such as acupuncture, have also been studied.

This paper aims to develop a virtual reality tool to assist in learning the lumbar puncture technique. Medical training often necessitates the performance of potentially bloody procedures, requiring materials, adequate environments, and patients to familiarize

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the trainee doctor with the tools and surroundings. However, achieving this objective proves challenging. Immersive virtual reality emerges as a promising tool to bridge the gap between theoretical knowledge and practical application in a realistic context. Here, we present the design of a virtual reality tool developed by Jaime I University of Castellón in collaboration with primary care of Department 21 of Orihuela. The goal is to enhance training opportunities for resident medical interns in a safe environment, as well as for medical students.

User-Centered Design (UCD) was employed, which is an interactive process that incorporates the needs, objectives, and preferences of users into the design. The aim is to create intuitive, usable, and satisfying designs. UCD encompasses stages such as user research, requirements gathering, prototyping, testing, and evaluation. By involving the user throughout the design process, it ensures that the final product meets expectations and fulfills needs. This approach enhances the user experience by creating products and services that are more effective, efficient, and enjoyable to use. The VR tool provides an immersive and realistic 3D environment, enabling MIR students and doctors to safely gain experience in the lumbar puncture maneuver. The objective of this tool is to offer accessible and effective training in lumbar puncture, leveraging the benefits of VR.

Methods

A multidisciplinary team, composed of physicians with supervisory roles in teaching, and a professor who specializes in the design and development of immersive virtual reality experiences, collaborated with researchers in their respective fields. The remainder of the team consisted of virtual environment developers.

A series of interviews were conducted to establish the requirements of the virtual environment. A "Focus Group" was convened where doctors, health experts, and developers defined the following functional requirements:

1. Preparation of Necessary Materials:

All materials required for the procedure must be arranged in a clean and accessible manner, including:

- Sterile gloves
- Coats
- Sterile cloths
- masks, which should be worn by all personnel present in the room to prevent sample contamination and minimize infection risk for the patient
- Sterile gauze dressings
- Antiseptic solution (0.5% alcoholic chlorhexidine)
- Lumbar puncture needles
- Sterile tubes for CSF collection (minimum 3)
- Anticipated pseudoanalgesia drugs may be necessary.

2. Patient Preparation:

- The patient's skin should be anesthetized before the procedure, unless contraindicated, commonly using 2.5% lidocaine.

- The puncture site is determined by locating the posterior superior iliac spines and drawing an imaginary perpendicular line between them. The intersection of this line with the spine indicates the puncture space, typically L3-L4 or L4-L5 depending on the patient's age.

- Preferably, the puncture site is covered with a transparent occlusive dressing.

3. Technique Execution:

- Ensure proper hand hygiene with alcohol solution or soap and water.

- Clean the patient's skin and disinfect the puncture area with an antiseptic using concentric circular movements from the inside out (Figure 1).

- Personnel performing the puncture should don sterile clothing, including gown, mask, and sterile gloves. A fenestrated sterile cloth is then applied between the stretcher and the patient.

- Anatomically locate the puncture point as described above.

- Perform the puncture (Figure 2).

- Remove the stylet and collect CSF without aspirating from the LP needle.

- After CSF collection, replace the stylet and remove the needle, then apply sterile gauze over the puncture site with slight pressure.

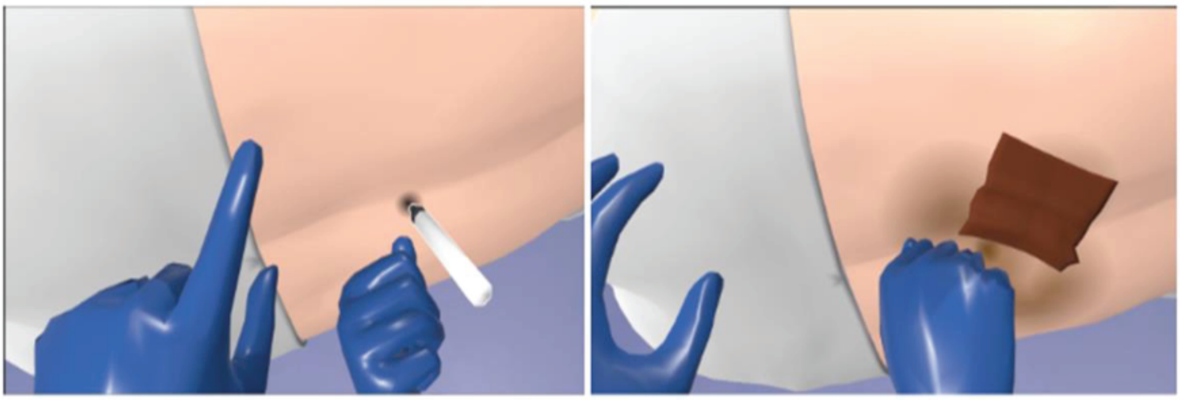

Figure 1: *The patient´s skin will be cleaned and the skin will be desinfected with an antiseptic. Area where the puncture will take place with concentric circular movements from the inside out.*

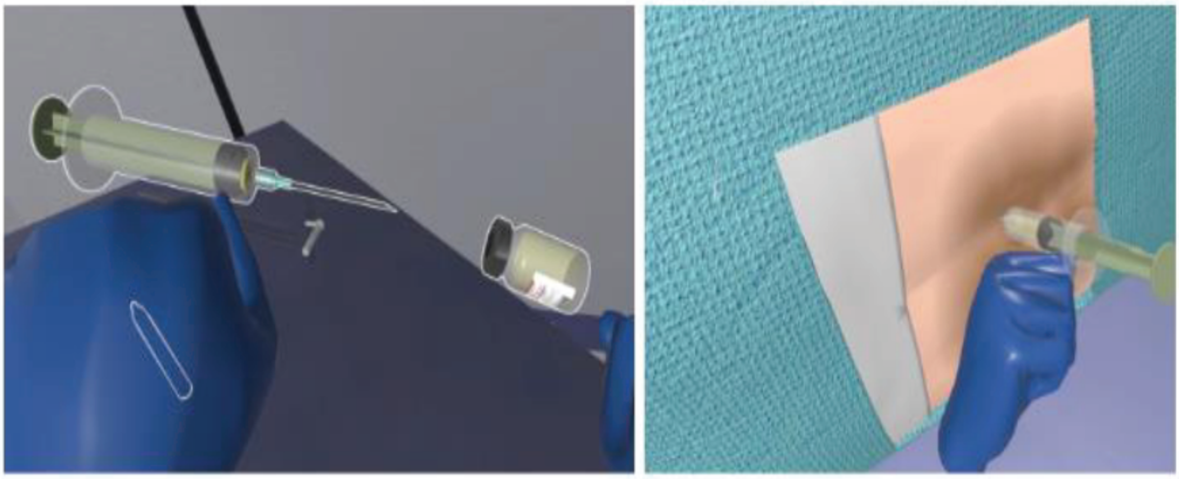

Figure 2: *Once the point is located, the puncture will be performed.*

The User-Centered Design (UCD) approach was utilized for the design process, focusing on understanding end-users thoroughly to meet their needs and validate design performance in a virtual environment. Collaboration with the Benejuzar health center involved collecting training needs and identifying issues in the teaching process. The UCD approach was guided by Design Thinking (DT) problem-solving methodology, involving empathizing with users, defining problems, generating solution ideas, prototyping, and testing.

jnUnity 3D (version 2020, build 256) was employed to create the virtual learning environment, along with Open XR libraries for VR, including the Interaction XR Toolkit, to connect development to the Oculus Quest 2 device (version 258). Scenes and elements were modeled using Blender. Development was conducted on a computer equipped with an Intel® CoreTM i7-10700F CPU and Nvidia GeForce RTX 3030 Ti graphics card with 8GB of memory (version 260), facilitated by Jaime I University of Castellón.

Results

This work is currently in a preliminary phase, wherein the tool is being evaluated by experts for subsequent experimentation with medical students or resident internal physicians. The results presented here depict the final virtual environment excluding validation or evaluation results. Control of the application is exclusively through the Meta Quest 2 controllers, providing haptic feedback in the form of vibration when interacting with objects within the virtual environment.

The training scenario unfolds in a doctor's office, where the user is tasked with performing the lumbar puncture. The patient lies on a stretcher in the left lateral decubitus position with knees bent. A screen displays the necessary steps for the procedure, updating with messages as correct steps are followed and highlighting errors while reminding the user of skipped steps. The environment is designed to enable users to correct errors and resume the activity from the point immediately before the error. Upon successful completion of all steps, the system congratulates the user with visual information. Throughout the process, users can explore the scene, examine instruments, and interact with them. Besides practicing the steps, the system immerses users in an environment that familiarizes them with both the procedure and its context. Users can repeat the simulation as needed, review steps, and correct actions. All attempts made are recorded in the user's profile conducting the simulation, allowing teachers to assess the progress and skills of participating students.

Conclusions

Traditional training methods, especially those involving medical simulation equipment, can be expensive or challenging to replicate. VR presents a cost-effective and accessible alternative. A tool has been developed for lumbar puncture procedure training, offering a safe and controlled virtual environment replicating the usual scenario. The environment provides immediate feedback on technique, enabling users to adjust and correct their performance in real-time. Although VR-based training have been technologically accepted with promising results, further research is needed, particularly regarding student adherence and motivation for their use. The immediate next step is to validate the described environment with medical users, comparing it with traditional methods. It is hypothesized that this comparison will demonstrate good technology acceptance and learning improvement.

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