Visual Guidance for Infant Lumbar Puncture Training in XR

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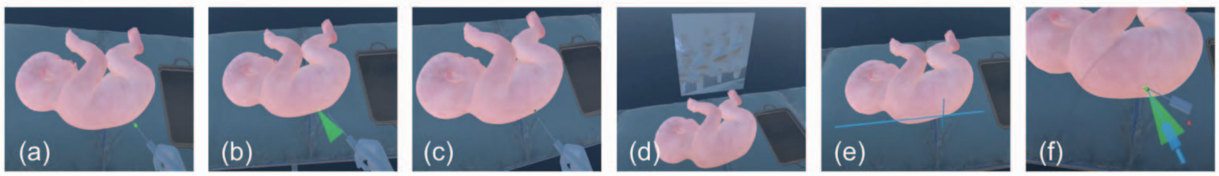

Figure 1: Visualizations supported by VirtuaLP: (a) Depth indicator. (b) Angle indicator. (c) Position indicator. (d) X-ray view. (e) Landmark hints. (f) Ghost needle (within angle indicator).

Abstract

Lumbar puncture is a necessary staple of pediatric diagnostic medicine. We developed VirtuaLP, an immersive training system for infant lumbar puncture that runs on a standalone extended reality headset, allowing for a more accessible and flexible training experience. We provide a suite of visual hints to guide the student through the procedure. Additionally, VirtuaLP provides feedback on each component of insertion accuracy, including ideal position, depth, and angle.

Index Terms: Computing methodologies—Computer graphics—Graphics systems and interfaces—Virtual Reality; Human-centered computing—Human–computer interaction (HCI)—Interaction paradigms

1 Introduction

We present VirtuaLP, an extended reality (XR) system designed to train physicians to improve their performance in infant lumbar puncture. Lumbar puncture (LP) is a medical procedure that involves inserting a needle between the L4 and L5 vertebrae of the patient to collect cerebrospinal fluid (CSF). To successfully perform LP, the operating physician must be mindful of the location, angle, and depth of the needle insertion, with each having a specific range of acceptable values. Not adhering to these ranges could result in bleeding or failure of the procedure, impacting the clinical outcome. To help trainees rapidly and repeatably practice the procedure and test themselves, we designed VirtuaLP to simulate in XR the task of needle insertion for infant LP. A suite of visualizations allows a trainee to directly see the acceptable ranges for each of the important parameters of the procedure (position, depth, and angle) to build an intuitive understanding of how to perform LP.

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2 Related Work

Huang et al. [4] introduced a mixed reality LP simulator that overlays internal anatomical structures on a manikin (medical dummy) to help guide the trainee to a correct insertion point. Xie et al. [7] developed a VR lumbar puncture simulator that evaluates a wide range of procedural skills with numerous metrics, but doesn't contain metrics for the insertion process or display visual guidance. This simulator also requires an extensive setup including an active force feedback device. Roehr et al. [5] developed and evaluated the effectiveness of a VR training system for adult LP, providing an interactive simulation of the anatomy and haptic feedback if the trainee punctured too deep. Vrillon et al. [6] demonstrated that a 3D VR video of LP for adults increased satisfaction and perceived benefit when viewed by inexperienced trainees. While these previous systems highlight the potential of immersive technologies for LP training, they either lack explicit visual guidance for correct needle insertion or require a more elaborate setup than a standalone VR headset and its controllers.

VirtuaLP addresses these gaps by integrating visualizations for angle, depth, and position, as well as a real-time feedback mechanism. Its compatibility with standard XR headsets enhances accessibility, allowing for frequent and practical training.

3 Methods

3.1 Design Process

Two coauthors are physicians with experience in LP. Their clinical and teaching experience was vital in determining the visual hints and feedback to include. They provided input throughout the entire design process, which was used to make improvements and suggest future work.

3.2 System Overview

VirtuaLP was developed using Unity version 2022.3.12f1 and deployed on Meta Quest 2 and 3 headsets. We assumed that the trainee has basic familiarity with LP and aimed to create a training environment that concentrates on correct needle insertion. At startup, the trainee is prompted with a main menu that allows them to enable or disable any of the available hints before proceeding to the training session. There, the trainee is placed beside a hospital bed. The trainee can perform the simulation either in a virtual room or in a passthrough mode where they can see their real-world surroundings. The infant[1] lies on the bed and the needle is placed on a tray, within

[1]https://www.turbosquid.com/3d-models/fetus-human-3d-1501977

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arm's reach of the trainee. The trainee uses the XR controller to pick up the needle. They then must carefully position and orient the needle to precisely puncture the infant's skin between the L4 and L5 vertebrae, ensuring accurate collection of CSF while avoiding contact with organs or bones. Inspired by Ban and Ujitoko [2], VirtuaLP slows down the motion of the virtual hand that holds the needle relative to the respective physical hand during the insertion, creating a visual illusion of resistance to make the simulation feel more realistic.

Once the needle is inserted, the trainee uses the XR controller to pull out the blocking stylet (an inner needle restricting CSF flow). When the stylet has been removed, the procedure ends and the trainee is presented with information about their performance. If the procedure is successful, the trainee will see CSF drip out of the needle and into a test tube. If the procedure is unsuccessful, the infant will cry, blood will drip out of the needle, and a "ghost needle" will appear at the correct insertion location, orientation, and depth. If the needle hits the spine during any point of the insertion, VirtuaLP provides haptic feedback through controller vibration. After completing the insertion, the trainee can go back to the menu and reattempt the procedure by pressing a button on the controller.

3.3 Visual Hints

We developed six visual hints to aid trainees, which can be seen in Figure 1:

a **Depth Indicator:** The ideal range of insertion depth for the needle is shown by a cylinder at the appropriate location on the needle. Our physician coauthors specified a range of 1–1.2 cm, based on clinical experience.

b **Angle Indicator:** We locate a pyramid at the insertion point to show the trainee the valid range of insertion angles: 15–45° along the spinal column (vertical relative to the head) and 0–5° perpendicular to the spinal column (horizontal relative to the head) [1].

c **Position Indicator:** We place a small virtual sphere on the patient's skin at the correct insertion point, located between the L4 and L5 vertebrae.

d **X-Ray View:** Following the visualizations of Huang et al. [4], our system also has an "X-ray" picture-in-picture camera that is attached to the tip of the needle. The camera allows the trainee to see a spinal column model through the skin of the patient to get a better sense of the trajectory of the needle.

e **Landmark Hints:** Physicians palpate anatomical landmarks, such as the spinal column and iliac crest, to locate the insertion point. Since we already use the only active haptic feedback our controllers provide (vibration) to warn users if they hit the spine, we instead use visual feedback to represent landmarks: two 3D lines along the spinal column and iliac crest.

f **Ghost Needle:** In the event of an erroneous insertion, the trainee is shown a "ghost needle" displaying the correct position, orientation, and depth. This provides the trainee with feedback on their performance by contrasting differences in needle position and angle.

3.4 Simulation and Metrics

Upon completion of the procedure, VirtuaLP presents a trainee with a panel containing metrics quantifying their performance, including vertical and horizontal angles, and distances from the ideal position along both axes. Metrics that were out of range, resulting in an unsuccessful procedure, are highlighted to communicate to the trainee what they did wrong. The virtual infant's skin briefly changes color to red to indicate failure or green to indicate success.

4 Conclusions and Future Work

We presented VirtuaLP, a training simulation for infant lumbar puncture that runs on standalone XR headsets. The system allows trainees to perform the insertion component of the procedure, monitoring needle position, depth, and angle. VirtuaLP composes the simulation realistically, with immersive components that mimic the real-life procedure. It frames the training with visualizations that guide trainees to perform the procedure correctly.

In the future, we intend to perform a user study with medical students to validate system usability and teaching effectiveness. The physician coauthors were satisfied with the majority of the hints developed, with the exception of the depth indicator. They felt it was not sufficiently intuitive and we intend to improve it.

We would like to expand VirtuaLP to more fully tackle the problem of *competency-based education* [3], the idea that medical students need to be competent in a procedure before working with live patients. To accomplish this, VirtuaLP could be extended to include a full end-to-end simulation of the entire procedure, not just the insertion component, in the spirit of Xie et al. [7], allowing for summative learning with a commercial XR headset and guidance visualizations.

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