Chapter 8

MONA: A Robotic Patient Simulator for Occupational Therapists Training

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Abstract

Most developed countries are facing the challenge of ageing populations and the associated care demands. Robotics and artificial intelligence (AI) can provide support for healthcare professionals. In this study, we present MONA, a robotic manikin for training Occupational Therapists (OTs) in patient assessment scenarios. The manikin incorporates over 4000 tactile sensing points to capture pressure distribution and magnitude during interactions. Silicone layers provide skin-like texture, and a motorised knee simulates mobility impairments. Sensor data are processed real-time to trigger adaptive responses, including vocal reactions and leg movements when pain thresholds are exceeded. Trainers can configure patient profiles, monitor sessions through a graphical user interface (GUI) and record data for later analysis.

The system was successfully deployed in a preliminary evaluation session with OT professionals, where it provided realistic and varied patient scenarios. Data from these interactions were captured in a questionnaire that will inform the development of hardware features and AI-driven patient models to further enhance training realism and adaptability.

Keywords: *Robot Patient Simulator, Tactile Sensing, Medical Training, Occupational Therapy*

Introduction

Robotics and artificial intelligence (AI) promise to revolutionise the healthcare sector[1] and together might provide a solution to one of the great challenges facing developed nations: population ageing. In the United Kingdom (UK), 18% of people are aged 65 or over[2] and globally this group is expected to double to 1.6 billion by 2050[3]. Meeting their care needs will require significant efforts and innovations to support care professionals and reduce the strain on the workforce.

[1]Pierre E. Dupont et al., “A Decade Retrospective of Medical Robotics Research From 2010 to 2020,” *Science Robotics* 6, no. 60 (November 10, 2021), https://doi.org/10.1126/scirobotics.abi8017

[2]UK Parliament. “The UK’s Changing Population.” House of Commons Library, July 16, 2024. Accessed September 6, 2025. https://commonslibrary.parliament.uk/the-uks-changing-population/

[3]United Nations, Department of Economic and Social Affairs, Population Division. *World Population Prospects 2022: Summary of Results*, 2022.

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During training, students are given very limited opportunities to experience with real patients[4], and robotic patient simulators can provide a worthy alternative[5]. Existing systems, though, usually only recreate just one limb, or half of the body and lack cognitive behaviour[6]. Some full-body high-fidelity patient simulators (HFPS) are available, but have limited sensors and actuators, focusing on breathing and hearth-related conditions. Crucially, large-area tactile sensing is still missing. Medical diagnosis or physiotherapy frequently requires interaction through touch[7]. Capturing and processing such information onboard the HFPS is therefore essential for it to simulate realistic reactions, such as pain after a forceful interaction, or a relaxed state after a calming stroke.

We present MONA, the first full-body robotic patient simulator with integrated tactile sensing for AI-driven reactive control (Figure **1**). The robot was developed in collaboration with Occupational Therapists (OTs) to decide sensor morphology and placement for two assessment scenarios: lower-leg range of motion and seating posture assessments. The robot was presented to 13 OTs, and their feedback was captured in a questionnaire that confirmed its satisfactory performance for preliminary deployment with OT students.

Materials and Methods

The robot design

Built from a modified nursing manikin, MONA has an RMD-X8-P9-25-C-N motor (MyActuator, China) integrated into the left knee. This unit provides high torque, backdrivability, and can fit within the knee profile. The manikin's left thigh and full lower leg were replaced with skin-coloured Polylactic Acid (PLA) substitutes, 3D printed on a Carbon X1 printer (BambuLab, China). Cables run internally for a clean, natural appearance.

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[4]Angelo Dante et al., "From High-Fidelity Patient Simulators to Robotics and Artificial Intelligence: A Discussion Paper on New Challenges to Enhance Learning in Nursing Education," in *Advances in Intelligent Systems and Computing*, 2020, 111–18, https://doi.org/10.1007/978-3-030-52287-2_11; Shun Ishikawa et al., "Assessment of Robotic Patient Simulators for Training in Manual Physical Therapy Examination Techniques," *PLoS ONE* 10, no. 4 (April 29, 2015): e0126392, https://doi.org/10.1371/journal.pone.0126392

[5]Zhifeng Huang et al., "Robot Patient Design to Simulate Various Patients for Transfer Training," *IEEE/ASME Transactions on Mechatronics* 22, no. 5 (July 25, 2017): 2079–90, https://doi.org/10.1109/tmech.2017.2730848; Nancy Robert, "How Artificial Intelligence Is Changing Nursing," *Nursing Management* 50, no. 9 (August 17, 2019): 30–39, https://doi.org/10.1097/01.numa.0000578988.56622.21; S. Abe et al., "Educational Effects Using a Robot Patient Simulation System for Development of Clinical Attitude," *European Journal of Dental Education* 22, no. 3 (November 1, 2017): e327–36, https://doi.org/10.1111/eje.12298
; Dante et al., "From High-Fidelity Patient Simulators," 111–18; Ellie Kazemi and Lisa M. Stedman-Falls, "Can Humanoid Robots Serve as Patient Simulators in Behavior Analytic Research and Practice?," *Behavior Analysis Research and Practice* 16, no. 3 (June 30, 2016): 135–46, https://doi.org/10.1037/bar0000046

[6]Dante et al., "From High-Fidelity Patient Simulators," 111–18.

[7]Raffaele Andrea Buono, Minna Nygren, and Nadia Bianchi-Berthouze, "Touch, Communication and Affect: A Systematic Review on the Use of Touch in Healthcare Professions," *Systematic Reviews* 14, no. 42 (2025), https://doi.org/10.1186/s13643-025-02769-4; Liang He et al., "Robotic Simulators for Tissue Examination Training With Multimodal Sensory Feedback," *IEEE Reviews in Biomedical Engineering* 16 (April 19, 2022): 514–29, https://doi.org/10.1109/rbme.2022.3168422

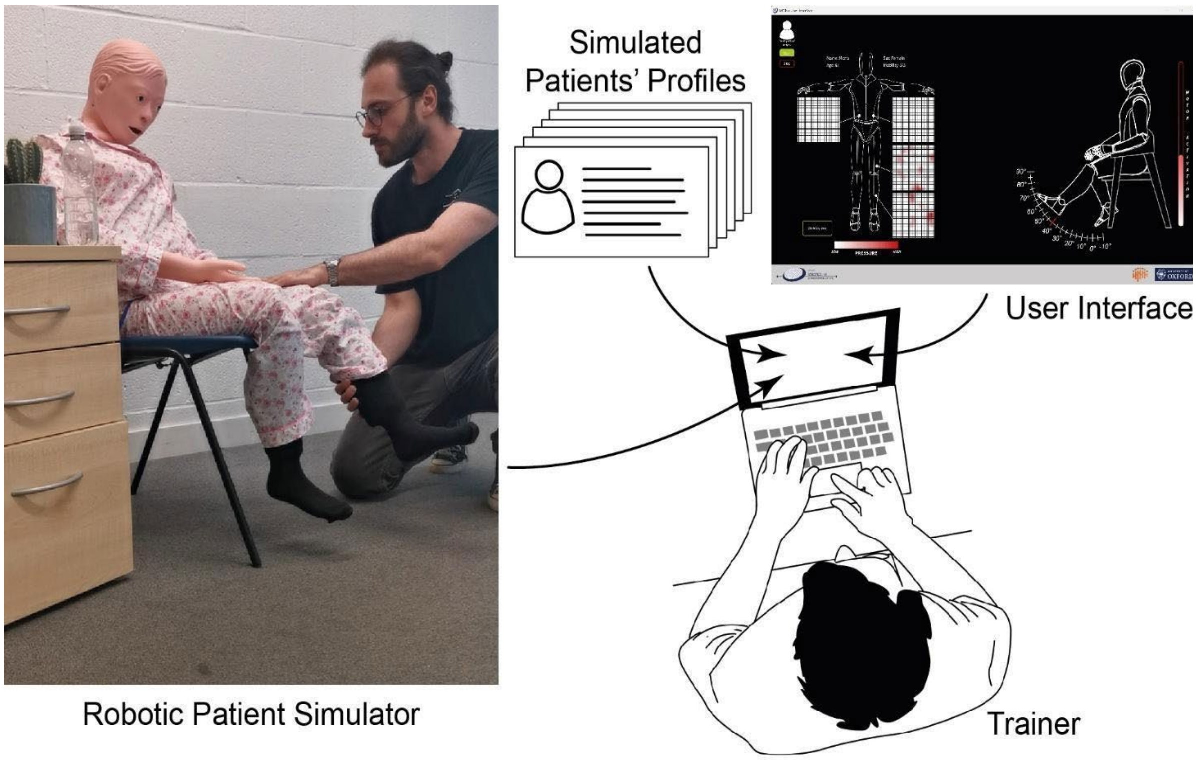

Figure 1: The robotic patient simulator for occupational therapists training and its intended use case.

Four FSR sheets (15 cm × 15 cm) record OT-robot interactions through custom-designed USB-powered readouts (ESP32S3, ADG731, AD4000, and SN74HCS595) for fast sampling of the 256 sensors per sheet. After discussions with OTs and having observed them perform the target assessments on the manikin, sensors were placed around the left lower leg, over the left thigh, and over the left and right ilium bones, symmetric about the manikin's sagittal plane. Additionally, 3.5 mm-thick silicone layers (DragonSkin 00-10, SmoothOn, US) cover the leg sensors for skin-like feel; in the pelvis, an additional layer of softer Ecoflex 00-30 silicone replicate fatty tissues. A flexible PCB with 16 RGBW LEDs is placed under the lower-leg silicone layer to simulate conditions like bruising or oedema. Finally, a loudspeaker enables pain vocalisation.

The user interface

The Python-based program consists of two threads. One acquires sensors and motor data for logging, the other processes the data for visualisation and to feedback information to the manikin. The interface displays one heatmap for each FSR sheet, while a protractor and a linear gauge show the knee angle and motor output torque respectively.

At launch, the trainer selects a patient profile defining age, sex, mobility, pain thresholds for sensor regions, and individual LED colours. When pressure on a skin area exceeds its threshold, the loudspeaker plays pre-recorded sounds, varying by sex and pain intensity. Motor torque is programmed as a linear function of knee angle, with slope and maximum set by the mobility range (1–3) in the patient profile. Behaviour was tuned with feedback from OTs to model mobility from normal to arthritic knees. If lower-leg pain thresholds are crossed, the motor triggers a sudden backward jerk, simulating spasm and muscle tension.

The questionnaire

The questionnaire consisted of three parts: (1) demographic of the participants, previous touch-related training experiences, and general perceptions about robots, (2) participants' feedback after simulating a passive range of movement assessment on the lower leg, and (3) longer reflection after the interaction with MONA. All questions related to the manikin were to be answered on a scale from 1 (not at all) to 5 (very much).

A total of 13 OTs (10.6 years of experience on average, SD=11.14) completed the questionnaire (c. 20 mins), with six interacting with the robot in full (c. 10 mins). The interaction was supervised by the platform developers for health and safety. Other participants could observe the interactions whilst filling the questionnaire.

Results and Discussion

An overwhelming 77% of OTs highlighted a strong need for systems like MONA during training (Figure **2**), with the remaining 23% finding it somewhat useful. Additionally, 54% reported very little to no training in touch and its functional or affective use, and only 7% gave a top rating, though all strongly agreed that touch training is important for OT students.

Regarding robot interaction, 50% found MONA somewhat to very useful in its current form, while 83% believed an improved version would be an important tool. MONA's responses to painful stimuli, physically and verbally, were appreciated, though 66% reported pain thresholds were too low. A future ability to understand vocal prompts was desired by 66%, and 83% found LED visual cues for sore spots very acceptable.

Key improvements relate to appearance and realism (joint degrees of freedom, leg weight), although 50% felt the knee motor resistance adequately represents low mobility, supporting the current motor choice. Half of participants found the interface intuitive, with 33% rating it very intuitive. All agreed MONA is an important training tool for OT students.

Conclusion

In summary, MONA addresses key needs of OT trainees by enabling early and frequent practice with patients in a controlled setting. Standardised, repeatable scenarios, and recorded interactions provide insights into how clinical professionals use touch, both for assessment and non-verbal communication. This allows comparisons between trainees and experienced OTs and the creation of datasets for more realistic patient profiles, a focus area following OT feedback.

Having validated the current version, we are already working on an AI pipeline (speech-to-text, LLM, text-to-speech) to understand and respond to trainee prompts. Interaction datasets will support gesture recognition algorithms, improving robot responses to tactile cues. Future improvements will feature a more articulated manikin for enhanced realism. We hope MONA will serve as a first-of-its-kind device to open new avenues of medical AI-empowered training, for better healthcare and a more sustainable future.

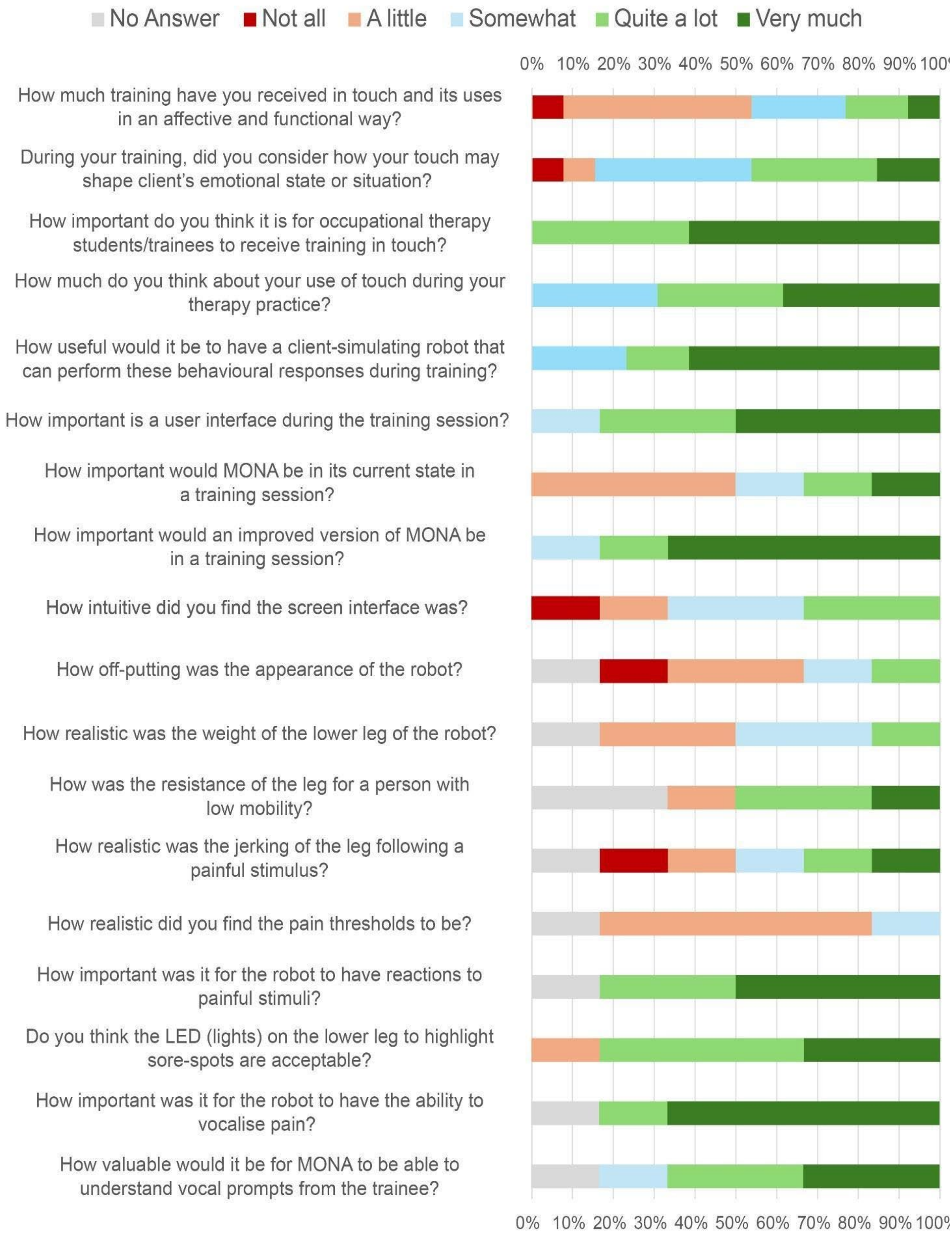

Figure 2: Summary of the questionnaire results of the preliminary deployment with 13 OTs.

Acknowledgements

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Ethical Approval

Ethical approval was acquired via UCL UCLIC Research Ethics Committee [UCLIC_2022_001_Berthouze].

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