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RESEARCH PROTOCOL

Usability and educational potential of a virtual reality software for training in a target-controlled infusion pump handling: a pilot study

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ABSTRACT

Background: Total Intravenous Anesthesia involves automated and controlled infusion of anesthetic drugs. Despite advancements in smart infusion pump technology, errors in their use remain significant, threatening patient safety. This study focused on the development and usability evaluation of a virtual reality software designed to train anesthesiologists in handling target-controlled infusion pumps during total intravenous anesthesia. Methods: A co-creation process guided the pilot development of the software. Participants engaged in a simulated virtual reality scenario, executing tasks that mimicked real-world use of a target-controlled infusion pump. Usability was assessed using the System Usability Scale questionnaire and qualitative feedback. Conclusion: The System Usability Scale score of 67.32 indicated a marginally acceptable level of usability. Participants positively evaluated the software in terms of realism, immersion, interactivity, and autonomy in performing tasks. Although qualitative evaluations were favorable, usability findings indicated areas for improvement to enhance the user experience and educational effectiveness of the tool.

KEYWORDS

Virtual reality; software; teaching; anesthesiology; infusion pumps

INTRODUCTION

Total Intravenous Anesthesia (TIVA) is a well-established anesthetic technique that exclusively relies on intravenous infusion for the administration of drugs. While inhalational general anesthesia remains a predominant method in many regions, including the United Kingdom and Ireland, TIVA is indispensable in specific scenarios. These include cases of malignant hyperthermia, where inhalational agents are contraindicated, or when patients have a high risk of postoperative nausea and vomiting[1,2].

To ensure the safe and effective implementation of TIVA, anesthesiologists must possess an in-depth understanding of pharmacokinetics and pharmacodynamics, alongside technical expertise in using infusion devices. Furthermore, they must accurately interpret intraoperative monitoring data, such as hemodynamics and the patient's level of consciousness. Smart infusion pumps, equipped with advanced features like dose error reduction systems

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(DERS) and drug libraries, are integral tools in TIVA. These devices allow for precise adjustments to infusion rates and bolus doses, helping to reduce the likelihood of human error[3].

Despite these advancements, several challenges persist. Errors such as incorrect programming, failure to select the appropriate drug from the library, and the silencing of alarms to avoid workflow interruptions remain common[4]. Pang et al.[5] highlighted the persistent nature of these errors, even with the widespread adoption of smart pumps. The National Audit Project further underscores the importance of comprehensive education and training, identifying inadequate preparation as a critical factor in adverse anesthetic events[6].

Realistic simulation has become a cornerstone of medical education, particularly in anesthesiology, where practitioners must develop complex technical and decision-making skills. However, the high costs of traditional simulation tools and the limited availability of skilled instructors often hinder broader implementation[7]. Virtual reality (VR) technology offers a promising alternative. By creating immersive and interactive learning environments, VR can significantly enhance engagement and motivation, facilitating quicker and more effective learning outcomes. Additionally, VR is more cost-effective and scalable compared to traditional high-fidelity simulation methods, making it an attractive option for educational institutions[8,9]. Compared to more traditional high fidelity realistic simulation methods, virtual reality can represent a lower financial cost for health education institutions and even a system for assessment and evaluation of anesthesiologists[10].

This study aimed to develop and evaluate a VR-based teaching tool tailored to anesthesiology training, with a particular focus on its usability for training with target-controlled infusion pumps.

METHODS

This descriptive and exploratory pilot study was designed to develop and evaluate the usability of VR software for anesthesiology training. The research followed the Consolidated Criteria for Reporting Qualitative Research (COREQ) guidelines and adopted a co-creation model inspired by Millard et al.[11] This approach emphasizes iterative development, integrating feedback from end-users to refine the software and ensure it meets their needs.

Development process

The development process involved five key phases:

1. **Scope definition**: Educational objectives and software functionalities were outlined, focusing on realistic simulation and interactivity.
2. **Graphic refinement**: The software's visual elements were designed to ensure high levels of realism and user engagement.
3. **Technology implementation**: Features such as interactive interfaces and task-based simulations were incorporated, aligning with predefined learning goals.
4. **User feedback and iterative refinement**: Early user feedback was gathered and integrated into subsequent development cycles to address identified issues.
5. **Finalization and usability evaluation**: The software was prepared for formal testing.

Participants and study environment

Participants were anesthesiologists from two Brazilian hospitals (both with accredited recognized residency training programs), categorized into four groups based on their training level: R1 (first-year residents), R2 (second-year residents), R3 (third-year residents), and staff anesthesiologists. Inclusion criteria required participants to be certified anesthesiologists or enrolled in a residency program. Those with prior experience using the VR software were excluded.

The study was conducted in a controlled room, free of physical risks for the participants. They used an Oculus Quest 2 headsets preloaded with the simulation software (Figure 1). Their tasks were to self-conduct a total intravenous anesthesia technique into the virtual environment represented by a surgical room with anesthesia and monitoring equipment, as well as a Terufusion target-controlled infusion pump (model TE 372 TCI/TIVA) connected to a virtual patient (Figure 2).

Usability assessment

The System Usability Scale (SUS), developed by Brooke[12] was used to assess the software's usability. This validated tool measures essentially the effectiveness (the extent to which users can achieve their objectives using the tool); the efficiency (the effort and resources required to complete tasks); and satisfaction (the overall user experience and ease of use).

Participants rated 10 statements on a Likert scale from 1 ("strongly disagree") to 5 ("strongly agree"). Odd-numbered items were scored by subtracting 1, while even-numbered items were calculated by subtracting the score from 5. The sum of these values was then multiplied by 2.5 to derive the final SUS score. Qualitative feedback was also collected through open-ended interviews, allowing participants to share insights on their experiences and suggest improvements.

Figure 1. Experimental setup: residents using the Oculus Quest 2.

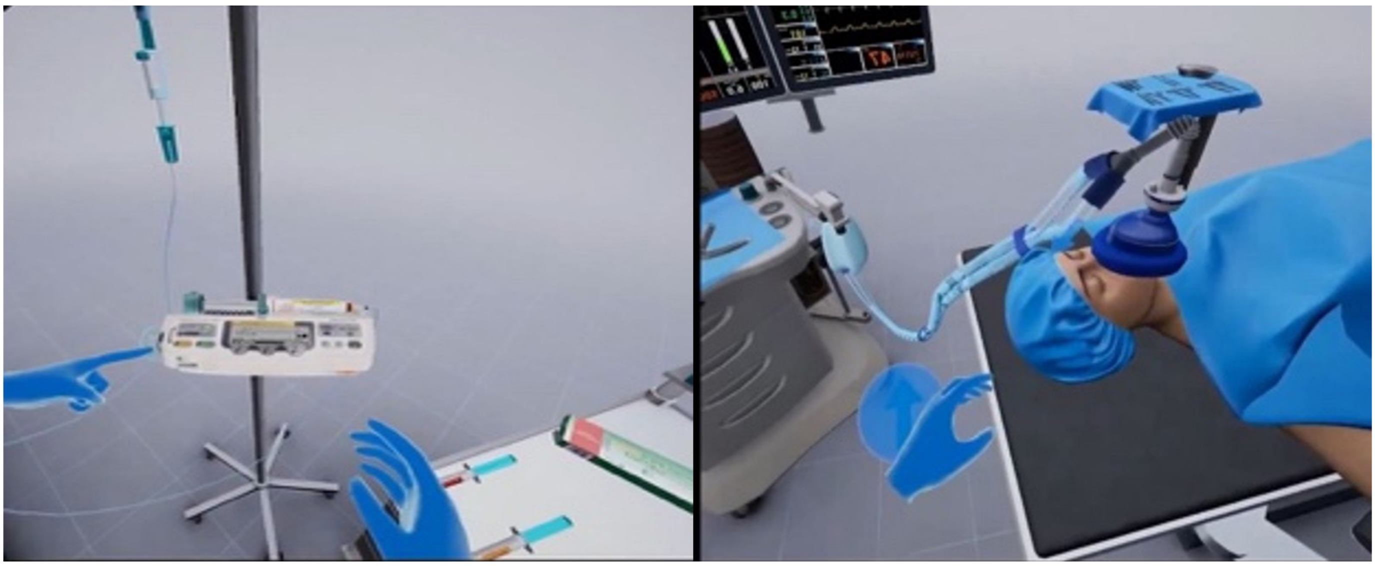

Figure 2. Virtual reality environment view.

Statistical analysis

Descriptive statistical analysis was performed using free software R-Project. To assess internal consistency, **Cronbach's alpha** was calculated. Additionally, an ANOVA with Bonferroni correction was conducted to explore potential relationships between questionnaire items. Further analysis of participant feedback was performed using qualitative coding techniques to identify common themes related to usability and user experience.

Figures 3–5 illustrate participant responses, highlighting immersion, graphical realism, and overall satisfaction. While the graphics and interactivity were praised, some participants encountered challenges with joystick controls and the fit of the VR headset over glasses.

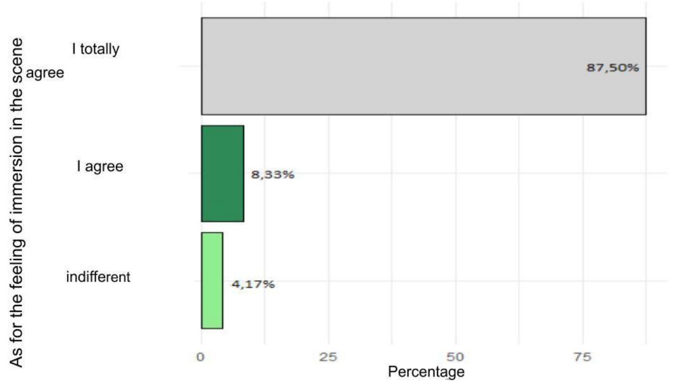

Figure 3. Immersion.

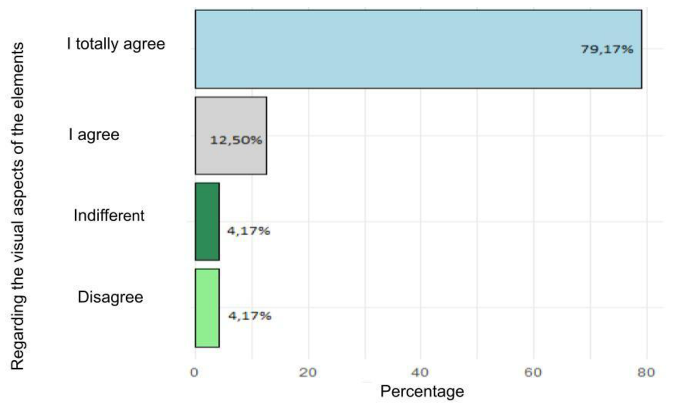

Figure 4. Realism.

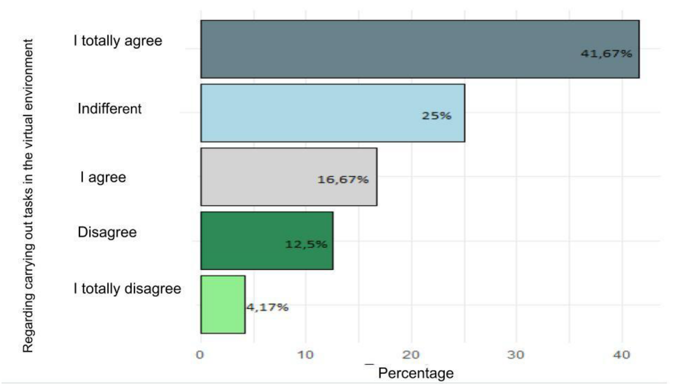

Figure 5. Overall satisfaction.

RESULTS

Demographics

The study included 28 participants, of whom 60.71% were under 30 years old. Males comprised 71.43% of the cohort (Figure 6).

Usability metrics

We obtained an average SUS score of 67.32 (Figure 7) which could be classified as marginally acceptable, according to Brooke at al.[12].

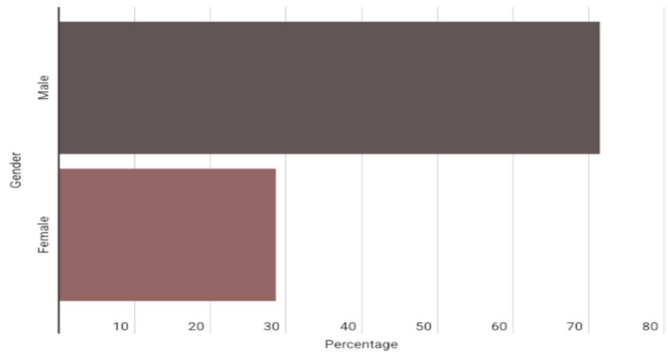

Figure 6. The gender distribution of the user population.

Graph 1:

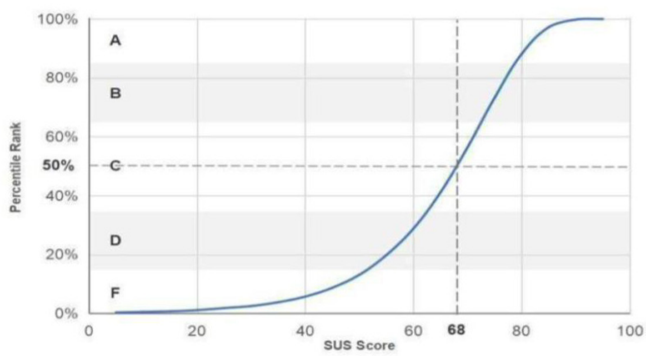

Figure 7. The result of the average SUS score in a percentile curve, demonstrating a marginally acceptable evaluation by the users.

Frequent use: 60.71% strongly agreed they would frequently use the software, while 10.71% expressed no interest.

Ease of use: 46.43% found the tool intuitive, though 50% required some level of technical assistance.

Functionality integration: 72% reported that the software's features were well-integrated.

Learning curve: 79% indicated they quickly adapted to the tool, while 95.8% felt immersed in the virtual environment.

DISCUSSION

This pilot study highlights the transformative potential of VR in medical education, particularly in anesthesiology training. Immersive simulations allow trainees to practice high-stake tasks in a controlled, risk-free environment, fostering skill acquisition and confidence.

Evaluating the usability of a virtual reality software allows us to identify the best user interface (UI). An ideal interface should promote the best relationship between immersion and efficiency, so that users feel immersed in the virtual environment, but at the same time free to perform functions and tasks, as if they were in the real world[13].

According to Bowman's et al. usability framework[14], our co-creation approach ensured the software met some of user needs, as reflected in the positive feedback on immersion, realism, and interactivity.

In a recent meta-analysis study, Maciej et al. demonstrated that standard SUS distribution for different categories (mean 68, SD 12,5) is applicable for benchmarking to evaluate digital health apps (when excluding physical activity apps) and could be used by health care organizations, such as the National Health Service. Despite this, we must look at this data with reservations because our application has a lot of variation in terms of content and method in relation to the studies referenced in this meta-analysis[15].

The study's limitations include its small sample size, single-session exposure, and the potential influence of the Hawthorne effect (explained by the difference between the SUS score and qualitative answers). Future research should include the search for more specific tools in VR applications and evaluate their impact on long-term learning outcomes.

CONCLUSION

This study described the design, implementation, and evaluation of a VR software for training anesthesiologists in the use of target-controlled infusion pumps. The software demonstrated a marginally acceptable usability score and significant potential as a cost-effective teaching tool. Despite these successes, the SUS score indicated areas for improvement, such as user confidence and technical support needs. Future works should incorporate enhancing tutorials, refining technical features, explore augmented reality (AR) integration and expand the sample size to evaluate long-term learning outcomes.

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