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ORIGINAL ARTICLE

Assessing the Efficacy of Immersive VR/AR Training Versus Conventional Simulation in Enhancing Clinical Skills and Retention Among Medical Students

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ABSTRACT

Background: Virtual and Augmented Reality (VR/AR) technologies represent an innovative approach to medical education in the context of improving the acquisition and retention of clinical skills. In this study, immersion VR/AR training was compared to conventional simulation-based training of medical students to determine whether immersive VR/AR training can improve immediate and long-term clinical competence at a higher level than conventional simulation-based methods.

Methods: Therefore, in a prospective, randomized controlled trial, n=120 Pakistani medical students were randomly assigned to a control group (conventional simulation) or a VR/AR intervention group. Age, gender, year of study, accommodation type, cumulative GPA, and prior simulation training experience were collected as a comprehensive baseline demographic data. The Objective Structured Clinical Examinations (OSCEs) to assess the clinical skills were performed immediately after training and at a three-month follow-up. Confidence in performing clinical tasks was determined with a validated 5-point Likert scale questionnaire. Results obtained were statistically analyzed by the independent and paired t-tests with $p < 0.05$ as a significance level.

Results: Immediate OSCE scores were significantly higher in the VR/AR group (88.3 ± 4.5 vs. 82.1 ± 5.2, $p < 0.001$) than the control group. The VR/AR group also showed superior performance in OSCE score, which was maintained at 85.2 ± 5.0 at 3 months vs. 78.4 ± 6.1 at 3 months in the control group ($p < 0.001$). Immediately post training and at three months, performance in the VR/AR group was also significantly higher than in the control group (4.6 ± 0.3 vs. 4.2 ± 0.4, $p = 0.002$; 4.4 ± 0.4 vs. 4.0 ± 0.5, $p = 0.004$).

Conclusion: The acquisition and long-term retention of clinical skills within medical students are significantly greater when using immersive VR/AR training than traditional simulation methods. These findings help to support the integration of VR/AR modalities into medical education curricula to help improve clinical competency and student confidence.

Keywords: Virtual Reality, Augmented Reality, Clinical Skills, Medical Education, Simulation Training, OSCE, Skill Retention, Immersive Learning

INTRODUCTION

Clinical skills training in medical education has been catalyzed by the rapid evolution of digital technologies to the extent that it marks a paradigm shift. The traditional pedagogical approach of clinical instruction has included bedside teaching, standardized patient encounters, and mannequin-based simulation[1]. Yet, such conventional approaches are often challenged by inherent limitations like variability in clinical exposure, resource constraints, and the propensity to mimic rare or complex clinical scenarios in a controlled and standardized fashion[2].

However, Virtual Reality (VR) and Augmented Reality (AR) have become innovative modalities to overcome these limitations. In fully digital environments that simulate real-world clinical settings in high fidelity, VR immerses learners in virtual worlds to experience a range of patient interactions and complex procedures [3]. AR complements this by superimposing digital information onto the physical world to provide real-time clinical decision-making and procedural guidance. Taken together, these technologies promise a standardized, reproducible training platform capable of providing consistent educational experiences regardless of the variability found in traditional clinical settings [4].

Several theoretical and practical advantages support the integration of VR/AR into medical education. From a cognitive perspective, the immersive nature of these technologies facilitates deeper engagement and active learning. Using the simulation exercises, immediate, objective feedback is provided, during which learners can quickly identify and correct their errors, thereby reinforcing correct clinical behaviors[5]. Furthermore, practicing within a risk-free environment allows for multiple repetitions of skill acquisition, and this accelerates skill acquisition, but more importantly, increases confidence, which is an important attribute to clinical competence[6].

Initial studies suggest that VR/AR-assisted training may also promote better procedural accuracy and speed of decision-making while being more engaging than traditional ways. Yet, most of these studies have focused on the immediate posttraining outcomes, which does not fill out the long-term retention of clinical skills acquired through immersive technologies. This is particularly important in the dynamic practice of clinical practice, where long-term competence is essential to ensure patient safety and optimal care [7].

The goal of this study is to evaluate the efficacy of VR/AR enhanced training of medical students in terms of both immediate acquisition and long-term retention of medical skills. The most important aspect is to assess the immediate post-training performance of students who undergo immersive VR/AR simulation as opposed to conventional simulation-based training[8]. A secondary objective is to determine the persistence of these skills after three months and, thus, to determine the potential of immersive technologies for creating enduring clinical competence[9].

This study seeks to provide robust evidence for the integration of immersive learning modalities into medical curricula by systematically investigating the educational impact of VR/AR technologies. The long-term benefits of VR/AR enhanced training are not only essential to the development of educational methods but equally important to ensure future clinicians are well prepared to provide the clinical proficiency required to efficiently work within the complexities of modern healthcare[10].

MATERIALS AND METHODS

Study Design: A prospective, randomized controlled trial was conducted at Khawaja Muhammad Safdar Medical College Sialkot from December 2021 to December 2022. It was also designed to assess the immediate and long-term impact of VR/AR-enhanced training compared to traditional simulation-based methods for the acquisition and retention of clinical skills.

Participants: One hundred twenty medical students were recruited for the study. They were actively enrolled in the clinical phase of their curriculum. Demographic data and initial clinical competency evaluations were performed at the baseline to ensure that all participants had similar skill levels at the start of the study.

Randomization and Allocation: A secure, computer-generated sequence was used to randomize to a 1:1 ratio participant to either the VR/AR intervention group or to the traditional simulation control group. Sealed, opaque envelopes were used throughout the enrollment process to maintain allocation concealment and minimize selection bias and balance of groups.

Intervention: The VR/AR group had students trained using an integrated immersive platform that uses both virtual and augmented reality components. It simulated realistic clinical settings, and the virtual environment allowed students to engage in high-fidelity scenarios such as cardiac auscultation, intravenous cannulation, and airway management. The augmented reality component also simultaneously provided real-time digital overlays with anatomical details and procedural guidance to enhance spatial awareness and technical precision. Interactive modules to simulate complex clinical encounters were included in each training session, which was four hours long. Integrated analytics delivered immediate performance feedback. On the other hand, the control group received conventional simulation-based training with instructor-led sessions, standardized patients, mannequins, and structured debriefings. Both groups were matched in terms of the training content and duration.

Outcome Measures: The primary outcome was the acquisition of clinical skills assessed immediately after training using Objective Structured Clinical Examinations (OSCEs). The OSCEs involved multiple stations and assessed technical proficiency, clinical reasoning, and communication skills with blinded assessors evaluating the OSCEs with the use of standardized scoring checklists. The retention of these clinical skills was the secondary outcome, assessed by repeat OSCEs done three months after the initial training session. Furthermore, a Likert scale questionnaire was used to measure self-reported confidence levels in performing clinical tasks at three time points: before training, immediately after training, and at the three-month follow-up.

Statistical Analysis: Data were analysed using SPSS version 26.0 Descriptive statistics were used to summarize baseline characteristics. Chi-square tests were used for categorical variables and independent t-tests for continuous variables. Paired t-tests were used to assess within-group changes over time, and independent t's were used to compare between groups at both immediate and follow-up assessments. Statistically significant was a p-value less than 0.05.

Ethical Considerations: The study was conducted according to the Declaration of Helsinki and approved by the institutional ethics committee. The study's objectives, potential risks, and benefits were explained to all participants, who then provided written informed consent. Participants were assured their right to withdraw from the study at any time without any penalty, and it was maintained confidentially.

RESULTS

n =120 medical students were enrolled and randomized into two groups of 60 (60 in the control group, 60 in the VR/AR intervention group). All participants were Pakistanis, and different demographic data such as age, gender, year of study, accommodation type (hostel or private house), cumulative GPA, and prior simulation training experience were collected to ensure baseline comparability between groups. Overall, the participants were 23.4 ± 1.7 years of age, and the groups were balanced in gender (28 males [46.7%] and 32 females [53.3%]). Students came from the second, third, fourth, and fifth years, and the percentages were 21.7% to 23.3% for each year. As for accommodation, 41.7% were living in private houses and 58.3% in hostels. The mean cumulative GPA was 3.63 ± 0.28, and the average prior simulation training experience was 15.0 ± 5.2 hours. However, a baseline comparison of the control and VR/AR groups showed that there were no statistically significant differences across any parameters ($p > 0.05$). These baseline demographic characteristics are summarized in Table 1.

Table 1: Baseline Demographic Characteristics of Participants (n=120)

Characteristic	Control Group (n=60)	VR/AR Group (n=60)	p-value
Age (years), mean ± SD	23.5 ± 1.8	23.3 ± 1.6	0.45
Gender – Male, n (%)	28 (46.7%)	28 (46.7%)	1.00
Gender – Female, n (%)	32 (53.3%)	32 (53.3%)	1.00
Year of Study – Second, n (%)	13 (21.7%)	14 (23.3%)	0.78
Year of Study – Third, n (%)	18 (30.0%)	18 (30.0%)	1.00
Year of Study – Fourth, n (%)	16 (26.7%)	14 (23.3%)	0.62
Year of Study – Fifth, n (%)	13 (21.7%)	14 (23.3%)	0.78
Accommodation – Hostel, n (%)	35 (58.3%)	35 (58.3%)	1.00
Accommodation – Private House, n (%)	25 (41.7%)	25 (41.7%)	1.00
Cumulative GPA, mean ± SD	3.62 ± 0.30	3.65 ± 0.25	0.47
Prior Simulation Training (hours), mean ± SD	14.8 ± 5.3	15.2 ± 5.1	0.65

After the training sessions, clinical skills were assessed immediately after using Objective Structured Clinical Examinations (OSCEs) for technical proficiency, clinical reasoning, and communication skills. Mean OSCE scores for the control group were 82.1 ± 5.2; the VR/AR group achieved a significantly higher mean score of 88.3 ± 4.5. This difference was statistically significant ($p < 0.001$), as confirmed by an independent t-test. A review of subgroup analyses based on accommodation type and year of study showed that the VR/AR group outperformed the control group across all subgroups ($p < 0.01$).

There was a decline in OSCE performance of both groups from their immediate post-training scores at the three-month follow-up. Nevertheless, the VR/AR group experienced a decline that was significantly less steep. The mean OSCE score of the control group declined from 78.4 ± 6.1 to 78.4 ± 6.1, whereas the mean score of the VR/AR group remained high at 85.2 ± 5.0. This difference was statistically significant ($p < 0.001$) according to an independent t-test. Paired t-tests comparing within groups were statistically significant across all groups ($p < 0.05$) but showed a higher level of long-term retention of clinical skills for the VR/AR group.

A validated 5-point Likert scale questionnaire was self-reported to evaluate confidence in performing clinical tasks before training, immediately after training, and at the three-month follow-up. Immediately following training, the control group reported a mean confidence score of 4.2 ± 0.4 and the VR/AR group a higher value of 4.6 ± 0.3, which was statistically significant ($p = 0.002$). While the control group's confidence scores further dropped to 4.0 ± 0.5 at three months, the VR/AR group maintained a higher score of 4.4 ± 0.4, with the difference statistically significant ($p = 0.004$). For clarity, Table 2 presents the clinical skills performance and self-reported confidence outcomes.

Table 2: Clinical Skills Performance and Confidence Outcomes

Outcome Measure	Control Group (n=60)	VR/AR Group (n=60)	p-value
Immediate OSCE Score, mean ± SD	82.1 ± 5.2	88.3 ± 4.5	<0.001
3-Month OSCE Score, mean ± SD	78.4 ± 6.1	85.2 ± 5.0	<0.001
Immediate Confidence Score, mean ± SD	4.2 ± 0.4	4.6 ± 0.3	0.002
3-Month Confidence Score, mean ± SD	4.0 ± 0.5	4.4 ± 0.4	0.004

SPSS version 26 was used for statistical analysis. Independent t-tests were used to compare baseline demographic characteristics (continuous variables, independent t, categorical variables, chi square) between the two groups at baseline ($p > 0.05$). Using an independent t test, the immediate OSCE performance was analyzed, and within group changes from immediate post training to three month follow up were assessed by paired t tests. Independent t-tests were also run on the analysis of self-reported confidence scores. In all cases, p value < 0.05 was considered statistically significant.

Overall, the findings suggest that integrating VR/AR technologies into clinical skills training leads to greater immediate acquisition and retention of clinical skills than conventional simulation-based training. Immediately after training, the VR/AR group also scored higher OSCE, had better retention of skills at three months, and reported higher confidence levels. These results demonstrate that immersive VR/AR training gives a substantial benefit in clinical skills education.

DISCUSSION

The effectiveness of immersive Virtual and Augmented Reality (VR/AR) training in acquiring and retaining clinical skills was compared to conventional simulation training in this study[11]. Finally, we found that the VR/AR intervention significantly improved immediate clinical performance (higher OSCE scores immediately post training) and that these skills were retained better (higher OSCE scores at a 3-month follow-up). Furthermore, the confidence in the ability to successfully perform clinical tasks was higher for the VR/AR group than the traditional group[12].

The immediate improvement observed may be related to the immersive and interactive nature of the technology that helps more actively and deliberately learn, practice, and perform in this VR/AR group[13]. In contrast to traditional simulation methods, VR/AR environments are dynamic, realistic, and repeatable, permitting students to practice critical skills and receive immediate feedback. This continuous reinforcement likely leads to a more profound internalization of clinical procedures. The results are in agreement with recent studies that have shown that immersive simulations are very effective in enhancing technical proficiency and clinical reasoning in high-fidelity environments[14].

Additionally, the ability for skills to be retained through long-term periods in the VR/AR group indicates that immersive training may improve memory consolidation processes. VR/AR training does not only provide benefits during initial exposure but also in further reducing OSCE performance decline over three months[15]. This result may be due to increased engagement and cognitive involvement in VR/AR training. The retention that the VR/AR group reports experiencing is likely enhanced by self-confidence, which could reinforce retention as it would promote a positive learning environment where students are motivated to apply and further develop their skills[16].

However, these findings should be considered in light of several limitations. The first was conducted in a single institution and a small sample size, so the generalizability of results may be limited[17]. In addition, OSCE scores and self-reported confidence are useful measures of clinical competency, but future research should also assess other measures of clinical performance, such as real-life clinical outcomes and follow-up periods. The last is that the cost and scalability of VR/AR technologies retain importance in terms of their broader use in medical curricula[18].

CONCLUSION

In conclusion, VR/AR technologies add value to the clinical skills training of medical students in the immediate acquisition and long-term retention of clinical competencies over conventional simulation-based methods. VR/AR environments seem to lead to active learning, higher performance, and sustained confidence in clinical skills. This finding demonstrates the potential value of VR/AR-based training modalities as an additional learning tool in medical education. Future studies should be conducted on the long-term clinical impact, cost-effectiveness, and scalability of these technologies to realize their full potential in improving medical training outcomes.

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