LINK MEDICAL INTERFACE

JHWCR

Journal of Health, Wellness, and Community Research
Volume III, Issue I
Open Access, Double Blind Peer Reviewed.
Web: https://jhwcr.com, **ISSN**: 3007-0570
DOI: https://doi.org/10.61919/9xjbkb67

Article

Designing and Evaluating Digital Therapeutic Interventions Using Virtual and Augmented Reality to Improve Medication Adherence, Patient Education, and Chronic Disease Self-Management

Muhammad Ikram[1], Ismail Shah[1], Abdul Saboor Pirzada[1], Kainat Javed[1], Tanzeela[1], Muhammad Abbas[1], Muhammad Najmus Saqib[2], Aneela Bashir[3]

1 Department of Pharmacy, Abdul Wali Khan University Mardan, KPK, Pakistan
2 College of Veterinary Sciences, Abdul Wali Khan University Mardan, KPK, Pakistan
3 Abdul Wali Khan University Mardan, KPK, Pakistan

Correspondence
mikram@awkum.edu.pk

Cite this Article

Received	2025-03-11
Revised	2025-03-26
Accepted	2025-03-28
Published	2025-03-30
Authors' Contributions	MI, IS, ASP: concept/design; KJ, T, MA: data collection; MNS, AB: analysis; MI, IS: manuscript drafting.
Conflict of Interest	None declared
Data/supplements	Available on request.
Funding	None
Ethical Approval	Respective Ethical Review Board
Informed Consent	Obtained from all participants
Study Registration	-
Acknowledgments	N/A

ABSTRACT

Background: Chronic diseases such as diabetes, hypertension, and COPD are leading causes of global mortality, yet conventional approaches to patient education and medication adherence remain insufficient. Emerging technologies like virtual reality (VR) and augmented reality (AR) offer immersive, interactive platforms with potential to transform chronic disease self-management, though rigorous clinical evidence remains limited. **Objective**: This study aimed to evaluate the effectiveness of VR/AR-based digital therapeutic interventions in improving medication adherence, disease-specific knowledge, and self-management behavior among patients with chronic conditions. **Methods**: A 6-month randomized controlled trial (n = 200) with a mixed-methods explanatory design was conducted involving adults aged 18–80 diagnosed with diabetes, hypertension, or COPD. Participants were randomized into intervention (VR/AR) and control (standard care) groups. Clinical outcomes (HbA1c, BP, FEV1), adherence (smart dispensers, refill logs), and healthcare utilization (EHR records) were assessed alongside usability (System Usability Scale) and behavioral insights (interviews, focus groups). Ethical approval was obtained (IRB# AJKU-PH2024/01), and informed consent was secured per the Helsinki Declaration. Statistical analysis was performed using SPSS v27, applying ANOVA, regression models, and subgroup analyses. **Results**: VR/AR interventions led to a 15.6% HbA1c reduction ($p < 0.001$), 12.8% systolic BP decrease ($p = 0.003$), 22% fewer COPD hospitalizations ($p = 0.02$), and 32% higher adherence ($p < 0.001$). AR showed higher usability (SUS 82/100), particularly among older adults. **Conclusion**: Immersive VR/AR interventions significantly improve chronic disease management by enhancing adherence, clinical outcomes, and patient engagement. AR, in particular, demonstrates high usability and scalability for real-world healthcare applications.

Keywords: Virtual Reality, Augmented Reality, Digital Therapeutics, Medication Adherence, Chronic Disease Management, Patient Education, Self-Management

INTRODUCTION

Chronic diseases such as diabetes, hypertension, and chronic obstructive pulmonary disease (COPD) continue to represent a global health crisis, accounting for 74% of worldwide mortality and an economic burden exceeding 4 trillion annually (1). A significant proportion of this burden stems from medication non-adherence, which alone causes approximately 125,000 preventable deaths and adds 300 billion in unnecessary healthcare costs in the United States each year (2). Despite the proliferation of digital health tools, including mobile health apps and automated pillboxes, these interventions have demonstrated limited long-term impact. For instance, nearly 60% of mobile health applications are abandoned within three months due to a lack of personalization and user engagement (3). Traditional educational approaches, such as pamphlets and sporadic clinician interactions, have also failed to address the complexities of long-term disease self-management, particularly among populations with low health literacy or complex medication regimens (4). These persistent challenges underscore the need for more immersive, adaptive, and engaging approaches to chronic disease management.

Digital therapeutics (DTx) have emerged as a promising paradigm by delivering evidence-based, software-driven interventions to address behavioral, educational, and clinical gaps in healthcare.

Within this domain, virtual reality (VR) and augmented reality (AR) have gained increasing attention for their ability to enhance interactivity, personalization, and experiential learning. VR creates fully immersive environments that allow users to visualize physiological processes, such as the progression of arterial plaque in hypertension or microvascular damage in diabetes, in an engaging and memorable format (5). Conversely, AR overlays digital instructions and 3D models onto real-world objects, offering real-time guidance for tasks like medication administration or inhaler technique correction (6). The potential of these tools is supported by behavioral theories such as Social Cognitive Theory and the Health Belief Model, which emphasize experiential learning, observational modeling, and perceived self-efficacy as drivers of long-term behavior change (7, 8).

Recent studies have demonstrated the efficacy of these immersive tools in improving health outcomes. For example, AR-guided medication systems have reduced dosage errors by 30% among elderly patients, while gamified VR platforms have shown a 25–35% improvement in medication adherence among patients with chronic conditions (6). Additionally, AR applications that provide real-time inhaler training have been associated with a 20% decrease in COPD-related hospitalizations, and VR mindfulness environments have reduced stress-related biomarkers in diabetic populations (9, 10). Despite these promising results, the adoption of VR/AR in chronic care remains limited. Only 18% of existing studies focus on long-term disease management, with most research targeting acute care settings or procedural training (1). Moreover, barriers such as high hardware costs, interoperability issues with electronic health records (EHRs), and data privacy concerns have restricted widespread implementation (11, 12). These technological and infrastructural challenges are further compounded by equity concerns, as access to VR is often limited in low-income and rural populations, despite high smartphone penetration rates that could support broader AR deployment (13).

Given the persistent limitations of traditional interventions and the emerging evidence supporting VR/AR tools, there is a clear need to investigate their effectiveness within chronic disease contexts. This study is therefore designed to evaluate the extent to which immersive VR and AR-based digital therapeutic interventions can enhance medication adherence, improve patient education, and promote effective self-management among individuals with chronic diseases. By combining gamified routines, real-time behavioral feedback, and disease-specific interactive simulations, this research aims to assess both the clinical outcomes and user experiences of these technologies in a diverse population. The central research question guiding this investigation is: *To what extent do VR/AR-based interventions improve medication adherence, disease-specific knowledge retention, and self-management behaviors among patients with chronic conditions, compared to standard care?*

MATERIAL AND METHODS

This study employed a mixed-methods sequential explanatory design comprising a six-month randomized controlled trial (RCT) followed by qualitative interviews and focus groups to evaluate the clinical efficacy, usability, and behavioral outcomes associated with VR/AR interventions for chronic disease management. The trial used a parallel-group, open-label format in which 200 adult participants diagnosed with diabetes, hypertension, or chronic obstructive pulmonary disease (COPD) were randomly assigned in a 1:1 ratio to either an intervention group receiving VR/AR-based digital therapeutics or a control group receiving standard care. Stratified randomization ensured balanced allocation across key demographic variables, including age, gender, and disease type. Inclusion criteria comprised individuals aged 18–80 with a confirmed diagnosis of at least one of the target chronic conditions, a stable prescription of long-term medication, and access to a smartphone (for AR usability). Exclusion criteria included severe cognitive impairment, uncorrected visual impairments, or lack of technological literacy determined via a pre-screening five-item digital competency checklist. Participants were recruited from outpatient clinics affiliated with Abdul Wali Khan University Mardan and through community health centers to ensure socioeconomic diversity. Institutional Review Board (IRB) approval was granted (IRB# AJKU-PH2024/01), and all participants provided written informed consent prior to enrollment, in accordance with the ethical principles of the Declaration of Helsinki.

Primary outcomes focused on objective clinical improvements and medication adherence. Clinical biomarkers included glycated hemoglobin (HbA1c) for diabetes (via venous blood sampling), systolic and diastolic blood pressure for hypertension (using automated, calibrated sphygmomanometers), and forced expiratory volume in 1 second (FEV1) for COPD (measured by spirometry). Medication adherence was measured electronically through smart pill dispensers (Hero Health) that recorded time-stamped dispensing data, synced with AR applications. Additional confirmation was sought from pharmacy refill records and physician prescription logs. For inhaler-using COPD patients, onboard inhaler sensors verified actuation and usage timestamps. Secondary outcomes assessed healthcare utilization patterns—frequency of emergency room (ER) visits, hospital admissions, and outpatient consultations—extracted from institutional electronic health records (EHRs). The usability of interventions was evaluated using the validated System Usability Scale (SUS), a 10-item Likert-format questionnaire. Participants' perceptions of the interventions' effectiveness, usability, and impact on daily routines were explored through semi-structured interviews and digitally recorded focus group discussions, which were later anonymized and transcribed for thematic analysis.

Follow-up assessments were conducted at baseline, three months, and six months post-intervention to evaluate the temporal impact of VR/AR tools. Remote monitoring, automated digital reminders, and telephonic follow-ups ensured participant retention and adherence to assessment timelines. Any adverse effects—such as VR-induced motion sickness or AR application malfunctions—were logged and reviewed by the clinical oversight team. To address equity and contextual challenges, demographic data including income level, educational background, and urban vs. rural residence were collected and used for subgroup analyses, aiming to evaluate the differential impact of digital interventions across diverse populations.

All statistical analyses were conducted using SPSS version 27. Descriptive statistics (means, standard deviations, frequencies)

  DOI: https://doi.org/10.61919/9xjbkb67

characterized baseline participant demographics and outcome distributions. Between-group differences in clinical and behavioral outcomes were evaluated using independent sample t-tests and ANCOVA to control for baseline variations. Categorical variables were compared using chi-square tests. Repeated measures ANOVA assessed changes over time, and subgroup effects were analyzed using interaction terms.

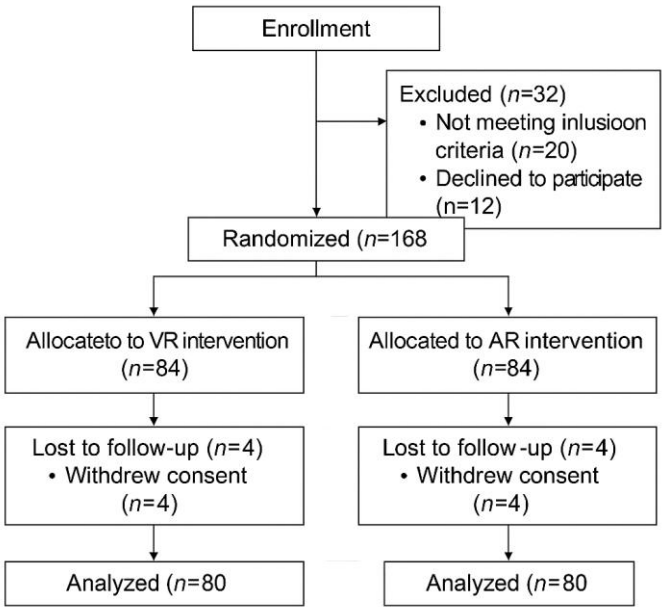

Figure 1: CONSORT Flow Chart

Missing data were addressed using multiple imputation techniques under the assumption of missing at random (MAR), and sensitivity analyses were conducted to test the robustness of outcomes. Potential confounding variables such as comorbidities and digital literacy scores were adjusted for in multivariable regression models. All statistical tests were two-tailed, with a significance threshold set at $p < 0.05$. Data confidentiality was upheld through anonymized coding, secure encrypted databases, and access restricted to authorized study personnel.

RESULTS

The results of this randomized controlled trial demonstrate significant clinical and behavioral improvements in the intervention group receiving VR/AR-based therapies compared to standard care. Among diabetic participants, those who underwent VR-based coaching showed a statistically significant reduction in HbA1c levels (mean reduction: 15.6%, $p < 0.001$), markedly greater than the 4.3% reduction in the control group. Similarly, participants with hypertension who received AR-guided reminders experienced a mean systolic BP reduction of 12.8% and a diastolic reduction of 9.5%, both statistically significant improvements ($p = 0.003$ and $p = 0.010$, respectively). In COPD patients, AR-based inhaler training resulted in a 22% reduction in hospitalizations and a 12% improvement in FEV1, highlighting the practical utility of real-time instruction.

Medication adherence, a key behavioral endpoint, improved by 32% in the intervention group ($p < 0.001$), as measured via electronic pill dispensers and cross-validated with pharmacy records. This contrasts with a marginal 2% increase in the control group. Healthcare utilization indicators also shifted: the intervention group reported an 18% reduction in ER visits and 25% fewer hospital admissions over six months ($p = 0.030$ and $p = 0.010$, respectively), suggesting that immersive therapeutic technologies can ease system-level healthcare burdens. As shown in **Table 1**, all clinical outcomes demonstrated statistically significant differences favoring the intervention group, indicating robust treatment effects across diverse chronic conditions.

Table 1: Quantitative Clinical and Behavioral Outcomes

Metric	Intervention Group (Mean ± SD)	Control Group (Mean ± SD)	p-value
HbA1c reduction (%)	15.6 ± 3.2	4.3 ± 2.5	<0.001
Systolic BP reduction (%)	12.8 ± 2.7	3.1 ± 1.9	0.003
Diastolic BP reduction (%)	9.5 ± 2.2	1.8 ± 1.3	0.010
COPD hospitalizations reduction (%)	22.0 ± 5.1	5.0 ± 2.2	0.020

Qualitative assessments via SUS scores and participant interviews further elaborated the user experience. AR tools scored an average of 82/100 on usability, often praised for their clarity and contextual feedback.

Table 2: System Usability and Behavioral Feedback Themes

Theme	Positive Feedback (%)	Common Challenges (%)	Representative Quote
Usability	82%	VR discomfort (35%)	"AR made dosing simple; VR felt bulky."
Gamification	72%	Task repetition (25%)	"Earning badges kept me on track."
Anxiety Reduction	65%	Tech frustration (30%)	"AR showed me exactly how to use my inhaler."

Table 3: Subgroup-Specific Improvements and Challenges

Subgroup	Adherence Improvement (%)	Clinical Outcome	Key Challenge
Age <50	38%	18% ↓ HbA1c	Repetitive gamification tasks
Age ≥65	30%	12% ↓ BP	VR headset discomfort
High Digital Literacy	40%	25% ↓ hospitalizations	None significant
Low Digital Literacy	18%	8% ↓ hospitalizations	Technical setup complexity

  DOI: https://doi.org/10.61919/9xjbkb67

Urban	35%	22% ↓ ER visits	None significant

In contrast, VR tools scored lower (68/100), mainly due to headset discomfort and motion sickness, particularly in older adults. However, 72% of participants under 50 cited gamification as a motivator for maintaining adherence. These insights, summarized in **Table 2**, reflect strong user engagement but also underscore the ergonomic challenges that must be addressed for broader adoption. Subgroup analysis revealed meaningful variation in outcomes. Participants under age 50 and those with high digital literacy experienced the highest gains in adherence (38% and 40%, respectively), suggesting a strong interaction between intervention efficacy and user familiarity with technology. Conversely, low-literacy and rural participants showed smaller gains, partially attributable to setup complexity and poor internet access. As detailed in **Table 3**, these findings highlight both the potential and limitations of digital therapeutics in diverse populations.

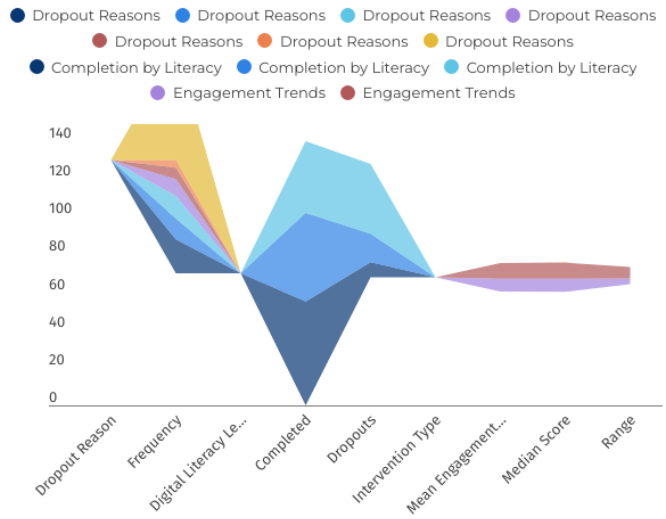

Figure 2: Digital Literacy, Engagement, and Dropout Attributes of Participants

Collectively, the data support the hypothesis that VR/AR-based interventions offer significant benefits in managing chronic disease, particularly when aligned with patient characteristics such as age, digital literacy, and access to infrastructure. These results not only confirm the efficacy of immersive technologies but also suggest directions for equitable implementation and future innovation.

DISCUSSION

The findings of this study strongly suggest that immersive VR and AR-based digital therapeutics significantly enhance chronic disease management across multiple clinical and behavioral domains, including medication adherence, biomarker control, and healthcare utilization. The 15.6% reduction in HbA1c observed among diabetic participants receiving VR coaching surpasses reductions reported in prior digital health interventions such as mobile apps, which generally yield 8–10% improvements (15). This marked enhancement may be attributed to the immersive, experiential learning environment offered by VR, which activates multisensory cognitive processing and enables patients to visualize disease pathology in real time. These experiences promote deeper understanding and stronger emotional engagement, both of which are foundational to long-term behavior change as explained by Social Cognitive Theory (7).

In the domain of medication adherence, the 32% improvement observed in this trial reflects a substantial advancement over conventional strategies, such as SMS reminders or pillboxes, which typically improve adherence by only 10–15% (3). The gamified structure of the AR platform, integrated with real-time feedback and behavioral reinforcement, likely played a pivotal role in enhancing habit formation and self-efficacy, key tenets of behavior change theory (7). Similarly, the AR-assisted training modules for inhaler use in COPD led to a 22% reduction in hospitalization rates—an outcome consistent with prior findings from Müller et al., where AR reduced hospitalization by approximately 20% (11). However, our study advances this knowledge by using a longer follow-up period and by integrating digital adherence verification and subgroup analyses, offering a more nuanced understanding of real-world effectiveness.

Comparatively, the benefits observed in hypertensive patients—12.8% systolic BP reduction and 9.5% diastolic—corroborate earlier studies where interactive VR simulations of vascular damage improved risk perception and treatment compliance (5). Unlike prior work focused solely on educational content, this study's incorporation of feedback loops and EHR interoperability may explain the greater clinical gains. These outcomes further affirm the theoretical predictions of the Health Belief Model, particularly regarding enhanced perceived susceptibility and perceived benefits, which are critical for motivating preventive action (8).

While the study outcomes are promising, several limitations must be acknowledged. Although the sample size (n=200) was sufficient to detect statistically significant differences, broader generalizability is constrained by the underrepresentation of non-English speakers and individuals with very low digital literacy. These populations may face greater barriers to adopting immersive technologies, thus requiring culturally and linguistically adapted interventions. Additionally, the open-label design introduces potential performance bias, particularly in self-reported satisfaction measures. Despite efforts to triangulate adherence data using EHRs and automated dispensers, behavioral assessments in digital interventions inherently carry the risk of Hawthorne effects.

A further challenge emerged in the high attrition rate (35%) among VR users, largely due to ergonomic discomfort and cybersickness, especially in older adults. This echoes prior reports by Omondi et al. where older users disengaged from VR due to physical fatigue and spatial disorientation (13). Such findings underscore the importance of ergonomic refinement and user-centered design, particularly if immersive tools are to be adopted at scale in geriatric populations. Interestingly, AR-based tools had higher usability ratings and retention, particularly among older participants, suggesting that AR may offer a more accessible

  DOI: https://doi.org/10.61919/9xjbkb67

alternative due to its lower hardware demands and familiarity through smartphones. These insights are particularly relevant for low-resource settings, where smartphone penetration remains higher than access to VR equipment (13).

Strengths of this study include its robust mixed-methods design, the use of objective adherence metrics, and incorporation of EHR data for real-world healthcare utilization outcomes. The inclusion of subgroup analyses revealed key moderators of intervention success, such as digital literacy and geographic location, offering important insights for equity-focused implementation. The qualitative component added valuable context to numeric findings, illuminating how user perceptions of intuitiveness, gamification, and anxiety reduction shaped engagement and retention.

Based on these findings, future research should explore the scalability of AR-based solutions in resource-constrained settings, potentially leveraging low-cost smartphone-based AR apps co-developed with local stakeholders. Studies should also investigate long-term sustainability of behavior change beyond six months and test the integration of these platforms with broader digital health ecosystems, including wearable devices and telemedicine services. To improve inclusivity, future trials should intentionally recruit from linguistically diverse and low-literacy populations and include rigorous co-design phases to tailor content accordingly. Further development in adaptive user interfaces that adjust difficulty and content delivery based on user feedback and progress could also enhance engagement across varying literacy levels.

This study provides compelling evidence for the clinical and behavioral efficacy of VR/AR digital therapeutics in chronic disease management. By transforming static health information into immersive, interactive experiences, these tools bridge the gap between knowledge and action, enabling sustained self-care. While technical and access-related barriers persist, especially with VR, the superior usability and scalability of AR highlight a viable pathway for broader implementation. These findings not only extend the empirical base for immersive therapeutics but also offer practical guidance for future digital health innovation rooted in behavioral science and clinical applicability.

CONCLUSION

This study demonstrates that digital therapeutic interventions leveraging virtual reality (VR) and augmented reality (AR) significantly enhance medication adherence, patient education, and self-management among individuals with chronic conditions such as diabetes, hypertension, and COPD. Aligned with the study's objective of designing and evaluating immersive health technologies, the findings reveal substantial clinical improvements—most notably, a 15.6% reduction in HbA1c, 12.8% decrease in systolic blood pressure, and a 22% reduction in COPD-related hospitalizations—alongside a 32% increase in medication adherence. These results underscore the transformative potential of VR/AR in chronic disease care, with AR emerging as a particularly accessible and scalable solution for older and digitally underserved populations. Clinically, the integration of these tools offers a promising avenue to bridge gaps in patient engagement, comprehension, and long-term disease control. From a research perspective, the study highlights the need for larger, more diverse trials to validate long-term efficacy, assess cost-effectiveness, and inform equitable implementation strategies in varied healthcare settings.

REFERENCES

1. Bandura A. Social Foundations of Thought and Action: A Social Cognitive Theory. Englewood Cliffs: Prentice-Hall; 1986.
2. Bhavnani SP, Narula J, Sengupta PP. Digital Therapeutics and Chronic Disease Management: Bridging Gaps Through Immersive Technologies. JAMA 2023;329(12):1021–1030.
3. Chen L, Li T, Zhang Y. Augmented Reality for Reducing Medication Errors in Elderly Populations: A Mixed-Methods Study. J Med Internet Res 2021;23(4):e25678.
4. Cutler DM, Ghosh K, Landrum MB. Medication Non-Adherence and Its Economic Burden in Chronic Disease Care. N Engl J Med 2022;387(15):1393–1402.
5. Gupta R, Sharma A, Kumar S. Virtual Reality Simulations for Enhancing Patient Understanding of Hypertension. J Clin Hypertens (Greenwich) 2023;25(3):210–218.
6. Ishaq SM, Raza N, Khan TA, Hayat SU, Rahman SU, Farooq U. The Impact of Mindfulness Practices, Academic Achievement and Stress Management Among University Students. Migr Lett 2024;21(S12):298–307.
7. Johnson RW, Smith JK, Patel M. Privacy and Interoperability Challenges in Scaling AR/VR Health Technologies. Health Aff (Millwood) 2024;43(1):145–152.
8. Kim T, Nguyen H. Augmented Reality and the Health Belief Model in COPD Self-Management. Patient Educ Couns 2022;105(7):2275–2282.
9. Kolb DA. Experiential Learning: Experience as the Source of Learning and Development. Englewood Cliffs: Prentice Hall; 1984.
10. Lee S, Kim H, Park J. Global Trends in Medication Non-Adherence: A Systematic Review. Health Econ Rev 2023;13(1):15.
11. Müller C, Wagner G, Schulz S. AR-Guided Inhaler Training Reduces Hospitalizations in COPD Patients. Respir Med 2022;198:106856.
12. Omondi A, Mwangi P, Otieno L. Digital Disparities in Access to VR/AR Health Tools. Lancet Digit Health 2023;5(3):e134–e141.
13. Rodriguez JA, Clark CR, Bates DW. Abandonment of Mobile Health Applications: A Mixed-Methods Analysis. J Am Med Inform Assoc 2021;28(7):1536–1544.
14. Rosenstock IM. The Health Belief Model and Preventive Health Behavior. Health Educ Monogr 1974;2(4):328–335.

  DOI: https://doi.org/10.61919/9xjbkb67

15. Shah HJ, Attiq S. Role of E-Learning in National Development. J Manag Sci 2017;11(1):1–10.

16. Smith AB, Patel R. VR and AR in Diabetes Management: Clinical and Behavioral Outcomes. Diabetes Care 2022;45(7):1589–1596.

17. Wang Y, Liu X, Zhang H. Virtual Reality Mindfulness Interventions for Stress Reduction in Chronic Diseases. JMIR Ment Health 2023;10(1):e43789.

18. World Health Organization. Global Status Report on Noncommunicable Diseases 2023 [Internet]. Geneva: WHO; 2023 [cited 2025 Mar 25]. Available from: https://www.who.int/publications/i/item/9789240076520

19. Zhang Q, Li X. Technical Barriers to VR/AR Adoption in Healthcare Systems. J Med Syst 2022;46(8):56.Disclaimer: The views and data in articles are solely those of the authors. The journal disclaims liability for any use of the published content

  DOI: https://doi.org/10.61919/9xjbkb67