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Virtual Reality Based on Social Cognitive Theory for Type 2 Diabetes Management in Indonesia

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ABSTRACT

Introduction: Diabetes has become a significant global health problem, particularly burdening low-income countries economically. Innovative and integrated digital solutions can help reduce the impact of diabetes and improve the quality of care. However, virtual reality (VR) digital solutions have never been applied in Gorontalo. This study aims to demonstrate the novel integrated effect of diabetes health literacy, self-efficacy, physical activity, and HbA1c blood sugar control.

Methods: A quasi-experimental study with two intervention groups was conducted in Indonesian from October to December 2024. For the first time, researchers trained the intervention group to use virtual reality.

Results: This study demonstrated that both intervention groups, Virtual Reality (VR) and WhatsApp (WA), showed significant improvements in knowledge ($p < 0.0001$) and self-efficacy ($p < 0.0001$) post-intervention. Physical activity also significantly increased in both groups ($p < 0.0001$). Moreover, a significant reduction in HbA1c levels was observed in the VR group (median reduction 1.36%, $p = 0.0005$) and the WA group (mean reduction 0.67%, $p = 0.0002$). Comparatively, VR was more effective in improving self-efficacy (Post-VR median = 58.00 vs. Post-WA = 54.00; $p < 0.0001$), while WA was more effective in increasing physical activity (Post-WA median = 1824 MET-minutes/week vs. Post-VR = 953.3 MET-minutes/week; $p = 0.0006$) and reducing HbA1c levels (Post-WA median = 9.05% vs. Post-VR = 10.70%; $p = 0.0049$). No significant difference was found between groups in knowledge improvement.

Conclusion: As this intervention yielded significant improvements in self-management among T2DM patients, researchers recommend that policy-makers replicate this intervention as a national program and promote increased use of digital devices (VR) to enhance health literacy, self-efficacy, physical activity, and clinical outcomes (HbA1c) in T2DM management.

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INTRODUCTION

The global prevalence of Diabetes Mellitus (DM) has increased significantly in recent years, particularly in low- and middle-income countries. The rise in diabetes prevalence is associated with modifiable risk factors such as self-management (dietary habits, physical activity, and overweight or obesity (1).

Globally, 415 million adults have DM, and this number is projected to reach 642 million by 2040. Type 2 Diabetes Mellitus (T2DM) accounts for more than 90% of these cases (2).

In 2019, the global prevalence of diabetes was estimated at 9.3% (463 million people), increasing to 10.2% (578 million) by 2030, and 10.9% (700 million) by 2045. In Asia, the prevalence of T2DM continues to rise, from 78 million in 2015 to 140 million in 2040 (3).

In Indonesia, the prevalence of T2DM rose from 10.3 million in 2017 to 16.7 million in 2045, ranking seventh globally (4). Data from the Gorontalo Provincial Health Office reported 400,099 (87.2%) individuals diagnosed with DM in 2023, distributed across six regions in Gorontalo Province (5).

The rising incidence and complications of T2DM significantly affect patients' quality of life and contribute to increased mortality (6). Early prevention and management of T2DM involve lifestyle modifications, including a healthy diet and increased physical activity (7). Physical activity is one of the most essential treatment foundations for T2DM patients (8). It enhances insulin sensitivity, lowers fasting and postprandial blood glucose levels, reduces cardiovascular risk factors and body weight, and promotes the well-being of individuals with T2DM. Previous studies have shown that physical activity is effective in improving metabolism and glycemic control. However, in reality, regular physical activity remains low (2). Most people with T2DM have irregular physical activity levels (9). Study in Indonesia reported that 89.3% of individuals had low levels of physical activity, and the majority (58.9%) reported sitting for more than three hours per day (10).

New methods are being developed to prevent and rehabilitate the physical and psychological consequences of diabetes mellitus. Technological advancements have led to modern tools for diabetes prevention and diabetes monitoring (11). Among various technologies applied in healthcare is Virtual Reality (VR), which has been successfully used for prevention and education about chronic disease consequences, including diabetes. Serious games have been designed. including prototypes to teach healthy lifestyle habits and to facilitate physical activity, especially among diabetic patients in the community (12).

VR applications are being developed to enhance indoor exercise motivation. VR offers realistic real-world experiences by simulating environments that are otherwise difficult or impossible to access in reality (13). VR technology uses computer-generated environments to give users a perception of reality (14). VR programs significantly enhance learning by creating immersive experiences and increasing user focus through powerful simulations. VR users are effectively motivated and able to maintain interest, additionally, VR offers continuous education and training, and a safe learning environment. Contributing to improved participation and concentration (15).

In healthcare, VR therapy has recently proven effective in improving motor performance, cognitive function, and fall prevention among patients with Parkinson's disease and stroke (13). Currently, VR-based training is recognized as a novel method to promote physical activity. Systems represent an innovative treatment approach that reinforces task-oriented motor learning and positively impacts the acquisition and enhancement of functional skills. Specifically, the ability to perform daily activities requiring physical effort (14). Thus, VR programs offer T2DM patients the opportunity for self-education, improve and maintain effective physical activity, which helps regulate blood sugar levels and improve functional capacity. However, despite previous VR applications, there is a scarcity of studies applying VR interventions for T2DM patients.

This study aims to improve health literacy, self-efficacy, physical activity, and HbA1c clinical outcomes among people with T2DM using VR guided by the Social Cognitive Theory (SCT) framework. This theory was used to design a physical activity program via VR for T2DM patients. The intervention design was developed based on the SCT framework, emphasizing participant-centered, evidence-based interventions to maximize feasibility, acceptability, and success potential. The framework focuses on the behavior change wheel approach (16). The SCT framework is presented through a picture (**Figure 1**).

Each VR intervention component was explicitly mapped to a core SCT construct. Behavioural capability was addressed through structured instruction on self-monitoring of vital signs and blood glucose and on safe walking technique. Observational learning was operationalised through immersive VR modelling, in which participants watched and rehearsed correct physical-activity behaviours within a simulated real-world environment. Mastery experience and self-efficacy were targeted by allowing participants to practise the activity repeatedly in a safe VR setting with graded difficulty. Outcome expectations were reinforced by visualising the link between regular activity and improved glycaemic control. Self-regulation was supported through goal-setting and daily activity targets, while reinforcement was provided via real-time in-session feedback and staff supervision. In the WhatsApp arm, the same SCT constructs were operationalised through different channels: behavioural capability via daily educational visual materials, observational learning and reinforcement via peer and educator interaction in the group, and self-regulation via reminders and prompts. This explicit construct-to-component mapping is summarised in Supplementary Table S1 and is revisited in the Discussion to interpret the observed differential effects.

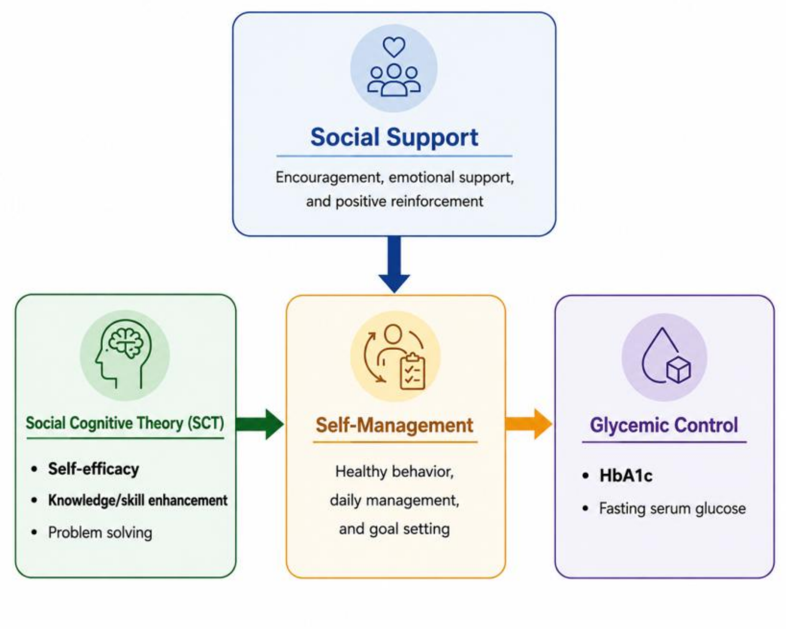

Figure 1. Social Cognitive Theory

This study makes four intended contributions. First, it operationalizes Social Cognitive Theory into concrete intervention components rather than invoking the theory only as a label, by mapping self-efficacy, observational learning, outcome expectations, behavioral capability, reinforcement, and self-regulation onto specific VR and WhatsApp activities (see Methods). Second, it offers a head-to-head comparison of an immersive technology (VR) and a ubiquitous, low-cost mobile platform (WhatsApp) delivered under the same theoretical framework and clinical conditions. Third, it combines behavioral outcomes (knowledge, self-efficacy, physical activity) and a clinical outcome (HbA1c) within a single protocol. Fourth, it tests these digital interventions in a real-world, low-resource primary-care program (Prolanis) in eastern Indonesia, a setting that is under-represented in the digital-health literature. The intended contribution is therefore theoretical and methodological rather than simply the first local application of VR.

This study was conducted to evaluate physical activity using a VR program to control blood sugar levels in people with T2DM. The physical activity intervention using a VR program was developed by researchers using VR based on social cognitive theory (SCT). SCT focuses on influencing a person's behavior, including personal, behavioral, and environmental factors, designed through VR. Researchers designed the VR program to promote PA by developing substantial formative materials to inform people about diabetes and physical activity. Therefore, the use of a VR program is a new concept that will provide opportunities for people with T2DM to educate themselves and increase their knowledge and maintain effective physical activity, which can help control blood sugar levels and improve exercise function.

METHODS

Study Design and Subjects

This study used a quantitative quasi-experimental design with a pre-test and post-test control group design approach. This study aims to analyze the effectiveness of Virtual Reality (VR) interventions based on Social Cognitive Theory (SCT) on Health Literacy, physical activity, self-efficacy, glycemic control (HbA1c) in Type 2 Diabetes Mellitus (T2DM) patients evaluated for 12 weeks (17).

Data Collection Methods: This study was conducted in two community health centers implementing the Prolanis Program. Initial data screening was carried out using Prolanis records from April to September 2024. A total of 160 patients were initially screened using purposive sampling. Sampling in this study was a non-probability sampling technique. Sampling was conducted selectively by establishing the following inclusion and exclusion criteria: clinically diagnosed with Type 2 Diabetes Mellitus (T2DM), HbA1c ≥ 6.5% (preferably within the last 3 months), willing to participate by signing an informed consent and completing a questionnaire, no history of major surgery in the previous 5 months or surgery planned within the next 5 months, currently receiving oral or injection therapy, and no cognitive impairment. Participants were excluded if they had a medical condition that prevented them from walking for 15–30 minutes per day. Exclusion criteria: Gestational diabetes mellitus, young adult-onset diabetes, or other forms of diabetes, History of serious illness such as severe hypertension, heart attack or stroke within the last 1 year, Type 2 DM accompanied by nephropathy, Pregnancy, breastfeeding, or planning a pregnancy during the 6-month study.

However, the target sample size was not fully achieved due to the limited number of respondents who met the inclusion criteria, participant dropout during the intervention period, and limited participation in the use of Virtual Reality (VR) technology. In addition, several respondents, particularly older participants, experienced difficulties adapting to the VR device, which affected the continuity of their participation throughout the study. Following the screening process, only 70 patients with T2DM met the eligibility criteria and were successfully recruited into the study **(Figure 3).**

Intervention Groups

The VR intervention group received a 12-week education program on health literacy, self-efficacy, physical activity, and HbA1c management using Virtual Reality (VR) technology. The educational content included self-monitoring, self-management, and physical activity guidance. Participants were also informed about diabetes conditions and risks, and instructed to monitor vital signs independently before using VR. VR models are presented through a picture **(Figure 2).**

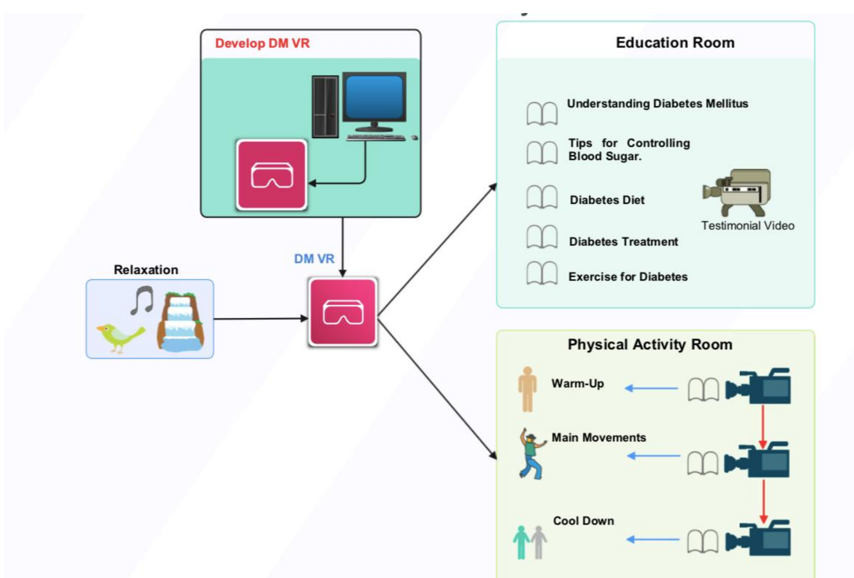

Figure 2. DM Virtual Reality (VR) technology

The control group received daily educational messages via WhatsApp containing visual materials emphasizing the importance of physical activity. Patients were added to WhatsApp groups and monitored by *Puskesmas* staff to facilitate communication and educational content delivery.

VR intervention protocol. To allow for assessment of intervention fidelity, the VR PA program was delivered as supervised sessions over a 12-week period, with a frequency of three sessions per week and a maximum duration of 10 minutes per session. The short session duration was intentionally chosen for safety reasons in the elderly population, given that longer VR exposure is associated with an increased risk of cybersickness.

Each session was conducted under the supervision of an enumerator and a prolanis program support person who recorded attendance, monitored vital signs before the session, and provided real-time feedback and safety checks. Participant compliance was operationalized as successfully completing the VR-based physical activity three times per week as scheduled, with an average of 100% compliance and no dropouts.

Engagement and tolerability were monitored throughout the program. Side effects occurred in the initial phase of the intervention, including complaints of dizziness. In accordance with safety procedures, the team noted these complaints were addressed through initial precautions by temporarily stopping the session and then resuming it once the participant was stable, with all participants able to continue and complete the intervention. During the study, all side effects were mild, transient, and limited to the initial intervention period, consistent with the typical pattern of adaptation to VR exposure.

The Health Literacy-PA Implementation Protocol through the Physical Activity Module was conducted in four sessions over one week, each lasting approximately 30 minutes. Session I explained the basic concepts of diabetes mellitus (DM), session II explained diabetes management, and session III explained the prevention of acute and chronic complications. Session IV explained stress management through self-efficacy and the importance of physical activity (Brisk walking). At the end of the session, a post-test was conducted to assess knowledge. The following week, the physical activity intervention (Brisk walking) was conducted for 12 weeks, three times a week, with monitoring via telephone or WhatsApp group chat, involving family members as chaperones, and monitored by Prolanis program staff. At the end of the physical activity intervention (Brisk walking), post-HbA1c and post-self-efficacy blood samples were taken by the researchers and Prolanis program staff.

Data Collection Tools

Demographic data were collected via questionnaire, including: gender, age, education level, occupation, duration of diabetes, type of treatment, complications, smoking status, and family history of diabetes.

The interventions (VR and WhatsApp) aimed to increase physical activity (PA) among T2DM patients by encouraging daily physical movement. PA levels were measured using the International Physical Activity Questionnaire (IPAQ) based on METs and specifically for walking activity (18). Clinical outcomes were assessed using HbA1c measurements with NGSP-certified point-of-care (POC) devices (Afinion™ AS100 and DCA Vantage™ Analyzer) (19). Self-efficacy in PA was measured using the Exercise Self-Efficacy Scale (ESES), which has been validated in Indonesia, with a Content Validity Index (CVI) of 0.80–1.00 and Cronbach's alpha reliability between 0.78–0.92 (20).

Data Analysis Methods

Data analysis was conducted comprehensively to evaluate the effectiveness of the Virtual Reality (VR) intervention and WhatsApp-based monitoring on health literacy, self-efficacy, physical activity, and glycemic control (HbA1c) among T2DM patients. Within-group changes (pre- and post-intervention) in knowledge, self-efficacy, and physical activity were analyzed using the Wilcoxon Signed-Rank Test, a non-parametric test suitable for paired data that may not follow a normal distribution. Correlations between pre- and post-intervention scores were analyzed using Spearman's rank correlation coefficient. Within-group changes in HbA1c were analyzed differently: In the VR group, changes were assessed using the Wilcoxon Signed-Rank Test, reporting the median reduction. In the WA group, the Paired t-test was used, reporting the mean reduction, 95% confidence intervals (CI), and effect size (partial eta squared, η^2). Correlations in HbA1c data: Spearman correlation was used in the VR group. Pearson correlation was used in the WA group to assess reliability in pre-post measurements. Between-group comparisons (VR vs. WA post-intervention) on knowledge, self-efficacy, physical activity (IPAQ), and HbA1c were performed using the Mann-

Whitney U test. All statistical analyses were conducted using GraphPad Prism version 10, with a significance level set at $\alpha = 0.05$.

A comprehensive statistical analysis was conducted to evaluate the effectiveness of the Virtual Reality (VR) intervention and WhatsApp-based monitoring on health literacy, self-efficacy, physical activity, and glycemic control (HbA1c) in patients with type 2 diabetes mellitus (T2DM). Prior to the main analysis, data distribution was tested using the Shapiro–Wilk test to determine whether to use parametric or non-parametric tests. The results of the normality test indicated that most variables were not normally distributed, therefore non-parametric analysis was used. However, for the HbA1c variable, the data distribution differed between groups, being non-normal in the VR group but normal in the WA group. Therefore, the choice of statistical test was adjusted to the characteristics of the data distribution of each group. Within-group changes (pretest–posttest) in the variables of knowledge, self-efficacy, and physical activity were analyzed using the Wilcoxon Signed-Rank Test. The relationship between pre- and post-intervention scores was analyzed using the Spearman rank correlation coefficient. For the HbA1c variable, changes in the VR group were analyzed using the Wilcoxon Signed Rank Test and reported as median changes due to non-normal distribution of the data. In contrast, in the WA group, changes in HbA1c were analyzed using a paired t-test due to the data meeting the assumption of normality. Results are reported as mean changes, 95% confidence intervals (CIs), and effect sizes using partial eta-squared (η^2). The relationship between pre- and post-intervention HbA1c values was analyzed using Spearman correlation in the VR group and Pearson correlation in the WA group, according to the respective data distributions.

Intergroup comparisons (VR vs. WA) after the intervention on knowledge, self-efficacy, physical activity measured using the International Physical Activity Questionnaire (IPAQ), and HbA1c were performed using the Mann–Whitney U test. All statistical analyses were performed using GraphPad Prism version 10 with a significance level set at $\alpha = 0.05$.

Ethical Approval

This study has been approved by the Health Research Ethics Committee of STIKES Kendal, Indonesia (Ethics Approval Number: 074/EC/KEPK_STIKES_KENDAL/VIII/2024), which was approved on August 9, 2024. Written informed consent was obtained from all participants before enrollment in the study. The clinical trial has not been registered with ClinicalTrials.gov.

RESULTS

Participant Inclusion and Baseline Characteristics

At the beginning of the study, informed consent forms were distributed to 70 T2DM patients. A total of 63 patients agreed to participate and signed the eligibility forms. All 63 participants underwent the intervention simultaneously. After 12 weeks of intervention, data from 59 participants were successfully collected and analyzed **(Figure 3).**

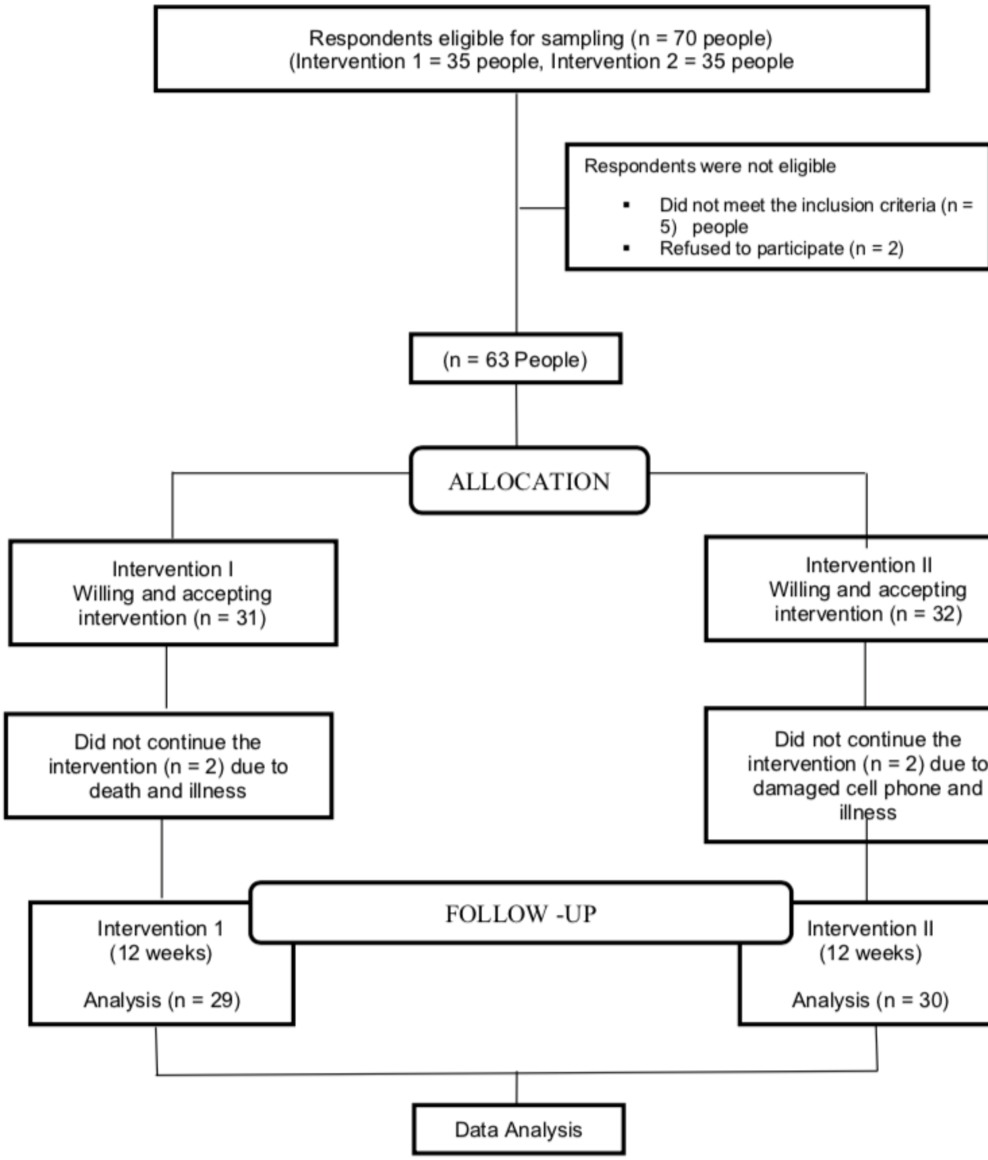

Figure 3. Presents The Flowchart of the Quantitative Quasi-Experimental Design

Basic demographic characteristics are shown in Table 1. The majority of participants were female and had had T2DM for ≥5 years. There were no significant demographic differences between the two study groups.

Table 1. Characteristics of T2DM Patients.

Characteristics of T2DM Patients	**Group**				**P-Value**
	Education Virtual Reality-PA		**Education PA Module Education via WhatsApp Monitoring**		
	(n=29)	**%**	**(n=30)**	**%**	
Gender					
Male	10	34,5	7	23,3	0,278
Female	19	65,5	23	76,7	

Characteristics of T2DM Patients	Group: *Education Virtual Reality-PA* (n=29)	%	Education PA Module Education via WhatsApp Monitoring (n=30)	%	P-Value
Education Level					
Not graduated from elementary	1	3,4	0	0	
Graduated from Elementary	2	6,9	3	10,0	
Graduated from Junior High School	4	13,8	6	20,0	0,930
Graduated from Senior High School	16	55,2	13	43,3	
Graduated from Diploma	1	3,4	1	3,3	
Graduated from University	5	17,2	7	23,3	
Occupation					
Unemployed	0	0	0	0	
PNS/TNI/Polri	4	13,8	7	23,3	
Private Employee	3	10,3	4	13,3	
Entrepreneur	3	10,3	3	10,0	0,204
Farmer	5	17,2	0	0	
Laborer / Driver Housewife	14	48,3	13	43,3	
Retired	0	0	3	10,0	
Marital Status					
Married	28	96,6	26	86,7	0,064
Widowed	1	34,4	4	13,3	
Duration of Diabetes					
< 5 Years	15	51,7	8	26,7	0,738
≥ 5 Years	14	48,3	22	73,3	
Type of Treatment					
Oral	17	58,6	15	50,0	
Injection	7	24,1	10	33,3	0,717
Oral/Injection	4	13,8	5	16,7	
Oral/Herbal	1	3,4	0	0	
Complication					
Vision Impairment	7	24,1	19	63,3	
Impotence	2	6,9	1	3,3	0,562
None	20	69,0	10	33,3	
Smoking Status					
Smoker	3	10,3	1	3,3	1,000
Non-Smoker	26	89,7	29	96,7	
Family History of Diabetes					
Yes	18	62,1	15	50,0	0,346
No	11	37,9	15	50,0	

Health Literacy Outcomes

Statistical analysis using the Wilcoxon signed-rank test showed a statistically significant improvement in cognitive scores in both intervention groups—Virtual Reality (VR) and WhatsApp (WA)—after the educational programs ($p < 0.0001$ for both groups).

In the VR group, the median difference between post- and pre-intervention scores was 4.0. The signed rank value (W) was 406.0 based on 29 paired data points. Spearman's correlation coefficient ($r_s = 0.5917$; $p = 0.0004$) indicated a strong positive correlation between pre- and post-intervention scores, confirming consistent data pairing.

In the WA group, the median increase was 2.0. The signed rank value (W) was 378.0 from 30 pairs. Spearman's correlation also showed a significant correlation ($r_s = 0.5288$; $p = 0.0013$), confirming reliable measurement. These findings confirm that both interventions had a significant positive effect on participants' knowledge regarding diabetes management. This supports the effectiveness of both VR and WhatsApp-based education in enhancing patient understanding. Details of the results of this analysis are presented in **Table 2.**

Table 2. Analysis of Differences in Knowledge Before and After Intervention (Virtual Reality-PA Education and Education PA Module Education via WhatsApp Monitoring)

Group	n	Median Δ Skor	W (Wilcoxon)	p-value (Wilcoxon)	r_s (Spearman)	p-value (Spearman)	Interpretation
Virtual Reality Education-PA	29	4,0	406,0	< 0,0001	0,5917	0,0004	Significant increase; strong correlation
Education PA Module Education via WhatsApp Monitoring	30	2,0	378,0	< 0,0001	0,5288	0,0013	Significant increase; moderate correlation

Wilcoxon Test Results and Spearman Correlation

Self-Efficacy

Virtual Reality (VR) and WhatsApp (WA). In the **VR group:** A statistically significant improvement in self-efficacy scores was found (median difference = 19.00; W = 465.0; $p < 0.0001$, two-tailed), indicating a strong impact of the VR-based educational intervention. However, Spearman's correlation coefficient ($r_s = 0.1683$; $p = 0.1870$) suggested a weak and non-significant correlation between pre- and post-intervention scores, indicating limited consistency in individual response patterns. In the **WA group:** A statistically significant increase in self-efficacy scores was also observed (median difference = 18.50; W = 465.0; $p < 0.0001$, two-tailed). Spearman's correlation revealed a weak and non-significant negative correlation ($r_s = –0.1337$; $p = 0.2406$), implying variability in individual responses. These results indicate that while both interventions were effective in increasing self-efficacy, the individual consistency of score improvements was limited in both groups. Details of the analysis results can be seen in **Table 3.**

Table 3. Analysis of Pre- and Post-Intervention Differences in Self-Efficacy Scores (Virtual Reality-PA Education vs Education PA Module Education via WhatsApp Monitoring)

Group	Comparison	Median Difference	Wilcoxon Statistic (W)	p-value (Wilcoxon)	Spearman's ρ (r_s)	p-value (Spearman)	Interpretation
VR-based PA Education	Pre-VR vs. Post-VR	19.00	465.0	< 0.0001	0.1683	0.1870	Significant improvement; weak correlation
Education PA Module Education via WhatsApp Monitoring	Pre-WA vs. Post-WA	18.50	465.0	< 0.0001	–0.1337	0.2406	Significant improvement; weak negative correlation

Wilcoxon Test and Spearman Correlation Analysis of Changes in Self-Efficacy Scores

Physical Activity Outcomes

The Wilcoxon signed-rank test was used to assess changes in participants' physical activity levels, measured using the International Physical Activity Questionnaire (IPAQ), before and after the interventions using Virtual Reality (VR) and WhatsApp (WA). In the **VR group**, a statistically significant increase was observed ($p < 0.0001$). The median increase in physical activity score was 312.0 MET-minutes/week. The positive and negative rank sums were 445.0 and –20.0, respectively (W = 425.0; n = 30). Spearman's correlation coefficient ($r_s = 0.9108$; $p < 0.0001$) showed a very strong and statistically significant relationship between pre- and post-intervention scores, indicating a consistent improvement. In the **WA group**, an even greater increase in median physical activity was observed: 1068 MET-minutes/week. All rankings were positive (positive/negative rank = 465.0 / 0.0; W = 465.0; n = 30). However, Spearman's correlation (r_s = 0.2642; p = 0.0791) indicated a weak and statistically non-significant relationship between pre- and post- intervention scores, reflecting some inconsistency in individual responses. These findings indicate that both VR and WhatsApp-based interventions effectively improved physical activity levels, though the VR group showed stronger individual consistency. Details of the analysis results can be seen in **Table 4.**

Table 4. Analysis of Pre- and Post-Intervention IPAQ Scores (Virtual Reality-PA Education vs. PA Module Education with WhatsApp Group Monitoring)

Group	Median IPAQ Difference	Positive Rank Sum	Negative Rank Sum	Wilcoxon W	n	p-value (Wilcoxon)	Spearman r_s	p-value (Spearman)
VR-based PA Education	312.0	445.0	–20.0	425.0	30	< 0.0001	0.9108	< 0.0001
Education PA Module Education via WhatsApp Monitoring	1068.0	465.0	0.0	465.0	30	< 0.0001	0.2642	0.0791

Wilcoxon Test and Spearman Correlation analysis

Analysis of physical activity levels measured using the International Physical Activity Questionnaire (IPAQ) showed a statistically significant increase in the group receiving the Virtual Reality (VR) intervention. The Wilcoxon Signed-Rank test revealed a significant difference between pre- and post-intervention scores (p < 0.0001, two-tailed), with a median difference of 312.0. All participants (n = 30) showed an increase in physical activity scores after the intervention, demonstrating the effectiveness of the VR-based approach in facilitating positive physical behavior changes.

HbA1c Clinical Outcomes

In the context of glycemic control, HbA1c levels showed a significant decrease following the implementation of the VR-based intervention. The Wilcoxon test yielded a p-value of 0.0005 (two-tailed), with a median reduction of 1.36%. The Spearman correlation coefficient (r_s = 0.8967; p < 0.0001) indicated a very strong paired consistency, supporting the reliability of the observed HbA1c changes. In the group receiving WhatsApp (WA)-based monitoring, analysis using the paired t-test also demonstrated a statistically significant reduction in HbA1c levels (p = 0.0002, two-tailed), with a mean decrease of 0.67% (95% CI: –0.9976 to –0.3424). The partial eta squared value of 0.3763 indicated a moderate to large effect size. Additionally, Pearson's correlation coefficient (r = 0.9218; p < 0.0001) suggested high reliability in pre- and post-intervention HbA1c measurements. The findings indicate that both the VR-based intervention and WhatsApp (WA)-based monitoring significantly improved glycemic control among patients with T2DM. However, the VR intervention demonstrated a greater reduction in HbA1c levels compared with the WA group. The VR group showed a median HbA1c reduction of 1.36%, which was substantially larger than the 0.67% reduction observed in the WA group. In addition, the very strong Spearman correlation coefficient (r_s = 0.8967; p < 0.0001) in the VR group suggests highly consistent paired changes in HbA1c measurements before and after the intervention.

Although the WA group also demonstrated statistically significant improvements with a moderate-to-large effect size, the magnitude and consistency of HbA1c reduction were more pronounced in the VR group. These findings suggest that the SCT-based VR intervention was more effective in improving glycemic control and may provide a stronger behavioral and motivational impact on diabetes self-management compared with WhatsApp-based monitoring alone. Detailed analysis is presented in **Table 5.**

Table 5. Analysis of Differences in HbA1c Levels Pre- and Post-Intervention (Virtual Reality-PA Education and PA Module Education with WhatsApp Group Monitoring)

Group	Statistical Test	HbA1c Reduction	p-value	CI 95%	Effect Size	Correlation	p-value (Correlation)
VR-based PA Education	Wilcoxon	1,36%	0,0005	-	-	r_s = 0,8967	< 0,0001
Education PA Module Education via WhatsApp Monitoring	Paired t-test	0,67%	0,0002	–0,9976 until –0,3424	η^2 = 0,3763	r = 0,9218	< 0,0001

Wilcoxon Test and Spearman Correlation analysis
Description:
HbA1c Reduction refers to the difference in HbA1c values before and after the intervention.
Effect Size (η^2) describes the strength of the effect in the WA group.
A tick (—) indicates data not relevant for that type of test (e.g., CI is not applicable for Wilcoxon).

Comparative Effectiveness of Virtual Reality and WhatsApp Group Interventions in Diabetes Management

A comparative analysis of the two intervention approaches—Virtual Reality (Post-VR) and WhatsApp-based monitoring (Post-WA)—across four outcome variables (knowledge, self-efficacy, physical activity [IPAQ], and HbA1c levels) revealed varying patterns of statistical significance. For the **Health Literacy** variable, no significant difference was observed between the two groups (Mann-Whitney U = 339; p = 0.1427; not significant), with relatively comparable median scores for Post-VR (20.00) and Post-WA (19.00). This suggests that both interventions were equally effective in improving participants' knowledge.

In contrast, **self-efficacy scores** showed a statistically significant difference (Mann-Whitney U = 149; p < 0.0001), with the Post-VR group achieving a higher median score (58.00) compared to the Post-WA group (54.00). This indicates that the VR-based intervention was more effective in enhancing participants' confidence in managing their condition.

Regarding **physical activity,** the Post-WA group demonstrated significantly higher results (median = 1824 MET-minutes/week) than the Post-VR group (median = 953.3 MET-minutes/week) (Mann-Whitney U = 222.5; p = 0.0006), indicating that WhatsApp-based monitoring was more successful in promoting physical activity engagement.

Furthermore, **glycemic control HbA1c,** measured by HbA1c levels, also showed a significant difference between the groups. The Post-WA group had a lower median HbA1c level (9.05%) compared to the Post-VR group (10.70%) (Mann-Whitney U = 262; p = 0.0049), suggesting a relatively greater success of the WhatsApp monitoring approach in reducing glycemic levels.

Overall, these findings suggest that the VR-based intervention was more effective in improving self-efficacy, whereas the WhatsApp-based monitoring approach demonstrated greater effectiveness in promoting physical activity and improving glycemic control among patients with Type 2 Diabetes Mellitus. Detailed results of the analysis can be found in Table 6 and Figure 4.

Table 6. Comparative Effectiveness of Post-VR and Post-WA Interventions (Outcomes on Knowledge, Self-Efficacy, Physical Activity, and HbA1c)

Outcome Variable	Group	Median	U Mann-Whitney	p-value	Significance	Interpretation
Health Literacy	Post-VR vs. Post-WA	20.00 vs. 19.00	339	0,1427	ns	Not significant
Self-Efficacy	Post-VR vs. Post-WA	58.00 vs. 54.00	149	< 0,0001	***	Significant – VR more effective
Physical Activity (IPAQ)	Post-VR vs. Post-WA	1824 vs. 953.3	222,5	0,0006	***	Significant – WA more effective

Outcome Variable	Group	Median	U Mann-Whitney	p-value	Significance	Interpretation
HbA1c	Post-VR vs. Post-WA	9.05% vs. 10.70%	262	0,0049	**	Significant – VR more effective

Description: *** = very significant (p < 0.001), ** = significant (p < 0.01), ns = not significant

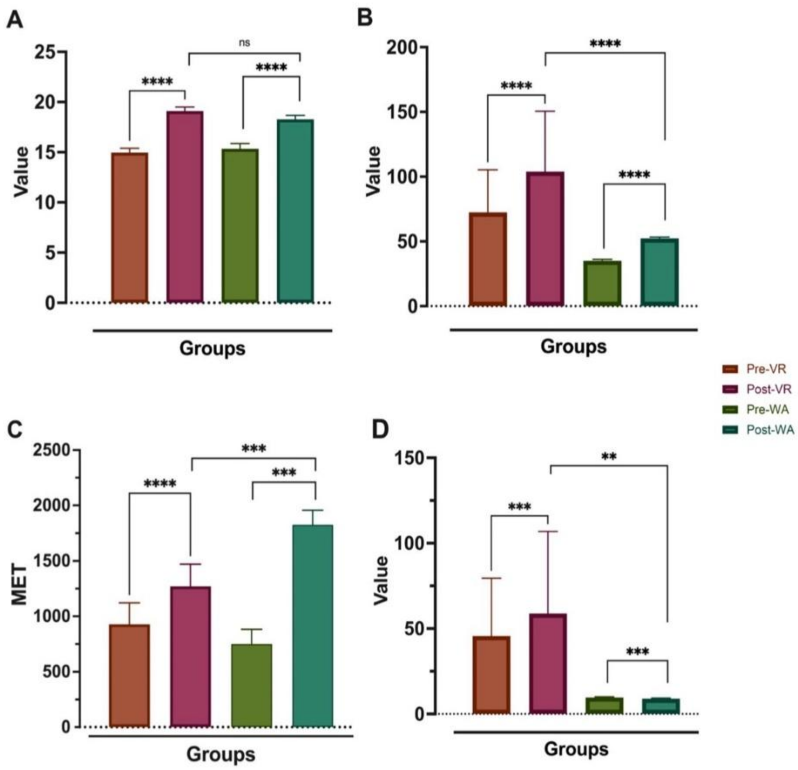

Figure 4. Comparison of Pre- and Post-Intervention Outcomes Across Groups: (A) Health Literacy Assessment, (B) Self-Efficacy, (C) Physical Activity, (D) HbA1c Levels.

Table 7. Baseline Comparability and Between-Group Comparison of Change Scores (Outcomes on Knowledge, Self-Efficacy, Physical Activity, and HbA1c)

Outcome Variable	Pre-VR ± SD	Pre-WA ± SD	p-value Baseline	ΔVR ± SD	95% CI	ΔWA ± SD	95% CI	p-value Δ	Cohen's d
Health Literacy	14.97 ± 2.275	15.33 ± 2.905	0.7015	4.138± 2.295	3.27-5.01	2.933± 2.363	2.05 – 3.82	380.0238	0.52
Self-Efficacy	39.52 ± 3.851	35.03 ± 5.846	0.0010	17.79± 4.411	16.11-19.47	17.23± 8.237	14.16–20.31	530.7453	0.08
Physical Activity (IPAQ)	927.9 ± 1059	750.9 ± 721.9	0.6516	342.6± 352.0	208.73-476.47	1075± 648.1	833.02–1316.98	0<0.0001	1.40
HbA1c	11.84 ± 2.426	9.613 ± 2.236	0.0005	1.251± 1.239	0.78-1.72	0.6700± 0.877	0.34 – 1.00	170.0417	0.54

DISCUSSION

This study aimed to evaluate the impact of health education using Virtual Reality (VR) and health education modules monitored through WhatsApp groups on changes in knowledge, self-efficacy, physical activity, and HbA1c control. The findings showed that both interventions led to significant within-group improvements in cognitive outcomes, suggesting that both VR-based education and WhatsApp-assisted monitoring are effective tools for enhancing knowledge about the importance of physical activity in patients with Type 2 Diabetes Mellitus (T2DM). This implies that VR and module-based education monitored through WhatsApp groups can improve patients' ability to read and comprehend health information, particularly regarding T2DM and the role of physical activity in controlling blood glucose levels (HbA1c).

The comparable median knowledge scores between the two intervention groups suggest that both VR and module-based education with WhatsApp monitoring were equally effective. The authors assume that using technology is highly effective in improving the knowledge of the elderly population.

The use of Virtual Reality (VR) in T2DM patient education has been shown to enhance knowledge about the importance of physical activity (13). Previous studies have demonstrated that VR positively impacts participants' engagement and learning abilities, primarily through increased concentration and active participation during the learning process. In this study, the VR intervention effectively improved T2DM patients' understanding of the importance of physical activity in disease management (21).

These results align with the effectiveness of module-based educational approaches combined with WhatsApp group monitoring. Field observations revealed that most patients were already familiar with WhatsApp, making it a relevant and effective communication platform for education. The use of WhatsApp allowed for two-way interaction between patients and educators without significant barriers related to age or education level.

These findings are supported by previous studies showing that patients with T2DM tend to use mobile devices and are familiar with applications such as WhatsApp. Interventions delivered through these platforms have been shown to be effective in improving patient knowledge and self-efficacy (22).

Furthermore, the use of health self-management applications via group-based information technology platforms has shown positive results, particularly in supporting health promotion strategies and increasing physical activity. This study also provides a reflective insight into the use of information and communication technology (ICT), particularly the interaction patterns between patients and researchers in the virtual WhatsApp space. Communication in the group can be understood as a process of social construction marked by symbolic exchanges among participants within a specific context (23). Within the relational communication framework, conversations in WhatsApp groups can be seen as communicative actions contributing to collective knowledge building among T2DM patients.

Based on the results presented in Table 6, a significant difference in self-efficacy scores was found between the intervention groups, highlighting the essential role of self-efficacy in T2DM self-management. Self-efficacy is a key cognitive-affective factor, reflecting individuals' confidence in their ability to maintain and improve their health. Previous studies have shown that low self-efficacy is correlated with poor self-care outcomes among T2DM patients and serves as a critical prerequisite in making informed health and care decisions (24).

VR-based interventions have demonstrated positive feedback and significantly encouraged patients to consistently implement dietary, physical activity, and daily glucose management programs (14). This form of digital education has been shown to enhance self-efficacy perceptions in diabetes self-care practices (25) creates an immersive and interactive learning environment that allows patients to engage directly with the material, focus more intensely, and experience greater intrinsic motivation. Such active engagement is a key factor in forming and reinforcing self-efficacy (26).

In this study, VR provided an optimal learning condition for increasing self-efficacy through safe experiential learning, real-time feedback, and heightened emotional involvement (13). Therefore, compared to conventional approaches like text-based delivery or chat group communication, VR-based interventions have greater potential to strengthen individual confidence in initiating behavioral change and performing self-management tasks effectively.
The effectiveness of both interventions can be coherently explained through the core mechanisms of Social Cognitive Theory (SCT), specifically how each modality activates distinct sources of self-efficacy. The superiority of VR in enhancing self-efficacy is consistent with Bandura's proposition that enactive mastery experience—the direct

experience of success—is the most powerful source of self-efficacy. VR environments allow participants to perform, repeat, and perfect target behaviors in a safe, controlled, and consequence-free simulation. Repeated success builds the belief that the behavior can be performed, and they can perform it with VR education. Furthermore, the immersive nature of VR facilitates observational learning through concrete visual modeling, reinforcing the encoding of behaviors before execution. This mechanism explains why VR's impact is most pronounced on cognitive-motivational constructs like self-efficacy, rather than solely on behavioral outcomes.

Conversely, WhatsApp's superiority in increasing physical activity can be traced to its capacity to provide social persuasion and sustained behavioral reinforcement within participants' real-life contexts. Unlike VR, which is episodic, WhatsApp operates as a distributed intervention embedded in daily routines through recurring reminders, feedback, and social support messages. Using WhatsApp groups to provide educational feedback to monitor their activities, participants can engage in WhatsApp messaging. Within the SCT framework, recurring reminders serve as behavioral cues that bridge intention and action, while social reinforcement from facilitators and fellow participants supports self-regulation—goal setting, self-monitoring, and behavior correction—which is essential for maintaining consistent physical activity behavior. Because physical activity requires repetition and continuity in a real-world environment, modalities capable of providing ongoing support and repeated contact are logically superior for these behavioral outcomes.

Thus, both findings reflect mechanistic complementarity: VR excels at establishing the cognitive prerequisites for behavior change through mastery experiences, while WhatsApp excels at supporting behavior execution and maintenance through persistent social reinforcement. This interpretation is in line with the view that self-efficacy and behavioral action are distinct but mutually influencing components in the SCT causal pathway, and implies that the combination of both modalities has the potential to provide a synergistic effect—VR for belief initiation and WhatsApp for behavior maintenance—which is supported by the results that VR and module-based education with WhatsApp monitoring were equally effective.

The results also indicated that VR interventions significantly increased physical activity levels, as did WhatsApp group monitoring. VR interventions have been shown to effectively reduce sedentary time and increase physical activity among office workers with T2DM (27).

Significant increases in physical activity have also been observed between intervention and control groups, particularly through reductions in sitting time (28). In general, mHealth technology-based programs can help shift time spent in sedentary behavior (29). Furthermore, increasing physical activity has been associated with significant improvements in the quality of life of individuals with T2DM (30). Enhanced physical activity has been linked to reduced disease complications and lower risk of premature mortality. Interventions targeting physical activity, even without app-based technology, have also successfully increased physical activity levels in primary care patients (31). Physical inactivity is a known risk factor for developing T2DM (32), while exercise is effective in both preventing and managing T2DM (33). Thus, physical activity is recommended as a foundational component of diabetes management (34). Individuals tend to benefit more from regular exercise with longer duration, higher intensity, or both (35). Therefore, accurate monitoring of exercise intensity, duration, and adherence is essential for training efficiency. Real-time VR-based exercise with trained staff supervision introduces a new dimension in physical activity engagement.

After three months, HbA1c levels in the VR group showed a significant reduction following the VR-based intervention. The Wilcoxon test yielded a p-value of 0.0005 (two-tailed), with a median reduction of 1.36%. After 12 weeks, the intervention group experienced a consistent improvement in HbA1c levels. VR-based education influenced self-efficacy and knowledge related to the importance of physical activity, thereby prompting patients to adopt improved self-management, which ultimately impacted clinical outcomes such as HbA1c.

Interpretation of Key Findings

This study shows that virtual reality (VR) and WhatsApp (WA) interventions are equally effective in increasing knowledge, self-efficacy, physical activity, and lowering HbA1c in patients with T2DM. VR is superior in increasing self-efficacy, while WhatsApp is more effective in behavioral change and glycemic control. These two digital approaches have the potential to complement each other in diabetes self-management (13,22).

The divergent pattern of effects can be interpreted through the SCT constructs that each modality most strongly activated. The stronger self-efficacy gain in the VR arm is consistent with mastery experience and observational learning: immersive VR let participants repeatedly rehearse physical activity in a safe, controlled environment with immediate feedback, and such enactive mastery is, within SCT, the most powerful source of self-efficacy. The heightened immersion, focus, and intrinsic motivation reported for VR plausibly reinforced participants' confidence in performing self-management tasks. By contrast, the larger physical-activity increase in the WA arm is consistent with social reinforcement, self-regulation, and outcome expectations operating through daily, low-barrier prompts. WhatsApp was already familiar to most participants, lowering the technology barrier, and the moderated group provided continual reminders, peer accountability, and two-way feedback that supported day-to-day behavioural enactment outside any session. In other words, VR may be especially suited to building the cognitive–motivational precursor (self-efficacy), whereas WhatsApp may be better at sustaining the repeated daily behaviour (activity) through social accountability and habit cues. This mechanistic reading also tempers the glycaemic findings: because HbA1c responds to cumulative behaviour over months and the arms differed at baseline, the within-group reductions are better explained by overall improvements in self-management in both groups than by the superiority of either modality. These interpretations remain hypotheses to be tested directly through mediation analysis in adequately powered randomised trials.

Limitations and Cautions

This study has several limitations that should be considered when interpreting the results. First, the target sample size of 160 participants was not achieved due to limitations in recruiting participants who met the inclusion criteria, participant withdrawals during the intervention period, and limited participation in VR technology. These conditions may reduce the statistical power of the study, thereby increasing the risk of error. Furthermore, the generalizability of the findings is further limited, and interpretation of the results should be approached with caution.

Second, the 12-week intervention duration was insufficient to assess the efficacy of behavioral change and long-term clinical outcomes (18). Third, measuring physical activity using the International Physical Activity Questionnaire (IPAQ) may introduce recall bias compared with measuring goals using accelerometers. Furthermore, the use of VR technology may have had a novel effect that influenced participants' initial motivation, especially since most were unfamiliar with using such devices. Some elderly participants also reported dizziness during VR use, suggesting the need for more user-friendly adaptations of the technology (21). Nevertheless, this study still provides preliminary evidence regarding the effectiveness of an SCT-based VR intervention among patients with T2DM.

Recommendations for Future Research

Future research is recommended to use a randomized controlled trial (RCT) design with a larger sample size to confirm the effectiveness of VR and WA and to evaluate a hybrid approach combining the two. The intervention duration should also be extended to 6–12 months to assess the sustainability of effects on HbA1c and health behaviors (17). Furthermore, the use of objective physical activity measurement devices, such as wearable devices or accelerometers, would improve data accuracy. Mediation and moderation analyses can help understand the relationship between increased self-efficacy and changes in clinical outcomes (24). Further studies should also consider tolerability in older adults by adapting the VR interface to make it more comfortable and safer. Cost-effectiveness evaluations and implementation research are needed to assess the feasibility of implementing this digital intervention in primary healthcare (34). Finally, mixed-methods research combining quantitative and qualitative data is recommended to understand user experiences and cultural factors that influence intervention success.

CONCLUSION

In summary, this study provides preliminary evidence that an SCT-based VR intervention, alongside an active WhatsApp-based intervention, can improve health literacy, self-efficacy, physical activity, and within-group glycemic control among patients with T2DM in a primary-care setting. VR offers an immersive, experiential learning environment that appears particularly useful for strengthening self-efficacy, while the WhatsApp approach supports day-to-day physical activity through familiar, low-barrier social reinforcement. Given the quasi-experimental design, non-randomised allocation, small sample, short follow-up, single-region setting, and absence of trial registration, these findings should be interpreted cautiously and not as a basis for large-scale roll-out. Adequately powered randomized controlled trials with longer follow-up, baseline-adjusted analyses, objective activity measurement, and mediation analysis of SCT mechanisms are needed before VR can be recommended for wider implementation in diabetes care.

AUTHOR'S CONTRIBUTION STATEMENT

HJ conceived and designed the study. Z supervised the study, validated data, and was responsible for manuscript review and editing. HH contributed to data collection and statistical analysis. FXW developed and validated the research instruments. W assisted in data interpretation. RYP managed data processing and visualization. SBK coordinated fieldwork and participant recruitment. All authors read, critically revised, and approved the final manuscript.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

DECLARATION OF GENERATIVE AI AND AI-ASSISTED TECHNOLOGIES IN THE WRITING PROCESS

The authors acknowledge the use of generative artificial intelligence (AI) and AI-assisted technologies, including OpenAI ChatGPT (GPT-5), DeepL Write, Grammarly and QuillBot, during the preparation of this manuscript to assist with language refinement, paraphrasing, and improving readability. All authors reviewed, edited, and approved the final version to ensure accuracy, originality, and compliance with ethical publication standards.

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