

IMPACT OF SMART SENSING-BASED AEROBIC EXERCISE ON FUNCTIONAL CAPACITY IN ADULTS WITH TYPE 2 DIABETES MELLITUS: A RANDOMIZED CONTROLLED TRIAL

Rija Khalid^{*1}, Tehreem Mukhtar²

^{*1}MS Neuromuscular Physical Therapy, Department of Rehabilitation Sciences, Faculty of Allied Health Sciences, Superior University, Lahore

²Department of Rehabilitation Sciences, Faculty of Allied Health Sciences, Superior University, Lahore

^{*1}su91-msrsw-f24-038@superior.edu.pk, ²tehreemmukhtar01@gmail.com

DOI: <https://doi.org/10.5281/zenodo.23204928>

Keywords

Type 2 Diabetes Mellitus; Aerobic Exercise; Exercise Tolerance; Glycaemic Control; Mobile Health Applications; Randomized Controlled Trials as Topic; Running; Treatment Adherence and Compliance; Walk Test; Walking

Article History

Received: 29 June 2026

Accepted: 20 September 2026

Published: 07 October 2026

Copyright @Author

Corresponding Author: *

Rija Khalid

Abstract

Background: Many patients with Type 2 Diabetes Mellitus (T2DM) in Pakistan and similar countries experience decline in their physical health, and have limited access to exercise programs. One potential way to provide exercise programs to these patients is through the use of real-time exercise programs and technology.

Objective: To determine the impact of a real-time exercise program, made available through an app, on the physical functionality and glycemic control of patients with T2DM.

Methods: This study was a randomized control group study. There was a total of 62 patients between the ages of 30-65 with a diagnosis of T2DM. The control group (n=31) received standard care. The exercise group (n=31) completed 20-25 exercise sessions, each 30-45 minutes long, over the 12 week period. Participants of the exercise group walked and jogged at a real time monitoring and logging system. At the end of the 12 weeks, all participants took a 6 minute walk test to evaluate VO₂ max. Blood was also drawn to assess HbA1c levels, and Fasting Blood Glucose levels. The primary outcome of the study was to evaluate the difference in the control and exercise groups in glycemic control and physical activity and exercise logging.

Results: Among the 58 participants in the Intervention group and 62 participants in the Control group with complete data, large improvements in all outcomes were observed for the Intervention group as follows: HbA1c (Intervention: 7.38%; Control: 8.12%; difference between means: -0.59%; $p < 0.001$; Cohen's d: -3.18); Fasting Blood Glucose (Control: 157.08 mg/dL; Intervention: reduction by 13.59 mg/dL from Control; $p < 0.001$; Cohen's d: -3.38); 6-Minute Walk Test (Control: 269.10 m; Intervention: 309.90 m; difference between means: 40.90 m; $p < 0.001$; Cohen's d: 4.14); Estimated VO₂ Max (Control: 12.76 ml/kg/min; Intervention: 13.18 ml/kg/min; difference between means: 0.42 ml/kg/min; $p < 0.001$; Cohen's d: 1.56), Walking distance (Control: 719.21 m; Intervention: 831.10 m; difference between means: 111.89 m; $p < 0.001$; Cohen's d: 3.42), and other outcomes. The Intervention group also demonstrated greater Running Distance and Duration and other outcomes. Overall, mean adherence to the Intervention was 82.2%. No one was determined to be a low adherent participant.

1.INTRODUCTION

Type 2 Diabetes Mellitus (T2DM) is a rapidly increasing public health problem due to its chronic nature, complication developmental process and potential to increase premature death. T2DM is defined by an impaired insulin secretion and/or insulin action resulting in hyperglycemia. T2DM is associated with numerous co-morbidities including cardiovascular disease, neuropathy and nephropathy. While various treatment options have been developed to control T2DM, the disease continues to reduce patients' health-related quality of life. Pharmacological treatment is less effective in controlling the disease progression if patients are physically inactive and/or poorly manage their condition. The situation in South Asia, including Pakistan, is comparable to other rapidly urbanizing regions. Various dietary and lifestyle modifications have increased the prevalence of T2DM in the region. Increased sedentary behavior has particularly accelerated the disease. Even in Pakistan, where the overall health facility and resource infrastructure is extremely limited, patients with T2DM do not have access to several follow ups and/or other supportive care between scheduled appointments and/or treatment. In such a scenario, the inclusion of regular and adequate physical activity or exercise in self-management of T2DM can result in considerable improvement of patients' health status and quality of life.

As an affordable aspect of treatment, aerobic exercise is essential in the management of type 2 diabetes mellitus (T2DM). Along with increased insulin sensitivity, aerobic exercise benefits include improved glucose tolerance, cardiovascular health and fitness. Numerous studies have shown that aerobic exercise improves health outcomes and quality of life of individuals with T2DM (1). Regular aerobic exercise improves glycemic control. However, challenges associated with long-term adherence to physical activity recommendations persist. These challenges include lack of motivation, inadequate access to controlled and supervised programs, fear of hypoglycemia, and inadequate self-monitoring of blood glucose levels (2). Supervised exercise programs offer benefits to patients of T2DM. However, the limited

number of such programs in Pakistan and similar low and middle income countries represents a major barrier to implementation.

The use of activity trackers and mHealth apps has shown potential in enhancing exercise adherence and self-management. Provided that sufficient evidence is offered, individualized goals and immediate feedback can facilitate and enhance physical activity (3). Positive impacts of mHealth interventions on the physical and psychological health of adults with Type 2 Diabetes have been documented (4). It has also been shown that mHealth interventions can improve the physical health of patients with Type 2 Diabetes and be as effective as conventional treatments (5).

Decline in functional capacity in Type 2 Diabetes are because of many factors including loss of skeletal muscles because of uncontrolled blood sugar levels, and because of increased sedentary behavior (6). Over time, these factors lead to a decrease in a person's capacity to perform basic tasks of daily living. As a result, the person becomes more dependent on the healthcare system. Therefore, health interventions that can be carried out outside the hospital by health care workers, and that do not require many health care personnel, are appropriate to address this issue in countries like Pakistan (7).

Rationale

There are functional and metabolic aspects of Type 2 Diabetes Mellitus (T2DM) and there are sustainable and realistic methods of improving these aspects of patient well being. One of those methods may be the utilization of smart sensing technology to improve patients' functional capacity as measured by the six-minute walk test (6MWT) and/or by estimating their VO₂ max. One of the methods of achieving the aforementioned aims may be the use of structured aerobic exercise programs in an outpatient setting in South Asia. Research to examine those methods is lacking.

Several smartphone applications include features to measure and monitor health. An example of such applications is Samsung Health. While there are health monitoring devices available to measure and evaluate health parameters, they are expensive and are not

available to the general public in Pakistan. Similarly, affordable and readily available smartphones can be used to engage in remote monitored exercise programs. This type of program may be beneficial to outpatient diabetes clinics in Pakistan and similar countries.

2. LITERATURE REVIEW

T2DM is a major health challenge of this century, affecting populations of all ages and socioeconomic status. It is a condition of relative insulin deficiency due to insulin resistance and relative β cell dysfunction. Long standing hyperglycemia causes vascular and other complications. In Pakistan, the risk factors for T2DM are increasing due to urbanization, change in diet and lifestyle.

Long term management of T2DM causes several complications due to loss of muscle mass and decline in function of the heart and other organs. These lead to decline in the ability to perform daily activities. T2DM patients also have neuropathy, which affects balance and leads to falling. Over the years, patients have become completely dependent on others for daily activities. Multiple reviews and studies have shown that functional capacity of T2DM patients has adversely been affected and that it can be improved on implementation of exercise interventions.

Aerobic exercise increases glucose uptake by muscle cells through multiple mechanisms. AMPK is a key enzyme in the insulin signaling pathway and is activated by various forms of exercise. Activation of AMPK leads to the translocation of GLUT-4 to the muscle cell membrane, increasing glucose uptake. The use of moderate- to high-intensity aerobic exercise shows significant reductions in blood glucose levels (8). Lower-intensity, longer-duration aerobic exercise has also been shown to decrease blood glucose levels and HbA1c (9).

Aerobic exercise and combined aerobic and resistance training improve multiple areas of health, including body composition and glycemic control (8). High Intensity Training (HIT) has benefits similar to combined training; however, HIT may provide greater improvements in glucose control. HIT has benefits in the short-term, but combined training may provide greater improvements in

the long-term. Aerobic exercise has multiple benefits for elderly and middle-aged populations, including improvements in quality of life, and may provide increased benefits in the reduction of overall body fat and waist circumference (2).

Evidence suggests that the main barrier to high adherence is the need for participants to personally set and pursue behavioral goals, rather than the training itself (10). However, the definition of high adherence is based on the accomplishment of 80% or more of the behavioral goals (11). It is generally accepted that the components of digital health interventions which focus on behavior change, including goal-setting and planning, as well as providing or reinforcing feedback, form the cornerstone of digital interventions to improve health (3). Digital goals and behavioral changes are facilitated via interactive, individualized, and real-time prompts on a computer, mobile, or other electronic device (12).

Mobile health (mHealth) technologies have the potential to change health behaviors and improve health outcomes in a range of medical conditions including diabetes and cardiovascular disease. mHealth tools are particularly useful to promote self-management and self-care behaviors (13). mHealth interventions which incorporate behavioral goals, engagement, and interactive components improve the therapeutic effect, especially when integrated with health education and patient self-care training (14).

The Samsung Health app was verified to be a research app for physical activity monitoring for various smartphone models and is ready for research use (15). Technology-assisted, self-monitored exercise interventions are less expensive than face-to-face supervised exercise interventions and are appropriate for low- and middle-income countries (LMICs). The availability of digital technology has improved access to various self-monitored interventions, including supervised exercise programs, in outpatient clinics. Evidence from controlled studies has demonstrated that exercise programs, including technology-based support and face-to-face supervision, significantly improved HbA1c levels and 6-minute walk test (6). Findings from more recent studies, such as

the non-inferiority trial of a technology-based, self-monitored outdoor exercise intervention compared to outpatient rehabilitation (8), the MOTIVATE-T2D digital study (16) and the 12-week digital wearable technology study (17) in Taiwan, indicate that digital and technology-based exercise interventions have the potential to reduce sedentary behavior and improve overall health. Additionally, digital interventions have the potential to improve adherence and participation in the intervention among the targeted study populations.

Outcome measures used in the study were based on validity and relevance to the outpatient setting. The 6-minute walk test (6MWT) was the primary measure of functional capacity. The test is simple, requires no special equipment and is related to functional capacity of the cardiorespiratory system. As direct cardiopulmonary exercise testing was not possible, the study used the equation developed by Jacobs and Simonson to estimate VO_2max from the 6MWT. Glycemic control was assessed by measurement of HbA1c to reflect control over the previous 8 to 12 weeks, and fasting blood glucose to assess control over the previous few hours. As in previous studies, exercise adherence was assessed based on the session log of the Samsung Health application, and adherence was defined as attending 80% or more of the exercise sessions.

Objective

To assess the effects of a smart sensing-based, app-driven aerobic exercise intervention on functional capacity, glycemic control, and adherence to exercise and physical activity (walking and running) among adults with Type 2 Diabetes Mellitus.

Hypotheses

Null Hypothesis (H0): Smart sensing technology incorporated into aerobic exercise will not affect functional capacity, glycemic control, or adherence to exercise in adults with type 2 diabetes mellitus (T2DM) compared to care provided under normal circumstances.

Alternative Hypothesis (H1): Smart sensing technology incorporated into aerobic exercise will improve functional capacity, glycemic control, adherence to exercise and physical

activity (walking and running), compared to care provided under normal circumstances, in adults with type 2 diabetes mellitus (T2DM).

Operational Definitions

Type 2 Diabetes Mellitus (T2DM): Medical record documentation of professional diagnosis by a physician 1 year prior to study enrollment. Additionally, record documentation of either a fasting plasma glucose ≥ 126 mg/dL or HbA1c $\geq 6.5\%$ from a standard lab test (18).

Aerobic Exercise: Defined as brisk walking (4 to 5 days a week, 30 to 45 minutes a session, 50% to 70% of maximum heart rate) that is monitored and documented using the Samsung Health app (15).

Functional Capacity: The capacity to perform aerobic activities, measured by the distance walked on the 6-minute-walk-test (19).

VO_2 Max: Maximal oxygen uptake, predicted from the 6 minute walk test (20).

Glycemic Control: Measured by HbA1c and Fasting Plasma Glucose (18).

Physical Activity: Walking and running, as documented by the Samsung Health app.

Exercise Adherence: Percent relative to the prescribed exercise sessions (2).

Literature Gap

Four major gaps exist in studies using technology to facilitate physical activity for T2DM. First, the majority of studies are conducted in high-income countries, especially in the West and East of Asia. There are very few studies conducted in South Asia, including Pakistan, despite the rising prevalence of diabetes in this region, as well as limited availability of supervised exercise therapy. Second, the majority of studies aim to assess the effects of technology on physical activity on HbA1c. Assessment of physical activity and functional capacity through other means (e.g., 6-Minute Walk Test, approximate VO_2 max) are often neglected. Third, the assessment of adherence to exercise is often based on subjective measures and varies across studies. Finally, no South Asian studies have assessed T2DM management using technology in an integrated manner to assess real world physical activity, adherence, and functional capacity. This study aims to fill this research gap.

3. MATERIALS AND METHODS

3.1 Research Design

The study design was a randomized controlled parallel group pretest-post-test trial, and is reported based on the CONSORT 2010 statement. The study enrolled 62 adults with T2DM. Subjects were randomized to the Intervention group (n=31) or Control group (n=31). Assessors of the primary outcome measure were blinded to the group allocation.

3.2 Setting and Duration

This study was conducted in the outpatient diabetic clinics of Lahore, Pakistan. Recruitment and data collection for a period of 6 months was undertaken. The 6 month period was divided into 3 months of recruitment, a 12 week intervention and a 3 month post-intervention

data collection. Thirty two weeks (8 months) was considered adequate to detect changes in blood glucose levels and the functionality of the participants as reported in the literature (21).

3.3 Sample Size

The sample size was calculated using G*Power (Version 3.1.9.2) for the primary outcome, considering 80% power and 5% alpha. The effect size was informed by previous studies (19). The predicted sample size was 62 (31 per group). Due to expected participant dropout, the recruitment target was increased by 10%. There was no dropout among the 62 participants enrolled in the study. The interventions were provided to the full sample, and no participant data was missing for the outcomes assessed using activity trackers.

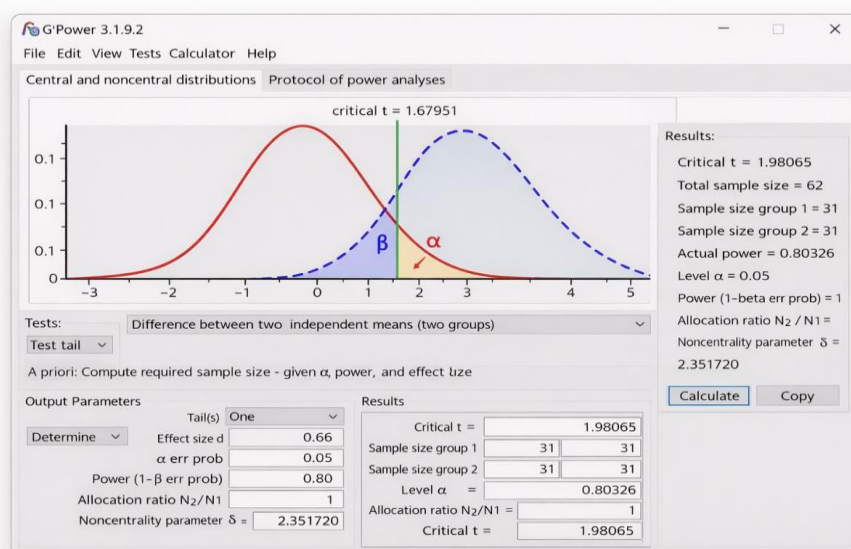


Figure 1. G*Power a priori sample-size calculation (difference between two independent means; α = 0.05, power = 0.80, effect size d = 0.66).

3.4 Sampling Technique

Non-probability purposive sampling was employed. Participants were recruited from outpatient diabetic clinic registers and physician referrals; all eligible, consenting patients meeting inclusion criteria were enrolled until the required sample was reached.

3.5 Inclusion and Exclusion Criteria

Inclusion Criteria

- Participants aged 30 to 65 years.
- Confirmed diagnosis of Type 2 Diabetes Mellitus by a qualified endocrinologist,

documented at least one year prior to enrolment.

- HbA1c $\geq$ 6.5% or fasting blood glucose $\geq$ 126 mg/dL on recent laboratory testing.
- Physically capable of performing moderate-intensity aerobic exercise.
- Provided written informed consent.

Exclusion Criteria

- Unstable cardiovascular conditions or a recent myocardial infarction ($<$ 3 months).
- Musculoskeletal disorder preventing safe aerobic exercise.

- Severe diabetic complications, such as advanced neuropathy or moderate-to-severe retinopathy.
- Participation in structured exercise within 3 months prior to enrolment.
- Cognitive impairment affecting ability to follow instructions or use the application.
- Pregnancy or planned pregnancy during the study period.

3.6 Ethical Consideration

The study was performed in accordance with the 1975 Declaration of Helsinki and was approved by the institutional review board of Superior University, Lahore. Written informed consent was provided by participants and was documented. To protect confidentiality and ensure anonymity, participants' names were not recorded. They were free to refuse to participate and withdraw from the study at any time, without effect on other benefits or services that they may have otherwise received.

3.7 Study Groups

Intervention Group (Group A)

The PAR-Q+ was used to assess participants' eligibility for exercise. Participants at risk completed a medical form to be signed by their doctor. Group A walked at a moderate pace for 30-45 minutes, 4-5 days a week for 12 weeks. The activity was self-paced and broken up by 5-10 minute warm ups and cool downs, with 20-30 minutes of activity time. The activity was designed for participants to keep their heart rate between 50-70% of their estimated maximum heart rate ($HR_{max} = 220 - \text{Age}$). The activity was monitored and designed in accordance with the American College of Sports Medicine. The activity was intended to help participants with T2DM.

Control Group (Group B)

Participants in Group B received conventional care for T2DM for 12 weeks and were free to use the app and take part in the exercise program as directed at a later stage. They continued to take their diabetes medications, and their diabetes was managed conventionally. During this stage of the study, no exercise goals were set, and no face-to-face contact with a physiotherapist occurred. Outcome assessments occurred at

baseline and Week 12 (6-minute walk test, HbA1c, and FBS). Data from the Samsung Health app (walking and running) was also recorded for the Intervention group. At the conclusion of the study, the exercise program and app were also offered to participants in the Control group.

3.8 Outcome Measures

A blinded assessor evaluated all outcomes under standardized conditions at baseline (T1) and post-intervention (T2, Week 12), across three domains: functional capacity, glycaemic control, and physical activity.

Six-Minute Walk Test (6MWT)

The 6MWT is a simple, low-cost, field-based measure of sub-maximal functional capacity in which participants walk as far as possible along a flat, measured pathway over six minutes, with total distance recorded in metres (2). Healthy adults typically cover 400–700 m; adults with T2DM walk considerably less due to cardiovascular and peripheral neuropathic limitations. An improvement of 14–30 m is considered the minimal clinically important difference (MCID) for this population.

Estimated VO_2 Max

VO_2 Max, an indicator of cardiorespiratory fitness, was estimated from 6MWT distance using a validated regression equation ($VO_2 \text{ Max} = [0.03 \times 6\text{MWT distance}] + 3.98$) (25), expressed in ml/kg/min. Typical values in T2DM range from 15–20 ml/kg/min, compared with 30–40 ml/kg/min in adults without diabetes.

HbA1c and Fasting Blood Glucose

Glycated haemoglobin (HbA1c), reflecting average glucose over the preceding 2–3 months, was measured via high-performance liquid chromatography. Fasting blood glucose (FBG), reflecting a single time-point after an 8–12-hour fast, was measured enzymatically. A decrease in either marker indicates improved glycaemic control; an HbA1c reduction of $\geq 0.5\%$ is considered clinically meaningful in T2DM management.

Walking and Running (Samsung Health Application)

Walking and running were assessed as physical activity variables using built-in Samsung Health tracking, recording distance, duration, and step count via the smartphone's accelerometer and GPS. The application has been validated for step-count accuracy against a video-recorded criterion measure across multiple Samsung smartphone models (17). Data were logged continuously for the Intervention group across the 12-week programme and exported for analysis at Week 12.

3.9 Data Collection Procedure

Recruitment happened consecutively from the outpatient clinic. Potential participants were screened for eligibility and, if eligible, had a doctor clear them for participation. Eligible participants provided consent and were randomly assigned to the intervention or control group. Allocation was concealed using opaque, sealed envelopes. The design of the study was single-blind. The investigators of the study were not blinded to the participants' group assignments.

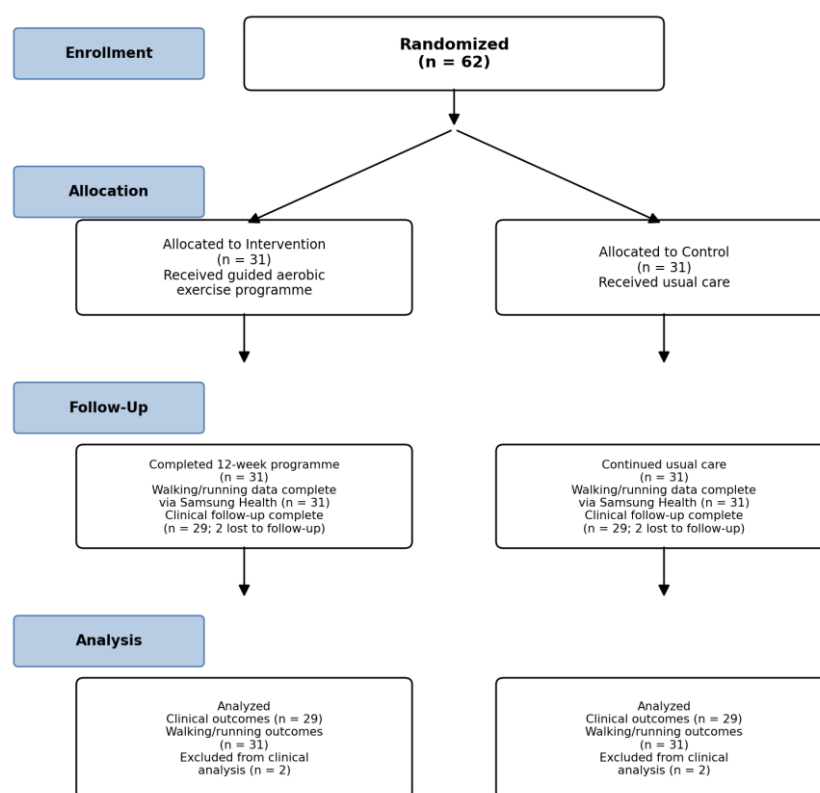


Figure 2. CONSORT flow diagram of participant enrolment, allocation, follow-up, and analysis.

3.10 Data Analysis

The analysis was conducted using IBM SPSS Statistics, version 26. The normality of the continuous variables was determined by the Shapiro-Wilk test. Paired samples t-tests were used to analyze the differences within a group before and after the intervention. Independent samples t-tests were used to compare the change scores (post – pre) to analyze the differences between the groups. This test is used when the baseline equality of the groups is minimal. The level of significance was set at 0.05. Effect sizes

were calculated using Cohen's d. Non-normal distributions were tested using the Wilcoxon signed rank test.

4. RESULTS

Sixty-two adults with T2DM were distributed to the Intervention and Control groups (n = 31, each). Two participants in each group (Intervention: work commitments; Control: move out) were lost to follow up at Week 12, and were excluded from the analysis (n = 58). For analysis of walking and running outcomes, all

enrolled participants ($n = 62$) were included. No adverse effects were reported. Equal and unrelated dropout rates (6.5% in each group) were observed and reported in compliance with the CONSORT 2010 statement.

Age and gender distribution were comparable in both groups ($p > 0.05$). Baseline levels of walking and running (if any) were similar in both groups

($p > 0.05$). A borderline significant difference was observed for FBG levels in the two groups ($p = 0.052$). It is standard and recommended for studies to use Post-Pre differences for the levels in which a baseline inequality was observed. Therefore, in this study, Post - Pre differences in FBG levels were used as the primary indicator of change for the two groups.

Table 1. Baseline Demographic Characteristics by Group (N = 62)

Variable	Intervention (n = 31) M $\pm$ SD	Control (n = 31) M $\pm$ SD	t / χ^2	df	p-value
Age (years)	50.1 $\pm$ 6.7	48.5 $\pm$ 6.7	t = 0.914	60	0.364
Gender (Male/Female)	21M / 10F	16M / 15F	$\chi^2 = 1.676$	1	0.196

Note. Independent-samples t-test for age; Pearson chi-square for gender. All $p > 0.05$ confirms baseline comparability.

4.1 Assumption Testing: Normality

Most of the outcome variables across the two groups and three time points, as evaluated by the Shapiro-Wilk test, showed a normally distributed population ($p > 0.05$). The Control group's FBG (fasting blood glucose) levels, at both time points, and the running variables of the Intervention group (duration and distance) showed positive skewness and non-normality. The Control group's participants were mostly sedentary and, therefore, showed a right-skewed distribution, as expected. The Intervention group was composed of 29 and 31 participants, respectively, for clinical and activity related outcomes. Therefore, for both groups, paired sample t-tests were considered appropriate, as supported by the CLT for $n \geq 25$. Sensitivity analyses, using the Wilcoxon signed-rank test, were carried out and showed similar results for FBG ($Z = -4.707$, $p < 0.001$).

4.2 Within-Group Change: Baseline to Week 12

The HbA1c of the Intervention group reduced from $8.12 \pm 0.75\%$ to $7.38 \pm 0.70\%$ (mean difference -0.74% , 95% CI -0.82% to -0.67%). The reduction was 3.40% and therefore far greater than the 0.5% reduction considered to be clinically relevant for individuals with Type 2 Diabetes Mellitus (T2DM) (12). The Control group demonstrated a clinically irrelevant

reduction in HbA1c from $8.09 \pm 0.46\%$ to $7.93 \pm 0.49\%$ (mean difference -0.16%).

The Intervention group demonstrated a mean reduction in Fasting Blood Glucose (FBG) of 15.59 (95% CI 13.78 to 17.39) from the baseline of 156.66 (28.17) mg/dL to 141.07 (17.44) mg/dL. Exercise induces translocation of the GLUT-4 transmembrane transport protein to the cell membrane of skeletal muscle, thereby increasing the uptake of blood glucose by skeletal muscle. The Control group demonstrated a clinically irrelevant reduction in FBG of -2 mg/dL from a baseline of 164.79 (13.04) mg/dL.

The distance covered on the 6MWT increased from 383.14 ± 29.91 m to 428.62 ± 33.33 m for the Intervention group (mean difference = $+45.48$ m; 95% CI = $[+40.81, +50.15]$; $t(28) = -19.090$, $p < 0.001$; $d = 3.54$). This increase is far greater than the minimal clinically important difference for the 6MWT (14-30 m) (2). The Control group also showed a small improvement on the 6MWT of $+4.59$ m ($d = 0.83$). The Intervention group also showed a clinically meaningful improvement from the estimated maximal aerobic capacity from (ml/kg/min), 15.47 ± 0.89 to 16.84 ± 1.00 (mean difference = $+1.36$; 95% CI = $[+1.23, +1.50]$; $t(28) = -19.242$, $p < 0.001$; $d = 3.57$). The Control group showed a very small, and clinically irrelevant improvement ($d = 0.84$).

There was a large, significant increase within the Intervention group in the duration and distance walked, and a small significant increase in the duration and distance run, through Samsung Health. The increases within the Intervention

group are in line with the program focus of brisk walking and away from the program focus of running. The Control group, also through Samsung Health, showed no changes in walking or running over the duration of the program.

Table 2. Within-Group Pre-Post Comparison: Paired-Samples t-Test

Variable	Group	Pre M ± SD	Post M ± SD	Mean Diff	t	p	d
HbA1c (%)	Intervention	8.12 ± 0.75	7.38 ± 0.70	-0.74	20.696	<0.001	-3.84
HbA1c (%)	Control	8.09 ± 0.46	7.93 ± 0.49	-0.16	4.736	<0.001	-0.88
FBG (mg/dL)	Intervention	156.66 ± 17.85	141.07 ± 17.44	-15.59	16.895	<0.001	-3.14
FBG (mg/dL)	Control	164.79 ± 13.04	162.79 ± 13.30	-2.00	3.914	<0.001	-0.73
6MWT (m)	Intervention	383.14 ± 29.91	428.62 ± 33.33	+45.48	-19.090	<0.001	3.54
6MWT (m)	Control	385.62 ± 28.55	390.21 ± 30.71	+4.59	-4.496	<0.001	0.83
VO ₂ Max (ml/kg/min)	Intervention	15.47 ± 0.89	16.84 ± 1.00	+1.36	-19.242	<0.001	3.57
VO ₂ Max (ml/kg/min)	Control	15.55 ± 0.86	15.69 ± 0.92	+0.14	-4.517	<0.001	0.84
Walking Duration (min/day)	Intervention	30.71 ± 6.35	47.52 ± 9.18	+16.81	12.333	<0.001	2.22
Walking Duration (min/day)	Control	32.52 ± 6.59	33.73 ± 7.47	+1.22	1.741	0.092	0.31
Walking Distance (km/day)	Intervention	2.24 ± 0.50	3.59 ± 0.81	+1.35	11.837	<0.001	2.13
Walking Distance (km/day)	Control	2.34 ± 0.43	2.45 ± 0.52	+0.11	1.912	0.066	0.34
Running Duration (min/day)	Intervention	1.65 ± 0.97	2.63 ± 1.81	+0.98	3.424	0.002	0.61
Running Duration (min/day)	Control	1.29 ± 1.09	1.29 ± 1.33	-0.01	-0.032	0.975	-0.01

Running Distance (km/day)	Intervention	0.20 ± 0.11	0.32 ± 0.22	+0.13	3.686	<0.001	0.66
Running Distance (km/day)	Control	0.16 ± 0.13	0.17 ± 0.18	+0.01	0.470	0.642	0.08

Note. Diff = Post – Pre. Negative difference = improvement for HbA1c/FBG; positive difference = improvement for 6MWT, VO₂ Max, and walking/running duration and distance. df = 28 for HbA1c, FBG, 6MWT, VO₂ Max (n = 29/group); df = 30 for walking/running variables (n = 31/group). Cohen's d: ≥0.2 small, ≥0.5 medium, ≥0.8 large (27).

4.3 Between-Group Comparison of Change Scores

Independent samples t-tests showed that the Intervention group showed larger improvements than the Control group for each of the eight outcomes assessed. The average difference in change score (mean difference) was as follows: HbA1c -0.59% (t(56) = -12.115, p < 0.001, d = -3.18); FBG -13.59 mg/dL (t(56) = -12.883, p < 0.001, d = -3.38); 6MWT +40.90 m (t(56) = 15.780, p < 0.001, d = 4.14); estimated VO₂ max +1.23 ml/kg/min (t(56) = 15.876, p < 0.001, d = 4.17).

For activity, the mean difference for the change in walking duration was +15.59 min/day (t(60) = 10.182, p < 0.001, d = 2.59), and for walking distance, it was +1.25 km/day (t(60) = 9.811, p < 0.001, d = 2.49). The mean differences for change in running distance and duration were less, but statistically significant, +0.12 km/day (t(60) = 2.632, p = 0.011, d = 0.67) and +0.98 min/day (t(60) = 2.808, p = 0.007, d = 0.71) respectively. For all eight comparisons, effects sizes were in the medium to large range.

Table 3. Between-Group Comparison of Change Scores: Independent-Samples t-Test

Outcome Variable	Intervention Change M ± SD	Control Change M ± SD	Mean Diff	t	p	d
HbA1c (%)	-0.74 ± 0.19	-0.16 ± 0.18	-0.59	-12.115	<0.001	-3.18
FBG (mg/dL)	-15.59 ± 4.97	-2.00 ± 2.75	-13.59	-12.883	<0.001	-3.38
6MWT Distance (m)	+45.48 ± 12.83	+4.59 ± 5.49	+40.90	15.780	<0.001	4.14
VO ₂ Max (ml/kg/min)	+1.36 ± 0.38	+0.14 ± 0.16	+1.23	15.876	<0.001	4.17
Walking Duration (min/day)	+16.81 ± 7.59	+1.22 ± 3.89	+15.59	10.182	<0.001	2.59
Walking Distance (km/day)	+1.35 ± 0.64	+0.11 ± 0.31	+1.25	9.811	<0.001	2.49
Running Duration (min/day)	+0.98 ± 1.59	-0.01 ± 1.13	+0.98	2.808	0.007	0.71
Running Distance (km/day)	+0.13 ± 0.19	+0.01 ± 0.15	+0.12	2.632	0.011	0.67

Note. Change = Post – Pre. Mean Diff = Intervention change – Control change. df = 56 for HbA1c, FBG, 6MWT, VO₂ Max (n = 29/group); df = 60 for walking/running variables (n = 31/group). Cohen's d: ≥0.2 small, ≥0.5 medium, ≥0.8 large (27).

4.4 Exercise Adherence

Objective adherence was defined as the ratio of completed to prescribed sessions, multiply by 100. Prescribed sessions were limited to 60 (12 weeks X 5 sessions per week). As such, the highest adherence that could be achieved was 100%. Mean adherence of the Intervention group was 82.2% with a range of 71.9-92.8%

Adherence. Of the 29 participants in the study that completed the intervention, 18 (62.1%) were classified as High Adherent, 11 (37.9%) as Moderate Adherent, and no one was classified as Low Adherent. This is more favourable compared to the 40-60% adherence to traditional, technology-unrestricted exercise interventions, reported in the literature.

Table 4. Exercise Adherence Descriptive Statistics – Intervention Group (n = 29)

Adherence Parameter	Value
Mean Adherence (%)	82.2
Standard Deviation (SD)	6.6
Minimum (%)	71.9
Maximum (%)	92.8
High Adherent ($\geq 80\%$)	n = 18 (62.1%)
Moderately Adherent (60–79%)	n = 11 (37.9%)
Low Adherent ($< 60\%$)	n = 0 (0.0%)

Note. Classification: $\geq 80\%$ High; 60–79% Moderate; $< 60\%$ Low (15). Adherence measured objectively via Samsung Health session logs (20).

4.5 Summary

There were no between-group differences on all variables other than a borderline difference on FBG. Therefore, baseline equivalence was assumed. All outcomes of the Intervention group improved after the 12-week period, and the effect sizes were large. Change scores from the Intervention group were significantly larger than the Control group on all outcomes ($p < 0.05$; $d = 0.67-4.17$). Furthermore, high adherence was reported and no participants were determined to be in the low adherence group. Overall, these results indicate the Samsung Health program has the potential to be used for other similar patient populations to provide an exercise intervention that can be facilitated outside of a clinical setting.

5. DISCUSSION

This study examined the effect of a 12-week Smart Sensing-based Aerobic Exercise Intervention, conducted and overseen via the Samsung Health application, on functional capacity, glycemic control, and exercise and physical activity behavior of adults with Type 2 Diabetes Mellitus (T2DM) who attend

outpatient departments. Participants in the Intervention group showed statistically and clinically significant improvement in all eight outcomes when compared to participants in the Control group.

The effect-sizes observed in the study are attributed to the Intervention and not to other confounding situations, because of similarity of the samples (in terms of age, sex, and most of the other outcome variables) at the time of allocation to the intervention and control groups. Only Fasting Blood Glucose levels (FBG) ($p = 0.052$) showed very small difference at the time of allocation to the intervention and control groups. Because of the small difference, and in accordance with what is recommended for minor baseline differences in a parallel group design, the use of the difference (or change) from pre-to-post intervention, in this case from pre- to post-test, was the main comparison of interest for this study.

Most of the participants in this study were from the South Asia region, and their demographic characteristics and T2DM related situation was similar to participants in other similar studies.

Hence, findings in this study can be generalized to similar situations and settings.

The change on the 6MWT far exceeded the clinically relevant improvement of 14-30 m expected with structured exercise for individuals with diabetes. Improvements on the 6MWT associated with the present exercise intervention far exceeded the improvements on the 6MWT associated with routine care, and thus routine clinical follow up, are likely attributed to incidental activities and the practice effect. These findings support the use of a home-based, app-based exercise intervention to improve function and rehabilitation, particularly relevant to the outpatient clinics in Pakistan.

The changes in hemoglobin A1c and FBG levels were in the clinically relevant range, and are consistent with the meta-analytic findings of aerobic exercise and glycemic control. Improvements in blood glucose levels with aerobic exercise are attributed to the translocation of GLUT-4. Improvements in both the intervention and the control group are likely attributed to routine clinical care.

A significant increase in the average walking duration and distance, along with an increase in running behavior, shows that the intervention brought about real-world changes in physical activity. Compared to the behavior change observed in other physical activity promoting interventions, the increases in walking duration and distance ($d = 2.22-2.59$) in this study were large. The behavior changes in the control group showed that absence of structured activities, as in the case of the participants of this study, results in little to no change in physical activity levels. The changes observed in the participants of this study cannot be attributed to the passage of time, or to other factors unrelated to the intervention, since significant changes were reported both during lab-based evaluations and outside the lab.

Out of 100 participants, 82.2% on average adhered to the exercise program, and 62.1% were classified as high-adherent. No one was classified as low-adherent. High mean adherence is expected since the study uses an activity tracker and provides users with real time feedback. Traditional exercise programs have reported adherence rates of 40 to 60%. The similar findings in the MOTIVATE-T2D study

further validate the adherence rates observed in the current study. Additionally, the Samsung Health app was found to be a reliable step counter. Therefore, the results of this study can be generalized. In the absence of low-adherent participants, implementation of this model is feasible.

The mobile phone application in conjunction with in-person visits positively impacted participants' health, both functionally and metabolically. Behavioral change was considerable and beyond the scope of usual care. The effects ranged from medium to very large. Overall, the results of this study support previous research that integration of health and exercise programs using digital interventions in low and middle-income countries is not only feasible, but also improves public health outcomes in low resource settings.

Limitations

- The 12-week mark is too short of a time frame to determine if improvements made by participants were maintained in the long-term.
- Adherence rates may have been overreported as a result of the participants' knowledge of the research (Hawthorne effect).
- Estimating VO₂ max from the 6MWT introduced error into the measurement.
- For the 31 participants in each group, measurements of HbA1c, FBG, VO₂ max and 6MWT were collected. For walking and running speed, all 31 participants were analyzed.
- For the remainder of the participants in the study, only walking and running were analyzed; therefore, other activities that may have been recorded by the Samsung Health application were disregarded.
- Change in diet and/or medication may have confounded study results.
- The sample only consisted of participants from clinics located in urban areas of Lahore, Pakistan; thus, results may not be representative of other rural areas or other geographical locations.

Recommendations

- Future studies could focus on the long-term sustainability of behavior change by extending the follow-up period to 6-12 months.

- Future studies should consider including dietary changes and adjusting medications to account for better control of potential confounders.
- Increasing the diversity of study populations to include higher levels of adherence heterogeneity should be pursued to define the adherence-outcome relationship further.
- To identify barriers to engagement with the mobile smart-sensing technology-based exercise program in the target population, future studies should include qualitative research methods.
- Future studies should aim to better determine the impact of smart-sensing technology by incorporating a traditional exercise-based control group.

6. CONCLUSION

A 12-week app-based, smart sensing, aerobic exercise program improved the functional capacity and glycemic control of adult patients with type 2 diabetes mellitus in Pakistan and improved their objectively assessed physical activity level. The improvement in health outcomes was observed with high adherence to the intervention. The integration of smart sensing technology to structured aerobic exercise enhanced diabetes care within the outpatient setting and improved the quality and accessibility of care in low-resource settings.

REFERENCES

- Piras A, Raffi M, editors. A narrative literature review on the role of exercise training in managing type 1 and type 2 diabetes mellitus. *Healthcare*; 2023: MDPI.
- Picorelli AMA, Pereira LSM, Pereira DS, Felício D, Sherrington C. Adherence to exercise programs for older people is influenced by program characteristics and personal factors: a systematic review. *Journal of physiotherapy*. 2014;60(3):151-6.
- Mair JL, Salamanca-Sanabria A, Augsburg M, Frese BF, Abend S, Jakob R, et al. Effective behavior change techniques in digital health interventions for the prevention or management of noncommunicable diseases: an umbrella review. *Annals of Behavioral Medicine*. 2023;57(10):817-35.
- Wu P-T, Baltich AA, Chu I-H, Chui KK. Wearable Activity Trackers to Improve Physical Activity and Cardiovascular Risk in Type 2 Diabetes: A Randomized Pilot Study. *Diabetology*. 2025;6(9):97.
- Koyama M, Himuro N, Nakata K, Oyatani K, Shinohara Y, Ohnishi H, et al. Effects of physical activity-promoting wearable devices on blood pressure in adults: a systematic review and meta-analysis. *Hypertension Research*. 2025;48(10):2677-87.
- Timurtas E, Inceer M, Mayo N, Karabacak N, Sertbas Y, Polat MG. Technology-based and supervised exercise interventions for individuals with type 2 diabetes: randomized controlled trial. *Primary care diabetes*. 2022;16(1):49-56.
- Cui J, Liu Q, Huang L, Yu H. Digital outdoor exercise program for obese patients with type 2 diabetes mellitus: a non-inferiority randomized controlled trial. *Frontiers in Endocrinology*. 2025;16:1654129.
- Ramírez-Alvarado C. Aerobic exercise as a protective factor in older adults with type 2 diabetes mellitus. *Mexican Journal of Medical Research ICSA*. 2023;11(22):54-60.
- Fitri N, Dewi YS, Suarilah I, Efendi C, Yazid SA. EFFECTIVENESS OF WALKING EXERCISE ON HBA1C AND BMI OF DIABETES MELLITUS TYPE 2: A SYSTEMATIC REVIEW. *Nurse and Health: Jurnal Keperawatan*. 2024;13(2):394-408.
- Wang C, Tang S. The effects of aerobic exercise on 24-hour mean blood glucose levels measured by continuous glucose monitoring in type 2 diabetes: a meta-analysis. *Frontiers in Physiology*. 2024;15:1496271.
- Almutairi AH, Almutairi NS, Mousa N, Elsayed A, El-Sehrawy A, Elmetwalli A. Aerobic exercise as a non-pharmacological intervention for improving metabolic and hemodynamic profiles in type 2 diabetes. *Irish Journal of Medical Science (1971-)*. 2024;193(6):2781-90.

- MacPherson MM, Merry KJ, Locke SR, Jung ME. mHealth prompts within diabetes prevention programs: a scoping review. *Mhealth*. 2022;8:20.
- Gomez-Garcia C, Maher CA, Sañudo B, Jurado-Castro JM. Mobile health interventions for individuals with type 2 diabetes and overweight or obesity—a systematic review and meta-analysis. *Journal of Functional Morphology and Kinesiology*. 2025;10(3):292.
- Nishi SK, Kavanagh ME, Ramboanga K, Ayoub-Charette S, Modol S, Dias GM, et al. Effect of digital health applications with or without gamification on physical activity and cardiometabolic risk factors: a systematic review and meta-analysis of randomized controlled trials. *EClinicalMedicine*. 2024;76.
- Beltrán-Carrillo VJ, Jiménez-Loaisa A, Alarcón-López M, Elvira JL. Validity of the “Samsung Health” application to measure steps: A study with two different samsung smartphones. *Journal of sports sciences*. 2019;37(7):788-94.
- Hesketh K, Low J, Andrews R, Blitz S, Buckley B, Falkenhain K, et al. Mobile Health Biometrics to Enhance Exercise and Physical Activity Adherence in Type 2 Diabetes (MOTIVATE-T2D): a decentralised feasibility randomised controlled trial delivered across the UK and Canada. *BMJ open*. 2025;15(3):e092260.
- Lin C-F, Chang H-M, Hsu C-Y, Yang C-T, Lin S-Y. Enhancing physical activity in older type 2 diabetic adults through remote patient monitoring: a pre-post study in Taiwan. *PeerJ*. 2025;13:e19659.
- Committee ADAPP. 2. Diagnosis and classification of diabetes: standards of care in diabetes—2026. *Diabetes Care*. 2025;49(Suppl 1):S27.
- Pfeifer LO, De Nardi AT, da Silva LXN, Botton CE, do Nascimento DM, Teodoro JL, et al. Association between physical exercise interventions participation and functional capacity in individuals with type 2 diabetes: a systematic review and meta-analysis of controlled trials. *Sports medicine-open*. 2022;8(1):34.
- Burr JF, Bredin SS, Faktor MD, Warburton DE. The 6-minute walk test as a predictor of objectively measured aerobic fitness in healthy working-aged adults. *The Physician and sportsmedicine*. 2011;39(2):133-9.
- Wrench E, Rattley K, Lambert JE, Killick R, Hayes LD, Lauder RM, et al. There is no dose-response relationship between the amount of exercise and improvement in HbA1c in interventions over 12 weeks in patients with type 2 diabetes: a meta-analysis and meta-regression. *Acta diabetologica*. 2022;59(11):1399-415.