diabetology

MDPI

Article

Wearable Activity Trackers to Improve Physical Activity and Cardiovascular Risk in Type 2 Diabetes: A Randomized Pilot Study

Pei-Tzu Wu [1,2,*], Ashlee A. Baltich [2], I-Hua Chu [3] and Kevin K. Chui [4]

[1] Doctor of Physical Therapy Program, Southern California University of Health Sciences, Whittier, CA 90604, USA
[2] Doctor of Physical Therapy Program, Pacific University, Hillsboro, OR 97124, USA; ashleebaltich@pacificu.edu
[3] Department of Sports Medicine, Kaohsiung Medical University, Kaohsiung City 80708, Taiwan; ihchu@kmu.edu.tw
[4] Department of Physical Therapy, Radford University, Roanoke, VA 24013, USA; kchui@radford.edu
* Correspondence: peitzuwu@scuhs.edu

Abstract

Background/Objectives: Type 2 diabetes (T2D) is associated with elevated cardiovascular risk and mortality. While physical activity can reduce cardiovascular risk, sustaining behavioral change remains challenging. Wearable activity trackers offer a scalable approach to promote physical activity, but their effects on cardiovascular outcomes in adults with T2D have not been well studied. To evaluate the impact of a wrist-worn activity tracker on physical activity, cardiovascular markers, and metabolic outcomes in adults with T2D over four weeks. **Methods:** This pilot randomized controlled trial included eight adults with T2D (mean age 54.9 ± 12.6 years; intervention (FIT) group: n = 5; control (CON) group: n = 3). The intervention group received an activity tracker. Both groups used the Fitbit app to track daily activity. Physical activity metrics (steps, walking distance, energy expenditure) and cardiovascular markers (blood pressure, augmentation index, pulse wave velocity, subendocardial viability ratio [SEVR]) were assessed pre- and post-intervention. Non-parametric tests and Spearman correlations were used due to the small sample size. **Results:** The FIT group showed significant increases in walking distance and energy expenditure and reductions in systolic/diastolic blood pressure, pulse pressure, and mean arterial pressure (all $p < 0.04$). SEVR trended toward improvement ($p = 0.07$). No significant changes were seen in the CON group. Increased physical activity was strongly correlated with reductions in pulse pressure ($\rho = -0.88$) and fasting glucose ($\rho = -0.82$; both $p < 0.05$). **Conclusions:** A brief wearable-based intervention improved physical activity and cardiovascular markers in adults with T2D, supporting feasibility for diabetes care.

Keywords: arterial stiffness; cardiovascular health; physical activity; type 2 diabetes; wearable activity trackers

check for updates

Received: 3 June 2025
Revised: 23 July 2025
Accepted: 1 September 2025
Published: 8 September 2025

Citation: Wu, P.-T.; Baltich, A.A.; Chu, I.-H.; Chui, K.K. Wearable Activity Trackers to Improve Physical Activity and Cardiovascular Risk in Type 2 Diabetes: A Randomized Pilot Study. *Diabetology* **2025**, *6*, 97. https://doi.org/10.3390/diabetology6090097

Copyright: © 2025 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).

1. Introduction

Diabetes mellitus represents a significant global health burden, currently affecting approximately 38 million Americans—12% of the U.S. population—and 589 million adults worldwide [1,2]. Global prevalence is projected to increase dramatically to 853 million by 2050, according to both established projections and recent systematic analyses [1]. Type 2 diabetes (T2D), which accounts for over 90% of all diabetes cases, is strongly associated

with increased risk of cardiovascular disease (CVD), and patients face a two- to four-fold higher risk of cardiovascular mortality compared to individuals without diabetes [3].

The etiology of T2D is multifactorial, but obesity and physical inactivity are the most significant modifiable risk factors. These factors can increase the risk of developing T2D by up to 17-fold [4]. While pharmacologic treatments such as metformin help regulate blood glucose, lifestyle interventions, particularly structured physical activity, have demonstrated greater efficacy in preventing or delaying disease onset [5]. Even modest weight loss (5–7%) and regular moderate physical activity (150 min per week) can significantly reduce the incidence of T2D and improve cardiovascular outcomes [5–8].

Despite these benefits, adherence to physical activity remains low due to barriers such as low self-efficacy, limited support, and environmental constraints [9–11]. Traditional provider-led interventions can improve adherence but are often labor-intensive and resource-demanding, creating a need for scalable, cost-effective alternatives [5,6,12].

Wearable activity trackers, such as Fitbit®, have emerged as promising tools to facilitate behavior change [13]. These devices support self-monitoring through real-time feedback, goal setting, motivational prompts, and health-related notifications. Wearable devices can increase daily step counts by approximately 775 steps [14] and offer modest improvements in weight management and glycemic control among individuals with T2D [15–20].

However, most prior studies have focused on behavioral or metabolic outcomes, with relatively few randomized controlled trials evaluating the cardiovascular effects of wearable interventions in people with T2D. Critical cardiovascular markers such as augmentation index (AIx), pulse wave velocity (PWV), and subendocardial viability ratio (SEVR) are often underreported. Arterial stiffness, a surrogate measure for cardiovascular risk, was found to decrease following a 1-year period of step count monitoring using pedometers in patients with T2D [15]; however, the relationship between the change of physical activity level and risk of developing CVD remains unclear. Moreover, few studies have directly linked wearable-facilitated physical activity to changes in cardiovascular risk in diabetic populations [21,22].

Recent work has emphasized the utility of wearable technologies in translating physical activity guidelines into real-world, patient-centered strategies for chronic disease prevention and management [18]. Given the rising global burden of diabetes, including its associated morbidity and mortality, there is a growing demand for innovative, accessible interventions that can complement traditional care models to reduce cardiovascular risk.

Accordingly, the objective of this study was to evaluate the effects of a wrist-worn activity tracker on physical activity levels and cardiovascular health indicators in adults with T2D over a four-week intervention period.

2. Materials and Methods

2.1. Study Design

This study was designed as a pilot randomized trial conducted over a four-week intervention period to evaluate the feasibility and preliminary effects of a wearable activity tracker intervention. Participants were randomly assigned in a 1:1 ratio to either the intervention group (FIT) or the control group (CON) using a simple randomization approach. The random allocation sequence was generated using a computer-based random number generator by a research team member. As the same individual also assisted with data collection, allocation was not concealed. This limitation is acknowledged given the pilot nature of the study.

Due to the nature of the intervention, participants were not blinded to group assignment. The intervention and control conditions were not designed to appear similar; therefore, participant blinding was not feasible.

This pilot study enrolled a small sample based on logistical feasibility. The sample size intended to explore feasibility and estimate preliminary effect sizes. The small sample size and exploratory nature precluded formal power analysis and definitive hypothesis testing. This trial was retrospectively registered with ClinicalTrials.gov (registration number: NCT07144774).

2.2. Participants

Participants were recruited from clinical and community settings in the Hillsboro, Oregon area. Eligibility criteria included adults aged 18 years or older with a confirmed diagnosis of T2D (hemoglobin A1c (HbA1c) $\geq$ 6.5% or fasting plasma glucose $\geq$ 126 mg/dL) [23].

Exclusion criteria comprised inability to ambulate independently without assistive devices, current smoking, pregnancy or breastfeeding, habitual engagement in $\geq$150 min of moderate-to-vigorous physical activity per week, and the presence of medical conditions that could interfere with participation in physical activity (e.g., severe musculoskeletal disorders, cognitive dysfunction). Screening was conducted via telephone or email interviews. Written informed consent was obtained from all participants prior to enrollment.

2.3. Intervention

Both groups had Fitbit app installed on their smartphones to monitor step count, walking/running distance, and energy expenditure (EE). However, only participants in the FIT group were provided with a Fitbit wrist-worn device (Inspire 2® activity tracker, Fitbit Inc., San Francisco, CA, USA) at baseline. Participants in the CON group did not receive a wearable device but were instructed to carry their smartphones throughout the day to enable step tracking via the app's MobileTrack feature.

All participants were encouraged to gradually increase their daily step count by 500–1000 steps per day (approximately 0.6–0.8 km), aiming to reach at least 7500 steps per day (approximately 5.6–5.8 km) by the end of the 4-week intervention. No structured exercise programs were prescribed to either group.

Harms were not systematically assessed in this pilot study, given the low-risk nature of the intervention. However, participants were encouraged to report any concerns, and no adverse effects were noted.

2.4. Outcome Measures

Outcome assessments were conducted at two time points: baseline (T0) and four weeks post-intervention (T1). Participants were instructed to fast for at least 8 h and abstain from caffeine and alcohol for 12 h prior to each testing session to standardize physiological measurements.

2.4.1. Primary Outcomes

Physical activity levels were assessed using daily step counts, walking distance, and EE recorded through the Fitbit app and via the Global Physical Activity Questionnaire (GPAQ) [24]. The GPAQ consists of 16 questions designed to estimate an individual's level of physical activity in 3 domains (work, transport, and recreational activities) and time spent in sedentary behavior [25]. This questionnaire has strong reliability and good validity [26].

Data were analyzed following the official GPAQ Analysis Guide from the World Health Organization [27]. For each activity domain, physical activity intensity was expressed in Metabolic Equivalent of Task (MET) units, and weekly physical activity was calculated in MET-minutes using the following formula:

$$\text{MET} - \text{min/week} = \text{days/week} \times \text{minutes/day} \times \text{MET value} \quad (1)$$

Standardized MET values were applied: 8.0 METs for vigorous-intensity activity and 4.0 METs for moderate-intensity and transport-related activities (e.g., walking or cycling). Total physical activity was determined by summing MET-min/week across all domains. Sedentary behavior was calculated as the average number of minutes spent sitting per day.

Participants were classified as meeting the WHO physical activity guidelines if they reported $\geq$600 MET-minutes per week, equivalent to at least 150 min of moderate-intensity or 75 min of vigorous-intensity physical activity per week.

Step counts, walking distance, and EE at baseline (T0) were determined using the 3-day average of Fitbit app-recorded data prior to the start of the 4-week intervention. At the end of the intervention (T1), average daily step count, walking distance, and EE through the 4 weeks of intervention were calculated and compared with baseline values to assess changes in physical activity within and between groups.

Cardiovascular risk indicators included systolic blood pressure (SBP) and diastolic blood pressure (DBP), measured using an automated sphygmomanometer. Pulse pressure (PP) and mean arterial pressure (MAP) were calculated from systolic and diastolic blood pressure. Arterial stiffness indices, including augmentation index (AIx) and pulse wave velocity (PWV) were assessed using applanation tonometry (SphygmoCor®, AtCor Medical, Sydney, Australia). The subendocardial viability ratio (SEVR) was also measured as an index of myocardial perfusion and coronary supply-demand balance.

2.4.2. Secondary Outcomes

Secondary outcomes included metabolic and anthropometric measures. Fasting plasma glucose was measured in duplicate using an Accu-Chek® Guide Me glucometer (Roche Diabetes Care, Inc., Indianapolis, IN, USA). Anthropometric measurements included height, weight, waist and hip circumferences, from which BMI and waist-to-hip ratio (WHR) were calculated.

In addition, the study explored potential associations between changes in physical activity and cardiovascular risk markers, including SBP, DBP, PP, MAP, AIx, PWV, and SEVR to evaluate whether increases in activity levels were linked to improvements in vascular health.

2.5. Statistical Analysis

Descriptive statistics were computed to summarize baseline demographic and clinical characteristics. Continuous variables were reported as means with standard deviations unless otherwise noted. GPAQ data were summarized using medians and minimum-maximum ranges. Categorical variables as frequencies and percentages.

All randomized participants who completed both baseline and post-intervention assessments were included in the final analysis and were analyzed according to their original group assignment. Participants with incomplete outcome data were excluded from the analysis. Given the small sample size and pilot nature of the study, no imputation methods were used to address missing data.

To evaluate changes in physical activity over the course of the 4-week intervention, repeated weekly measures (Week 0 to Week 4) were analyzed using the Friedman's tests. Where significant omnibus effects were detected, Wilcoxon signed-rank tests were performed as post hoc analyses to examine pairwise differences between time points.

To compare changes within groups from baseline (T0) to post-intervention (T1), the Wilcoxon signed-rank test was used. Between-group differences at follow-up were assessed using the Mann–Whitney U test. Associations between changes in physical activity and cardiovascular risk markers were explored using Spearman's rank correlation coefficients (ρ).

To complement *p*-values and provide a sense of clinical relevance, effect sizes (*r*) were calculated by dividing the standardized test statistic (Z) by the square root of the sample size (*n*). Effect sizes were interpreted according to Cohen's guidelines: small ($r \approx 0.1$), medium ($r \approx 0.3$), and large ($r \geq 0.5$) [28].

All statistical analyses were two-tailed, with a significance level set at $p < 0.05$. As this was a pilot feasibility study, findings should be interpreted with caution and used to inform future sample size estimations and study design. All analyses were performed using IBM SPSS Statistics for Windows, Version 29.0 (IBM Corp., Armonk, NY, USA). The full trial protocol and statistical analysis plan are available upon reasonable request from the corresponding author.

3. Results

3.1. Participant Characteristics

A total of sixteen individuals were screened for eligibility. Seven were excluded prior to randomization, and the remaining nine participants were randomized to either the FIT or CON group. One participant in the CON group withdrew during the intervention phase due to time constraints. The remaining eight participants (FIT: $n = 5$; CON: $n = 3$) completed the 4-week intervention and were included in the final analysis (Figure 1).

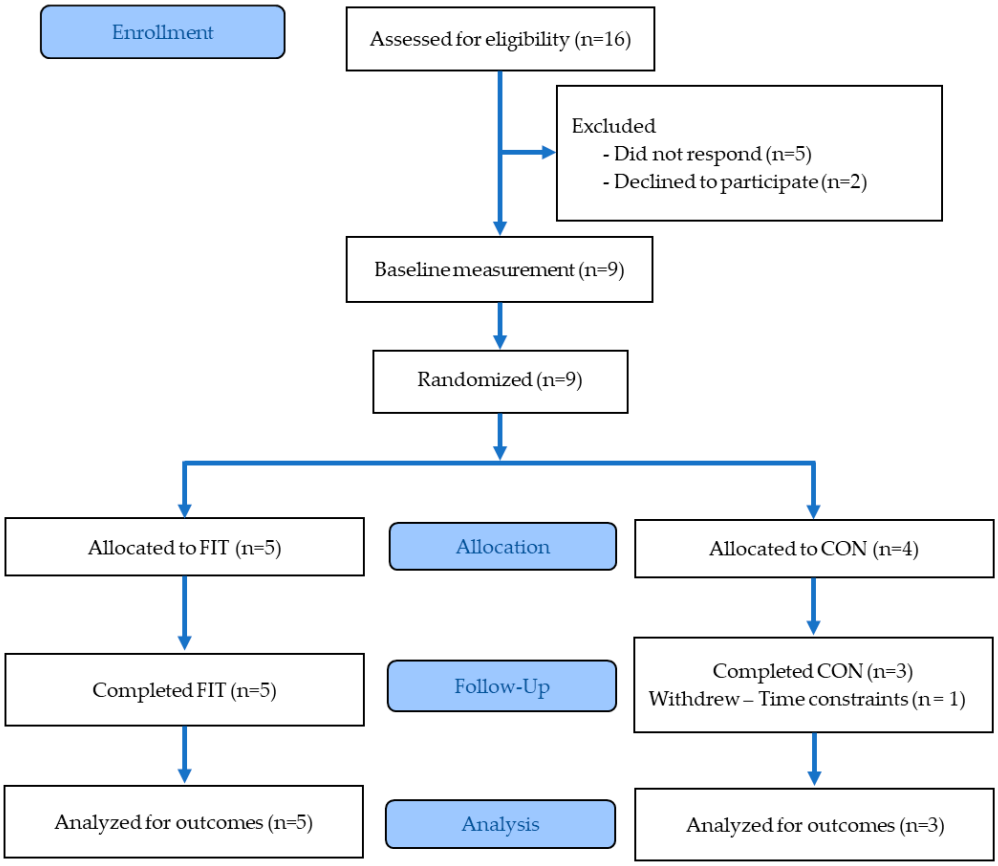


Figure 1. CONSORT diagram showing participant flow through screening, randomization, allocation, and follow-up for the 4-week intervention.

Baseline demographics and anthropometric characteristics are presented in Table 1. The groups were comparable at baseline in terms of age, sex distribution, and ethnicity. There were no significant differences between groups regarding initial measures of weight, height, BMI, waist circumference, hip circumference, waist-to-hip ratio, fasting glucose levels, physical activity level, and cardiovascular measures.

Table 1. Participant Characteristics and Outcome Measures.

Measure	FIT (n = 5)		CON (n = 3)	
	Baseline	**Week 4**	**Baseline**	**Week 4**
Age (years)	51 [43–67]	–	51 [47–59]	–
Female (N; %)	1 (20%)	–	1 (33.3%)	–
Weight (kg)	72.7 [64.2–78.2]	71.8 [64.1–79.1]	79.1 [75.5–124.8]	78.2 [75.5–124.1]
Height (cm)	175.0 [169.0–175.0]	175.0 [168.5–175.0]	175.0 [171.8–178.0]	175.5 [172.2–178.0]
Body Mass Index (BMI)	23.7 [23.0–27.4]	23.5 [23.2–27.9]	27.9 [25.7–40.0]	27.4 [25.5–39.8]
Waist Circumference (cm)	95.2 [89.0–101.5]	94.5 [89.0–98.8]	98.8 [96.6–134.1]	102.2 [100.1–137.1]
Hip Circumference (cm)	99.1 [93.5–106.0]	98.8 [94.8–109.2]	98.8 [96.6–134.1]	104.0 [102.5–138.0]
Waist-to-Hip Ratio	1.0 [1.0–1.0]	0.9 [0.9–1.0]	1.0 [0.9–1.0]	1.0 [1.0–1.0]
Fasting Glucose (mg/dL)	180.5 [122.5–193.0]	133.2 [128.4–139.1]	109.2 [104.0–137.6]	224.5 [197.5–270.2]
Heart Rate (bpm)	79.0 [73.5–79.0]	63.5 [59.5–67.4]	60.0 [59.0–63.5]	66.0 [61.5–80.0]
Systolic Blood Pressure (mmHg)	139.0 [130.0–142.0]	117.0 [110.5–123.0] *§	110.5 [98.8–116.8]	125.0 [109.5–130.2] §
Diastolic Blood Pressure (mmHg)	80.0 [79.5–86.0]	70.0 [63.0–79.5] *§	70.0 [66.5–74.8]	72.0 [68.8–80.0] §
Pulse Pressure (mmHg)	51.0 [44.0–62.0]	32.0 [31.0–53.0] *§	31.0 [27.5–42.0]	47.5 [38.0–50.2] §
Mean Arterial Pressure (mmHg)	100.7 [100.7–103.5]	87.7 [81.7–89.8] *§	87.7 [79.3–88.8]	89.7 [82.3–96.7] §
Augmentation Index HR75 (%)	30.0 [25.0–30.0]	28.0 [24.0–31.9]	31.5 [28.0–32.2]	23.0 [21.8–30.8]
Pulse Wave Velocity (m/s)	7.0 [6.9–9.7]	6.8 [6.7–7.6]	7.5 [7.0–7.9]	7.8 [7.0–8.6]
Subendocardial Viability Ratio (%)	118.0 [105.0–124.0]	153.2 [144.4–160.9]	160.0 [149.0–161.8]	144.0 [124.2–149.0]
Step Count (steps/day)	5296.0 [5267.0–5573.0]	8558.2 [7160.6–9162.2]	5691.1 [4862.6–6203.6]	5961.7 [3252.2–6257.2]
Walking Distance (km/day)	3.8 [3.5–4.0]	6.1 [4.7–6.5] *§	4.1 [3.6–4.4]	3.8 [2.1–4.1] §
Energy Expenditure (kcal/day)	1704.4 [1682.6–1726.0]	2385.8 [2291.6–2700.0] *§	1737.6 [1711.9–2334.2]	1726.8 [1715.9–2181.7] §

Data are presented as median and interquartile (IQR = 25th–75th percentile). * Indicates a statistically significant difference in change within group ($p < 0.05$). § Indicates a statistically significant difference in change between groups ($p < 0.05$).

3.2. Physical Activity Outcomes

As shown in Figure 2, participants in the FIT group demonstrated significantly increased daily step counts and walking distances during Week 2 and Week 3 compared to baseline (T0) (all $p < 0.04$; $r > 0.94$). Additionally, EE was significantly elevated from Week 1 through Week 4 (all $p < 0.05$; $r > 0.89$). When averaged across the 4-week intervention period, both daily walking distance and EE were significantly higher than baseline levels (both $p < 0.04$; $r > 0.90$). Although the average step count also increased, the change did not reach statistical significance ($p = 0.08$; $r = 0.78$).

When comparing changes between groups, the FIT group demonstrated significantly greater increases in daily walking distance and energy expenditure compared to the CON group (both $p < 0.04$; both $r = 0.79$). In contrast, the change in daily step count did not differ significantly between groups ($p = 0.14$; $r = 0.58$; Table 1).

Self-reported physical activity levels, as measured by the GPAQ, did not show statistically significant changes within or between groups over the 4-week intervention (Table A1). At baseline (T0), 2 participants in the FIT group (40%) and 1 participant in the CON group (33.3%) reported total physical activity levels exceeding 600 MET-minutes/week, consis-

tent with the WHO's recommended threshold for health-enhancing activity. By the end of the intervention, these numbers increased modestly to 3 participants (60%) in the FIT group and 2 participants (66.7%) in the CON group. Despite this upward trend, the small sample size and variability in GPAQ responses limited the ability to detect statistically significant differences.

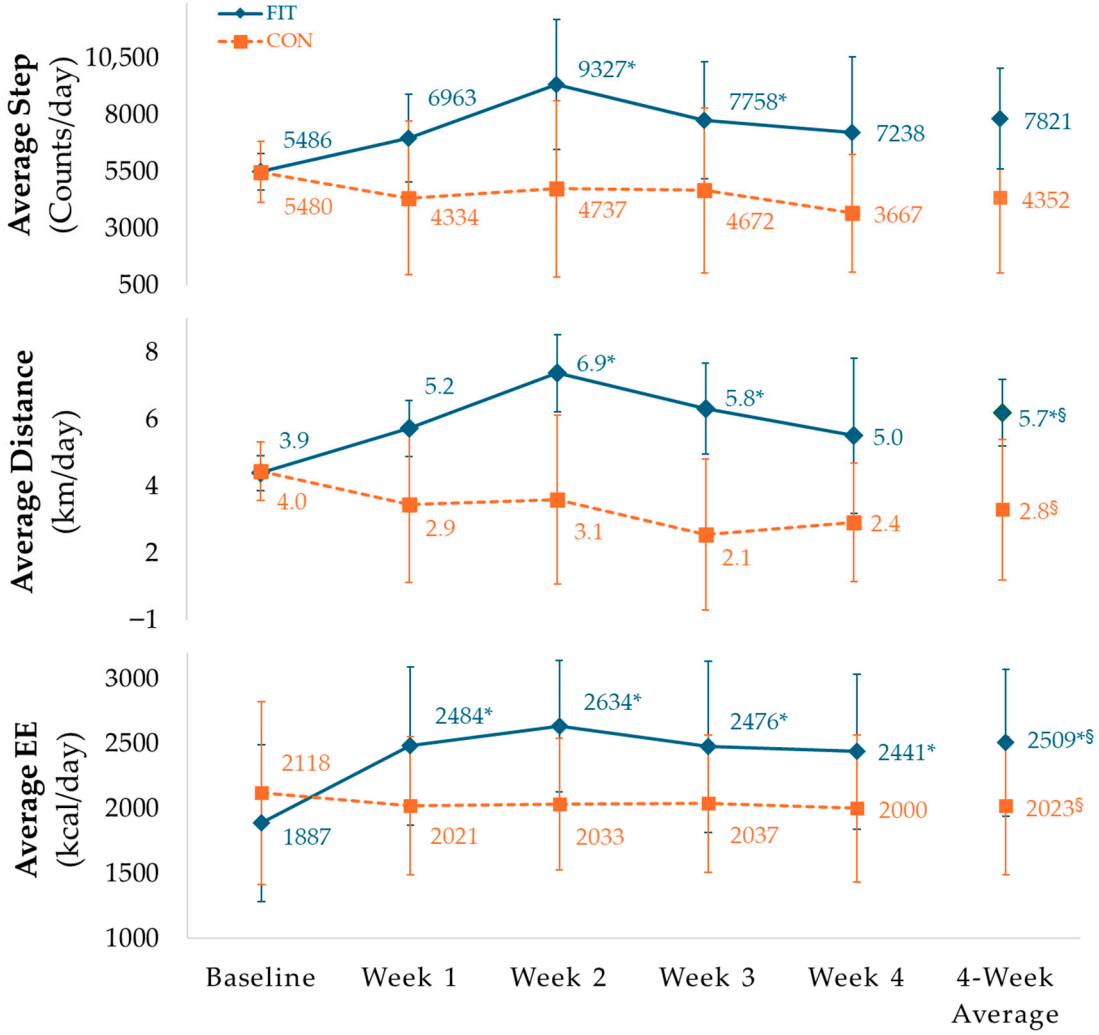


Figure 2. Weekly trends in physical activity during the 4-week intervention. Line graphs illustrate changes in average daily step count (top), walking distance (middle), and estimated energy expenditure (EE; bottom) across the 4-week intervention period for the intervention (FIT) and control (CON) groups. The FIT group demonstrated marked increases across all three metrics in Week 2, with sustained improvements in EE maintained through Week 4. In the control (CON) group, average daily step count, walking distance, and EE remained unchanged from baseline, showing no statistically significant differences either across the 4-week intervention or during any individual week (all $p > 0.11$; $r < 0.72$). Data are presented as mean ± standard deviation. * Indicate statistically significant differences from baseline within each group ($p < 0.05$). § Indicates a statistically significant difference in change between groups ($p < 0.05$).

3.3. Cardiovascular Health Outcomes

Compared to baseline (T0), the FIT group demonstrated significant reductions in SBP, DBP, PP, and MAP at the end of the 4-week intervention (all $p < 0.04$; $r > 0.90$). Although AIx, PWV, and SEVR did not show statistically significant changes from T0 to T1, SEVR showed a marginal improvement, increasing from 117.8 ± 19.2% to 152.0 ± 11.9% ($p = 0.07$; $r = 0.82$; Figure 3).

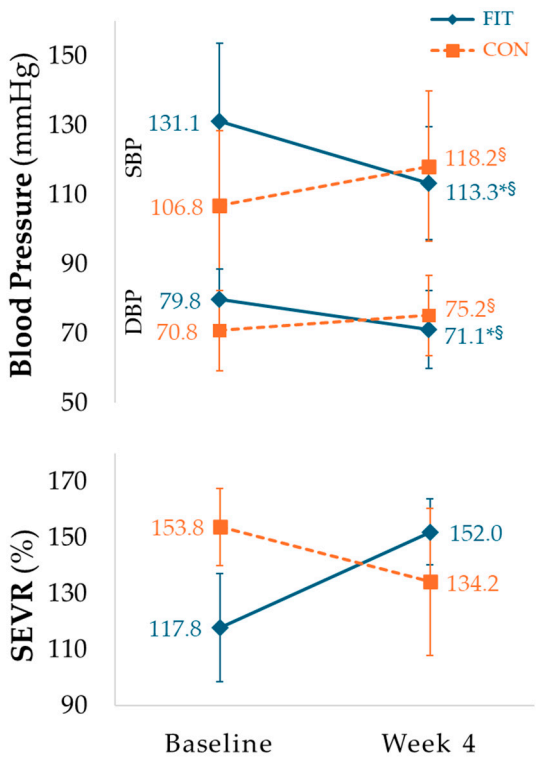


Figure 3. Changes in blood pressure and SEVR after the 4-week intervention. Line graphs show pre- to post-intervention changes in systolic and diastolic blood pressure (SBP and DBP; top) and subendocardial viability ratio (SEVR; bottom) for the intervention (FIT) and control (CON) groups. Data are presented as mean ± standard deviation. The FIT group demonstrated significant reductions in both SBP and DBP, along with an increase in SEVR, a surrogate marker of myocardial perfusion. * Indicate statistically significant differences from baseline within groups ($p < 0.05$). § Indicates a statistically significant difference in change between groups ($p < 0.05$).

In contrast, the CON group exhibited no significant changes in any cardiovascular outcomes after 4 weeks.

Between-group comparisons revealed that the FIT group experienced significantly greater reductions in SBP, DBP, PP, and MAP compared to the CON group (all $p < 0.04$; $r > 0.79$; Table 1). While no significant between-group differences were observed for AIx, PWV, or SEVR, the change in SEVR trended toward significance, with a notable improvement in the FIT group (34.2 ± 10.9%), compared to a decline in the CON group (−19.7 ± 12.4%; $p = 0.06$; $r = 0.75$).

3.4. Metabolic and Anthropometric Outcomes

Compared to baseline, neither group exhibited significant within-group changes in body weight, BMI, waist circumference, hip circumference, WHR, or fasting glucose levels following the 4-week intervention. Furthermore, no significant between-group differences were observed in changes in height, weight, BMI, waist circumference, WHR, or fasting glucose at follow-up (Table 1).

3.5. Associations Between Physical Activity and Cardiometabolic Outcomes

Correlation analyses revealed that improvements in cardiovascular health markers were significantly associated with increases in physical activity. A strong negative correlation was observed between the change in pulse pressure and the change in walking distance (Spearman's $\rho = -0.88$, $p = 0.004$; Figure 4). A similar significant inverse correlation was identified between changes in PP and EE (Spearman's $\rho = -0.81$, $p = 0.02$).

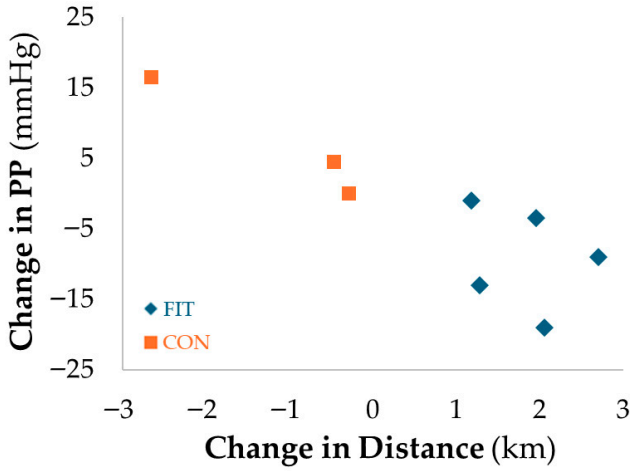


Figure 4. Association between changes in walking distance and PP after the 4-week intervention. Scatterplot illustrates the relationship between individual changes in daily walking distance and changes in pulse pressure (PP) from baseline to Week 4 in the intervention (FIT) and control (CON) groups. Each point represents one participant. A general trend of increased walking distance being associated with reduced pulse pressure is observed in the FIT group, suggesting a potential link between physical activity improvements and vascular health.

Additional associations emerged between changes in physical activity and metabolic and anthropometric measures. The reduction in waist circumference showed a negative correlation with increases in step count (Spearman's $\rho = -0.76$, $p = 0.03$). Moreover, a significant inverse correlation was found between the change in fasting glucose and the increase in EE (Spearman's $\rho = -0.82$, $p = 0.02$).

4. Discussion

This pilot randomized study demonstrates that the use of a wearable activity tracker over a four-week period can lead to significant improvements in physical activity and cardiovascular risk markers in adults with T2D. Participants in the intervention group (FIT) exhibited notable increases in daily walking distance and EE, along with significant reductions in SBP, DBP, PP, and MAP. These findings align with previous research demonstrating the benefits of wearable devices in promoting self-monitoring and increasing ambulatory activity [17,29].

The reductions in SBP and DBP observed in the FIT group are clinically meaningful. Prior evidence suggests that a 5 mm Hg reduction in SBP yields a 10% reductions in major cardiovascular events [7,30]. Given that the FIT group in our study achieved an SBP reduction exceeding this threshold, supporting the clinical relevance of the intervention in mitigating cardiovascular risk among individuals with T2D.

Although AIx and PWV did not change significantly, reductions in PP and MAP suggest early vascular improvements [31,32]. These findings may reflect enhanced endothelial function or reduced sympathetic tone. However, arterial stiffness indicators such as AIx and PWV may require longer intervention durations to show measurable effects. A meta-analysis demonstrated that aerobic exercise lasting at least 8 weeks significantly reduced arterial stiffness, with improvements in PWV, underscoring the need for longer interventions to detect meaningful changes in these parameters [33]. The upward trend in SEVR observed in the FIT group ($p = 0.07$) suggests potential improvement in myocardial perfusion and coronary supply-demand balance. These findings suggest early cardiovascular benefits that may precede detectable changes in arterial stiffness measures.

Fasting glucose did not differ significantly between groups, aligning with prior research suggesting that longer-duration interventions are typically needed to elicit measur-

able metabolic improvements. Structured exercise programs lasting more than 12 weeks have been associated with significant reductions in fasting glucose and HbA1c levels in individuals with T2D [34,35], and a meta-analysis demonstrated that interventions averaging 20 weeks yielded clinically meaningful glycemic benefits [36]. In addition, joint guidelines from the American Diabetes Association and the American College of Sports Medicine emphasize the need for sustained aerobic and resistance training to improve glycemic control [37]. Nonetheless, our exploratory analyses revealed that even within this 4-week intervention. increases in physical activity were associated with reductions in fasting glucose and waist circumference, indicating potential early metabolic responses that warrant further investigation in larger, longer-term trials.

While wearable-derived data captured meaningful increases in physical activity, self-reported GPAQ results did not reflect consistent changes. This discrepancy highlights known limitations of self-report tools, such as recall bias and overestimation of duration or intensity, and supports the greater sensitivity of device-based monitoring [38–40].

Despite the short duration, our findings suggest that even brief, unsupervised activity interventions can produce early improvements in cardiovascular health. Incorporating vascular metrics like SEVR, PWV, and AIx adds important insight into the functional impact of such interventions in T2D populations.

A key strength of this study is the use of objective physiological measurements, including tonometry-based indices of arterial stiffness (i.e., PWV and Aix), and wearable-derived physical activity metrics. The randomized design also enhances internal validity. However, several limitations must be acknowledged. First, the small sample size limits generalizability and statistical power. Given the strong observed effect sizes in physical activity and blood pressure ($r \geq 0.79$), a future adequately powered trial would require approximately 34–40 participants per group to achieve 80% power using $\alpha = 0.05$, two-tailed. Second, the short intervention period may not fully capture long-term cardiometabolic adaptations. Third, medication use was not documented, limiting our ability to account for potential pharmacologic confounders such as antihypertensives, glucose-lowering agents, or lipid-lowering drugs that may have influenced cardiovascular outcomes. Additionally, dietary intake was not monitored, which may have contributed to variability in outcomes such as body weight and fasting glucose. Future studies should include a pre-intervention acclimation period, track medication use, and monitor nutritional behavior.

Additionally, while participants in the FIT group were provided with Fitbit devices, those in the control group relied on the Fitbit app's MobileTrack function, which uses smartphone-based accelerometry. This approach does not capture heart rate or activity intensity and may underestimate step count, making it less accurate than wrist-worn device tracking. These methodological differences could introduce variability and measurement error in physical activity estimates. Despite these limitations, the study offers valuable preliminary evidence that wearable technologies can improve real-world physical activity engagement and cardiovascular outcomes in adults with T2D. The strong correlations between increased physical activity and reductions in pulse pressure and fasting glucose highlight the potential for wearable-facilitated interventions to target multiple facets of cardiometabolic risk.

5. Conclusions

In summary, this pilot study supports the use of wearable activity trackers as a feasible and potentially effective adjunct to standard diabetes care. Even within a brief intervention window, increased physical activity was associated with meaningful improvements in blood pressure and cardiovascular physiology. Notably, reductions in PP, a surrogate marker of

arterial stiffness and vascular load, suggest early favorable adaptations in vascular health despite the absence of significant changes in AIx, PWV, body weight, or fasting glucose.

Wrist-worn activity trackers demonstrate significant potential as a cost-effective strategy for promoting physical activity and reducing cardiovascular risk in adults with T2D. These findings warrant further investigation in larger, longer-duration trials to confirm efficacy, explore metabolic impacts, and evaluate the long-term sustainability of wearable-driven behavioral interventions.

Author Contributions: Conceptualization, P.-T.W. and I.-H.C.; methodology, P.-T.W., I.-H.C. and K.K.C.; software, P.-T.W.; validation, A.A.B.; formal analysis, P.-T.W.; investigation, P.-T.W. and A.A.B.; resources, P.-T.W., I.-H.C. and K.K.C.; data curation, P.-T.W. and A.A.B.; writing—original draft preparation, P.-T.W. and A.A.B.; writing—review and editing, P.-T.W., A.A.B., I.-H.C. and K.K.C.; visualization, P.-T.W. and A.A.B.; supervision, I.-H.C. and K.K.C.; project administration, P.-T.W. and A.A.B.; funding acquisition, P.-T.W. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the Pacific University Faculty Development Grant, FDG 23-24.

Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki, and approved by the Institutional Review Board of Pacific University (protocol code 048-23) on 14 September 2023.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study. Written informed consent has been obtained from the participants to publish this paper.

Data Availability Statement: The original contributions presented in this study are included in the article. Further inquiries can be directed to the corresponding author. The datasets generated and analyzed during the current study are available from the corresponding author upon reasonable request.

Acknowledgments: The authors thank all participants for their time and commitment to this project. We are also grateful to the following Pacific University Doctor of Physical Therapy students (listed alphabetically by last name)—Zubaidah Alrubaye, Kelvin Chang, Eryn De Jonge, Cali Lescas Hernandez, Kaila Mann, and Avery Peraza—for their assistance with participant recruitment, data collection, language translation, and visit coordination. We acknowledge the support of the Pacific University Doctor of Physical Therapy Program, particularly Derek Gerber (Program Director) and Tzurei Chen (Research Lab Coordinator), for providing access to program resources, laboratory space, and research software. We also thank the institutional and departmental administrative staff for their essential logistical support. We appreciate the guidance provided by the staff of the Pacific University Office of Scholarship & Sponsored Projects. Finally, we thank the editorial board and anonymous reviewers for their thoughtful feedback, which helped strengthen the final version of this manuscript.

Conflicts of Interest: The authors declare no conflicts of interest.

Abbreviations

The following abbreviations are used in this manuscript:

T2D	Type 2 Diabetes
CVD	Cardiovascular Disease
AIx	Augmentation Index
PWV	Pulse Wave Velocity
SEVR	subendocardial viability ratio
HbA1c	Hemoglobin A1c
BMI	Body Mass Index
FIT	Fitbit Intervention group
CON	Control group
EE	Energy Expenditure
GPAQ	Global Physical Activity Questionnaire

MET	Metabolic Equivalent of Task
SBP	Systolic Blood Pressure
DBP	Diastolic Blood Pressure
PP	Pulse Pressure
MAP	Mean Arterial Pressure
WHR	Waist-to Hip Ratio

Appendix A

Table A1. Participant-Reported Physical Activity and Sedentary Behavior (GPAQ).

Domain	FIT (n = 5)		CON (n = 3)	
	Baseline	**Week 4**	**Baseline**	**Week 4**
Work-related Activity				
Vigorous Intensity (Yes; %)	0	1 (20%)	0	2 (66.7%)
Moderate Intensity (Yes; %)	1 (20%)	3 (60%)	1 (33.3%)	0
MET-min/week	0 [0–480]	420 [0–5760]	0 [0–5760]	6720 [0–12,960]
Transport Activity				
Walking/Bicycling $\geq$ 10 min (Yes; %)	2 (40%)	4 (80%)	2 (66.7%)	2 (66.7%)
MET-min/week	0 [0–140]	480 [0–1120]	450 [0–480]	240 [0–500]
Recreational Activity				
Vigorous Intensity (Yes; %)	1 (20%)	0	0	0
Moderate Intensity (Yes; %)	3 (60%)	2 (40%)	1 (33.3%)	1 (33.3%)
MET-min/week	480 [0–820]	0 [0–1440]	0 [0–660]	0 [0–600]
Total Physical Activity (MET-min/week)	560 [0–1100]	1440 [0–6560]	450 [0–6900]	6720 [450–14,040]
Sedentary Behavior				
Sitting Time (min/day)	360 [300–720]	180 [180–720]	240 [180–720]	240 [210–360]

Note: MET = metabolic equivalent of task. Values are presented as n (%) or median [min–max].

References

1. International Diabetes Federation. Facts & Figures. Available online: https://idf.org/about-diabetes/diabetes-facts-figures/ (accessed on 14 May 2025).
2. Centers for Disease Control and Prevention. National Diabetes Statistics Report. Available online: https://www.cdc.gov/diabetes/php/data-research/index.html (accessed on 14 May 2025).
3. Raghavan, S.; Vassy, J.L.; Ho, Y.L.; Song, R.J.; Gagnon, D.R.; Cho, K.; Wilson, P.W.F.; Phillips, L.S. Diabetes Mellitus-Related All-Cause and Cardiovascular Mortality in a National Cohort of Adults. *J. Am. Heart Assoc.* **2019**, *8*, e011295. [CrossRef]
4. Hjerkind, K.V.; Stenehjem, J.S.; Nilsen, T.I. Adiposity, physical activity and risk of diabetes mellitus: Prospective data from the population-based HUNT study, Norway. *BMJ Open* **2017**, *7*, e013142. [CrossRef]
5. Knowler, W.C.; Barrett-Connor, E.; Fowler, S.E.; Hamman, R.F.; Lachin, J.M.; Walker, E.A.; Nathan, D.M. Reduction in the incidence of type 2 diabetes with lifestyle intervention or metformin. *N. Engl. J. Med.* **2002**, *346*, 393–403. [CrossRef]
6. Tuomilehto, J.; Lindström, J.; Eriksson, J.G.; Valle, T.T.; Hämäläinen, H.; Ilanne-Parikka, P.; Keinänen-Kiukaanniemi, S.; Laakso, M.; Louheranta, A.; Rastas, M.; et al. Prevention of type 2 diabetes mellitus by changes in lifestyle among subjects with impaired glucose tolerance. *N. Engl. J. Med.* **2001**, *344*, 1343–1350. [CrossRef]
7. Powell-Wiley, T.M.; Poirier, P.; Burke, L.E.; Després, J.-P.; Gordon-Larsen, P.; Lavie, C.J.; Lear, S.A.; Ndumele, C.E.; Neeland, I.J.; Sanders, P.; et al. Obesity and Cardiovascular Disease: A Scientific Statement from the American Heart Association. *Circulation* **2021**, *143*, e984–e1010. [CrossRef] [PubMed]
8. Eckert, K. Impact of physical activity and bodyweight on health-related quality of life in people with type 2 diabetes. *Diabetes Metab. Syndr. Obes.* **2012**, *5*, 303–311. [CrossRef] [PubMed]
9. Alharbi, M.; Gallagher, R.; Neubeck, L.; Bauman, A.; Prebill, G.; Kirkness, A.; Randall, S. Exercise barriers and the relationship to self-efficacy for exercise over 12 months of a lifestyle-change program for people with heart disease and/or diabetes. *Eur. J. Cardiovasc. Nurs.* **2017**, *16*, 309–317. [CrossRef]
10. Schmidt, S.K.; Hemmestad, L.; MacDonald, C.S.; Langberg, H.; Valentiner, L.S. Motivation and Barriers to Maintaining Lifestyle Changes in Patients with Type 2 Diabetes after an Intensive Lifestyle Intervention (The U-TURN Trial): A Longitudinal Qualitative Study. *Int. J. Environ. Res. Public Health* **2020**, *17*, 7454. [CrossRef]

11. Strecher, V.J.; DeVellis, B.M.; Becker, M.H.; Rosenstock, I.M. The role of self-efficacy in achieving health behavior change. *Health Educ. Q.* **1986**, *13*, 73–92. [CrossRef] [PubMed]
12. Pan, X.R.; Li, G.W.; Hu, Y.H.; Yang, W.-Y.; An, Z.-X.; Hu, Z.-X.; Lin, J.; Xiao, J.-Z.; Cao, H.-B.; Liu, P.-A.; et al. Effects of diet and exercise in preventing NIDDM in people with impaired glucose tolerance. The Da Qing IGT and Diabetes Study. *Diabetes Care* **1997**, *20*, 537–544. [CrossRef]
13. Kim, B.Y.; Lee, J. Smart Devices for Older Adults Managing Chronic Disease: A Scoping Review. *JMIR Mhealth Uhealth* **2017**, *5*, e69. [CrossRef]
14. Tudor-Locke, C.; Aguiar, E.J. Toward comprehensive step-based physical activity guidelines: Are we ready? *Kinesiol. Rev.* **2019**, *8*, 25–31. [CrossRef]
15. Dasgupta, K.; Rosenberg, E.; Joseph, L.; Cooke, A.B.; Trudeau, L.; Bacon, S.L.; Chan, D.; Sherman, M.; Rabasa-Lhoret, R.; Daskalopoulou, S.S.; et al. Physician step prescription and monitoring to improve ARTERial health (SMARTER): A randomized controlled trial in patients with type 2 diabetes and hypertension. *Diabetes Obes. Metab.* **2017**, *19*, 695–704. [CrossRef]
16. Baskerville, R.; Ricci-Cabello, I.; Roberts, N.; Farmer, A. Impact of accelerometer and pedometer use on physical activity and glycaemic control in people with Type 2 diabetes: A systematic review and meta-analysis. *Diabet. Med.* **2017**, *34*, 612–620. [CrossRef] [PubMed]
17. Hodkinson, A.; Kontopantelis, E.; Adeniji, C.; van Marwijk, H.; McMillian, B.; Bower, P.; Panagioti, M. Interventions Using Wearable Physical Activity Trackers Among Adults With Cardiometabolic Conditions: A Systematic Review and Meta-analysis. *JAMA Netw. Open* **2021**, *4*, e2116382. [CrossRef]
18. Gagnon, M.P.; Ouellet, S.; Attisso, E.; Supper, W.; Amil, S.; Rhéaume, C.; Paquette, J.-S.; Chabot, C.; Laferrière, M.-C.; Sasseville, M. Wearable Devices for Supporting Chronic Disease Self-Management: Scoping Review. *Interact. J. Med. Res.* **2024**, *13*, e55925. [CrossRef] [PubMed]
19. Peng, P.; Zhang, N.; Huang, J.; Jiao, X.; Shen, Y. Effectiveness of Wearable Activity Monitors on Metabolic Outcomes in Patients With Type 2 Diabetes: A Systematic Review and Meta-Analysis. *Endocr. Pract.* **2023**, *29*, 368–378. [CrossRef]
20. Luo, J.; Zhang, K.; Xu, Y.; Tao, Y.; Zhang, Q. Effectiveness of Wearable Device-based Intervention on Glycemic Control in Patients with Type 2 Diabetes: A System Review and Meta-Analysis. *J. Med. Syst.* **2021**, *46*, 11. [CrossRef]
21. Kooiman, T.J.M.; de Groot, M.; Hoogenberg, K.; Krijnen, W.P.; van der Schans, C.P.; Kooy, A. Self-tracking of Physical Activity in People With Type 2 Diabetes: A Randomized Controlled Trial. *Comput. Inform. Nurs.* **2018**, *36*, 340–349. [CrossRef] [PubMed]
22. Azar, K.M.; Koliwad, S.; Poon, T.; Xiao, L.; Lv, N.; Griggs, R.; Ma, J. The Electronic CardioMetabolic Program (eCMP) for Patients With Cardiometabolic Risk: A Randomized Controlled Trial. *J. Med. Internet Res.* **2016**, *18*, e134. [CrossRef]
23. American Diabetes Association. Blood Glucose & A1C—Understanding Diabetes Diagnosis. Available online: https://diabetes.org/about-diabetes/diagnosis (accessed on 30 May 2025).
24. Waxman, A. WHO global strategy on diet, physical activity and health. *Food Nutr. Bull.* **2004**, *25*, 292–302. [CrossRef]
25. Cleland, C.L.; Hunter, R.F.; Kee, F.; Cupples, M.E.; Sallis, J.F.; Tully, M.A. Validity of the Global Physical Activity Questionnaire (GPAQ) in assessing levels and change in moderate-vigorous physical activity and sedentary behaviour. *BMC Public Health* **2014**, *14*, 1255. [CrossRef] [PubMed]
26. Milton, K.; Bull, F.C.; Bauman, A. Reliability and validity testing of a single-item physical activity measure. *Br. J. Sports Med.* **2011**, *45*, 203–208. [CrossRef] [PubMed]
27. World Health Organization. *Global Physical Activity Questionnaire (GPAQ)—Analysis Guide*; World Health Organization: Geneva, Switzerland, 2021. Available online: https://www.who.int/docs/default-source/ncds/ncd-surveillance/gpaq-analysis-guide.pdf (accessed on 30 May 2025).
28. Cohen, J. *Statistical Power Analysis for the Behavioral Sciences*, 2nd ed.; Routledge: Abingdon, UK, 1988.
29. Szeto, K.; Arnold, J.; Singh, B.; Gower, B.; Simpson, C.E.M.; Maher, C. Interventions Using Wearable Activity Trackers to Improve Patient Physical Activity and Other Outcomes in Adults Who Are Hospitalized: A Systematic Review and Meta-analysis. *JAMA Netw. Open* **2023**, *6*, e2318478. [CrossRef] [PubMed]
30. Blood Pressure Lowering Treatment Trialists' Collaboration. Pharmacological blood pressure lowering for primary and secondary prevention of cardiovascular disease across different levels of blood pressure: An individual participant-level data meta-analysis. *Lancet* **2021**, *397*, 1625–1636. [CrossRef]
31. Franklin, S.S.; Khan, S.A.; Wong, N.D.; Larson, M.G.; Levy, D. Is pulse pressure useful in predicting risk for coronary heart Disease? The Framingham heart study. *Circulation* **1999**, *100*, 354–360. [CrossRef]
32. Safar, M.E. Pulse pressure, arterial stiffness and wave reflections (augmentation index) as cardiovascular risk factors in hypertension. *Ther. Adv. Cardiovasc. Dis.* **2008**, *2*, 13–24. [CrossRef]
33. Ho, L.Y.W.; Kwan, R.Y.C.; Yuen, K.M.; Leung, W.C.; Ni Tam, P.; Tsim, N.M.; Ng, S.S.M.; Heyn, P.C. The effect of aerobic exercises on arterial stiffness in older people: A systematic review and meta-analysis. *Gerontologist* **2024**, *64*, gnad123. [CrossRef]
34. Ambelu, T.; Teferi, G. The impact of exercise modalities on blood glucose, blood pressure and body composition in patients with type 2 diabetes mellitus. *BMC Sports Sci. Med. Rehabil.* **2023**, *15*, 153. [CrossRef]

35. Umpierre, D.; Ribeiro, P.A.; Kramer, C.K.; Leitão, C.B.; Zucatti, A.T.N.; Azevedo, M.J.; Gross, J.L.; Ribeiro, J.P.; Schaan, B.D. Physical activity advice only or structured exercise training and association with HbA1c levels in type 2 diabetes: A systematic review and meta-analysis. *JAMA* **2011**, *305*, 1790–1799. [CrossRef]
36. Boulé, N.G.; Haddad, E.; Kenny, G.P.; Wells, G.A.; Sigal, R.J. Effects of exercise on glycemic control and body mass in type 2 diabetes mellitus: A meta-analysis of controlled clinical trials. *JAMA* **2001**, *286*, 1218–1227. [CrossRef]
37. Colberg, S.R.; Sigal, R.J.; Fernhall, B.; Regensteiner, J.G.; Blissmer, B.J.; Rubin, R.R.; Chasan-Taber, L.; Albright, A.L.; Braun, B. Exercise and type 2 diabetes: The American College of Sports Medicine and the American Diabetes Association: Joint position statement. *Diabetes Care* **2010**, *33*, e147–e167. [CrossRef]
38. Fiedler, J.; Eckert, T.; Burchartz, A.; Woll, A.; Wunsch, K. Comparison of Self-Reported and Device-Based Measured Physical Activity Using Measures of Stability, Reliability, and Validity in Adults and Children. *Sensors* **2021**, *21*, 2672. [CrossRef] [PubMed]
39. Prince, S.A.; Adamo, K.B.; Hamel, M.E.; Hardt, J.; Connor Gorber, S.; Tremblay, M. A comparison of direct versus self-report measures for assessing physical activity in adults: A systematic review. *Int. J. Behav. Nutr. Phys. Act.* **2008**, *5*, 56. [CrossRef] [PubMed]
40. Skender, S.; Ose, J.; Chang-Claude, J.; Paskow, M.; Brühmann, B.; Siegel, E.M.; Steindorf, K.; Ulrich, C.M. Accelerometry and physical activity questionnaires - a systematic review. *BMC Public Health* **2016**, *16*, 515. [CrossRef] [PubMed]

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.