TITLE: Improved Glycemic Control in Adults with Type 2 Diabetes is More Strongly Associated with Exercise Duration Than with Volume, Frequency, or Consistency

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ABSTRACT

Purpose

Exercise interventions play a pivotal role in managing type 2 diabetes (T2D), yielding significant benefits in glycemic control. Despite the recognized role of exercise duration, volume, frequency, and consistency, the literature remains discrepant on which exerts the greatest effect. The purpose of this secondary analysis was to determine the relationship between exercise duration, volume, frequency, and consistency and markers of glycemic control [HbA1c and continuous glucose monitoring (CGM) metrics] following a 26-week mHealth intervention.

Methods

Inactive adults with newly diagnosed (<2 years) T2D (n = 58) completed blood and 14-day CGM testing before and after a 26-week personalized exercise intervention. Raw exercise data from fitness watches were extracted for each session. Duration, volume, frequency, and consistency were calculated for the full intervention and for the first 13 weeks (greater support) and last 13 weeks (reduced support).

Results

Average session duration (57 ± 36 minutes) significantly predicted HbA1c (β = -0.23 (0.07), P = 0.002), 24-hour mean glucose (β = -0.03 (0.01), P = 0.01), and glycemic variability (SD; β = -0.01 (0.0), P = 0.003; Beta coefficients are reported with standard errors). Total exercise time during the first 13 weeks (2931 ± 3362 minutes) also predicted HbA1c (β = -0.001 (0.0), P = 0.01), mean glucose (β = -0.002 (0.0), P = 0.01), and glycemic variability (β = -0.005 (0.0), P = 0.03). No other exercise metrics significantly predicted outcomes.

Conclusions

Average session duration and exercise time accumulated early in the intervention were the only significant predictors of improvements in HbA1c, mean glucose, and glucose variability. These findings suggest that promoting increased exercise duration, independent of type or intensity, may improve glycemic control among individuals with newly diagnosed T2D.

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KEYWORDS: mHealth intervention - continuous glucose monitoring - exercise prescription - insulin sensitivity - type 2 diabetes management

ABBREVIATIONS:

CV – coefficient of variation

eA1c - estimated A1c

HbA1c – glycated hemoglobin

HR – heart rate

HR_{max} – maximum heart rate

METS – metabolic equivalents

SD – standard deviation

T0 – baseline, before the beginning of the 26-week intervention

T1 – post, in the last 2 weeks of the 26-week intervention

T2D – type 2 diabetes

INTRODUCTION

Type 2 diabetes (T2D) poses a challenge to global healthcare systems, and its prevalence is escalating in parallel with sedentary behaviors and obesity rates [1]. Exercise is known to counteract metabolic disruptions that arise from a sedentary behavior [2–4] and is fundamental to the treatment of T2D. As such, lifestyle modifications, particularly exercise interventions, stand as cornerstone strategies in the management of T2D [5].

Exercise interventions result in clinically meaningful benefits to glycemic control, insulin sensitivity, and cardiovascular health in T2D [6–9]. Aerobic exercise, resistance training, or a combination of both demonstrate efficacy in improving glucose tolerance and reducing HbA1c levels [10,11]. In addition, exercise interventions can support weight loss (maintenance) and help mitigate obesity, a major risk factor for T2D [12]. Mechanistically, exercise enhances skeletal muscle glucose uptake via insulin-independent pathways and improves whole-body insulin sensitivity, thereby ameliorating hyperglycemia [13]. The glucose-lowering benefits of exercise underscore the importance of tailored exercise interventions in the comprehensive management of T2D.

Central to the idea of individualized exercise interventions is the prescribing and monitoring of the exercise intervention itself. In individuals with T2D, exercise duration, volume, intensity, frequency, and consistency, and the interplay between them, are key determinants of both metabolic responses and therapeutic outcomes [14]. Collectively, these factors influence insulin sensitivity, glucose uptake, lipid metabolism, cardiovascular function, and overall glycemic control; effects that are critical for mitigating disease progression and reducing cardiometabolic risk [15,16]. To contextualize these outcomes, it is important to consider the principal components of the exercise prescription that include duration, intensity, volume, and consistency/frequency, and their established roles in influencing metabolic and glycemic control.

Exercise duration, defined as the total duration of an exercise session, is an important consideration as it influences substrate utilization and metabolic regulation. Prolonged bouts of exercise may be linked with glycogen depletion and greater reliance on fatty acid oxidation, which may counteract insulin resistance [11]. Extended session durations have been associated with improvements in insulin sensitivity, lipid profiles, and cardiovascular parameters, independent of weight loss [17].

Exercise volume, defined as the total calories expended during exercise, represents the interplay between duration and intensity. By creating an acute negative energy balance, higher volumes can support weight regulation and attenuate insulin resistance [18]. A recent meta-analysis identified a non-linear dose–response relationship between exercise volume and HbA1c, with an optimal dose of ~1100 MET·min·week^{-1} [19]. High-intensity interval training (HIIT), characterized by brief vigorous bursts interspersed with recovery periods [20], has emerged as a potent strategy for enhancing glycemic control, cardiovascular fitness, and insulin sensitivity, with potentially greater effects when compared to moderate-intensity training [21,22].

Exercise frequency and consistency determine the persistence of training-induced metabolic benefits. Enhancements in glycemic control diminish within 24–48 hours post-exercise [23,24] underscoring the need for regular sessions. Current recommendations suggest exercise at least every 48 hours, with three to five sessions per week combining aerobic and resistance training shown to improve glycemic outcomes [10,18,23,24]

Despite robust evidence that these factors contribute to improved glycemic control, the literature remains inconsistent regarding which exerts the most potent influence [19,25]. Thus, to demystify the interplay between these exercise metrics, the present study leveraged data from the main MOTIVATE-T2D pilot feasibility trial - an intervention targeting real-world exercise and physical activity in 120 individuals with newly diagnosed T2D [28]. Previously published results from the main trial demonstrated the feasibility and preliminary efficacy of an mHealth-supported

exercise intervention in individuals with recently diagnosed T2D, with potential benefits of the mHealth intervention for initiation and maintenance of purposeful exercise when compared to an active control group that received the same exercise prescription without mHealth support [26]. Although not powered on changes in HbA1c, there was a tendency for improvements in glycemic control in the mHealth group but high heterogeneity in the amount and type of exercise performed [26]. A previously published secondary analysis of the data from the main trial has also shown that a single bout of exercise performed in real-world conditions without dietary control can lower glucose for up to 24 hours, reinforcing current physical activity guidelines [27]. Building on this foundation, our present study aimed to determine the relationships between exercise duration, volume, frequency, and consistency and markers of glycemic control—including HbA1c, mean 24-hour glucose, glycemic variability [standard deviation (SD), coefficient of variation (CV)], and estimated HbA1c (eA1c) derived from continuous glucose monitoring (CGM). As a secondary aim, we explored differences in these outcomes among individuals performing the majority of sessions as moderate aerobic, interval, vigorous aerobic, or strength training during the 26-week MOTIVATE-T2D randomized controlled trial.

METHODS

Research Design

This study was a secondary analysis of the MOTIVATE T2D trial (NCT04653532); an RCT that investigated the feasibility of an mHealth exercise intervention in individuals with newly diagnosed T2D. MOTIVATE T2D was approved by the UBC Clinical Research Ethics Board in Canada and by the South East Scotland Research Ethics Committee 01 in the UK (20/SS/0101) and carried out in accordance with the Helsinki Declaration. All participants provided informed written consent to take part in the trial prior to data collection.

MOTIVATE T2D was a two-center (Canada and UK), parallel-group RCT whereby inactive individuals with T2D (N = 120) completed pre-randomization baseline testing (T0) before participating in a 26-week supported exercise intervention. In the last two weeks of the intervention (T1), participants completed assessments while continuing their exercise program, which was tracked across the entire 26-week intervention using the Polar Ignite fitness watch (Polar Electro Inc., Finland). Participants wore a blinded CGM (Freestyle Libre Pro, Abbott Technologies) for 14 days at T0 (before commencing the exercise intervention) and T1 (the last 2 weeks of the exercise intervention). Participants also completed at-home blood draws at T0 and T1 for measurement of HbA1c. As the objective of the study was to examine how exercise duration, volume, frequency and consistency impacted glucose control in the real-world, no dietary instructions, control, or logs were provided. Only data from the intervention group (who wore the fitness watch to enable exercise session identification) are used for these analyses. The full protocol and primary outcome for the MOTIVATE T2D trial have been published previously [28]

Exercise Intervention

During the 26-week exercise intervention, all participants received a personalized progressive exercise program delivered and explained to them by a trained exercise counsellor who met with the participant individually five times over the course of the intervention to deliver evidence-based behaviour change techniques over the phone or zoom. Participants independently performed their tailored pre-programmed workouts that were automatically synced to the provided fitness watch by their exercise counsellor using the Polar Flow software (Polar Electro Inc., Finland). Each participant's exercise program was individualized, with the same aims to increase exercise intensity and duration during the first 12 weeks in order to meet the current physical activity guidelines of 150-300 minutes of moderate-to-vigorous intensity physical activity per week. Exercise prescriptions focused on moderate aerobic, vigorous aerobic, interval, and strength training depending on participant preference. In addition to the five exercise counselling sessions that took place during the intervention, text message support and feedback was also given during the first 13 weeks. During exercise consultations and in text messages, participants were held accountable, set their level of enjoyment for their program, and were able to suggest changes that would be decided upon and implemented in conjunction with the exercise counsellor. In the last 13 weeks of the intervention (weeks 14-26) participants had limited contact with the exercise counsellor but were encouraged to at least maintain current physical activity guidelines. Participants were given a choice of exercise types (traditional endurance, interval exercise, resistance training, exercise classes, dance or sports) and modes (gym, outdoor, home-based or commuting) depending on personal preferences and available options to increase adherence and feasibility in daily life. Participants were also encouraged to increase their daily physical activity aside from structured exercise.

As part of the mHealth nature of the program, participants were given a Polar Ignite fitness watch as well as a Polar Verity HR strap (Polar Electro Inc., Finland), which provided haptic feedback and visual cues to guide them through the exercise specialist-programmed workouts

and to track their heart rate (HR) during exercise. For every exercise session recorded with a Polar device, the Polar platform outputs a value for exercise duration and the total energy expended during the session. Though the exact algorithm used by the Polar platform to calculate the energy expended during exercise is not known due to proprietary legalities, it is known that Polar uses a combination of accelerometer- and HR-based estimates [29]. The accelerometer-based estimate is based on the amplitude of deviation from the acceleration signals while the HR-based estimate is based off the equation from Byrne and colleagues [30]. The Polar method for deriving exercise energy-expenditure has shown a systematic bias of +3.3% and a mean absolute error of 20.6% compared to gold standard methods [31] and is widely accepted for measuring real-world energy expenditure. The same Polar device utilized for these studies has also shown high levels of agreement when measuring HR compared to criterion electrocardiogram HR [32].

Exercise Metrics

Raw 1-Hz sampled HR data from the Polar Ignite watch paired to the Polar Verity HR strap were extracted for each exercise session completed by each participant during the 26-week intervention. Exercise sessions ≥10 minutes were automatically included in the analysis. All recorded sessions were cross-checked against cadence, speed, GPS data, and participant notes/texts to confirm validity. For analysis, only sessions with a total duration ≥10 minutes were included. To be included, sessions were also required to have valid HR data available for the entire session.

Using the included exercise sessions, the elapsed time and energy expended were obtained for subsequent summing and averaging across participants for the entire 26-week intervention. Considering the marked drop in exercise counsellor support (text messages and consultations) at the halfway point of the intervention (i.e., week 13) the exercise metrics were also summed and averaged for the first 13 weeks of the intervention and the last 13 weeks of the intervention.

The elapsed time for each session was termed ‘exercise duration’ and the caloric expenditure for each session was termed ‘exercise volume’. From these exercise sessions, total and average calories per session as well as total and average session duration across the intervention were calculated. A variable for exercise frequency was created by counting the number of sessions completed during either the first 13 weeks of the intervention, the last 13 weeks of the intervention, or the entire 26 weeks. An exercise consistency variable was calculated as the number of weeks where 2 or more exercise sessions were conducted. Exercise adherence was calculated as the proportion of sessions completed relative to those prescribed over the 26 weeks, and exercise compliance was calculated as the extent to which participants met the prescribed time in each heart rate zone during sessions, based on whether average heart rate during each prescribed period fell within the target zone.

To achieve our secondary objective of assessing the effect of exercise modality on glycemic outcomes, we labelled each bout of exercise to correspond with one of the five different exercise types that were predominantly prescribed in the program (moderate aerobic, vigorous aerobic, interval training, strength, other). Due to the free-living, unsupervised, individualized nature of the study, sessions were assigned according to the predominant HR zone achieved during the session in conjunction with what was known to be prescribed by the exercise counsellor for the session and with what exercise type was selected by the participant on the fitness watch. Moderate aerobic sessions were defined as at least 50% of the duration of a session where HR was 60-70% of age-predicted HRmax. Vigorous aerobic sessions were defined as 50% of the duration of a session where HR was >70% age predicted HRmax and no evidence of intervals/HR decline to below 60% HRmax (recovery) were present. Interval training sessions were defined as sessions where at least 2 or more intervals (regardless of interval time) were noted, where >70% HRmax was achieved at some point during the interval, and where recovery (HR decline) between intervals was present. Strength training sessions were

defined through comparing session prescription/participant-recorded session notes and text message feedback whenever the participant marked a session as strength. Sessions were classified as 'other' when the HR did not ever exceed 50% of age predicated HRmax at any time during the session.

Based off the classification of each exercise session, an 'exercise majority' variable was created which corresponded to whatever type of session was performed predominantly during the 26-week intervention period.

CGM Analysis

CGM metrics were calculated across the wear-time at both T0 and T1. Inclusion in this analysis required participants to have complete HbA1c and CGM data at T0 and T1.

Blinded CGMs were inserted and worn on the upper arm per the manufacturer's recommendations (Freestyle Libre Pro, Abbott Technologies). Upon completion of the 14-day wear period, participants returned their sensors via mail to the research center. Data from the sensors were then retrieved using the LibreView software. Per Batellino et al. [33], data were considered valid if at least 70% of possible readings were recorded over the course of the 14 days. Raw excel files were downloaded from LibreView and all CGM outcome variables were calculated using Diametrics (University of Exeter), an advanced CGM data analysis web platform designed in accordance with the International Consensus on Use of Continuous Glucose Monitoring [34].

HbA1c

Remote capillary blood samples were collected for the purpose of measuring HbA1c. All participants were provided with two Microtainer Contact-Activated high flow lancets and one BD Microtainer blood tube (1 mL) with EDTA (Becton-Dickinson Co., Rutherford, N.J.) along with alcohol swabs, sterile gauze and spot bandages. All collections took place at home and

participants completed collection either by themselves or had assistance from others in their home. If a participant disclosed an aversion to blood or lancets, they were encouraged to receive help from others and were reminded that they could withdraw from the study at any time or for any reason.

All of the blood samples were received by a central laboratory and were processed according to standard operating procedures. Due to the multi-site nature of the trial, blood samples from participants in the UK were sent to a central laboratory in the UK while blood samples from participants in Canada were sent to a central laboratory in Canada. Upon receipt of the sample by the respective laboratory, the sample (whole blood) was maintained at room temperature and vortexed briefly before immediate analysis. In Canada, HbA1c analysis was performed on a commonly used and validated point-of-care machine (Afinion 2, Abbott Technologies) and in the UK, HbA1c analysis was performed on the Sebia CAP3 analyzer (Sebia, Lisse, France). Recent evidence suggests inter-laboratory HbA1c measurement amongst varying manufacturers shows very low bias (<2.2%) [35].

Statistical Analysis

Baseline participant characteristics are presented as means (standard deviations). For the primary outcome of this study, a linear model was used to examine the predictors of mean 24-hour glucose, glycemic variability (SD, CV), HbA1c and eA1c at T1. The model was adjusted for age and sex. Results are reported as beta coefficients (standard error) with accompanying overall model fit. For the secondary outcome of this study, a linear mixed model was used to examine the differences between exercise majority type on mean 24-hour glucose, glycemic variability (SD, CV), HbA1c, and eA1c across time. This model included a fixed effect for time (pre/T0 vs. post/T1) and exercise type majority (and the interaction of the two), a random effect for participant ID, and was adjusted for age and sex. Preplanned between-group comparisons are reported as the main effect of interest and presented as effect estimates alongside

corresponding 95% confidence intervals and estimated marginal means derived from the model for each group. Assumptions were assessed via visual inspection of diagnostic plots. No missing data were imputed as per contemporary guidelines [36]. Statistical tests were performed using R (version 4.3.2, RStudio, PBC, Boston, MA). Statistical significance was accepted when $P < 0.05$.

RESULTS

Study Participants

A total of 61 individuals were randomized to the mHealth intervention group of the main feasibility trial with n = 58 used for these analyses. Baseline values for included participants are provided in **Table 1**.

Exercise Metrics

Exercise Adherence

Exercise adherence (defined as the percentage of sessions completed vs. prescribed) for the intervention had a range from 0% to 517% with 30/58 (51.7%) participants achieving >100% adherence, 12/58 (20.7%) achieving 60-99% adherence, 12/58 (20.7%) achieving 30-59% adherence and 4/58 (6.9%) achieving 0-29% adherence. Greater than 100% adherence was possible if participants completed additional sessions outside of those prescribed.

Exercise Compliance

Exercise compliance (defined as adherence to the prescribed time in each heart rate zone per session, determined by whether the participant's average heart rate during the allotted duration matched the target zone) to the session HR zones had a range from 100% to 0% with 40/58 participants achieving ≥100% compliance, 7/58 achieving 60-99% compliance, 7/58 achieving 30-59% compliance and 4/58 achieving 0-29% compliance.

Exercise Duration, Volume, Frequency and Consistency

Figure 1 presents means and standard deviations of exercise duration, volume and consistency over the 26-week intervention, in the first 13-weeks of the intervention, and during the last 13-weeks of the intervention. The average number of calories expended during an exercise session was 285 ± 175 kcals and the average duration of an exercise session was 57 ± 36 minutes. The

248 average number of exercise sessions (frequency) conducted over the 26-week intervention was
249 88 ± 71.

250 **Exercise Majority Variable**

251 N = 39 participants completed a majority of their exercise sessions as moderate aerobic
252 exercise, n = 10 as vigorous aerobic, n = 7 as strength, n = 1 as interval, and n = 1 as 'other'
253 (HR below 50% HRmax). Descriptive characteristics of the exercise majority variable can be
254 found in **Table 2.**

255 ***Medications***

256 At T0, n = 28 participants were not prescribed any diabetes medications of any kind and n = 30
257 were prescribed Metformin (< 2000 mg per day). After the intervention (T1), n = 31 participants
258 were not prescribed any diabetes medications of any kind, n =25 participants were prescribed
259 Metformin (< 2000 mg per day), n = 1 was prescribed empagliflozin (25 mg), and n = 1 was
260 prescribed dapagliflozin (10 mcg). Of those at T1, n = 46 participants had no change in their
261 diabetes medications, n = 5 had an increase in the dosage or additional medications added, n =
262 5 had a decrease in their dosage, and n = 2 had doctor-prescribed removal of diabetes
263 medications from their prescription.

264 **Determinants of Mean 24-hour Glucose, Glycemic Variability (SD, CV), HbA1c, and eA1c**
265 **at T1**

266 **Exercise Metrics**

267 Average session duration (β = -0.23 (0.07), P = 0.002) and exercise duration (β = -0.001 (0.0), P
268 = 0.01) during the first 13 weeks of the intervention were found to significantly predict HbA1c at
269 T1 (Table 3). Average session duration (β = -0.01 (0.0), P = 0.003) and exercise volume (β = -
270 0.002 (0.0), P = 0.01) during the last 13 weeks of the intervention and exercise duration during

the first 13 weeks of the intervention (β = -0.005 (0.0), P = 0.03) also significantly predicted glycemic variability (SD) at T1 (Table 3). Significant predictors for mean 24-hour glucose at T1 were average session duration over the intervention (β = -0.03 (0.01), P = 0.01) and exercise duration over the first 13 weeks of the intervention (β = -0.002 (0.0), P = 0.01) (Table 3). Significant predictors of eA1c at T1 were average session duration over the intervention (β = -0.02 (0.01), P = 0.01) and exercise duration during the first 13 weeks of the intervention (β = -0.0001 (0.0), P = 0.01) (Table 3). No other exercise metrics significantly predicted the mean 24-hour glucose, glycemic variability (SD, CV), HbA1c and eA1c at T1. Complete model fits for significant predictors can be found in Table 3. Full model reporting for each outcome variable can be found in Supplemental tables 1.1-1.5. Sensitivity analyses excluding participants who performed a majority of sessions as resistance training (n = 7; where duration may be less relevant) yielded similar results, with exercise duration during the first 13 weeks and average session duration remaining significant predictors of glycemic outcomes (Supplementary Table 1.7).

Age and Sex

Age and sex were not predictors of mean 24-hour glucose, glycemic variability (SD, CV), HbA1c or eA1c in any of the models at T1 (Supplementary Tables 1.1-1.5).

Differences in Mean 24-hour Glucose, Glycemic Variability (SD, CV), HbA1c, and eA1c between Exercise Types and Exercise Majority

Due to only one participant completing a majority of their sessions as either interval and other exercise types, the statistical comparisons between exercise type majority only included moderate aerobic (n=39), vigorous aerobic (n=10) and strength (n=7) exercise. The group-by time-interaction was not statistically significant (P = 0.19). However, mean 24-hour glucose appeared to increase in the strength exercise majority group (effect estimate; +1.2 mmol/L [95%

CI 0.0, 2.4], P=0.05) from T0 (6.4 mmol/L [95% CI 4.5, 8.3]) to T1 (7.6 mmol/L [95% CI 5.7, 9.5]). eA1c also significantly increased in the strength exercise majority group (effect estimate; +0.7% [95% CI 0.0, 1.5], P=0.05) from T0 (5.7% [95% CI 4.5, 6.9]) to T1 (6.4% [95% CI 5.2, 7.6]). No other significant effects of exercise type majority were found for glycemic variables across the intervention. The estimated marginal means with accompanying confidence intervals for all glycemic control variables within exercise type majority can be found in Supplementary Table 1.6.

DISCUSSION

The main exercise metric that emerged as a significant predictor of glycemic control at the end of the 26-week intervention was exercise duration. This finding highlights an apparent dose-response relationship between exercise duration and glycemic control, suggesting that accumulating more time exercising during each session may lead to greater improvements in glycemic indices.

The present study demonstrates that specifically average session duration during the mHealth intervention predicted glycemic indices at the end of the 26 weeks. Additionally, the duration of exercise accumulated during the first 13 weeks of the intervention (when the most exercise counsellor support was provided) predicted measures of glycemic control at 26 weeks. In general, greater average session duration and accumulated exercise duration during the first 13 weeks were associated with small improvements in glycemic variables. This may reflect that duration represents the most 'behaviorally stable' and physiologically relevant component of the exercise stimulus in people with newly diagnosed T2D. To aid clinical interpretation, our regression coefficients suggest that each 1-minute increase in average session duration across the intervention was associated with approximately a 0.23-mmol/mol (≈-0.02%) reduction in HbA1c at follow-up. If extrapolated, this implies that extending the average session duration by 15 minutes (e.g. from 30 to 45 minutes) across the intervention was associated with a reduction of roughly 3.45 mmol/mol (≈-0.3%) in HbA1c. Although modest, such an effect could be clinically relevant when accumulated over multiple sessions per week and complements prior evidence that longer bouts elicit more pronounced post-exercise glycemic improvements [37–39].

Although underpowered due to the exploratory nature and unequal group sizes, participants who self-selected to perform a majority of strength training throughout the intervention appeared to show an increase in glycemic indices, possibly relating to the noticeably reduced cumulative

exercise duration in strength compared with aerobic training (Table 2). These findings underscore the importance of exercise as a tool for aiding the management and treatment of T2D, and suggest that total exercise time may be a key variable to consider in intervention design.

Previous reviews support the notion that higher durations of exercise training are more closely associated with improved glycemic outcomes in individuals with diabetes than higher intensities [37–39]. Similarly, a randomized controlled trial in individuals with obesity compared high- versus low-intensity exercise at different durations over 24 weeks and found that improvements in insulin action were dependent on exercise duration (115 min/week or 170 min/week), whereas intensity had no effect [40]. Likewise, a prior study reported similar HbA1c reductions after 6 weeks of exercise training with the same session duration (50 minutes) but differing exercise intensities (50–60% HRmax vs. 75–85% HRmax) [41]. When matched for energy cost, prolonged continuous low-to-moderate intensity training was found to be equally effective in lowering HbA1c as continuous moderate-to-high intensity training over 24 weeks [42]. Thus, our findings from real-world, unsupervised exercise align with those of highly controlled, supervised interventions.

In contrast to our findings, a review by Boule et al. [43] showed that weekly exercise duration was not associated with changes in glycemic control, but that exercise intensity was inversely related to HbA1c levels after lower-intensity training. A crossover study in men with T2D compared 7 days of training at either 50% VO_2peak for 70 minutes or 70% VO_2peak for 50 minutes and concluded that improvements in exercise-induced insulin sensitivity were more strongly influenced by intensity [44]. Differences in study design (e.g., supervised vs. unsupervised, short- vs. long-term, male vs. female participants) may contribute to discrepant findings in the literature regarding the relative influence of exercise duration and intensity on glucoregulatory outcomes.

Interestingly, our study did not find that exercise volume, assessed as estimated energy expenditure, was a significant determinant of the glycemic indices at 26 weeks. Although exercise volume integrates duration, frequency, and intensity, total volume (being a derived metric) may be more prone to variability in measurement (e.g., MET estimations, watch imprecision) and collinearity with duration, decreasing its apparent effect. The stable associations between longer session duration and changes in HbA1c, mean glucose, and glycemic variability across multiple models make it unlikely that these results are due to random chance. In the main MOTIVATE T2D trial [26], the 26-week exercise intervention demonstrated a potentially favourable change in HbA1c (although not statistically significant) yet the high heterogeneity in exercise completed by participants raised the question of whether different exercise metrics played a role in determining changes in HbA1c. Importantly, none of our other calculated exercise metrics significantly predicted glycemic indices at 26 weeks. Nevertheless, given the interdependence of duration and volume, future randomized trials with larger samples are needed to disentangle their independent contributions to glycemic outcomes.

The present study contributes to the existing body of research by highlighting the importance of exercise duration as a predictor of glycemic control in a real-world mHealth intervention. Though the exact mechanisms by which exercise duration, volume, and intensity influence glycemic control were not explored here, several plausible explanations exist. Acute bouts of exercise are known to stimulate glucose uptake through insulin-independent pathways, increase muscle glucose transport, and enhance glycogen turnover, leading to transient improvements in insulin sensitivity that may last 24–48 hours [23,24,45]. When such bouts are repeated and accumulated, these acute responses may translate into longer-term adaptations in glucose delivery, transport, and metabolism [46]. This could explain why participants who accumulated greater exercise duration during the first 13 weeks (when more counsellor support was provided) demonstrated lasting improvements in glycemic control, even when support was

reduced in the latter half of the intervention. Moreover, prior evidence suggests that improvements in insulin sensitivity are not strictly dependent on exercise intensity [47] but rather on the accumulation of exercise over time, which may account for why exercise duration, and not total volume, emerged as a more consistent predictor in this study. It is also possible that longer exercise durations during the first 13 weeks reflect higher engagement and more durable behavioral changes that are not fully captured by exercise metrics alone.

In addition to these physiological mechanisms, behavioral and energy balance–related factors may also contribute to our findings [45,48,49]. Changes in appetite and energy intake have been observed in individuals with T2D during exercise interventions [50,51] as well as in healthy individuals [49]. Increases in energy intake may counteract the negative energy balance created by exercise, thereby attenuating improvements in glycemic control. Notably, such compensatory responses have not been consistently linked to exercise duration [50] though a recent review suggested that greater exercise volume may provoke compensatory behaviors [51]. One explanation relates to non-exercise activity thermogenesis (NEAT), where reductions in NEAT after prolonged or intense exercise may occur due to higher fatigue levels. Relevant to this discussion is the role of weight loss in mediating improvements in glycemic control. For example, a randomized controlled trial in women with overweight reported that exercise duration was more strongly associated with weight loss than vigorous intensity [52] In contrast, a more recent review concluded that high- and moderate-intensity training did not differ in their effects on weight, BMI, or body fat mass in adults with overweight and obesity [53]. We did not track energy intake, diet, compensatory behaviors, NEAT, or body composition in this study, and therefore cannot draw specific conclusions on these mechanisms.

There are certain limitations that merit consideration when interpreting our findings. Primarily, this study was a secondary analysis of a larger randomized controlled trial and as such the data used were not collected with the primary aim of addressing the objectives stated here. Future

randomized controlled trials are needed to substantiate our findings and confirm the relative importance of exercise duration compared with exercise volume, frequency, and consistency in predicting glycemic outcomes. Importantly, we did not have measured exercise metrics at T0 (prior to the initiation of the exercise intervention) so could not compare the change in predictors across the intervention. Additionally, the magnitude of the resultant beta coefficients is small (i.e., a large change in the predictor variable is needed to effect even a small change in the outcome variable) and should be interpreted with caution. We also did not include data from the trial's control group because the present study required exercise data (from a fitness watch and HR strap) that was reliable and accurate and the control group in the main intervention trial did not, by design, meet these criteria. Finally, the small number of participants in our non-aerobic exercise groups limited the power to detect meaningful subgroup differences.

CONCLUSION

The role of exercise in glycemic control among individuals with diabetes is well established, yet the contribution of specific exercise metrics (e.g., duration, volume, frequency, consistency) remains less clear. This study provides novel evidence from a real-world mHealth intervention that exercise duration is a key predictor of glycemic outcomes in adults with newly diagnosed T2D. Importantly, greater exercise duration accumulated during the first 13 weeks (when support from exercise counselors was highest) was associated with lasting improvements in glycemic indices. These findings underscore the importance of early engagement and sustained exercise behavior, facilitated through trained exercise specialists applying behavior change techniques. A practical message emerging from this work is that encouraging individuals with T2D to accumulate more minutes of exercise, regardless of type or intensity, may enhance adoption and improve glycemic control in real-world settings.

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CONFLICT OF INTEREST

The authors declare no conflicts of interest.

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635

TABLES

Table 1. Descriptive characteristics of participants at baseline.

Descriptive Characteristic	Overall
N	58
Age, years	55.0 (8.7)
Sex, N (%)	
Male	27 (47)
Female	31 (53)
Months of diagnosis, months	13 (7)
eA1C, %	6.3 (1.9)
HbA1c, %; mmol/mol	6.7(3.0); 50.1 (8.8)
BMI, kg/m^2	33.3 (6.2)
Mean arterial pressure, mmHg	96 (10)
CGM wear time, days	12 (3)

Note: Data are presented as means (SD) unless otherwise specified as N (%).

Table 2. Descriptive characteristics according to the exercise type participants completed for the majority (>50%) of their intervention sessions.

Descriptive Characteristic	Moderate	Vigorous	Strength	Interval	Other
N	39	10	7	1	1
HbA1c, %; mmol/mol	6.8 (2.9); 50.4 (9.2)	6.5 (2.7); 47.5 (5.9)	6.6 (2.8); 48.5 (7.1)	8.7; 72.0	11.1; 97.6
eA1c, %	6.0 (1.1)	6.7 (2.7)	5.7 (0.6)	10.3	13.3
Average glucose, mmol/L	6.9 (1.7)	8.1 (4.4)	6.4 (0.9)	13.8	18.6
CV, %	24.9 (6.5)	20.9 (5.0)	20.4 (6.8)	22.9	15.8
SD, mmol/L	1.7 (0.6)	1.8 (1.1)	1.3 (0.4)	3.2	2.9
Min glucose, mmol/L	3.6 (1.3)	4.2 (2.0)	3.6 (1.0)	4.2	12.6
Max glucose, mmol/L	13.5 (3.3)	13.8 (5.4)	11.8 (1.9)	22.3	22.3
AUC, mmol/h/L	5.17 (1.3)	6.1 (3.3)	4.80 (0.7)	10.4	13.9
Average Session Duration (minutes)	63 (39)	56 (26)	40 (6)	18	44
Exercise duration, first 13 weeks (minutes)	3089 (3418)	3524 (4211)	2159 (869)	261	1059
Exercise duration, last 13 weeks (minutes)	2305 (1756)	2030 (1636)	1645 (905)	290	0

Note: Data are presented as means (SD) unless otherwise specified as N (%).

Table 3. Average exercise session duration, exercise duration during the first 13 weeks and exercise duration during the last 13 weeks as predictors of mean 24-hour glucose, glycemic variability (SD, CV), HbA1c and eA1c at T1.

	Average session duration, 26 weeks			**Exercise duration, first 13 weeks**			**Exercise duration, last 13 weeks**		
	β (SE)	P value	Model	β (SE)	P value	Model	β (SE)	P value	Model
HbA1c, %; mmol/mol	-0.23 (0.07)	P = 0.002	$F_{(3, 34)}$ = 3.68, P = 0.02; R^2 = 0.20	-0.001 (0.0)	P = 0.01	$F_{(3, 45)}$ = 2.4, P = 0.08; R^2 = 0.14	0.0 (0.0)	P = 0.22	$F_{(3, 45)}$ = 0.63, P 0.60= ; R^2 = 0.04
eA1c, %	-0.02 (0.01)	P = 0.01	$F_{(3 \text{ and } 48)}$ = 2.57, P = 0.05; R^2 = 0.14	- 0.0001 (0.0)	P = 0.01	$F_{(3, 48)}$ = 2.30, P = 0.09; R^2 = 0.12	0.0 (0.0)	P = 0.18	$F_{(3. 48)}$ = 0.71, P = 0.55; R^2 = 0.04
Mean 24-hour glucose, mmol/L	-0.03 (0.01)	P = 0.01	$F_{(3, 48)}$ = 2.57, P = 0.05; R^2 = 0.14	-0.002 (0.0)	P = 0.01	$F_{(3, 48)}$ = 2.27, P = 0.09; R^2 = 0.12	0.0 (0.0)	P = 0.18	$F_{(3, 48)}$ = 0.71, P = 0.55; R^2 = 0.04
SD, mmol/L	-0.01 (0.0)	P = 0.003	$F_{(3, 48)}$ = 3.60, P = 0.02; R^2 = 0.18	-0.005 (0.0)	P = 0.03	$F_{(3, 48)}$ = 1.83, P = 0.15; R^2 = 0.10	0.0 (0.0)	P = 0.17	$F_{(3, 48)}$ = 0.93, P = 0.43; R^2 = 0.05
CV, %	-0.03 (0.03)	P = 0.31	$F_{(3, 48)}$ = 1.01, P = 0.39; R^2 = 0.06	0.0 (0.0)	P = 0.90	$F_{(3, 48)}$ = 0.65, P = 0.59; R^2 = 0.04	0.0 (0.0)	P = 0.86	$F_{(3, 48)}$ = 0.66, P = 0.58; R^2 = 0.04

FIGURE CAPTIONS

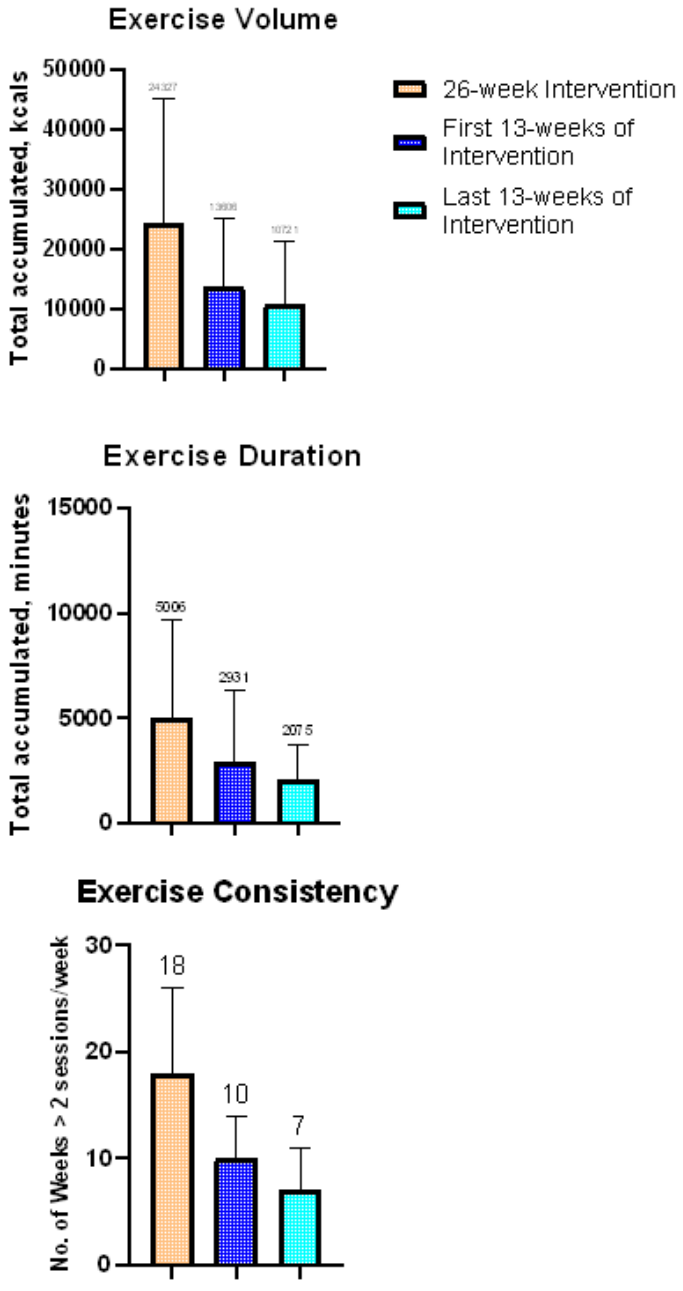

Figure 1. Comparison of selected exercise metrics between the entire 26-week intervention, the first 13 weeks of the intervention, and the last 13 weeks of the intervention. *Exercise consistency represents the number of weeks participants exercised more than 2 times (averaged across participants).

Supplementary Material

SUPPLEMENTARY TABLES

Supplementary Table 1.1 Models showing determinants of eA1c at T1.

Dependent Variables	Age and sex		Total exercise volume, 26 weeks		Exercise type split grouping		Exercise type majority		Exercise duration, 26 weeks		Exercise frequency, 23 weeks		Exercise consistency, 26 weeks		Exercise adherence	
	Beta	P value	Beta	P value	Beta	P value	Beta	P value	Beta	P value	Beta	P value	Beta	P value	Beta	P value
Total exercise volume, 26 weeks			0.00 (0.00)	P = 0.23												
Exercise type majority								P = 0.58								
Exercise duration, 26 weeks									0.0 (0.0)	P = 0.18						
Exercise frequency, 23 weeks											0.0 (0.0)	P = 0.31				
Exercise consistency, 26 weeks													-0.03 (0.03)	P = 0.35		
Exercise adherence															-0.35 (0.28)	P = 0.23
Age	0.01 (0.03)	P = 0.59	0.01 (0.03)	P = 0.59	0.01 (0.03)	P = 0.63	0.01 (0.03)	P = 0.73	0.0 (0.0)	P = 0.93	0.02 (0.03)	P = 0.39	0.02 (0.03)	P = 0.40	0.02 (0.03)	P = 0.37
Sex	0.08 (0.41)	P = 0.84	0.06 (0.49)	P = 0.90	0.04 (0.44)	P = 0.93	0.07 (0.42)	P = 0.86	0.0 (0.0)	P = 0.89	0.22 (0.43)	P = 0.62	0.17 (0.42)	P = 0.69	0.21 (0.42)	P = 0.63
Model	$F_{(2,49)} = 0.15$, P = 0.86; R^2 = 0.01		$F_{(3,48)} = 0.60$, P = 0.62; R^2 = 0.04		$F_{(4, 47)} = 0.12$, P = 0.98; R^2 = 0.01		$F_{(5, 46)} = 0.46$, P = 0.80; R^2 = 0.05		$F_{(3, 48)} = 0.72$, P = 0.54; R^2 = 0.04		$F_{(3, 49)} = 0.45$, P = 0.72; R^2 = 0.03		$F_{(3, 48)} = 0.40$, P = 0.75; R^2 = 0.02		$F_{(3, 48)} = 0.60$, P = 0.62, R^2; 0.04	

Supplementary Table 1.1 (continued) Models showing determinants of the eA1c at T1.

	Average session duration, 26 weeks		Average session volume, 26 weeks		Exercise volume, first 13 weeks		Exercise volume, last 13 weeks		Exercise duration, first 13 weeks		Exercise duration, last 13 weeks		Exercise consistency, first 13 weeks		Exercise consistency, last 13 weeks	
	Beta	P value	Beta	P value	Beta	P value	Beta	P value	Beta	P value	Beta	P value	Beta	P value	Beta	P value
Average session duration, 26 weeks	-0.02 (0.01)	P = 0.01														
Average session volume, 26 weeks			0.0 (0.0)	P = 0.93												
Exercise volume, first 13 weeks					0.0 (0.0)	P = 0.51										
Exercise volume, last 13 weeks							0.0 (0.0)	P = 0.09								
Exercise duration, first 13 weeks									-0.0001 (0.0)	P = 0.01						
Exercise duration, last 13 weeks											0.0 (0.0)	P = 0.18				
Exercise consistency, first 13 weeks													-0.05 (0.07)	P = 0.47		
Exercise consistency, last 13 weeks															-0.05 (0.05)	P = 0.32
Age	0.0 (0.02)	P = 0.99	0.01 (0.03)	P = 0.60	0.0 (0.0)	P = 0.53	0.0 (0.0)	P = 0.35	0.0 (0.03)	P = 0.91	0.03 (0.03)	P = 0.33	0.02 (0.03)	P = 0.48	0.02 (0.03)	P = 0.38
Sex	0.23 (0.39)	P = 0.56	0.06 (0.50)	P = 0.90	0.0 (0.0)	P = 0.66	0.0 (0.0)	P = 0.29	0.13 (0.39)	P = 0.75	0.21 (0.42)	P = 0.61	0.11 (0.42)	P = 0.79)	0.20 (0.43)	P = 0.64
Model	$F_{(3 \text{ and } 48)}$ = 2.57, P = 0.05; R^2 = 0.14		$F_{(3, 38)}$ = 0.10, P = 0.96; R^2 = 0.01		$F_{(3, 48)}$ = 0.25, P = 0.86; R^2 = 0.02		$F_{(3, 48)}$ = 1.1, P = 0.36, R^2 = 0.06		$F_{(3, 48)}$ = 2.30, P = 0.09; R^2 = 0.12		$F_{(3. 48)}$ = 0.71, P = 0.55; R^2 = 0.04		$F_{(3, 48)}$ = 0.26, P = 0.84; R^2 = 0.02		$F_{(3, 48)}$ = 0.43, P = 0.73; R^2 = 0.03	

Supplementary Table 1.2. Models showing determinants of mean 24-hour glucose at T1

Dependent Variables	Age and sex		Total exercise volume, 26 weeks		Exercise type split grouping		Exercise type majority		Exercise duration, 26 weeks		Exercise frequency, 26 weeks		Exercise consistency, 26 weeks		Exercise adherence	
	Beta	P value	Beta	P value	Beta	P value	Beta	P value	Beta	P value	Beta	P value	Beta	P value	Beta	P value
Total exercise volume, 26 weeks			0.0 (0.0)	P = 0.93												
Exercise type majority								P = 0.58								
Exercise duration, 26 weeks									0.0 (0.0)	P = 0.18						
Exercise frequency, 26 weeks											0.0 (0.0)	P = 0.31				
Exercise consistency, 26 weeks													-0.05 (0.05)	P = 0.35		
Exercise adherence															-0.56 (0.43)	P = 0.22
Age	0.02 (0.04)	P = 0.59)	0.02 (0.04)	P = 0.59	0.02 (0.04)	P = 0.63	0.01 (0.04)	P = 0.73	0.0 (0.0)	P = 0.93	0.04 (0.04)	P = 0.39	0.04 (0.04)	P = 0.40	0.04 (0.04)	P = 0.38
Sex	0.13 (0.66)	P = 0.84	0.10 (0.78)	P = 0.90	0.06 (0.69)	P = 0.93	0.11 (0.67)	P = 0.86	0.0 (0.0)	P = 0.89	0.35 (0.69)	P = 0.62	0.27 (0.67)	P = 0.69	0.33 (0.67)	P = 0.63
Model	$F_{(2, 49)}$ = 0.16, P = 0.86; R^2 = 0.0		$F_{(3, 48)}$ = 0.10, P = 0.96; R^2 = 0.0		$F_{(4, 47)}$ = 0.12, P = 0.98; R^2 = 0.0		$F_{(5, 46)}$ = 0.46, P = 0.81; R^2 = 0.05		$F_{(3, 48)}$ = 0.72, P = 0.54; R^2 = 0.04		$F_{(3, 48)}$ = 0.45, P = 0.72; R^2 = 0.03		$F_{(3, 48)}$ = 0.40, P = 0.75; R^2 = 0.02		$F_{(3, 48)}$ = 0.61, P = 0.61; R^2 = 0.04	

Table 1.2 (continued) Models showing determinants of mean 24-hour glucose at T1.

	Average session duration, 26 weeks		Average session volume, 26 weeks		Exercise volume, first 13 weeks		Exercise volume, last 13 weeks		Exercise duration, first 13 weeks		Exercise duration, last 13 weeks		Exercise consistency, first 13 weeks		Exercise consistency, last 13 weeks	
	Beta	P value	Beta	P value	Beta	P value	Beta	P value	Beta	P value	Beta	P value	Beta	P value	Beta	P value
Average session duration, 26 weeks	-0.03 (0.01)	P = 0.01														
Average session volume, 26 weeks			0.0 (0.0)	P = 0.93												
Exercise volume, first 13 weeks					0.0 (0.0)	P = 0.51										
Exercise volume, last 13 weeks							0.0 (0.0)	P = 0.09								
Exercise duration, first 13 weeks									-0.002 (0.0)	P = 0.01						
Exercise duration, last 13 weeks											0.0 (0.0)	P = 0.18				
Exercise consistency, first 13 weeks													-0.05 (0.07)	P = 0.47		
Exercise consistency, last 13 weeks															-0.05 (0.05)	P = 0.32
Age	0.0 (0.04)	P = 0.99	0.01 (0.03)	P = 0.59	0.0 (0.0)	P = 0.53	0.0 (0.0)	P = 0.35	0.0 (0.0)	P = 0.91	0.03 (0.03)	P = 0.32	0.02 (0.03)	P = 0.48	0.02 (0.03)	P = 0.38
Sex	0.37 (0.62)	P = 0.56	0.06 (0.49)	P = 0.90	0.0 (0.0)	P = 0.66	0.0 (0.0)	P = 0.30	0.0 (0.0)	P = 0.75	0.21 (0.42)	P = 0.61	0.11 (0.42)	P = 0.79	0.20 (0.43)	P = 0.64
Model	$F_{(3, 48)}$ = 2.57, P = 0.05; R^2 = 0.14		$F_{(3, 48)}$ = 0.10, P = 0.96; R^2 = 0.01		$F_{(3, 48)}$ = 0.25, P = 0.86; R^2 = 0.02		$F_{(3, 48)}$ = 1.1, P = 0.36; R^2 = 0.06		$F_{(3, 48)}$ = 2.27, P = 0.09; R^2 = 0.12		$F_{(3, 48)}$ = 0.71, P = 0.55; R^2 = 0.04		$F_{(3, 48)}$ = 0.28, P = 0.84; R^2 = 0.02		$F_{(3, 48)}$ = 0.43, P = 0.73; R^2 = 0.03	

Supplementary Table 1.3. Models showing determinants of glycemic variability (SD) at T1.

Dependent Variables	Age and sex		Total exercise volume, 26 weeks		Exercise type split grouping		Exercise type majority		Exercise duration, 26 weeks		Exercise frequency, 26 weeks		Exercise consistency, 26 weeks		Exercise adherence	
	Beta	P value	Beta	P value	Beta	P value	Beta	P value	Beta	P value	Beta	P value	Beta	P value	Beta	P value
Total exercise volume, 26 weeks			0.0 (0.0)	P = 0.91												
Exercise type majority								P = 0.95								
Exercise duration, 26 weeks									0.0 (0.0)	P = 0.29						
Exercise frequency, 26 weeks											0.0 (0.0)	P = 0.09				
Exercise consistency, 26 weeks													-0.02 (0.01)	P = 0.18		
Exercise adherence															-0.20 (0.12)	P = 0.09
Age	0.0 (0.01)	P = 0.60	0.01 (0.01)	P = 0.63	0.0 (0.01)	P = 0.55	0.0 (0.01)	P = 0.63	0.0 (0.0)	P = 0.88	0.01 (0.01)	P = 0.28	0.01 (0.01)	P = 0.34	0.01 (0.01)	P = 0.32
Sex	-0.11 (0.17)	P = 0.52	-0.1 (0.21)	P = 0.63	-0.11 (0.18)	P = 0.55	-0.12 (0.18)	P = 0.50	0.0 (0.0)	P = 0.49	-0.02 (0.17)	P = 0.92	-0.06 (0.18)	P = 0.74	-0.04 (0.18)	P = 0.81
Model	$F_{(2, 49)}$ = 0.41, P = 0.66; R^2 = 0.02		$F_{(3, 48)}$ = 0.28, P = 0.84; R^2 = 0.02		$F_{(4, 47)}$ = 0.66, P = 0.62; R^2 = 0.05		$F_{(5, 46)}$ = 0.23, P = 0.95; R^2 = 0.02		$F_{(3, 48)}$ = 0.66, P = 0.58; R^2 = 0.04		$F_{(3, 48)}$ = 1.29, P = 0.29; R^2 = 0.07		$F_{(3, 48)}$ = 0.89, P = 0.45; R^2 = 0.05		$F_{(3, 48)}$ = 1.23, P = 0.31; R^2 = 0.07	

Supplementary Table 1.3 (continued) Models showing determinants of glycemic variability (SD) at T1.

	Average session duration, 26 weeks		Average session volume, 26 weeks		Exercise volume, first 13 weeks		Exercise volume, last 13 weeks		Exercise duration, first 13 weeks		Exercise duration, last 13 weeks		Exercise consistency, first 13 weeks		Exercise consistency, last 13 weeks	
	Beta	P value	Beta	P value	Beta	P value	Beta	P value	Beta	P value	Beta	P value	Beta	P value	Beta	P value
Average session duration, 26 weeks	-0.01 (0.0)	P = 0.003														
Average session volume, 26 weeks			0.0 (0.0)	P = 0.91												
Exercise volume, first 13 weeks					0.0 (0.0)	P = 0.26										
Exercise volume, last 13 weeks							-0.002 (0.0)	P = 0.01								
Exercise duration, first 13 weeks									-0.005 (0.0)	P = 0.03						
Exercise duration, last 13 weeks											0.0 (0.0)	P = 0.17				
Exercise consistency, first 13 weeks													-0.03 (0.03)	P = 0.37		
Exercise consistency, last 13 weeks															-0.03 (0.02)	P = 0.13
Age	0.0 (0.01)	P = 0.93	0.0 (0.01)	P = 0.63	0.0 (0.0)	P = 0.50	0.0 (0.0)	P = 0.27	0.0 (0.0)	P = 0.97	0.0 (0.0)	P = 0.33	0.0 (0.01)	P = 0.46	0.01 (0.01)	P = 0.29
Sex	-0.04 (0.16)	P = 0.79	0.0 (0.21)	P = 0.63	0.0 (0.0)	P = 0.87	0.0 (0.0)	P = 0.50	0.0 (0.0)	P = 0.57	0.0 (0.0)	P = 0.76	-0.10 (0.18)	P = 0.58	-0.04 (0.18)	P = 0.84

Model	$F_{(3, 48)} = 3.60$, $P = 0.02$; $R^2 = 0.18$	$F_{(3, 48)} = 0.28$, $P = 0.84$; $R^2 = 0.02$	$F_{(3, 48)} = 0.72$, $P = 0.55$; $R^2 = 0.04$	$F_{(3, 48)} = 2.30$, $P = 0.08$; $R^2 = 0.13$	$F_{(3, 48)} = 1.83$, $P = 0.15$; $R^2 = 0.10$	$F_{(3, 48)} = 0.93$, $P = 0.43$; $R^2 = 0.05$	$F_{(3, 48)} = 0.55$, $P = 0.65$; $R^2 = 0.03$	$F_{(3, 48)} = 1.06$, $P = 0.37$; $R^2 = 0.06$

Supplementary Table 1.4. Models showing determinants of glycemic variability (CV) at T1.

Dependent Variables	Age and sex		Total exercise volume, 26 weeks		Exercise type split grouping		Exercise type majority		Exercise duration, 26 weeks		Exercise frequency, 26 weeks		Exercise consistency, 26 weeks		Exercise adherence	
	Beta	P value	Beta	P value	Beta	P value	Beta	P value	Beta	P value	Beta	P value	Beta	P value	Beta	P value
Total exercise volume, 26 weeks			0.0 (0.01)	P = 0.61												
Exercise type split grouping						P = 0.08										
Exercise duration, 26 weeks									0.0 (0.0)	P = 0.98						
Exercise frequency, 26 weeks											-0.01 (0.01)	P = 0.20				
Exercise consistency, 26 weeks													-0.05 (0.12)	P = 0.67		
Exercise adherence															-1.00 (1.03)	P = 0.33
Age	0.0 (0.09)	P = 0.99	-0.01 (0.10)	P = 0.90	0.02 (0.10)	P = 0.86	0.02 (0.09)	P = 0.80	0.0 (0.0)	P = 0.98	0.04 (0.10)	P = 0.67	0.01 (0.10)	P = 0.89	0.02 (0.10)	P = 0.79
Sex	-2.10 (1.48)	P = 0.17	-1.60 (1.75)	P = 0.36	-1.90 (1.50)	P = 0.21	-2.14 (1.50)	P = 0.15	0.0 (0.0)	P = 0.18	-1.44 (1.55)	P = 0.36	-1.92 (1.53)	P = 0.22	-1.71 (1.53)	P = 0.27
Model	$F_{(2, 49)} = 0.99$, P = 0.38; $R^2 = 0.04$		$F_{(3, 48)} = 0.74$, P = 0.54; $R^2 = 0.04$		$F_{(4, 47)} = 1.81$, P = 0.14; $R^2 = 0.13$		$F_{(5, 46)} = 1.26$, P = 0.30; $R^2 = 0.12$		$F_{(3, 48)} = 0.65$, P = 0.59; $R^2 = 0.04$		$F_{(3, 48)} = 1.23$, P = 0.31; $R^2 = 0.07$		$F_{(3, 48)} = 0.71$, P = 0.55; $R^2 = 0.04$		$F_{(3, 48)} = 0.98$, P = 0.41; $R^2 = 0.06$	

Supplementary Table 1.4. Models showing determinants of glycemic variability (CV) at T1.

	Average session duration, 26 weeks		Average session volume, 26 weeks		Exercise volume, first 13 weeks		Exercise volume, last 13 weeks		Exercise duration, first 13 weeks		Exercise duration, last 13 weeks		Exercise consistency, first 13 weeks		Exercise consistency, last 13 weeks	
	Beta	P value	Beta	P value	Beta	P value	Beta	P value	Beta	P value	Beta	P value	Beta	P value	Beta	P value
Average session duration, 26 weeks	-0.03 (0.03)	P = 0.31														
Average session volume, 26 weeks			0.0 (0.0)	P = 0.61												
Exercise volume, first 13 weeks					0.0 (0.0)	P = 0.42										
Exercise volume, last 13 weeks							0.0 (0.0)	P = 0.14								
Exercise duration, first 13 weeks									0.0 (0.0)	P = 0.90						
Exercise duration, last 13 weeks											0.0 (0.0)	P = 0.86				
Exercise consistency, first 13 weeks													0.0 (0.26)	P = 0.97		
Exercise consistency, last 13 weeks															-0.13 (0.20)	P = 0.50
Age	-0.02 (0.09)	P = 0.82	-0.01 (0.10)	P = 0.90	0.0 (0.0)	P = 0.92	0.0 (0.0)	P = 0.73	0.0 (0.0)	P = 0.96	0.0 (0.0)	P = 0.96	0.0 (0.10)	P = 0.99	0.02 (0.10)	P = 0.81
Sex	-1.85 (1.50)	P = 0.22	-1.60 (1.75)	P = 0.36	0.0 (0.0)	P = 0.34	0.0 (0.0)	P = 0.67	0.0 (0.0)	P = 0.18	0.0 (0.0)	P = 0.20	-2.10 (1.51)	P = 0.18	-1.77 (1.55)	P = 0.26
Model	$F_{(3, 48)}$ = 1.01, P = 0.39; R^2 = 0.06		$F_{(3, 48)}$ = 0.74, P = 0.54; R^2 = 0.04		$F_{(3, 48)}$ = 0.88, P = 0.46; R^2 = 0.05		$F_{(3, 48)}$ = 1.44, P = 0.24; R^2 = 0.08		$F_{(3, 48)}$ = 0.65, P = 0.59; R^2 = 0.04		$F_{(3, 48)}$ = 0.66, P = 0.58; R^2 = 0.04		$F_{(3, 48)}$ = 0.65, P = 0.59; R^2 = 0.04		$F_{(3, 48)}$ = 0.80, P = 0.50; R^2 = 0.05	

Supplementary Table 1.5. Models showing determinants of HbA1c at T1.

Dependent Variables	Age and sex		Total exercise volume, 26 weeks		Exercise type split grouping		Exercise type majority		Exercise duration, 26 weeks		Exercise frequency, 26 weeks		Exercise consistency, 26 weeks		Exercise adherence	
	Beta	P value	Beta	P value	Beta	P value	Beta	P value	Beta	P value	Beta	P value	Beta	P value	Beta	P value
Total exercise volume, 26 weeks			0.0 (0.02)	P = 0.91												
Exercise type majority								P = 0.87								
Exercise duration, 26 weeks									0.0 (0.0)	P = 0.17						
Exercise frequency, 26 weeks											-0.02 (0.03)	P = 0.45				
Exercise consistency, 26 weeks													-0.30 (0.26)	P = 0.25		
Exercise adherence															-1.62 (2.30)	P = 0.49
Age	0.05 (0.22)	P = 0.81	0.05 (0.23)	P = 0.84	0.10 (0.22)	P = 0.81	0.07 (0.23)	P = 0.77	-0.01 (0.22)	P = 0.95	0.11 (0.23)	P = 0.63	0.13 (0.23)	P = 0.56	0.10 (0.23)	P = 0.66
Sex	-1.55 (3.39)	P = 0.65	-1.33 (4.02)	P = 0.74	-1.03 (3.57)	P = 0.77	-1.69 (3.51)	P = 0.63	-1.79 (3.36)	P = 0.60	-0.81 (3.55)	P = 0.82	-0.77 (3.44)	P = 0.82	-1.05 (3.50)	P = 0.76
Model	$F_{(2, 46)}$ = 0.17, P = 0.85; R^2 = 0.01		$F_{(3, 45)}$ = 0.11, P = 0.95; R^2 = 0.01		$F_{(4, 44)}$ = 0.17, P = 0.95; R^2 = 0.01		$F_{(5, 43)}$ = 0.21, P = 0.96; R^2 = 0.02		$F_{(3, 45)}$ = 0.75, P = 0.53; R^2 = 0.05		$F_{(3, 45)}$ = 0.30, P = 0.82; R^2 = 0.02		$F_{(3, 45)}$ = 0.56, P = 0.65; R^2 = 0.04		$F_{(3, 45)}$ = 0.27, P = 0.84; R^2 = 0.02	

Supplementary Table 1.5 (continued) Models showing determinants of HbA1c at T1.

	Average session duration, 26 weeks		Average session volume, 26 weeks		Exercise volume, first 13 weeks		Exercise volume, last 13 weeks		Exercise duration, first 13 weeks		Exercise duration, last 13 weeks		Exercise consistency, first 13 weeks		Exercise consistency, last 13 weeks	
	Beta	P value	Beta	P value	Beta	P value	Beta	P value	Beta	P value	Beta	P value	Beta	P value	Beta	P value
Average session duration, 26 weeks	-0.23 (0.07)	P = 0.002														
Average session volume, 26 weeks			0.0 (0.02)	P = 0.91												
Exercise volume, first 13 weeks					0.0 (0.0)	P = 0.72										
Exercise volume, last 13 weeks							0.0 (0.0)	P = 0.17								
Exercise duration, first 13 weeks									-0.001 (0.0)	P = 0.01						
Exercise duration, last 13 weeks											0.0 (0.0)	P = 0.22				
Exercise consistency, first 13 weeks													-0.62 (0.57)	P = 0.28		
Exercise consistency, last 13 weeks															-0.46 (0.43)	P = 0.29
Age	0.02 (0.20)	P = 0.91	0.05 (0.23)	P = 0.84	0.0 (0.0)	P = 0.79	0.11 (0.22)	P = 0.62	-0.03 (0.20)	P = 0.88	0.13 (0.23)	P = 0.56	0.10 (0.22)	P = 0.64	0.14 (0.23)	P = 0.56
Sex	-0.33 (3.12)	P = 0.92	-1.33 (4.02)	P = 0.74	0.0 (0.0)	P = 0.77	1.04 (3.84)	P = 0.79	-1.25 (3.20)	P = 0.70	-0.65 (3.50)	P = 0.85	-1.22 (3.40)	P = 0.72	-0.61 (3.50)	P = 0.86
Model	$F_{(3, 34)}$ = 3.68, P = 0.02; R^2 = 0.20		$F_{(3, 45)}$ = 0.11, P = 0.95; R^2 = 0.01		$F_{(3, 45)}$ = 0.15, P = 0.93; R^2 = 0.01		$F_{(3, 45)}$ = 0.76, P = 0.52; R^2 = 0.05		$F_{(3, 45)}$ = 2.4, P = 0.08; R^2 = 0.14		$F_{(3, 45)}$ = 0.63, P = 0.60; R^2 = 0.04		$F_{(3, 45)}$ = 0.51, P = 0.68; R^2 = 0.03		$F_{(3, 45)}$ = 0.49, P = 0.69; R^2 = 0.03	

Supplementary Table 1.6 Outcomes by Assigned Exercise Majority

	Moderate Aerobic, EMM (95% CI)		Vigorous Aerobic, EMM (95% CI)		Strength, EMM (95% CI)	
	PRE	*POST*	*PRE*	*Post*	*PRE*	*POST*
Mean 24-hour glucose, mmol/L	7.0 (6.2, 7.8)	7.1 (6.5, 7.8)	8.4 (6.9, 10.0)	8.3 (6.7, 9.9)	6.4 (4.5, 8.3)	7.6 (5.7, 9.5)
Standard deviation, mmol/L	1.7 (1.5, 1.9)	1.7 (1.5, 1.9)	1.9 (1.4, 2.4)	1.9 (1.4, 2.4)	1.3 (0.7, 1.8)	1.6 (1.1, 2.2)
Coefficient of variation (%)	24.8 (22.9, 26.7)	24.2 (22.4, 26.1)	22.2 (18.3, 26.0)	22.3 (18.0, 26.5)	20.3 (15.6, 25.0)	21.9 (17.2, 26.6)
HbA1c	6.8 (6.4, 7.1)	6.6 (6.3, 5.9)	6.9 (6.2, 7.6)	6.9 (6.3, 7.7)	6.6 (5.8, 7.4)	6.7 (5.8, 7.5)
eA1c	6.0 (5.6, 6.5)	6.1 (5.6, 6.6)	6.9 (5.9, 7.9)	6.9 (5.8, 7.9)	5.7 (4.5, 6.9)	6.4 (5.2, 7.6)

Supplementary Table 1.7 Sensitivity Analysis at T1 without Resistance Training Group

	Average session duration, 26 weeks		Exercise duration, first 13 weeks		Exercise duration, last 13 weeks	
	Beta	P value	Beta	P value	Beta	P value
HbA1c	-0.25 (0.07)	P = 0.003	0.0 (0.0)	P = 0.02	0.0 (0.0)	P = 0.20
Model	$F_{(3, 40)}$ = 3.55, P = 0.02; R^2 = 0.21		$F_{(3, 10)}$ = 2.14, P = 0.11; R^2 = 0.14		$F_{(3, 40)}$ = 0.68, P = 0.57; R^2 = 0.05	
Mean 24-hour glucose	-0.03 (0.01)	P = 0.01	0.0 (0.0)	P = 0.02	0.0 (0.0)	P = 0.18
Model	$F_{(3, 42)}$ = 2.45, P = 0.08; R^2 = 0.15		$F_{(3, 42)}$ = 2.08, P = 0.12; R^2 = 0.13		$F_{(3, 42)}$ = 0.66, P = 0.58; R^2 = 0.04	
Glycemic variability (SD)	0.01 (0.0)	P = 0.01	0.0 (0.0)	P = 0.07	0.0 (0.0)	P = 0.13
Model	$F_{(3, 42)}$ = 3.446, P = 0.03; R^2 = 0.20		$F_{(3, 42)}$ = 1.75, P = 0.17; R^2 = 0.11		$F_{(3, 42)}$ = 1.40, P = 0.26; R^2 = 0.09	
eA1c	-0.02 (0.0)	P = 0.01	0.0 (0.0)	P = 0.02	0.0 (0.0)	P = 0.18
Model	$F_{(3, 42)}$ = 2.45, P = 0.07; R^2 = 0.15		$F_{(3, 42)}$ = 2.08, P = 0.12; R^2 = 0.13		$F_{(3, 42)}$ = 0.66, P = 0.58; R^2 = 0.04	