Lower objectively measured physical activity is linked with perceived risk of hypoglycemia in type 1 diabetes

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Aims. Compare physical activity (PA) levels in adults with and without type 1 diabetes and identify diabetes-specific barriers to PA.

Methods. Forty-four individuals with type 1 diabetes and 77 non-diabetic controls in the Coronary Artery Calcification in Type 1 Diabetes study wore an accelerometer for 2 weeks. Moderate-to-vigorous physical activity (MVPA) was compared by diabetes status using multiple linear regression. The Barriers to Physical Activity in Type 1 Diabetes questionnaire measured diabetes-specific barriers to PA, and the Clarke hypoglycemia awareness questionnaire measured hypoglycemia frequency.

Results. Individuals with type 1 diabetes engaged in less MVPA, fewer bouts of MVPA, and spent less time in MVPA bouts per week than individuals without diabetes (all $p<0.05$), despite no difference in self-reported PA ($p>0.05$). The most common diabetes-specific barrier to PA was risk of hypoglycemia. Individuals with diabetes reporting barriers spent less time in MVPA bouts per week than those not reporting barriers ($p=0.047$).

Conclusions. Individuals with type 1 diabetes engage in less MVPA than those without diabetes despite similar self-reported levels, with the main barrier being perceived risk of hypoglycemia. Adults with type 1 diabetes require guidance to meet current PA guidelines and reduce cardiovascular risk.

Keywords: type 1 diabetes, physical activity, accelerometer

1. Introduction

Cardiovascular disease (CVD) is the leading cause of death in individuals with type 1 diabetes, is a common complication of type 1 diabetes, and presents at significantly higher rates and earlier in life in individuals with type 1 diabetes than in individuals without diabetes.[1,2] In people under 40 years of age, the CVD mortality rate is 9 times higher in men and 40 times higher in women with type 1 diabetes as compared to men and women without diabetes,[3] and CVD prevalence continues to rise.[4] Glycemic dysregulation is associated with increases in CVD risk and weight gain, both of which have become more prevalent in individuals with type 1 diabetes along with obesity; [5–7] thus, glycemic and weight control are important to prevent future cardiovascular and microvascular complications and to improve overall health in individuals with type 1 diabetes.[1,8]

The American Heart Association and the American Diabetes Association both recommend physical activity (PA) for optimizing blood glucose control in individuals with type 1 diabetes.[9,10] PA is known to reduce risk of CVD and to aid in the management of diabetes complications, [9] and higher levels of PA are associated with better glycemic control, lower levels of obesity, and a decrease in cardiovascular risk factors in individuals with type 1 diabetes.[11,12]

Previous studies have identified barriers to PA that are specific to diabetes and prevent individuals with diabetes from engaging in consistent PA,[13] suggesting that PA may be lower in this population due to unique barriers. Additionally, studies have shown that self-reported PA levels often differ from objective measures of PA.[14–16] The primary aim of this study was to compare planned leisure-time PA levels in adults with and without type 1 diabetes using objective data measured by an accelerometer. In addition, we examined diabetes-specific barriers to PA and explored how barriers and hypoglycemic episodes impacted PA in people

with type 1 diabetes.

2. Materials and Methods

2.1 Study population

We collected data on PA from 121 adults between the ages of 35 and 76 who initially enrolled in the Coronary Artery Calcification in Type 1 Diabetes (CACTI) study between March 2000 and May 2002. Participants were followed for 15 years and provided data at follow-up study visits occurring between May 2014 and June 2016. A total of 44 adults with type 1 diabetes and 77 adults without diabetes agreed to wear an accelerometer to collect PA data for a period of two weeks at the follow-up visit and were included in these analyses. All participants provided informed consent at baseline and follow-up visits, and all protocols were reviewed and approved by the Colorado Multiple Institute Review Board.

2.2 Physical activity

Study participants wore an Actigraph wGT3X-BT triaxial accelerometer on the hip for the two-week period (mean wear time 14.4 ± 3.6 days). The accelerometer was worn at all times except during water activities. Activity counts, calculated as a function of the frequency and intensity of acceleration on the X, Y, and Z axes,[17] were collected at 1-minute intervals. Participants additionally logged their PA for the full two-week period and completed a validated questionnaire[18] capturing self-reported sports and leisure PA. Participants reported approximate weekly and yearly occupational and leisure periods of PA, and we calculated level of activity based on energy expenditure algorithms specific to each activity.[19]

Wear time validation was conducted in ActiLife version 6.13 to remove periods of non-wear from further analysis. The algorithm proposed by Choi et al. was chosen to identify periods of wear and non-wear time.[20] Only participants wearing the accelerometer for a total of at least 4 days, with at least 1 weekend day, were included in the analysis to ensure

representative data were captured.

Activity levels were defined using Freedson adult definitions for sedentary, light, moderate, vigorous, and very vigorous activity based on the activity counts per minute.[21] Sedentary activity was defined as 0-99 counts per minute; light activity as 100-1951 counts per minute; moderate activity as 1952-5724 counts per minute; vigorous activity as 5725-9498; and very vigorous activity as greater than 9499 counts per minute. Individuals were considered to be in extended bouts of moderate-to-vigorous PA (MVPA) if they engaged in moderate, vigorous, or very vigorous activity for at least 10 minutes with a maximum cumulative of 2 minutes of rest or inactivity that fell below the MVPA threshold. The bout definitions are intended to capture periods of planned activity and are the default in the ActiLife software. They are based on current guidelines and research regarding pauses in PA bouts.[21,22] Bouts of MVPA are comparable to the periods of planned PA described by the questionnaire used to capture self-reported PA. Non-bout periods of MVPA would include activity meeting the threshold for at least moderate activity but lasting fewer than 10 minutes, such as a brisk walk to catch a bus.

The MVPA outcomes assessed in the primary and secondary exploratory analyses were average weekly time spent in MVPA, including non-bout periods of MVPA; average weekly time spent in bouts of MVPA; and weekly number of MVPA bouts.

2.3 Barriers to physical activity

We administered the validated Barriers to Physical Activity in Type 1 Diabetes (BAPAD1) questionnaire[13] to all study participants: participants without diabetes completed a modified version of the BAPAD1 with diabetes-specific barriers removed. The questionnaire consists of 8 universal barriers to PA relevant to all study participants and 4 diabetes-specific barriers (**Table 1**). Participants were asked how likely each potential barrier is to prevent them from

participating in PA using a Likert scale of 1 (extremely unlikely) to 7 (extremely likely). We defined individuals as having barriers if they assigned any potential barrier a score of 4 or greater. Scores less than 4 were not considered barriers as these were unlikely to prevent study participants from engaging in PA.

2.4 Hypoglycemia frequency

All study participants with type 1 diabetes completed the Clarke hypoglycemia awareness questionnaire[23] to assess their history of hypoglycemia. Participants self-reported past hypoglycemic episodes and the frequency of moderate hypoglycemic episodes in the prior six months. Moderate hypoglycemic episodes are those where the participant felt confused, disoriented, or lethargic and was unable to treat their hypoglycemia. We designated study participants as experiencing infrequent moderate hypoglycemia if they reported fewer than 2 occurrences in the previous 6 months, and frequent moderate hypoglycemia if they reported 2 or more occurrences in the previous 6 months.

2.5 Statistical analysis

All data analyses were conducted using SAS 9.4 (SAS Institute Inc., Cary, NC). Study participants' demographics, clinical and PA information were compared by diabetes status. Mean values and standard deviations of continuous characteristics were obtained and compared by diabetes status using two-sided t-tests. Proportions of categorical variables were obtained and compared by diabetes status using chi-squared tests for independence.

The three PA outcomes (average time in MVPA per week, average time in MVPA bouts per week, number of MVPA bouts per week) were compared between individuals with and without diabetes. We used multiple linear regression to model the mean outcomes for each exposure of interest. Because PA levels have been shown to differ between men and women, particularly among those with type 2 diabetes,[24,25] we tested the interaction between sex and

the exposure of interest in all models. The final regression models were adjusted for age, sex, and accelerometer wear-time. If the interaction p-value between sex and the exposure variable was <0.10, this term was included in the model for the purpose of hypothesis generating regarding sex differences. For all other analyses, a relationship was considered significant at a p-value of 0.05.

3. Results

3.1 Physical activity

Characteristics of study population by diabetes status were compared (**Table 2)**. Participants with type 1 diabetes were younger on average and had a more favorable lipid profile than participants without diabetes, as previously described.[26] There was no difference between the two groups in sex, BMI, or systolic blood pressure. Self-reported PA did not differ between groups: the number of participants reporting universal barriers to PA, the total scores on these universal barriers, and the time spent in planned MVPA per week did not differ by diabetes status. Based on accelerometer-measured objective PA data, individuals with type 1 diabetes spent significantly less time in MVPA bouts per week.

We compared differences in least-square means for the three MVPA outcomes in both participants with and without diabetes (**Table 3**). After adjustment for age, sex, and accelerometer wear-time, individuals with type 1 diabetes spent less time engaging in MVPA per week, less time in MVPA bouts per week, and had fewer MVPA bouts total per week than individuals without diabetes.

3.2 Barriers to physical activity

The frequency with which participants assigned a score of 4 or greater to each diabetes-specific barrier is presented in **Figure 1**. The two most common diabetes-specific barriers identified were the risk of hypoglycemia, with 11 out of 44 participants (25%) with diabetes

identifying it as a barrier (i.e., reporting a Likert score of ≥4), and the fear of loss of control over diabetes, with 9 out of 44 participants (21%) identifying it as a barrier.

Characteristics of study participants with type 1 diabetes stratified by whether or not they identified at least one diabetes-specific barrier to PA were compared (**Table A.1** in the appendix). Participants reporting barriers were younger than those not reporting barriers. Participants had similar clinical characteristics and self-reported weekly time spent in planned MVPA, regardless of whether they reported diabetes-specific barriers. However, participants who reported barriers spent significantly less time engaging in objectively measured MVPA per week and engaged in fewer bouts of MVPA per week with less time spent in each bout than those who did not report barriers.

To examine whether reporting diabetes-specific barriers was associated with the low levels of PA in participants with type 1 diabetes, we present results for the linear regression analysis of PA outcomes in **Table 4**. Participants reporting barriers spent significantly less time in MVPA bouts per week and engaged in significantly fewer bouts of MVPA per week than participants who did not report barriers after adjusting for age, sex, and accelerometer wear-time. There was not a statistically significant difference between groups in average time spent in MVPA per week. Diabetes-specific barriers to PA were associated with less MVPA across all outcomes, while reporting major universal or no barriers to PA was associated with higher levels of MVPA.

3.3 Hypoglycemia frequency

Given that the risk of hypoglycemia was the most common barrier to PA in participants with type 1 diabetes, we further investigated whether there was a difference in PA by how often participants reported having experienced hypoglycemia on the Clarke hypoglycemia

questionnaire. Specifically, we aimed to explore whether awareness of frequent hypoglycemic episodes in the prior 6 months was associated with the lower PA levels in participants with type 1 diabetes. There were significant interactions between sex and multiple measures of PA when examining hypoglycemia frequency, and so all results are presented further stratified by sex.

Characteristics of study participants who reported frequent versus infrequent moderate hypoglycemic episodes by sex are shown in **Table A.2**. Within the sample of adults with type 1 diabetes, 21 participants (14 women) reported frequent hypoglycemic episodes in the previous 6 months, and 23 (11 women) reported infrequent hypoglycemic episodes in the previous 6 months. There were no significant differences by sex in age or diabetes duration within the hypoglycemia frequency groups. There were no significant differences in HbA1c, lipid levels, and blood pressure measures. In addition, there were no significant differences in either self-reported PA, but there was a significant difference in objectively measured total MVPA per week between men and women who reported infrequent hypoglycemia.

Finally, regression models for each PA outcome by frequent versus infrequent hypoglycemia were examined (**Table A.3**). There was a significant interaction between sex and average time spent in MVPA bouts per week ($p=0.03$) as well as between sex and number of MVPA bouts per week ($p=0.08$); therefore, results for these outcomes are reported separately for women and men. There was no significant difference between individuals who experienced frequent hypoglycemia compared to those who experienced infrequent hypoglycemia in the overall time spent in MVPA per week. Among women, there was no significant difference by hypoglycemia frequency in the average time in MVPA bouts per week and the number of MVPA bouts per week. However, men reporting frequent hypoglycemia spent less time in MVPA bouts per week and had significantly fewer MVPA bouts per week compared to men

who reported infrequent hypoglycemia.

4. Discussion

Despite similar self-reported PA levels, participants with type 1 diabetes engaged in less MVPA activity as measured objectively by an accelerometer than participants without diabetes, suggesting that participants with diabetes may overestimate their PA levels. Earlier assessments of the CACTI study cohort also showed no significant differences in self-reported PA by diabetes status (p=0.79),[27] but objectively measured PA data were not previously collected and could not be compared by diabetes status or to self-reported PA levels. Regardless of diabetes status, objective measurements of PA were lower than self-reported measurement of PA, a discrepancy consistent with other studies that have compared self-reported and objective PA,[15,16] and the difference between objectively measured and self-reported PA was greater in individuals with type 1 diabetes than in those without diabetes. This difference by diabetes status may be driven by unawareness of reduced exercise capacity, or due to inaccurate perceptions of greater exercise intensity that have been found in individuals with type 2 diabetes.[28] Our results emphasize that adults with type 1 diabetes engage in low levels of actual PA compared to recommended guidelines and to a similar group of non-diabetic individuals, despite reporting similar universal barriers to PA. Diabetes-specific barriers, primarily the perceived risk of hypoglycemia, appear to show strong associations with lower levels of PA in individuals with type 1 diabetes despite higher perceived levels of PA.

Previous research and current medical guidelines have detailed the importance of PA, especially MVPA, in reducing the risk of CVD. The Centers for Disease Control and Prevention, the American Heart Association, and the American Diabetes Association all prescribe a standard of 150 minutes per week of moderate intensity PA in adults to improve

cardiovascular health.[9,10,29] Meeting these guidelines for PA is of even greater importance in individuals with type 1 diabetes, who are at increased risk of developing CVD when compared to individuals without diabetes. Type 1 diabetes and CVD prevalence both continue to increase, and individuals with type 1 diabetes are often diagnosed in childhood or adolescence, amplifying their risk of developing CVD.[1] Increased PA is one way of lowering the risk of CVD events in individuals with type 1 diabetes, and, conversely, physical inactivity has been shown to predict cardiovascular events even after adjusting for other markers of CVD risk (RR 1.26, 95% CI: 1.08, 1.46).[30]

Previous studies have explored PA levels and the risk of CVD among individuals with type 1 diabetes. One study found that participation in consistent low-intensity aerobic activity resulted in improved endothelial function and capillary density,[31] stressing the clinical importance of PA in individuals with type 1 diabetes. The majority (63%) of 18,028 participants with type 1 diabetes in the Diabetes-Patienten-Verlaufsdokumentation (DPV) registry were inactive and only 17.8% of the participants engaged in PA more than twice a week, highlighting the need to increase levels of PA in this population.[12] In comparison, CACTI participants with diabetes engaged in bouts of PA 3 times a week on average, but still significantly less than participants without diabetes. A study of participants in the Type One Diabetes Exchange Registry found that a higher BMI and longer duration of type 1 diabetes were both associated with increased odds of no PA.[32] This study suggested that individuals concerned about blood glucose levels may engage in less PA as frequent checking of blood glucose levels was associated with lower odds of PA, suggesting that individuals who are concerned about blood glucose levels may engage in less PA. Awareness of previous hypoglycemic episodes has the potential to influence the decision to engage in PA, and our results did show an association between frequent hypoglycemic episodes and planned bouts of MVPA that differed by sex, where the relationship was only significant among men.

Participants who experienced frequent hypoglycemia in the CACTI sample also tended to spend less overall time in MVPA per week; however, differences were not statistically significant, perhaps due to the small sample size (n=44).

Finally, studies exploring barriers to PA in children and adults with type 1 diabetes have identified the risk of hypoglycemia[13,33,34] and the risk of hyperglycemia[34,35] as targets that must be addressed when creating effective exercise guidelines for this population. PA may result in hyperglycemia during exercise or in delayed hypoglycemia, and previous episodes of hypoglycemia are associated with future episodes of hypoglycemia.[36] A 2017 review summarized the benefits of PA in type 1 diabetes management and the importance of considering glycemic imbalance when publishing exercise guidelines. While the risk of delayed onset hypoglycemia can be mitigated by reduced insulin doses or increased carbohydrate consumption before aerobic PA, all PA requires constant monitoring of blood glucose levels to ensure hypoglycemia does not occur.[37] In our sample, the most common barrier to PA likely preventing an individual from exercising was the risk of hypoglycemia. Diabetes-specific barriers to PA were associated with spending less time in and engaging in fewer MVPA bouts per week among individuals with diabetes, indicating that addressing potential barriers, particularly the perceived risk of hypoglycemia, might improve PA rates in populations with type 1 diabetes.

The current study has inherent strengths and limitations. One major limitation of these analyses is the small sample size of CACTI participants who had accelerometer data; however, the results of these analyses inform the development of studies with increased power in the future. Additionally, it is possible that PA was not accurately captured by the accelerometer. We addressed this limitation by using a validated algorithm for identifying periods of wear and non-wear with the understanding that activity done during periods of

non-wear (e.g., water activities) were not captured and were only recorded via self-report. To ensure that these periods of non-wear were not driving the results we saw, we recalculated self-reported PA without water activities and found that these activities did not account for the discrepancy between objective and self-reported PA. Although we supplemented the objective PA data with self-reported data from a number of validated questionnaires, interpretation of the self-reported data alongside the objective data should be done with caution due to the various time periods being considered by each measurement tool. For example, the hypoglycemia awareness questionnaire refers to hypoglycemic episodes that occurred in the previous six months which may not be directly comparable to the two weeks that the accelerometer was worn. Furthermore, we did not measure fear of hypoglycemia, which differs from measurement of perceived risk of hypoglycemia as a barrier to PA that we did measure using the BAPAD1. Finally, these analyses were cross-sectional in nature and a potential observer effect may have caused study participants who agreed to wear the accelerometer to engage in more PA than usual. These results cannot be extrapolated to PA at previous visits. Nevertheless, the longitudinal CACTI study has collected self-report PA data on individuals with and without type 1 diabetes for more than 15 years which can be examined over time for temporal trends, although likely not an accurate representation of actual PA.

5. Conclusions

Addressing the perceived risk of hypoglycemia associated with PA and the other diabetes-specific barriers – having diabetes, loss of control over diabetes, and the risk of hyperglycemia – is imperative for improving cardiovascular health in this population, as actual PA levels are lower than they may be perceived. PA recommendations should be developed for balancing glycemic control with PA and to align with current guidelines.[34,35] To meet current guidelines, individuals with type 1 diabetes may require additional support

and guidance to objectively measure their PA levels, engage in PA safely, and increase overall PA.

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Author contributions: A.K conducted final analyses and wrote the manuscript. A.R.P and J.K.S conceived the study. T.L.B and J.K.S conducted preliminary analyses. A.K, T.L.B, L.M.D, and R.M.S engaged in participant recruitment, data collection, and ensuring data quality. R.P.W contributed to preliminary data interpretation, discussion, and review of the manuscript. J.K.S directed the study, oversaw data collection and analysis, and contributed to writing and reviewing the manuscript.

Declarations of interest: None.

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8. Tables and Figures

Table 1. Universal and diabetes-specific barriers measured by the BAPAD1.

Universal barriers	Diabetes-specific barriers
Fear of being tired	Loss of control over diabetes
Fear of hurting self	Risk of hypoglycemia
Fear of suffering a heart attack	Fact that you have diabetes
Low fitness level	Risk of hyperglycemia
Actual physical health status (excluding diabetes)	
Weather conditions	
Location of a gym	
Work schedule	

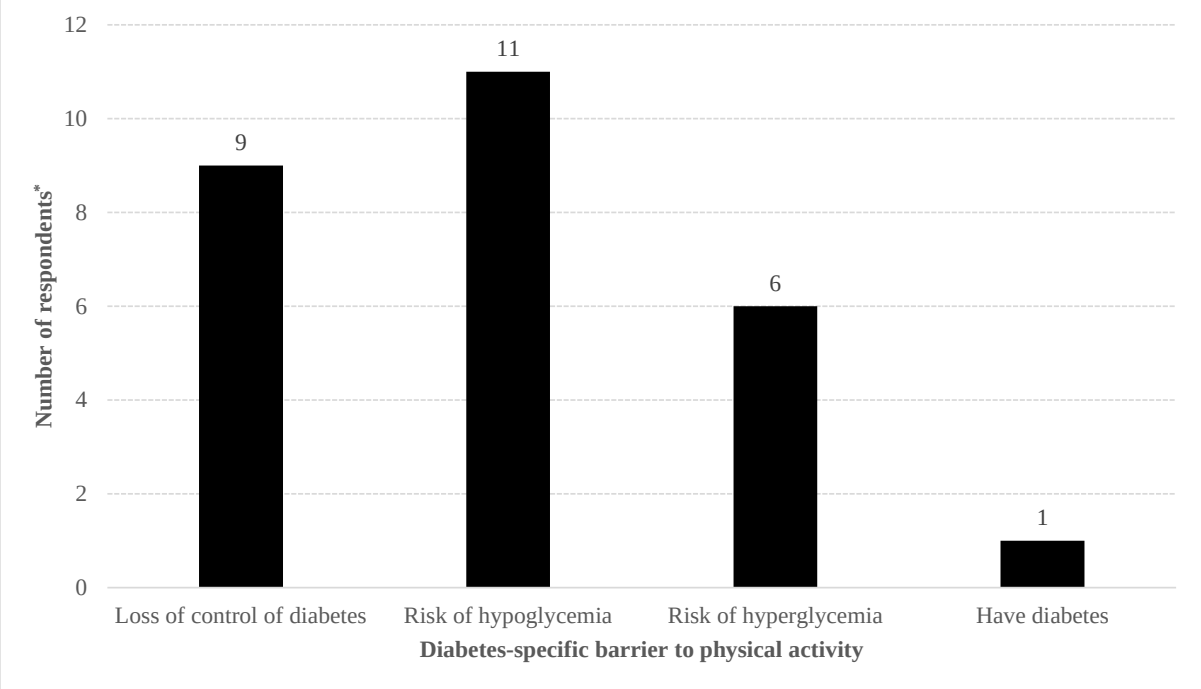
Table 2. Study population characteristics by diabetes status.

Participant characteristic	Type 1 diabetes (n=44)	Non-diabetic (n=77)	p-value
Demographics			
Age (mean years ± SD)	49 ± 9	56 ± 8	<0.0001
Female sex (n [%])	25 [56.8]	40 [52.0]	0.61
Duration of diabetes (mean years ± SD)	36 ± 8	--	--
Use of insulin pump (vs. insulin injection, n [%])	17 [38.6]	--	--
CGM use (n, [%])	33 [75.0]		
Clinical information			
HbA1c (mean % ± SD [mean mmol/mol ± SD])	7.7 ± 1.4 [61 ± 15.2]	5.6 ± 0.6 [38 ± 6.2]	<0.0001
Total cholesterol (mean mg/dL ± SD)	159 ± 37	176 ± 33	0.01
HDL-cholesterol (mean mg/dL ± SD)	58 ± 14	52 ± 14	0.02
LDL-cholesterol (mean mg/dL ± SD)	89 ± 31	106 ± 27	0.002
Triglycerides (mean mg/dL ± SD)	62 ± 20	92 ± 53	<0.0001
BMI (mean kg/m^2 ± SD)	26.9 ± 4.8	27.1 ± 5.1	0.80
Systolic blood pressure (mean mmHg ± SD)	118 ± 10	120 ± 16	0.29
Diastolic blood pressure (mean mmHg ± SD)	72 ± 8	76 ± 10	0.04
Self-reported PA information			
Time in planned MVPA per week (mean min ± SD)	274 ± 188	261 ± 360	0.83
Universal barriers to PA with score ≥ 4 (n [%])	24 [54.6]	41 [53.3]	0.89
Score on universal barriers to PA (mean score ± SD)	16 ± 7	15 ± 7	0.46
Diabetes-specific barriers to PA with score ≥ 4 (n [%])	15 [34.1]	--	--
Score on diabetes-specific barriers to PA (mean score ± SD)	7 ± 4	--	--
Measured PA information			
Total time in MVPA per week (mean min ± SD)	209 ± 180	335 ± 224	0.002
Number of MVPA bouts per week (mean number ± SD)	3 ± 4	5 ± 6	0.01
Time in MVPA bouts per week (mean min ± SD)	37 ± 64	70 ± 100	0.03

Table 3. Least square means and 95% CIs for linear regression models of PA outcomes by diabetes status, adjusted for age, sex, and accelerometer wear-time.

Outcome of interest	Type 1 diabetes (n=44)	Non-diabetic (n=77)	p-value
Average time in MVPA per week (min.)	201.0 (136.1, 265.8)	344.3 (296.4, 392.2)	0.0009
Average time in MVPA bouts per week (min.)	33.6 (6.4, 60.8)	73.5 (53.4, 93.7)	0.03
Number of MVPA bouts per week (min.)	2.4 (0.9, 3.9)	5.1 (4.0, 6.3)	0.008

Figure 1. Number of participants with type 1 diabetes who reported diabetes-specific barriers to PA.



*Total number of participants with diabetes = 44

Table 4. Least square means and 95% CIs of linear regression models of PA outcomes for type 1 diabetic participants by reporting of diabetes-specific barriers, adjusted for age, sex, and accelerometer wear-time.

Outcome of interest	One or more barriers with score ≥ 4 (n=15)	No barriers with score ≥ 4 (n=29)	p-value
Average time in MVPA per week (min.)	142.2 (48.6, 235.7)	257.8 (192.5, 323.1)	0.06
Average time in MVPA bouts per week (min.)	12.5 (-19.9, 44.9)	54.4 (31.8, 77.0)	0.047
Number of MVPA bouts per week (min.)	0.6 (-1.2, 2.4)	4.0 (2.7, 5.2)	0.005

APPENDIX A. Additional tables for exploratory analyses

Table A.1. Characteristics of study participants with type 1 diabetes by report of diabetes-specific barriers to PA.

	Barriers with score ≥ 4 (n=15)	No barriers with score ≥ 4 (n=29)	p-value
Demographics			
Age (mean years ± SD)	43 ± 4	52 ± 10	0.0001
Female sex (n [%])	8 [53.3]	17 [58.6]	0.74
Duration of diabetes (mean years ± SD)	33 ± 6	37 ± 9	0.13
Use of insulin pump (vs. insulin injection, n [%])	4 [26.7]	13 [44.8]	0.24
CGM use (n [%])	14 [93.3]	19 [65.5]	0.04
Clinical information			
HbA1c (mean % ± SD [mean mmol/mol ± SD])	7.3 ± 0.8 [57 ± 9.2]	8.0 ± 1.5 [63 ± 16.7]	0.09
Total cholesterol (mean mg/dL ± SD)	157 ± 49	161 ± 29	0.78
HDL-cholesterol (mean mg/dL ± SD)	52 ± 14	62 ± 13	0.03
LDL-cholesterol (mean mg/dL ± SD)	92 ± 42	87 ± 24	0.63
Triglycerides (mean mg/dL ± SD)	62 ± 24	62 ± 18	0.99
BMI (mean kg/m^2 ± SD)	27.9 ± 4.4	26.4 ± 5.0	0.34
Systolic blood pressure (mean mmHg ± SD)	120 ± 12	116 ± 10	0.28
Diastolic blood pressure (mean mmHg ± SD)	76 ± 8	70 ± 6	0.02
Self-reported PA information			
Time in planned MVPA per week (mean min ± SD)	364 ± 393	229 ± 198	0.24
Universal barriers to PA with score ≥ 4 (n [%])	11 [73.3]	13 [44.8]	0.07
Score on universal barriers to PA (mean score ± SD)	20 ± 8	14 ± 6	0.27
Score on diabetes-specific barriers to PA (mean score ± SD)	12 ± 5	5 ± 2	0.001
Measured PA information			
Total time in MVPA per week (mean min ± SD)	137 ±73	245 ± 208	0.02
Number of MVPA bouts per week (mean number ± SD)	1 ±1	3 ± 4	0.01
Time in MVPA bouts per week (mean min ± SD)	18 ±27	47 ± 75	0.07

Table A.2. Characteristics of participants with type 1 diabetes by frequency of moderate hypoglycemic episodes.

	Frequent hypoglycemia		Infrequent hypoglycemia	
	Men (n=9)	**Women (n=14)**	**Men (n=10)**	**Women (n=11)**
Demographics				
Age (mean years ± SD)	46 ± 9	53 ± 8	51 ± 10	45 ± 7
Duration of diabetes (mean years ± SD)	35 ± 6	37 ± 10	38 ± 10	33 ± 4
Use of insulin pump (vs. insulin injection, n [%])	2 [22.2]	7 [50.0]	4 [40.0]	4 [36.4]
CGM use (n, [%])	7 [77.8]	9 [64.3]	8 [80.0]	9 [81.8]
Clinical information				
HbA1c (mean % ± SD [mean mmol/mol ± SD])	7.9 ± 2.1 [63 ± 23]	7.9 ± 1.2 [63 ± 13.1]	7.4 ± 0.7 [57 ± 7.7]	7.7 ± 1.3 [61 ± 14.2]
Total cholesterol (mean mg/dL ± SD)[†]	172 ± 36	169 ± 35	153 ± 47	142 ± 22
HDL-cholesterol (mean mg/dL ± SD)	59 ± 18	63 ± 13	49 ± 10	60 ± 14
LDL-cholesterol (mean mg/dL ± SD)	101 ± 26	94 ± 33	89 ± 42	71 ± 12
Triglycerides (mean mg/dL ± SD)	62 ± 26	59 ± 11	73 ± 23	57 ± 19
BMI (mean kg/m^2 ± SD)	25.5 ± 3.0	28.5 ± 5.5	27.2 ± 3.3	25.8 ± 6.0
Systolic blood pressure (mean mmHg ± SD)	114 ± 16	120 ± 10	122 ± 8	116 ± 8
Diastolic blood pressure (mean mmHg ± SD)	76 ± 12	68 ± 4	74 ± 4	72 ± 6
Self-reported PA information				
Time in planned MVPA per week (mean min ± SD)	447 ± 462	268 ± 197	134 ± 111	267 ± 255
Universal barriers to PA with score ≥ 4 (n [%])	6 [66.7]	7 [50.0]	4 [40.0]	7 [63.6]
Score on universal barriers to PA (mean score ± SD)	17 ± 5	15 ± 6	13 ± 5	19 ± 10
Diabetes-specific barriers to PA with score ≥ 4 (n [%])	4 [44.4]	2 [14.3]	3 [30.0]	6 [54.6]
Score on diabetes-specific barriers to PA (mean score ± SD)	8 ± 4	6 ± 2	6 ± 3	10 ± 7
Measured PA information				
Total time in MVPA per week (mean min ± SD)[*]	259 ± 289	138 ± 112	312 ± 168	163 ± 95
Number of MVPA bouts per week (mean number ± SD)	1.9 ± 1.7	1.7 ± 2.1	5.5 ± 6.4	1.8 ± 2.0
Time in MVPA bouts per week (mean min ± SD)	12 ± 9	23 ± 29	94 ± 113	25 ± 29

[*]Participant characteristics that differ significantly by sex ($p<0.05$)

[†]Participant characteristics that differ significantly by hypoglycemia frequency ($p<0.05$)

Table A.3. Least square means and 95% CIs of linear regression models of PA outcomes by frequency of hypoglycemia among participants with type 1 diabetes, adjusted for age, sex, and accelerometer wear-time.

Outcome of interest	Frequent hypoglycemia (n=21)	Infrequent hypoglycemia (n=23)	p-value
Average time in MVPA per week (min.)	196.1 (123.7, 268.5)	241.6 (166.7, 316.5)	0.38
Average time in MVPA bouts per week (min.)			0.03
Women	26.1 (-6.8, 58.9)	21.5 (-15.5, 58.5)	0.86
Men	9.3 (-30.7, 49.3)	95.2 (57.5, 132.9)	0.003
Number of MVPA bouts per week (min.)			0.08
Women	1.9 (-0.1, 3.8)	1.6 (-0.7, 3.8)	0.83
Men	1.8 (-0.6, 4.2)	5.6 (3.4, 7.9)	0.02