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No effect of physical activity in the management of diabetes. The CoLaus|PsyCoLaus study

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NO EFFECT OF PHYSICAL ACTIVITY IN THE MANAGEMENT OF DIABETES. THE COLAUS|PSYCOLAUS STUDY

Running title: physical activity and diabetes in Switzerland

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Abstract

Introduction: physical activity (PA) is recommended in all type 2 diabetes mellitus (T2DM) patients to improve their glycaemic control. Whereas PA levels are associated with T2DM control has seldom been assessed.

Research design and methods: three cross-sectional analyses of a prospective cohort conducted in Lausanne, Switzerland. PA levels (sedentary, light, moderate and vigorous) were either self-reported via questionnaire (first and second survey) or objectively assessed using accelerometry (second and third survey). T2DM control was defined by a FPG <7.0 mmol/L or a glycated haemoglobin <6.5% (48 mmol/mol).

Results: data from 195 (30.3% women), 199 (30.1% women) and 151 (44.4% women) participants with T2DM were analysed in the first (2009-2012), second (2014-2017) and third (2018-2021) surveys. Approximately half of the participants were not controlled by FPG. Using subjective data, over 90% (first survey) and 75% (second survey) of participants reported moderate and vigorous PA >150 min/week. After multivariable adjustment, no differences were found regarding all types of self-reported PA levels between controlled and uncontrolled participants. Objective assessment of PA led to considerable differences according to the software used: 90% and 20% of participants with moderate and vigorous PA >150 min/week, respectively. After multivariable adjustment, no differences were found for all PA levels between controlled and uncontrolled participants, irrespective of the analytical procedure used. Using glycated haemoglobin, almost two-thirds of participants were considered as uncontrolled, and no differences were found for objectively assessed PA between controlled and uncontrolled participants.

Conclusions: in this population-based study, PA levels were not associated with a better control of T2DM.

Abstract word count: 250

Keywords: physical activity; diabetes; control; epidemiology

KEY MESSAGES

What is already known on this topic

Adequate levels of physical activity help prevent type 2 diabetes and facilitate its management.

What this study adds

In people treated for diabetes, physical activity levels did not differ between people with controlled and uncontrolled diabetes.

How this study might affect research, practice or policy

Practitioners should motivate their patients with diabetes to exercise and not to rely solely on medications.

INTRODUCTION

Diabetes Mellitus affects 537 million adults in the world, 90% of whom by Type 2 Mellitus Diabetes (T2DM), and it is predicted that this number will increase until 783 million for 2045. Diabetes has also a financial cost estimated at USD 966 billion dollars, representing 9% of total adult health spending. [1]

Besides quitting smoking and adopting a healthy diet, physical activity is recommended in all T2DM patients to improve their glycaemic control, insulin action, lipid levels and blood pressure [2], thus reducing the risk of cardiovascular disease. Simple activity such as walking 30 minutes per day can promote weight loss and improve glycaemic control [3]. More structured exercise programs are more effective to reduce insulin resistance in T2DM [4]. The exercise programs can be focused on aerobic training, resistance training or combined training, leading to significant improvements in HbA1c levels [5]. Still, it has been reported that patients with T2DM seldom adhere to the recommended amounts of physical activity. Indeed, barriers can affect the adhesion to recommended physical activity such as old age, female sex, lack of motivation, feeling of obligation, depression, and fatigue [6]. For instance, in the EUROASPIRE IV and V studies, over half of patients with CVD and self-reported diabetes did not intend to do regular planned physical activity, and only one quarter (26%) did it [7].

In Switzerland, it was estimated that, in 2021, 389'600 people aged between 20 and 79 years lived with diabetes, and 1'249'700 were affected by impaired glucose tolerance, the health costs amounting to $4.9 billion [8]. Still, the level of physical activity among people with T2DM and its impact on T2DM control have never been assessed.

Hence, we aimed to assess the effect of subjectively and objectively measured PA levels in subjects treated for T2DM according to diabetes control, using data from a population-based study.

MATERIALS AND METHODS

Participants

The CoLaus|PsyCoLaus study is a population-based prospective study assessing the clinical, biological, and genetic determinants of cardiovascular disease aged 35 to 75 years at baseline, living in the city of Lausanne, Switzerland [9]. In each survey, participants answered questionnaires, underwent a clinical examination and blood samples were drawn for analyses. Recruitment began in June 2003 and ended in May 2006. The first follow-up was performed between April 2009 and September 2012; the second follow-up was performed between May 2014 and April 2017, and the third follow-up was performed between April 2018 and May 2021. For more details, see www.colaus-psycolaus.ch.

Self-reported physical activity

Subjective physical activity was assessed using the Physical Activity Frequency Questionnaire (PAFQ). This self-reported questionnaire has been validated in the population of Geneva, Switzerland, and assesses the type and duration of 70 kinds of (non)professional activities and sports during the previous week. Sedentary status was defined as spending more than 90% of the daily energy in activities below moderate- and high-intensity (defined as requiring at least 4 times the basal metabolic rate, BMR) [10]. BMR multiples are close to Metabolic Equivalent of Task (MET) multiples, although MET multiples do not consider participant sex, age or height.

For the purpose of this study, each type of activity was categorized into sedentary behaviour (SB, <2 metabolic equivalent of tasks - METs), light physical activity (LPA, 2 to <3 METs), moderate physical activity (MPA, 3-6 METs) and vigorous physical activity (VPA, >6 METs) according to the compendium of physical activities [11]. Total PA was defined as the sum of LPA, MPA and VPA. For each item of the PAFQ, the time spent per week was computed as average hours per day multiplied by the number of days performing the activity. For each item category (i.e., corresponding to SB, LPA, MPA or VPA), the times were summed up and divided by 7 to estimate an average daily time.

Accelerometry-assessed physical activity

Physical activity was objectively assessed using a wrist-worn triaxial accelerometer (GENEActiv, Activinsights Ltd, United Kingdom, www.activinsights.com). These devices are the

same that have been used in the UK biobank study [12], weight 16 g, and allow continuous monitoring of physical activity for a maximum of 45 days. The devices were pre-programmed with a 50 Hz sampling frequency and subsequently attached to the participants' right wrist. Participants were requested to wear the device continuously for 14 days in their free-living conditions.

Raw accelerometry data were downloaded using the GENEActiv software version 2.9 (GENEActiv, Activinsights Ltd, United Kingdom) and transformed into 1-minute epoch files. Data were analysed using the GENEActiv Excel macro file 'General physical activity' version 1.9, which had been previously validated [13]. A valid day was defined as ≥10 h (i.e., 600 min-epoch) and ≥8 h (i.e., 480 min-epoch) of diurnal wear-time on weekdays and weekend days, respectively. The Excel macro file can be provided upon request.

A second analysis was performed on the raw accelerometry data using the R-package GGIR version 1.5–9 (http://cran.r-project.org) [14] with the thresholds defined by [15], i.e. an acceleration between 85 and 180 milli-g to define light PA, between 181 and 437 milli-g to define moderate PA, and >437 milli-g to define vigorous PA. The code used to analyse the data is provided in **Annex 1**.

Participants were considered as complying with the recommendations if the weekly amount of MPA and VPA exceeded 150 minutes.

Diabetes assessment

Participants were considered as presenting with diabetes if they reported taking any antidiabetic drug. Diabetes control was defined as a fasting plasma glucose <7 mmol/L; a second analysis was conducted using diabetes control defined as a glycated haemoglobin <6.5% (48 mmol/mol).

Blood was drawn in the fasting state and biological assays were performed by the CHUV Clinical Laboratory on fresh blood samples within 2 hours of blood collection. The following analytical procedures (with maximum inter and intra-batch CVs) were used: glucose by glucose hexokinase (1.6%-0.8%). In the second and third follow-ups, glycated haemoglobin levels were also measured by high performance liquid chromatography (HPCL) using Bio-Rad, D-10TM system, with measurement range 3.8% (18 mmol/mol) to 18.5% (179 mmol/mol).

Eligibility and exclusion criteria

All participants reporting being treated for diabetes were eligible for the study. Participants were excluded if they lacked physical activity data.

Covariates

Participants were queried regarding their personal and family history of cardiovascular risk factors, medical treatment, and socio-economic status. Educational level was categorized into low (mandatory or apprenticeship), medium (high school) and high (university). Smoking status was categorized into never, former, and current.

Body weight and height were measured with participants barefoot and in light indoor clothes. Body weight was measured in kilograms to the nearest 100 g using a Seca® scale (Hamburg, Germany). Height was measured to the nearest 5 mm using a Seca® (Hamburg, Germany) height gauge. Body mass index (BMI) was computed and categorized into normal (<25 kg/m^2), overweight (≥25 and <30 kg/m^2) and obese (≥30 kg/m^2).

Statistical analysis

Statistical analyses were performed separately for each study period using Stata version 16.0 for windows (Stata Corp, College Station, Texas, USA). Descriptive results were expressed as number of participants (percentage) for categorical variables and as average standard deviation or median and [interquartile range] for continuous variables. Bivariate analyses were performed using chi-square or Fisher's exact test for categorical variables and Student's t-test, analysis of variance (ANOVA) or Kruskal-Wallis nonparametric test for continuous variables. Multivariable analysis of continuous data was performed using ANOVA and results were expressed as adjusted mean±standard error of the mean (sem). Multivariable analysis of categorical data was performed using logistic regression and results were expressed as odds ratio (95% confidence interval). Multivariable analyses were conducted adjusting for sex (male, female), age (continuous), BMI categories (normal, overweight, obese), smoking status (never, former, current), educational level (low, medium, high). Statistical significance was assessed for a two-sided test with $p<0.05$.

Ethical statement

The institutional Ethics Committee of the University of Lausanne, which afterwards became the Ethics Commission of Canton Vaud (www.cer-vd.ch) approved the baseline

CoLaus study (reference 16/03). The approval was renewed for the first (reference 33/09), the second (reference 26/14) and the third (reference PB_2018-00040) follow-ups. The approval for the entire CoLaus|PsyCoLaus study was confirmed in 2021 (reference PB_2018-00038, 239/09). The full decisions of the CER-VD can be obtained from the authors upon request. The study was performed in agreement with the Helsinki declaration and its former amendments, and in accordance with the applicable Swiss legislation (LRH 810.30). All participants gave their signed informed consent before entering the study.

RESULTS

Characteristics of participants

The selection procedure of the participants for the first, second and third follow-ups is summarized in **figure 1** and the characteristics of the participants according to adequate or inadequate control of diabetes stratified by survey are provided in **table 1**. Overall, one half of the participants treated for diabetes did not achieve adequate control. There were no consistent differences between controlled and uncontrolled participants, except that in the second follow-up, controlled participants were older and more frequently smokers.

Table 1: characteristics of participants according to diabetes control as per fasting plasma glucose, stratified by survey, CoLaus|PsyColaus study, Lausanne, Switzerland.

	First survey (2009-2012)			Second survey (2014-2017)			Third survey (2018-2021)		
	Not controlled	Controlled	p-value	Not controlled	Controlled	p-value	Not controlled	Controlled	p-value
Sample size	121	74		97	102		72		
Women (%)	37 (30.6)	22 (29.7)	1.000	28 (28.9)	32 (31.4)	0.758	29 (40.5)	35 (48.6)	0.330
Age (years)	65.1 ± 8.8	65.9 ± 8.4	0.519	66.6 ± 8.7	69.5 ± 8.8	0.020	68.8 ± 8.7	68.1 ± 8.7	0.652
Swiss born (%)	85 (70.3)	43 (58.1)	0.090	59 (60.8)	67 (65.7)	0.556	50 (69.6)	42 (58.3)	0.175
Education (%)			0.212			0.589			1.000
High	11 (9.1)	13 (17.6)		12 (12.4)	12 (11.9)		8 (11.4)	8 (11.1)	
Middle	29 (24.0)	18 (24.3)		24 (24.7)	19 (18.8)		16 (22.8)	17 (23.6)	
Low	81 (66.9)	43 (58.1)		61 (62.9)	70 (69.3)		46 (65.8)	47 (65.3)	
BMI (kg/m^2)	30.5 ± 5.6	29.4 ± 4.1	0.161	30.5 ± 4.9	30.6 ± 5.1	0.924	29.8 ± 4.6	29.0 ± 5.6	0.378
BMI categories (%)			0.711			1.000			0.319
Normal	17 (14.1)	10 (13.5)		11 (11.5)	12 (11.8)		11 (13.9)	15 (20.8)	
Overweight	50 (41.3)	35 (47.3)		37 (38.5)	39 (38.2)		33 (41.8)	33 (45.8)	
Obese	54 (44.6)	29 (39.2)		48 (50.0)	51 (50.0)		35 (44.3)	24 (33.3)	
Smoking categories (%)			0.770			0.022			0.950
Never	37 (30.6)	25 (33.8)		26 (26.8)	39 (38.2)		29 (36.7)	28 (38.9)	
Former	65 (53.7)	40 (54.1)		57 (58.8)	40 (39.2)		38 (48.1)	34 (47.2)	
Current	19 (15.7)	9 (12.2)		14 (14.4)	23 (22.6)		12 (15.2)	10 (13.9)	
Hypertension (%)	99 (81.8)	55 (74.3)	0.277	76 (78.4)	80 (78.4)	1.000	67 (84.8)	57 (79.2)	0.401
Hypolipidemic ttt (%)	67 (55.4)	51 (68.9)	0.071						
History of CVD (%)	18 (14.9)	12 (16.2)	0.839	18 (18.6)	20 (19.6)	0.859	16 (20.3)	13 (18.1)	0.837

BMI, body mass index; CVD, cardiovascular disease. Results expressed as mean ± standard deviation for continuous variables or as number of participants (percentage) for categorical variables. Statistical analysis by student's t-test or chi-square test.

Physical activity levels according to diabetes control as per fasting plasma glucose

The bivariate analysis of reported PA levels between controlled and uncontrolled participants for the first and the second follow-ups are presented in **supplementary table 1**. Overall, over 90% and 75% of participants were compliant with the 150 min/week of MPA+VPA. Participants spent half of their time in SB and very little in VPA. No differences in PA (in absolute time or as percentage of day) were found between controlled and uncontrolled participants, and similar findings were obtained after multivariable adjustment (**table 2**).

Table 2: multivariable analysis, self-reported physical activity by control group, stratified by survey, CoLaus|PsyCoLaus study, Lausanne, Switzerland.

	First survey (2009-2012)			Second survey (2014-2017)		
	Not controlled	**Controlled**	**p-value**	**Not controlled**	**Controlled**	**p-value**
Sample size	121	74		52	48	
Intensity of PA (min/day)						
Sedentary	527 ± 15	542 ± 19	0.543	525 ± 25	556 ± 26	0.395
Light	197 ± 10	166 ± 13	0.056	204 ± 16	176 ± 16	0.237
Moderate	186 ± 11	191 ± 15	0.819	181 ± 17	185 ± 18	0.864
Vigorous	32 ± 8	46 ± 10	0.250	43 ± 10	26 ± 11	0.262
At least 150 minutes MVPA per week	1 (ref)	NC		1 (ref)	0.85 (0.35 - 2.09)	0.731 §
Intensity of PA (% of daily time)						
Sedentary	56 ± 1.5	57.3 ± 2	0.608	54.8 ± 2.4	58.8 ± 2.5	0.257
Light	20.9 ± 1	17.7 ± 1.3	0.057	21.4 ± 1.6	18.8 ± 1.7	0.275
Moderate	19.7 ± 1.2	20.2 ± 1.5	0.798	19.3 ± 1.9	19.6 ± 1.9	0.291
Vigorous	3.4 ± 0.8	4.8 ± 1	0.260	4.6 ± 1	2.8 ± 1.1	0.257

PA, physical activity; MVPA, moderate and vigorous physical activity. Results are expressed as mean ± sem for continuous variables and as odds ratio and (95% confidence interval) for categorical variables. Statistical analysis by analysis of variance for continuous variables and by logistic regression for categorical variables, adjusted for sex (male, female), age (continuous), BMI categories (normal, overweight, obese), smoking status (never, former, current), educational level (low, medium, high). NC, not computable. § n=76 as several variables were dropped due to collinearity.

The results of the bivariate analysis of the objectively assessed PA levels using the GENEActiv macro between controlled and uncontrolled participants for the second and third follow-ups are presented in **supplementary table 2**. Overall, over 90% of participants were compliant with the 150 min/week of MPA+VPA. Participants spent three quarters of their time in SB; conversely, they spent almost two hours per day on MPA. In the second survey, participants not controlled had higher levels and percentages of LPA and MPA, and lower level and percentage of SB. No difference was found between controlled and uncontrolled participants in the third survey. After multivariable adjustment, no significant differences were observed (**table 3**).

Table 3: multivariable analysis, objectively assessed physical activity by control group as defined using fasting plasma glucose, stratified by survey, CoLaus|PsyCoLaus study, Lausanne, Switzerland.

	Second survey (2014-2017)			Third survey (2018-2021)		
	Not controlled	**Controlled**	**p-value**	**Not controlled**	**Controlled**	**p-value**
Sample size	97	102		79	72	
Intensity of PA (min/day)						
Sedentary	609 ± 12	634 ± 11	0.131	601 ± 14	591 ± 15	0.634
Light	97 ± 4	86 ± 4	0.028	92 ± 4	83 ± 4	0.138
Moderate	122 ± 7	106 ± 7	0.124	122 ± 9	119 ± 9	0.798
Vigorous	1 ± 1	1 ± 1	0.684	1 ± 1	1 ± 1	0.476
At least 150 minutes MVPA per week	1 (ref)	0.94 (0.23 - 3.77)	0.925	1 (ref)	1.45 (0.39 - 5.42)	0.576
Intensity of PA (% of daily time)						
Sedentary	73.8 ± 1.1	77.1 ± 1.1	0.035	74.3 ± 1.2	74.7 ± 1.3	0.812
Light	11.7 ± 0.4	10.2 ± 0.4	0.011	11.1 ± 0.4	10.3 ± 0.4	0.280
Moderate	14.4 ± 0.8	12.5 ± 0.8	0.105	14.5 ± 1.1	14.7 ± 1.1	0.897
Vigorous	0.2 ± 0.1	0.1 ± 0.1	0.679	0.1 ± 0.1	0.2 ± 0.1	0.232

PA, physical activity; MVPA, moderate and vigorous physical activity. Results are expressed as mean ± sem for continuous variables and as odds ratio and (95% confidence interval) for categorical variables. Statistical analysis by analysis of variance for continuous variables and by logistic regression for categorical variables, adjusted for sex (male, female), age (continuous), BMI categories (normal, overweight, obese), smoking status (never, former, current), educational level (low, medium, high). Physical activity data assessed using the GENEActiv macro file 'General physical activity' version 1.9.

The results of the bivariate analysis of the objectively assessed PA levels using the R-package GGIR between controlled and uncontrolled participants for the second and the third follow-ups are presented in **supplementary table 3**. Overall, less than 25% of participants were compliant with the 150 min/week of MPA+VPA. Participants spent approximately one-quarter of an hour per day on MPA, and 90% of their time in SB. In the second survey, participants not controlled had higher levels and percentages of LPA and MPA, and lower level and percentage of SB. After multivariable adjustment, no significant differences were observed (**supplementary table 4**).

Physical activity levels according to diabetes control as per glycated haemoglobin

The results of the bivariate analysis of the objectively assessed PA levels using the GENEActiv macro between controlled and uncontrolled participants for the second and the third follow-ups are presented in **supplementary table 5**. Almost two-thirds of participants were considered as uncontrolled. No differences were found between controlled and uncontrolled participants in bivariate and multivariable analyses (**table 4**).

Table 4: multivariable analysis, objectively assessed physical activity by control group as defined by glycated haemoglobin, stratified by survey, CoLaus|PsyCoLaus study, Lausanne, Switzerland.

	Second survey (2014-2017)			Third survey (2018-2021)		
	Not controlled	**Controlled**	**p-value**	**Not controlled**	**Controlled**	**p-value**
Sample size	123	76		95	56	
Intensity of PA (min/day)						
Sedentary	613 ± 10	636 ± 13	0.172	599 ± 13	592 ± 17	0.736
Light	94 ± 3	87 ± 4	0.216	89 ± 4	85 ± 5	0.543
Moderate	118 ± 6	106 ± 8	0.253	123 ± 8	118 ± 10	0.725
Vigorous	1 ± 1	1 ± 1	0.978	1 ± 1	1 ± 1	0.445
At least 150 minutes MVPA per week	1 (ref)	1.54 (0.41 - 5.79)	0.525	1 (ref)	1.11 (0.29 - 4.33)	0.879
Intensity of PA (% of daily time)						
Sedentary	74.6 ± 1.0	76.9 ± 1.2	0.143	74.4 ± 1.1	74.8 ± 1.5	0.821
Light	11.3 ± 0.3	10.4 ± 0.4	0.108	10.8 ± 0.4	10.5 ± 0.5	0.798
Moderate	14.0 ± 0.7	12.6 ± 0.9	0.225	14.7 ± 0.9	14.5 ± 1.2	0.884
Vigorous	0.1 ± 0.1	0.1 ± 0.1	0.925	0.1 ± 0.1	0.2 ± 0.1	0.394

PA, physical activity; MVPA, moderate and vigorous physical activity. Results are expressed as mean ± sem for continuous variables and as odds ratio and (95% confidence interval) for categorical variables. Statistical analysis by analysis of variance for continuous variables and by logistic regression for categorical variables, adjusted for sex (male, female), age (continuous), BMI categories (normal, overweight, obese), smoking status (never, former, current), educational level (low, medium, high). Physical activity data assessed using the GENEActiv macro file 'General physical activity' version 1.9.

The results of the bivariate and multivariable analysis of the objectively assessed PA levels using the R-package GGIR between controlled and uncontrolled participants for the second and the third follow-ups are presented in **supplementary table 6** (bivariate) and **supplementary table 7** (multivariable). Almost two-thirds of participants were considered as uncontrolled. No differences were found between controlled and uncontrolled participants in bivariate and multivariable analyses,

DISCUSSION

Our results show over half of participants treated for diabetes are not controlled. They also show that neither self-reported nor objectively assessed PA levels differ according to diabetes control.

Characteristics of participants

Overall, participants with controlled T2DM represented less than half of the participants in each of the three follow-ups. These values are lower than reported in most European countries [16 17]. The reasons of such a low control are not easily identifiable: no differences were found between controlled and uncontrolled participants for almost all covariates analysed, and a previous study showed no differences in dietary intakes [18]. Hence, the factors associated to T2DM control may be a lesser effective health care or differences in PA levels, which will be detailed in the next section. Overall, our results indicate that over half of treated diabetics does not achieve adequate control in this Swiss population-based sample.

Physical activity levels according to diabetes control

PA is a cost-saving treatment [19 20]. Patients with T2DM who regularly participate to aerobic exercises activities have a better control of their disease [21]. According to Swiss and international guidelines, it is recommended to have 150 min/week moderate to vigorous PA [2].

In our study, participants with T2DM reported over 150 minutes per day of MPA. Those findings suggest that most participants with T2DM comply with PA recommendations, although a reporting bias cannot be excluded. Conversely, the results of the objectively assessed PA differed considerably according to the analytical method applied. According to

the GENEActiv macro, almost all participants treated for T2DM were compliant with the current PA recommendations, while according to the R-package GGIR this percentage was less than 25%. Those differences between analytical methods have been reported previously [22] and raise the importance of standardization of PA accelerometry measurements [23].

After multivariable adjustment, no differences were found between controlled and uncontrolled participants regarding all PA levels, either as time or as % of day. Our findings agree with a study conducted in Poland, where no differences in both subjectively and objectively assessed PA levels were found between controlled and uncontrolled participants [24]. Conversely, our findings do not replicate those of two other studies, which showed significant improvement in glycaemic control in participants with T2DM when regular PA was part of a healthy lifestyle [25 26]. Possible explanations include the methods used to categorize participants. For instance, both studies used self-filled questionnaire to categorize participants into active and inactive, while ours used both subjective and objective PA assessment. It is likely that the relatively small sample size of our study led to a low statistical power, and we cannot exclude an indication bias, participants with uncontrolled T2DM being recommended more frequently to exercise than those who are controlled.

Female sex, older age, comorbidities such as obesity and depression, lack of motivation, and social influence have been suggested to decrease adherence to PA [27]. It would thus be useful to consider these barriers in subjects with T2DM when prescribing regular PA [6] and considering routine activities as domestic chores to increase PA [28].

Strengths and limitations

This study used both subjectively and objectively assessed PA. It used two different software to analyse PA and two different criteria (fasting plasma glucose and glycated haemoglobin) to define T2DM. The results were replicated in two time points and a population-based sample was used.

This study also has some limitations. First, the study was conducted in a single location, and results might not be extrapolated to other settings, although similar findings were obtained elsewhere [24]. Second, a possible selection bias might have occurred, more motivated participants accepting to wear the accelerometer. Hence, it is likely that the amounts of PA might be overestimated, but not the comparisons between controlled and

uncontrolled participants. Finally, the amounts of light, moderate and vigorous PA differed considerably according to the analytical procedure applied. This issue has already been discussed [22] and recommendations have been issued [22 29]. Further, the results of the comparison between controlled and uncontrolled participants were identical irrespective of the analytical procedure applied.

Conclusion

In this population-based study focusing on participants treated for T2DM, no differences were found between controlled and uncontrolled T2DM regarding self-reported or objectively assessed PA levels.

CREDIT AUTHOR STATEMENT

Gaël Vonlanthen: investigation; formal analysis, visualisation; writing - original draft. Pedro Marques-Vidal: conceptualization; data curation; formal analysis; writing - review & editing; supervision. Pedro Marques-Vidal had full access to the data and is the guarantor of the study.

CONFLICT OF INTEREST

The authors report no conflict of interest.

FUNDING

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DATA AVAILABILITY

The CoLaus|PsyCoLaus cohort data used in this study cannot be fully shared as they contain potentially sensitive patient information. As discussed with the competent authority, the Research Ethic Committee of the Canton of Vaud, transferring or directly sharing this data would be a violation of the Swiss legislation aiming to protect the personal rights of participants. Non-identifiable, individual-level data are available for interested researchers, who meet the criteria for access to confidential data sharing, from the CoLaus Datacenter (CHUV, Lausanne, Switzerland). Instructions for gaining access to the CoLaus data used in this study are available at https://www.colaus-psycolaus.ch/professionals/how-to-collaborate/.

PATIENT AND PUBLIC INVOLVEMENT

It was not possible to involve patients or the public in the design, or conduct, or reporting, or dissemination plans of our research.

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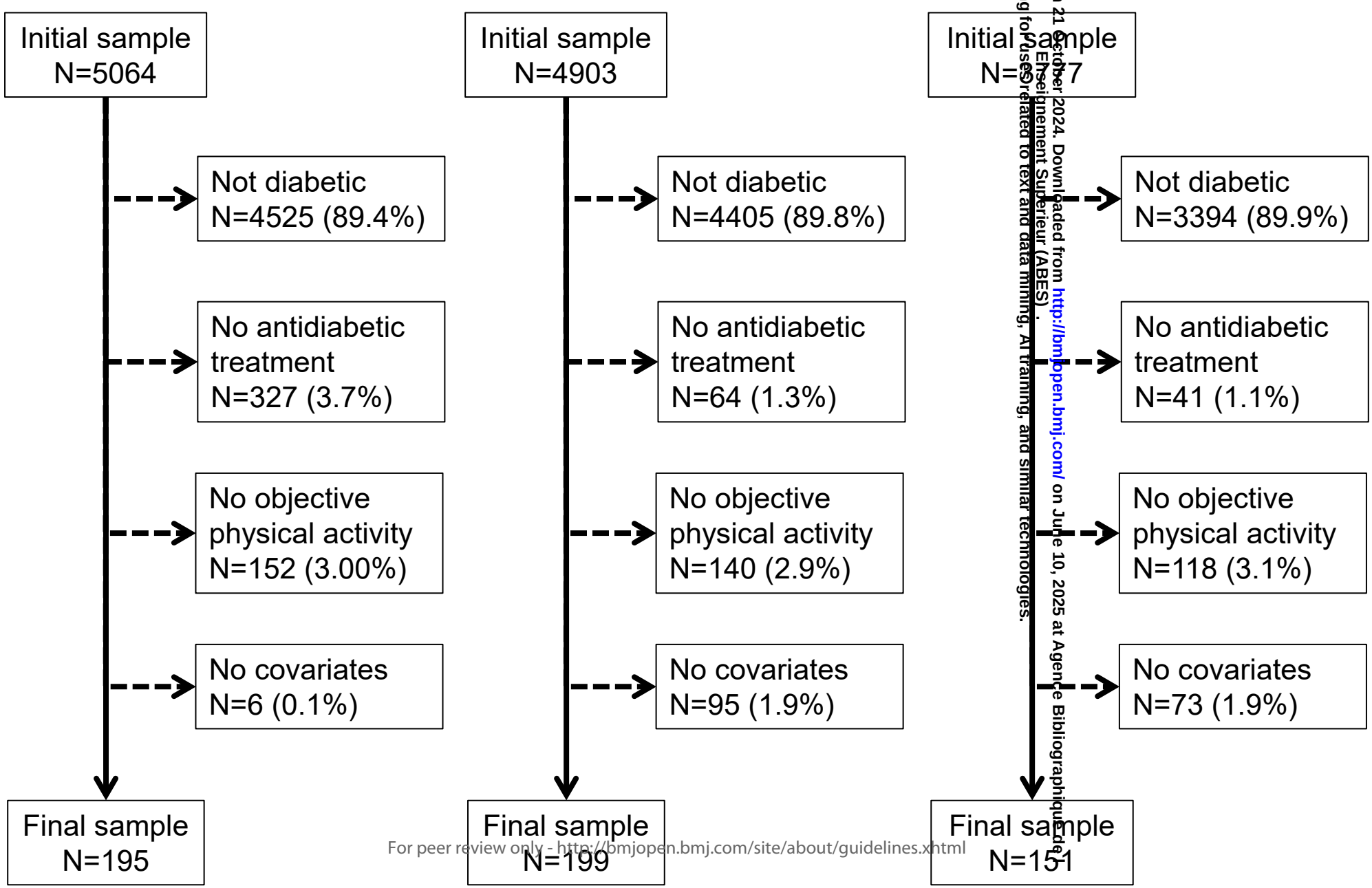
FIGURE LEGENDS

Figure 1: selection procedure for the first, second and third follow-ups, CoLaus|PsyColaus study, Lausanne, Switzerland.



Supplementary information

Supplementary table 1: bivariate analysis, self-reported physical activity by diabetes control group as defined by fasting plasma glucose, stratified by survey, CoLaus|PsyCoLaus study, Lausanne, Switzerland.

	First survey (2009-2012)			Second survey (2014-2017)		
	Not controlled	Controlled	p-value	Not controlled	Controlled	p-value
Sample size	121	74		52	48	
Intensity of PA (min/day)						
Sedentary	522 [394 - 660]	557 [449 - 651]	0.379	555 [405 - 665]	532 [469 - 648]	0.637
Light	185 [107 - 272]	156 [109 - 243]	0.128	168 [125 - 249]	157 [123 - 242]	0.567
Moderate	164 [95 - 249]	155 [107 - 265]	0.862	143 [105 - 246]	161 [104 - 221]	0.992
Vigorous	0.7 [0 - 4]	0.8 [0 - 4.5]	0.995	18 [0 - 46]	15 [0 - 55]	0.997
At least 150 minutes MVPA per week	118 (97.5)	73 (98.7)	§	51 (78.5)	45 (76.3)	0.270
Intensity of PA (% of daily time)						
Sedentary	57.2 [42.4 - 68.8]	59.4 [46.8 - 68.4]	0.418	60.1 [44.6 - 68.0]	58.0 [48.3 - 68.0]	0.551
Light	19.3 [11.2 - 29.7]	16.6 [12.0 - 24.5]	0.108	18.5 [13.8 - 26.7]	17.7 [12.8 - 26.6]	0.801
Moderate	17.2 [10.7 - 25.8]	16.2 [11.2 - 26.9]	0.823	15.0 [10.3 - 26.8]	15.7 [11.4 - 24.2]	0.866
Vigorous	6.0 [0 - 37.0]	6.0 [0 - 39.0]	0.980	1.9 [0 - 5.2]	1.4 [0 - 6.0]	0.963

PA, physical activity; MVPA, moderate and vigorous physical activity. Results expressed as median [interquartile range] for continuous variables and as number of participants (column percentage) for categorical variables. Statistical analysis by Kruskal-Wallis test for continuous variables and chi-square or Fisher's exact test (§) for categorical variables.

Supplementary table 2: bivariate analysis, objectively assessed physical activity by diabetes control group as defined by fasting plasma glucose, stratified by survey, CoLaus|PsyCoLaus study, Lausanne, Switzerland.

	Second survey (2014-2017)			Third survey (2018-2021)		
	Not controlled	Controlled	p-value	Not controlled	Controlled	p-value
Sample size	97	102		79	72	
Intensity of PA (min/day)						
Sedentary	624 [522 - 691]	640 [561 - 734]	0.061	625 [515 - 693]	588 [503 - 690]	0.341
Light	92 [69 - 124]	83 [58 - 111]	0.024	87 [65 - 115]	83 [68 - 102]	0.378
Moderate	108 [65 - 165]	91 [54 - 134]	0.057	117 [56 - 161]	111 [60 - 160]	0.780
Vigorous	0 [0 - 1]	0 [0 - 1]	0.021	0 [0 - 2]	0 [0 - 2]	0.683
At least 150 minutes MVPA per week (%)	93 (95.9)	94 (92.2)	0.271	71 (89.9)	67 (93.1)	0.486
Intensity of PA (% of daily time)						
Sedentary	74.7 [67.0 - 82.6]	79.2 [72.1 - 85.1]	0.011	75.7 [68.1 - 84.9]	74.5 [66.7 - 82.3]	0.587
Light	11.1 [9.1 - 14.1]	9.8 [7.5 - 13.0]	0.008	11 [8.0 - 13.1]	10.7 [8.4 - 12.9]	0.631
Moderate	12.5 [8.3 - 20.0]	10.3 [7.3 - 16.4]	0.039	14.1 [6.9 - 18.8]	14.0 [8.4 - 18.9]	0.479
Vigorous	0.1 [0 - 0.2]	0 [0 - 0.1]	0.021	0 [0 - 0.2]	0 [0 - 0.2]	0.582

PA, physical activity; MVPA, moderate and vigorous physical activity. Results expressed as median [interquartile range] for continuous variables and as number of participants (column percentage) for categorical variables. Statistical analysis by Kruskal-Wallis test for continuous variables and chi-square or Fisher's exact test (§) for categorical variables. Physical activity data assessed using the GENEActiv macro file 'General physical activity' version 1.9.

Supplementary table 3: bivariate analysis, objectively assessed physical activity by diabetes control group as defined by fasting plasma glucose, stratified by survey, CoLaus|PsyCoLaus study, Lausanne, Switzerland.

	Second survey (2014-2017)			Third survey (2018-2021)		
	Not controlled	**Controlled**	**p-value**	**Not controlled**	**Controlled**	**p-value**
Sample size	95	100		31	27	
Intensity of PA (min/day)						
Sedentary	750 [708 - 811]	770 [722 - 822]	0.123	768 [725 - 809]	742 [706 - 821]	0.591
Light	72 [43 - 107]	60 [35 - 89]	0.076	81 [43 - 106]	66 [40 - 105]	0.198
Moderate	11 [6 - 22]	9 [3 - 16]	0.039	13 [6 - 22]	9 [6 - 19]	0.239
Vigorous	1 [0 - 1]	0 [0 - 1]	0.041	1 [0 - 2]	0 [0 - 1]	0.080
At least 150 minutes MVPA per week	19 (20.0)	13 (13.0)	0.187	8 (25.8)	6 (22.2)	0.750
Intensity of PA (% of daily time)						
Sedentary	90.2 [85 - 94.1]	92.1 [87.8 - 95.1]	0.057	89.1 [85.5 - 94.0]	91.6 [86.6 - 95.0]	0.233
Light	8.2 [5.3 - 12.2]	6.8 [4.3 - 10.5]	0.062	9.1 [5.4 - 12.3]	7.3 [4.4 - 11.1]	0.252
Moderate	1.3 [0.7 - 2.4]	1.1 [0.4 - 1.8]	0.032	1.6 [0.7 - 2.4]	1.0 [0.7 - 2.2]	0.239
Vigorous	0.1 [0 - 0.2]	0 [0 - 0.1]	0.033	0.1 [0 - 0.2]	0 [0 - 0.1]	0.072

PA, physical activity; MVPA, moderate and vigorous physical activity. Results expressed as median [interquartile range] for continuous variables and as number of participants (column percentage) for categorical variables. Statistical analysis by Kruskal-Wallis test for continuous variables and chi-square for categorical variables. Physical activity data assessed using the R-package GGIR version 1.5–9.

Supplementary table 4: multivariable analysis, objectively assessed physical activity by control group as defined by fasting plasma glucose, stratified by survey, CoLaus|PsyCoLaus study, Lausanne, Switzerland.

	Second survey (2014-2017)			Third survey (2018-2021)		
	Not controlled	**Controlled**	**p-value**	**Not controlled**	**Controlled**	**p-value**
Sample size	95	100		31	27	
Intensity of PA (min/day)						
Sedentary	761 ± 7	769 ± 7	0.403	756 ± 14	770 ± 15	0.527
Light	78 ± 4	69 ± 4	0.184	85 ± 9	71 ± 9	0.317
Moderate	15 ± 1	13 ± 1	0.509	18 ± 3	15 ± 3	0.528
Vigorous	1 ± 1	1 ± 1	0.394	1 ± 1	1 ± 1	0.370
At least 150 minutes MVPA per week	1 (ref)	0.85 (0.34 - 2.14)	0.727	1 (ref)	0.39 (0.07 - 2.07)	0.268
Intensity of PA (% of daily time)						
Sedentary	89.3 ± 0.6	90.4 ± 0.6	0.212	88.2 ± 1.3	90.0 ± 1.3	0.353
Light	8.9 ± 0.5	8.0 ± 0.5	0.177	9.6 ± 0.9	8.2 ± 1.0	0.316
Moderate	1.7 ± 0.1	1.5 ± 0.1	0.501	2.0 ± 0.3	1.7 ± 0.4	0.581
Vigorous	0.2 ± 0.1	0.1 ± 0.1	0.432	0.2 ± 0.1	0.1 ± 0.1	0.395

PA, physical activity; MVPA, moderate and vigorous physical activity. Results are expressed as mean ± sem for continuous variables and as odds ratio and (95% confidence interval) for categorical variables. Statistical analysis by analysis of variance for continuous variables and by logistic regression for categorical variables, adjusted for sex (male, female), age (continuous), BMI categories (normal, overweight, obese), smoking status (never, former, current), educational level (low, medium, high). Physical activity data assessed using the R-package GGIR version 1.5–9.

Supplementary table 5: bivariate analysis, objectively assessed physical activity by diabetes control group as defined by glycated haemoglobin, stratified by survey, CoLaus|PsyCoLaus study, Lausanne, Switzerland.

	Second survey (2014-2017)			Third survey (2018-2021)		
	Not controlled	Controlled	p-value	Not controlled	Controlled	p-value
Sample size	123	76		95	56	
Intensity of PA (min/day)						
Sedentary	626 [532 - 697]	638 [569 - 731]	0.151	600 [509 - 693]	603 [520 - 687]	0.742
Light	89 [65 - 121]	81 [59 - 110]	0.113	90 [63 - 112]	82 [70 - 100]	0.455
Moderate	106 [62 - 162]	89 [54 - 134]	0.140	123 [63 - 166]	102 [53 - 151]	0.552
Vigorous	0 [0 - 1]	0 [0 - 1]	0.139	0 [0 - 2]	0 [0 - 2]	0.843
At least 150 minutes MVPA per week (%)	116 (94.3)	71 (93.4)	0.798	87 (91.6)	51 (91.1)	0.914
Intensity of PA (% of daily time)						
Sedentary	75.0 [68.2 - 83.1]	79.0 [72.0 - 85.2]	0.082	73.9 [66.3 - 83.9]	75.5 [68.4 - 82.3]	0.726
Light	11.0 [8.9 - 13.7]	9.9 [7.1 - 13.2]	0.074	11.2 [8.0 - 13.2]	10.1 [8.5 - 12.6]	0.520
Moderate	12.5 [7.9 - 19.6]	10.3 [7.2 - 16.7]	0.106	14.6 [7.6 - 19.4]	12.3 [7.6 - 17.7]	0.540
Vigorous	0 [0 - 0.2]	0 [0 - 0.1]	0.144	0 [0 - 0.2]	0 [0 - 0.2]	0.777

PA, physical activity; MVPA, moderate and vigorous physical activity. Results expressed as median [interquartile range] for continuous variables and as number of participants (column percentage) for categorical variables. Statistical analysis by Kruskal-Wallis test for continuous variables and chi-square for categorical variables. Physical activity data assessed using the GENEActiv macro file 'General physical activity' version 1.9.

Supplementary table 6: bivariate analysis, objectively assessed physical activity by diabetes control group as defined by glycated haemoglobin, stratified by survey, CoLaus|PsyCoLaus study, Lausanne, Switzerland.

	Second survey (2014-2017)			Third survey (2018-2021)		
	Not controlled	Controlled	p-value	Not controlled	Controlled	p-value
Sample size	119	76		38	20	
Intensity of PA (min/day)						
Sedentary	752 [719 - 812]	770 [722 - 827]	0.210	764 [727 - 803]	742 [706 - 819]	0.612
Light	69 [40 - 105]	60 [35 - 85]	0.146	77 [41 - 106]	68 [45 - 97]	0.935
Moderate	10 [5 - 19]	9 [4 - 17]	0.344	13 [6 - 22]	10 [7 - 17]	0.731
Vigorous	1 [0 - 1]	0 [0 - 1]	0.317	1 [0 - 2]	0 [0 - 1]	0.185
At least 150 minutes MVPA per week (%)	20 (16.8)	12 (15.8)	0.852	10 (26.3)	4 (20.0)	0.593
Intensity of PA (% of daily time)						
Sedentary	90.4 [85.5 - 94.3]	92.1 [87.6 - 95.1]	0.172	89.6 [85.5 - 94.1]	91.3 [87.1 - 93.5]	0.806
Light	7.9 [5.1 - 12.1]	6.9 [4.3 - 10.1]	0.116	8.6 [5.0 - 12.5]	7.6 [5.4 - 11.0]	0.909
Moderate	1.2 [0.6 - 2.2]	1.1 [0.4 - 2.0]	0.324	1.5 [0.7 - 2.4]	1.1 [0.8 - 2.0]	0.659
Vigorous	0.1 [0 - 0.2]	0 [0 - 0.2]	0.113	0.1 [0 - 0.2]	0.1 [0 - 0.1]	0.191

PA, physical activity; MVPA, moderate and vigorous physical activity. Results expressed as median [interquartile range] for continuous variables and as number of participants (column percentage) for categorical variables. Statistical analysis by Kruskal-Wallis test for continuous variables and chi-square for categorical variables. Physical activity data assessed using the R-package GGIR version 1.5–9.

Supplementary table 7: multivariable analysis, objectively assessed physical activity by control group as defined by glycated haemoglobin, stratified by survey, CoLaus|PsyCoLaus study, Lausanne, Switzerland.

	Second survey (2014-2017)			Third survey (2018-2021)		
	Not controlled	Controlled	p-value	Not controlled	Controlled	p-value
Sample size	119	76		38	20	
Intensity of PA (min/day)						
Sedentary	761 ± 6	770 ± 8	0.353	766 ± 12	756 ± 17	0.664
Light	76 ± 4	68 ± 5	0.221	76 ± 8	84 ± 11	0.570
Moderate	13 ± 1	15 ± 1	0.494	16 ± 3	18 ± 4	0.614
Vigorous	1 ± 1	1 ± 1	0.974	1 ± 1	1 ± 1	0.238
At least 150 minutes MVPA per week	1 (ref)	1.31 (0.53 - 3.28)	0.560	1 (ref)	0.62 (0.11 - 3.42)	0.586
Intensity of PA (% of daily time)						
Sedentary	89.5 ± 0.5	90.3 ± 0.7	0.392	89.4 ± 1.1	88.3 ± 1.6	0.571
Light	8.8 ± 0.4	7.9 ± 0.5	0.199	8.6 ± 0.8	9.5 ± 1.2	0.554
Moderate	1.5 ± 0.1	1.7 ± 0.2	0.484	1.8 ± 0.3	2.1 ± 0.4	0.580
Vigorous	0.1 ± 0.1	0.1 ± 0.1	0.982	0.2 ± 0.1	0.1 ± 0.1	0.228

PA, physical activity; MVPA, moderate and vigorous physical activity. Results are expressed as mean ± sem for continuous variables and as odds ratio and (95% confidence interval) for categorical variables. Statistical analysis by analysis of variance for continuous variables and by logistic regression for categorical variables, adjusted for sex (male, female), age (continuous), BMI categories (normal, overweight, obese), smoking status (never, former, current), educational level (low, medium, high). Physical activity data assessed using the R-package GGIR version 1.5–9.

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ASSOCIATION BETWEEN PHYSICAL ACTIVITY AND DIABETES CONTROL: MULTIPLE CROSS-SECTIONAL STUDIES AND A PROSPECTIVE STUDY IN A POPULATION-BASED, SWISS COHORT

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ASSOCIATION BETWEEN PHYSICAL ACTIVITY AND DIABETES CONTROL: MULTIPLE CROSS-SECTIONAL STUDIES AND A PROSPECTIVE STUDY IN A POPULATION-BASED, SWISS COHORT

Running title: Physical activity and diabetes in Switzerland

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Abstract

Introduction: physical activity (PA) is recommended in type 2 diabetes mellitus (T2DM) patients to improve their glycaemic control. We aimed to assess PA levels among participants with controlled and uncontrolled T2DM.

Research design and methods: three cross-sectional analyses of a prospective cohort conducted in Lausanne, Switzerland. PA levels (sedentary, light, moderate and vigorous) were either self-reported via questionnaire (first and second survey) or objectively assessed using accelerometry (second and third survey). T2DM control was defined as glycaemia <7.0 mmol/L or glycated haemoglobin <6.5% (48 mmol/mol).

Results: data from 195 (30.3% women), 199 (30.1% women) and 151 (44.4% women) participants with T2DM were analysed in the first (2009-2012), second (2014-2017) and third (2018-2021) surveys. Approximately half of the participants did not have controlled glycaemia. Using subjective data, over 90% (first survey) and 75% (second survey) of participants reported moderate and vigorous PA >150 min/week. After multivariable adjustment, no differences were found regarding all types of self-reported PA levels between controlled and uncontrolled participants. Objective assessment of PA led to considerable differences according to the software used: 90% and 20% of participants with moderate and vigorous PA >150 min/week, respectively. After multivariable adjustment, no differences were found for all PA levels between controlled and uncontrolled participants, irrespective of the analytical procedure used. Using glycated haemoglobin, almost two-thirds of participants were considered as uncontrolled, and no differences were found for objectively assessed PA between controlled and uncontrolled participants.

Conclusions: no differences in PA levels were found between participants with controlled and uncontrolled T2DM.

Abstract word count: 250

Keywords: physical activity; diabetes; control; epidemiology

STRENGTHS AND LIMITATIONS OF THIS STUDY

- Physical activity levels were assessed using accelerometer.
- Diabetes control was assessed using both fasting plasma glucose and glycated haemoglobin.
- Study was conducted in a single location; hence, generalizability might be an issue.
- Possible selection bias exists as only motivated participants accepted to wear the accelerometer.

INTRODUCTION

Diabetes mellitus affects 537 million adults in the world, 90% of whom have type 2 diabetes mellitus (T2DM). It is predicted that this number of people with diabetes will increase to 783 million by 2045. Diabetes also has a financial cost estimated at USD 966 billion dollars, representing 9% of total adult health spending. [1]

Besides quitting smoking and adopting a healthy diet, physical activity (PA) is recommended in all patients with T2DM to improve their glycaemic control, insulin action, lipid levels and blood pressure [2], thus reducing the risk of cardiovascular disease. Simple activity such as walking 30 minutes per day can promote weight loss and improve glycaemic control [3]. More structured exercise programs are more effective to reduce insulin resistance in T2DM [4]. Exercise programs can be focused on aerobic, resistance or combined training, leading to significant improvements in HbA1c levels [5]. Still, it has been reported that patients with T2DM seldom adhere to the recommended amounts of PA. Indeed, barriers such as old age, female sex, lack of motivation, feeling of obligation, depression, and fatigue, can affect adhesion to recommended PA [6]. For instance, in the EUROASPIRE IV and V studies, over half of patients with cardiovascular disease (CVD) and self-reported diabetes did not intend to do regular planned PA, and only one quarter (26%) did [7].

In Switzerland, it was estimated that, in 2021, 389,600 people aged between 20 and 79 years lived with diabetes, and 1,249,700 were affected by impaired glucose tolerance, with health costs amounting to $4.9 billion [8]. Still, the level of PA among people with T2DM and its impact on T2DM control have never been assessed.

Hence, we aimed to assess the effect of subjectively and objectively measured PA levels in subjects treated for T2DM according to diabetes control, using data from a population-based study.

MATERIALS AND METHODS

Participants

The CoLaus|PsyCoLaus study is a population-based prospective study assessing the clinical, biological, and genetic determinants of cardiovascular disease aged 35 to 75 years at baseline, living in the city of Lausanne, Switzerland [9]. In each survey, participants answered questionnaires, underwent a clinical examination and blood samples were drawn for analyses. Recruitment began in June 2003 and ended in May 2006. The first follow-up was performed between April 2009 and September 2012; the second follow-up was performed between May 2014 and April 2017, and the third follow-up was performed between April 2018 and May 2021. For more details, see www.colaus-psycolaus.ch.

Self-reported physical activity

Subjective PA was assessed using the Physical Activity Frequency Questionnaire (PAFQ). This self-reported questionnaire has been validated in the population of Geneva, Switzerland, and assesses the type and duration of 70 kinds of (non)professional activities and sports during the previous week. Sedentary status was defined as spending more than 90% of daily energy in activities below moderate- and high-intensity (defined as requiring at least 4 times the basal metabolic rate, BMR) [10]. BMR multiples are close to Metabolic Equivalent of Task (MET) multiples, although MET multiples do not consider participant sex, age, or height.

For the purpose of this study, each type of activity was categorized into sedentary behaviour (SB, <2 metabolic equivalent of tasks - METs), light physical activity (LPA, 2 to <3 METs), moderate physical activity (MPA, 3-6 METs) and vigorous physical activity (VPA, >6 METs) according to the compendium of physical activities [11]. Total PA was defined as the sum of LPA, MPA and VPA. For each item of the PAFQ, the time spent per week was computed as average hours per day multiplied by the number of days when the activity was performed. For each item category (i.e., corresponding to SB, LPA, MPA or VPA), the times were summed up and divided by 7 to estimate an average daily time.

We chose to include sedentary behaviour in the analysis as we have previously shown that it is associated with an increased risk of developing T2DM [12].

Accelerometry-assessed physical activity

Physical activity was objectively assessed using a wrist-worn triaxial accelerometer (GENEActiv, Activinsights Ltd, United Kingdom, www.activinsights.com). These devices are the same that have been used in the UK biobank study [13], weigh 16 g, and allow continuous monitoring of PA for a maximum of 45 days. The devices were pre-programmed with a 50 Hz sampling frequency and subsequently attached to the participants' right wrist. Participants were requested to wear the device continuously for 14 days in their free-living conditions.

Raw accelerometry data were downloaded using the GENEActiv software version 2.9 (GENEActiv, Activinsights Ltd, United Kingdom) and transformed into 1-minute epoch files. Data were analysed using the GENEActiv Excel macro file 'General physical activity' version 1.9, which had been previously validated [14]. A valid day was defined as ≥10 h (i.e., 600 min-epoch) and ≥8 h (i.e., 480 min-epoch) of diurnal wear-time on weekdays and weekend days, respectively. The Excel macro file can be provided upon request.

A second analysis was performed on the raw accelerometry data using the R-package GGIR version 1.5–9 (http://cran.r-project.org) [15] with the thresholds defined by [16], i.e. an acceleration between 85 and 180 milli-g to define light PA, between 181 and 437 milli-g to define moderate PA, and >437 milli-g to define vigorous PA. The code used to analyse the data is provided in **Annex 1**.

Participants were considered as complying with the recommendations if the weekly amount of MPA and VPA exceeded 150 minutes, as per European Society of Cardiology/ European Association for the Study of Diabetes (ESC/EASD) guidelines [2].

Diabetes assessment

Participants were considered as presenting with treated diabetes if they reported taking any antidiabetic drug. Diabetes control was defined as a fasting plasma glucose <7 mmol/L; a second analysis was conducted using diabetes control defined as a glycated haemoglobin <6.5% (48 mmol/mol).

Blood was drawn in the fasting state and biological assays were performed by the Centre Hospitalier Universitaire Vaudois Clinical Laboratory on fresh blood samples within 2 hours of blood collection. The following analytical procedures (with maximum inter and intra-batch CVs) were used: glucose by glucose hexokinase (1.6%-0.8%). In the second and third

follow-ups, glycated haemoglobin levels were also measured by high performance liquid chromatography (HPCL) using Bio-Rad, D-10TM system, with measurement range 3.8% (18 mmol/mol) to 18.5% (179 mmol/mol).

Eligibility and exclusion criteria

All participants reporting being treated for diabetes were eligible for the study. Participants were excluded if they lacked PA data.

Covariates

Participants were queried regarding their personal and family history of cardiovascular risk factors, medical treatment, and socio-economic status. Educational level was categorized into low (mandatory or apprenticeship), medium (high school) and high (university). Smoking status was categorized into never, former, and current.

Body weight and height were measured with participants barefoot and in light indoor clothes. Body weight was measured in kilograms to the nearest 100 g using a Seca® scale (Hamburg, Germany). Height was measured to the nearest 5 mm using a Seca® (Hamburg, Germany) height gauge. Body mass index (BMI) was computed and categorized into normal (<25 kg/m^2), overweight (≥25 and <30 kg/m^2) and obese (≥30 kg/m^2).

Blood pressure was measured using an Omron® HEM-907 automated oscillometric sphygmomanometer after at least a 10-minute rest in a seated position, and the average of the last two measurements was used. Hypertension was defined by a SBP ≥ 140 mm Hg or a DBP ≥ 90 mm Hg or presence of antihypertensive drug treatment.

Patient and Public Involvement

It was not possible to involve patients or the public in the design, or conduct, or reporting, or dissemination plans of our research.

Statistical analysis

Statistical analyses were performed separately for each study period using Stata version 18.0 for windows (Stata Corp, College Station, Texas, USA). Descriptive results were expressed as number of participants (percentage) for categorical variables and as average standard deviation or median and [interquartile range] for continuous variables. Bivariate analyses were performed using chi-square or Fisher's exact test for categorical variables and Student's t-test, analysis of variance (ANOVA) or Kruskal-Wallis nonparametric test for

continuous variables. Multivariable analysis of continuous data was performed using ANOVA and results were expressed as adjusted mean±standard error of the mean (sem). Multivariable analysis of categorical data was performed using logistic regression and results were expressed as odds ratio (95% confidence interval). Multivariable analyses were conducted adjusting for sex (male, female), age (continuous), BMI categories (normal, overweight, obese), smoking status (never, former, current), educational level (low, medium, high). Statistical significance was assessed for a two-sided test with $p<0.05$.

RESULTS

Characteristics of participants

The selection procedure of the participants for the first, second and third follow-ups is summarized in **figure 1** and the characteristics of the participants according to adequate or inadequate control of diabetes stratified by survey are provided in **supplementary table 1**. Overall, one half of the participants treated for diabetes did not achieve adequate control. There were no consistent differences between controlled and uncontrolled participants, except that in the second follow-up, controlled participants were older and more frequently smokers.

Sedentary behaviour and physical activity levels according to diabetes control as per fasting plasma glucose

The bivariate analysis of reported PA levels between controlled and uncontrolled participants for the first and the second follow-ups are presented in **supplementary table 2**. Overall, over 90% and 75% of participants were compliant with the 150 min/week of MPA+VPA in the first and second surveys, respectively. Participants spent half of their time in SB and very little in VPA. No differences in PA (in absolute time or as percentage of day) were found between controlled and uncontrolled participants, and similar findings were obtained after multivariable adjustment (**table 1**).

Table 1: multivariable analysis, self-reported physical activity by control group, stratified by survey, CoLaus|PsyCoLaus study, Lausanne, Switzerland.

	First survey (2009-2012)			Second survey (2014-2017)		
	Not controlled	**Controlled**	**p-value**	**Not controlled**	**Controlled**	**p-value**
Sample size	121	74		52	48	
Intensity of PA (min/day)						
Sedentary	527 ± 15	542 ± 19	0.543	525 ± 25	556 ± 26	0.395
Light	197 ± 10	166 ± 13	0.056	204 ± 16	176 ± 16	0.237
Moderate	186 ± 11	191 ± 15	0.819	181 ± 17	185 ± 18	0.864
Vigorous	32 ± 8	46 ± 10	0.250	43 ± 10	26 ± 11	0.262
At least 150 minutes MVPA per week	1 (ref)	NC		1 (ref)	0.85 (0.35 - 2.09)	0.731 §
Intensity of PA (% of daily time)						
Sedentary	56 ± 1.5	57.3 ± 2	0.608	54.8 ± 2.4	58.8 ± 2.5	0.257
Light	20.9 ± 1	17.7 ± 1.3	0.057	21.4 ± 1.6	18.8 ± 1.7	0.275
Moderate	19.7 ± 1.2	20.2 ± 1.5	0.798	19.3 ± 1.9	19.6 ± 1.9	0.291
Vigorous	3.4 ± 0.8	4.8 ± 1	0.260	4.6 ± 1	2.8 ± 1.1	0.257

PA, physical activity; MVPA, moderate and vigorous physical activity. Results are expressed as mean ± sem for continuous variables and as odds ratio and (95% confidence interval) for categorical variables. Statistical analysis by analysis of variance for continuous variables and by logistic regression for categorical variables, adjusted for sex (male, female), age (continuous), BMI categories (normal, overweight, obese), smoking status (never, former, current), educational level (low, medium, high). NC, not computable. § n=76 as several variables were dropped due to collinearity.

The results of the bivariate analysis of the objectively assessed PA levels using the GENEActiv macro between controlled and uncontrolled participants for the second and third follow-ups are presented in **supplementary table 3**. Overall, over 90% of participants were compliant with the 150 min/week of MPA+VPA. Participants spent three quarters of their time in SB; conversely, they spent almost two hours per day on MPA. In the second survey, uncontrolled participants had higher levels and percentages of LPA and MPA, and a lower level and percentage of SB. In the third survey, no difference was found between controlled and uncontrolled participants . After multivariable adjustment, no significant differences were observed (**table 2**).

Table 2: multivariable analysis, objectively assessed physical activity by control group as defined using fasting plasma glucose, stratified by survey, CoLaus|PsyCoLaus study, Lausanne, Switzerland.

	Second survey (2014-2017)			Third survey (2018-2021)		
	Not controlled	**Controlled**	**p-value**	**Not controlled**	**Controlled**	**p-value**
Sample size	97	102		79	72	
Intensity of PA (min/day)						
Sedentary	609 ± 12	634 ± 11	0.131	601 ± 14	591 ± 15	0.634
Light	97 ± 4	86 ± 4	0.028	92 ± 4	83 ± 4	0.138
Moderate	122 ± 7	106 ± 7	0.124	122 ± 9	119 ± 9	0.798
Vigorous	1 ± 1	1 ± 1	0.684	1 ± 1	1 ± 1	0.476
At least 150 minutes MVPA per week	1 (ref)	0.94 (0.23 - 3.77)	0.925	1 (ref)	1.45 (0.39 - 5.42)	0.576
Intensity of PA (% of daily time)						
Sedentary	73.8 ± 1.1	77.1 ± 1.1	0.035	74.3 ± 1.2	74.7 ± 1.3	0.812
Light	11.7 ± 0.4	10.2 ± 0.4	0.011	11.1 ± 0.4	10.3 ± 0.4	0.280
Moderate	14.4 ± 0.8	12.5 ± 0.8	0.105	14.5 ± 1.1	14.7 ± 1.1	0.897
Vigorous	0.2 ± 0.1	0.1 ± 0.1	0.679	0.1 ± 0.1	0.2 ± 0.1	0.232

PA, physical activity; MVPA, moderate and vigorous physical activity. Results are expressed as mean ± sem for continuous variables and as odds ratio and (95% confidence interval) for categorical variables. Statistical analysis by analysis of variance for continuous variables and by logistic regression for categorical variables, adjusted for sex (male, female), age (continuous), BMI categories (normal, overweight, obese), smoking status (never, former, current), educational level (low, medium, high). Physical activity data assessed using the GENEActiv macro file 'General physical activity' version 1.9.

Supplementary table 4 shows the bivariate analysis between controlled and uncontrolled participants of follow-ups 2 and 3, for objectively assessed PA, using the R-package GGIR . Overall, less than 25% of participants were compliant with the 150 min/week of MPA+VPA. Participants spent approximately one-quarter of an hour per day in MPA, and 90% of their time in SB. In the second survey, uncontrolled participants had higher levels and percentages of LPA and MPA, and a lower level and percentage of SB. After multivariable adjustment, no significant differences were observed (**supplementary table 5**).

Sedentary behaviour and physical activity levels according to diabetes control as per glycated haemoglobin

The results of the bivariate analysis of the objectively assessed PA levels using the GENEActiv macro between controlled and uncontrolled participants for the second and the third follow-ups are presented in **supplementary table 6**. Almost two-thirds of participants were considered as uncontrolled. No differences were found between controlled and uncontrolled participants in bivariate and multivariable analyses (**table 3**).

Table 3: multivariable analysis, objectively assessed physical activity by control group as defined by glycated haemoglobin, stratified by survey, CoLaus|PsyCoLaus study, Lausanne, Switzerland.

	Second survey (2014-2017)			Third survey (2018-2021)		
	Not controlled	**Controlled**	**p-value**	**Not controlled**	**Controlled**	**p-value**
Sample size	123	76		95	56	
Intensity of PA (min/day)						
Sedentary	613 ± 10	636 ± 13	0.172	599 ± 13	592 ± 17	0.736
Light	94 ± 3	87 ± 4	0.216	89 ± 4	85 ± 5	0.543
Moderate	118 ± 6	106 ± 8	0.253	123 ± 8	118 ± 10	0.725
Vigorous	1 ± 1	1 ± 1	0.978	1 ± 1	1 ± 1	0.445
At least 150 minutes MVPA per week	1 (ref)	1.54 (0.41 - 5.79)	0.525	1 (ref)	1.11 (0.29 - 4.33)	0.879
Intensity of PA (% of daily time)						
Sedentary	74.6 ± 1.0	76.9 ± 1.2	0.143	74.4 ± 1.1	74.8 ± 1.5	0.821
Light	11.3 ± 0.3	10.4 ± 0.4	0.108	10.8 ± 0.4	10.5 ± 0.5	0.798
Moderate	14.0 ± 0.7	12.6 ± 0.9	0.225	14.7 ± 0.9	14.5 ± 1.2	0.884
Vigorous	0.1 ± 0.1	0.1 ± 0.1	0.925	0.1 ± 0.1	0.2 ± 0.1	0.394

PA, physical activity; MVPA, moderate and vigorous physical activity. Results are expressed as mean ± sem for continuous variables and as odds ratio and (95% confidence interval) for categorical variables. Statistical analysis by analysis of variance for continuous variables and by logistic regression for categorical variables, adjusted for sex (male, female), age (continuous), BMI categories (normal, overweight, obese), smoking status (never, former, current), educational level (low, medium, high). Physical activity data assessed using the GENEActiv macro file 'General physical activity' version 1.9.

The results of the bivariate and multivariable analysis of the objectively assessed PA levels using the R-package GGIR between controlled and uncontrolled participants for the second and the third follow-ups are presented in **supplementary table 7** (bivariate) and **supplementary table 8** (multivariable). Almost two-thirds of participants were considered as uncontrolled. No differences were found between controlled and uncontrolled participants in bivariate and multivariable analyses,

DISCUSSION

Our results show that over half of participants treated for type 2 diabetes are not controlled. They also show that neither self-reported nor objectively assessed PA levels differ according to diabetes control.

Characteristics of participants

Overall, participants with controlled T2DM represented less than half of the participants in each of the three follow-ups. These values are lower than those reported in most European countries [17 18]. The reasons for such a low control are not easily identifiable: no differences were found between controlled and uncontrolled participants for almost all covariates analysed, and a previous study showed no differences in dietary intakes [19]. Hence, the factors associated to T2DM control may be a less effective health care or differences in PA levels, which will be detailed in the next section. Overall, our results indicate that over half of treated diabetics do not achieve adequate control in this Swiss population-based sample.

Sedentary behaviour and physical activity levels according to diabetes control

PA is a cost-saving treatment [20 21]. Patients with T2DM who regularly participate in aerobic exercise have a better control of their disease [22]. According to Swiss and international guidelines, it is recommended to spend 150 min/week doing moderate to vigorous PA [23].

In our study, participants with T2DM reported over 150 minutes per day of MPA. Our findings suggest that most participants with T2DM comply with PA recommendations, although a reporting bias cannot be excluded. Conversely, the results of the objectively assessed PA differed considerably according to the analytical method applied. According to

the GENEActiv macro, almost all participants treated for T2DM were compliant with current PA recommendations, while according to the R-package GGIR this percentage was less than 25%. These differences between analytical methods have been reported previously [24] and raise the importance of standardization of PA accelerometry measurements [25].

After multivariable adjustment, no differences were found between controlled and uncontrolled participants regarding all PA levels, either as absolute time or as % of day. Our findings agree with a study conducted in Poland, where no differences in both subjectively and objectively assessed PA levels were found between controlled and uncontrolled participants [26]. Conversely, our findings do not replicate those of two other studies, which showed significant improvement in glycaemic control in participants with T2DM when regular PA was part of a healthy lifestyle [27 28]. Possible explanations include the methods used to categorize participants. For instance, both studies used self-filled questionnaire to categorize participants into active and inactive, while ours used both subjective and objective PA assessment. It is likely that the relatively small sample size of our study led to a low statistical power, and we cannot exclude an indication bias, participants with uncontrolled T2DM being recommended more frequently to exercise than those who are controlled.

Female sex, older age, comorbidities such as obesity and depression, lack of motivation, and social influence have been suggested to decrease adherence to PA [29]. It would thus be useful to consider these barriers in subjects with T2DM when prescribing regular PA [6] and consider routine activities as domestic chores to increase PA [30].

Strengths and limitations

The major strengths of this study is the use of both subjectively and objectively assessed PA. It used two different software to analyse PA and two different criteria (fasting plasma glucose and glycated haemoglobin) to define T2DM. The results were replicated in two time points and a population-based sample was used.

This study also has some limitations. First, the study was conducted in a single location, and results might not be extrapolated to other settings, although similar findings were obtained elsewhere [26]. Second, a possible selection bias might have occurred, as more motivated participants may acceptto wear the accelerometer more easily. Hence, it is likely that the amounts of PA might be overestimated, but not the comparisons between controlled

and uncontrolled participants. Finally, the amounts of light, moderate and vigorous PA differed considerably according to the analytical procedure applied. This issue has already been discussed [24] and recommendations have been issued [24 31]. Further, the results between controlled and uncontrolled participants were identical irrespective of the analytical procedure applied.

Conclusion

In this population-based study focusing on participants treated for T2DM, no differences were found between controlled and uncontrolled T2DM regarding self-reported or objectively assessed PA levels.

CONTRIBUTORY STATEMENT

Gaël Vonlanthen: investigation; formal analysis, visualisation; writing - original draft. Pedro Marques-Vidal: conceptualization; data curation; formal analysis; writing - review & editing; supervision. Pedro Marques-Vidal had full access to the data and is the guarantor of the study.

COMPETING INTERESTS

The authors report no conflict of interest.

FUNDING

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DATA SHARING STATEMENT

The CoLaus|PsyCoLaus cohort data used in this study cannot be fully shared as they contain potentially sensitive patient information. As discussed with the competent authority, the Research Ethic Committee of the Canton of Vaud, transferring or directly sharing this data would be a violation of the Swiss legislation aiming to protect the personal rights of participants. Non-identifiable, individual-level data are available for interested researchers, who meet the criteria for access to confidential data sharing, from the CoLaus Datacenter (CHUV, Lausanne, Switzerland). Instructions for gaining access to the CoLaus data used in this study are available at https://www.colaus-psycolaus.ch/professionals/how-to-collaborate/.

ETHICAL STATEMENT

The institutional Ethics Committee of the University of Lausanne, which afterwards became the Ethics Commission of Canton Vaud (www.cer-vd.ch) approved the baseline CoLaus study (reference 16/03). The approval was renewed for the first (reference 33/09), the second (reference 26/14) and the third (reference PB_2018-00040) follow-ups. The approval

for the entire CoLaus|PsyCoLaus study was confirmed in 2021 (reference PB_2018-00038, 239/09). The full decisions of the CER-VD can be obtained from the authors upon request. The study was performed in agreement with the Helsinki declaration and its former amendments, and in accordance with the applicable Swiss legislation (LRH 810.30). All participants gave their signed informed consent before entering the study.

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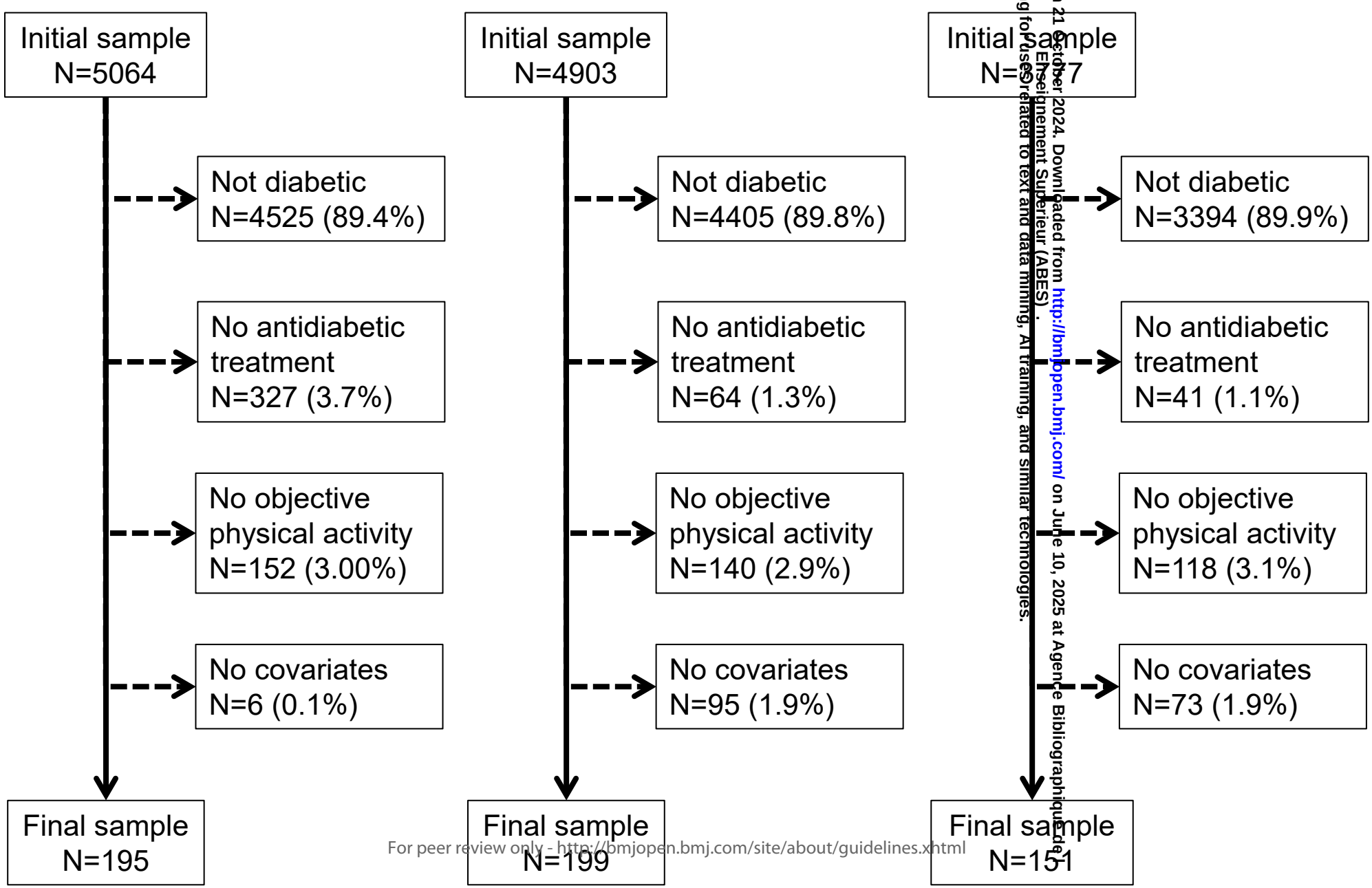
FIGURE LEGENDS

Figure 1: selection procedure for the first, second and third follow-ups, CoLaus|PsyColaus study, Lausanne, Switzerland.



Supplementary information

Table 1: characteristics of participants according to diabetes control as per fasting plasma glucose, stratified by survey, CoLaus|PsyColaus study, Lausanne, Switzerland.

	First survey (2009-2012)			Second survey (2014-2017)			Third survey (2018-2021)		
	Not controlled	Controlled	p-value	Not controlled	Controlled	p-value	Not controlled	Controlled	p-value
Sample size	121	74		97	102			72	
Women (%)	37 (30.6)	22 (29.7)	1.000	28 (28.9)	32 (31.4)	0.758	(40.5)	35 (48.6)	0.330
Age (years)	65.1 ± 8.8	65.9 ± 8.4	0.519	66.6 ± 8.7	69.5 ± 8.8	0.020	8.7	68.1 ± 8.7	0.652
Swiss born (%)	85 (70.3)	43 (58.1)	0.090	59 (60.8)	67 (65.7)	0.556	(69.6)	42 (58.3)	0.175
Education (%)			0.212			0.589			1.000
High	11 (9.1)	13 (17.6)		12 (12.4)	12 (11.9)		(11.4)	8 (11.1)	
Middle	29 (24.0)	18 (24.3)		24 (24.7)	19 (18.8)		18 (22.8)	17 (23.6)	
Low	81 (66.9)	43 (58.1)		61 (62.9)	70 (69.3)		52 (65.8)	47 (65.3)	
BMI (kg/m^2)	30.5 ± 5.6	29.4 ± 4.1	0.161	30.5 ± 4.9	30.6 ± 5.1	0.924	29.8 ± 4.6	29.0 ± 5.6	0.378
BMI categories (%)			0.711			1.000			0.319
Normal	17 (14.1)	10 (13.5)		11 (11.5)	12 (11.8)		11 (13.9)	15 (20.8)	
Overweight	50 (41.3)	35 (47.3)		37 (38.5)	39 (38.2)		33 (41.8)	33 (45.8)	
Obese	54 (44.6)	29 (39.2)		48 (50.0)	51 (50.0)		35 (44.3)	24 (33.3)	
Smoking categories (%)			0.770			0.022			0.950
Never	37 (30.6)	25 (33.8)		26 (26.8)	39 (38.2)		29 (36.7)	28 (38.9)	
Former	65 (53.7)	40 (54.1)		57 (58.8)	40 (39.2)		38 (48.1)	34 (47.2)	
Current	19 (15.7)	9 (12.2)		14 (14.4)	23 (22.6)		12 (15.2)	10 (13.9)	
Hypertension (%)	99 (81.8)	55 (74.3)	0.277	76 (78.4)	80 (78.4)	1.000	67 (84.8)	57 (79.2)	0.401
Hypolipidemic ttt (%)	67 (55.4)	51 (68.9)	0.071						
History of CVD (%)	18 (14.9)	12 (16.2)	0.839	18 (18.6)	20 (19.6)	0.859	16 (20.3)	13 (18.1)	0.837

BMI, body mass index; CVD, cardiovascular disease; ttt, treatment. Results expressed as mean ± standard deviation for continuous variables or as number of participants (percentage) for categorical variables. Statistical analysis by student's t-test or chi-square test.

Supplementary table 2: bivariate analysis, self-reported physical activity by diabetes control group as defined by fasting plasma glucose, stratified by survey, CoLaus|PsyCoLaus study, Lausanne, Switzerland.

	First survey (2009-2012)			Second survey (2014-2017)		
	Not controlled	Controlled	p-value	Not controlled	Controlled	p-value
Sample size	121	74		52	48	
Intensity of PA (min/day)						
Sedentary	522 [394 - 660]	557 [449 - 651]	0.379	555 [405 - 665]	532 [469 - 648]	0.637
Light	185 [107 - 272]	156 [109 - 243]	0.128	168 [125 - 249]	157 [123 - 242]	0.567
Moderate	164 [95 - 249]	155 [107 - 265]	0.862	143 [105 - 246]	161 [104 - 221]	0.992
Vigorous	0.7 [0 - 4]	0.8 [0 - 4.5]	0.995	18 [0 - 46]	15 [0 - 55]	0.997
At least 150 minutes MVPA per week	118 (97.5)	73 (98.7)	§	51 (78.5)	45 (76.3)	0.270
Intensity of PA (% of daily time)						
Sedentary	57.2 [42.4 - 68.8]	59.4 [46.8 - 68.4]	0.418	60.1 [44.6 - 68.0]	58.0 [48.3 - 68.0]	0.551
Light	19.3 [11.2 - 29.7]	16.6 [12.0 - 24.5]	0.108	18.5 [13.8 - 26.7]	17.7 [12.8 - 26.6]	0.801
Moderate	17.2 [10.7 - 25.8]	16.2 [11.2 - 26.9]	0.823	15.0 [10.3 - 26.8]	15.7 [11.4 - 24.2]	0.866
Vigorous	6.0 [0 - 37.0]	6.0 [0 - 39.0]	0.980	1.9 [0 - 5.2]	1.4 [0 - 6.0]	0.963

PA, physical activity; MVPA, moderate and vigorous physical activity. Results expressed as median [interquartile range] for continuous variables and as number of participants (column percentage) for categorical variables. Statistical analysis by Kruskal-Wallis test for continuous variables and chi-square or Fisher's exact test (§) for categorical variables.

Supplementary table 3: bivariate analysis, objectively assessed physical activity by diabetes control group as defined by fasting plasma glucose, stratified by survey, CoLaus|PsyCoLaus study, Lausanne, Switzerland.

	Second survey (2014-2017)			Third survey (2018-2021)		
	Not controlled	Controlled	p-value	Not controlled	Controlled	p-value
Sample size	97	102		79	72	
Intensity of PA (min/day)						
Sedentary	624 [522 - 691]	640 [561 - 734]	0.061	625 [515 - 693]	588 [503 - 690]	0.341
Light	92 [69 - 124]	83 [58 - 111]	0.024	87 [65 - 115]	83 [68 - 102]	0.378
Moderate	108 [65 - 165]	91 [54 - 134]	0.057	117 [56 - 161]	111 [60 - 160]	0.780
Vigorous	0 [0 - 1]	0 [0 - 1]	0.021	0 [0 - 2]	0 [0 - 2]	0.683
At least 150 minutes MVPA per week (%)	93 (95.9)	94 (92.2)	0.271	71 (89.9)	67 (93.1)	0.486
Intensity of PA (% of daily time)						
Sedentary	74.7 [67.0 - 82.6]	79.2 [72.1 - 85.1]	0.011	75.7 [68.1 - 84.9]	74.5 [66.7 - 82.3]	0.587
Light	11.1 [9.1 - 14.1]	9.8 [7.5 - 13.0]	0.008	11 [8.0 - 13.1]	10.7 [8.4 - 12.9]	0.631
Moderate	12.5 [8.3 - 20.0]	10.3 [7.3 - 16.4]	0.039	14.1 [6.9 - 18.8]	14.0 [8.4 - 18.9]	0.479
Vigorous	0.1 [0 - 0.2]	0 [0 - 0.1]	0.021	0 [0 - 0.2]	0 [0 - 0.2]	0.582

PA, physical activity; MVPA, moderate and vigorous physical activity. Results expressed as median [interquartile range] for continuous variables and as number of participants (column percentage) for categorical variables. Statistical analysis by Kruskal-Wallis test for continuous variables and chi-square or Fisher's exact test (§) for categorical variables. Physical activity data assessed using the GENEActiv macro file 'General physical activity' version 1.9.

Supplementary table 4: bivariate analysis, objectively assessed physical activity by diabetes control group as defined by fasting plasma glucose, stratified by survey, CoLaus|PsyCoLaus study, Lausanne, Switzerland.

	Second survey (2014-2017)			Third survey (2018-2021)		
	Not controlled	Controlled	p-value	Not controlled	Controlled	p-value
Sample size	95	100		31	27	
Intensity of PA (min/day)						
Sedentary	750 [708 - 811]	770 [722 - 822]	0.123	768 [725 - 809]	742 [706 - 821]	0.591
Light	72 [43 - 107]	60 [35 - 89]	0.076	81 [43 - 106]	66 [40 - 105]	0.198
Moderate	11 [6 - 22]	9 [3 - 16]	0.039	13 [6 - 22]	9 [6 - 19]	0.239
Vigorous	1 [0 - 1]	0 [0 - 1]	0.041	1 [0 - 2]	0 [0 - 1]	0.080
At least 150 minutes MVPA per week	19 (20.0)	13 (13.0)	0.187	8 (25.8)	6 (22.2)	0.750
Intensity of PA (% of daily time)						
Sedentary	90.2 [85 - 94.1]	92.1 [87.8 - 95.1]	0.057	89.1 [85.5 - 94.0]	91.6 [86.6 - 95.0]	0.233
Light	8.2 [5.3 - 12.2]	6.8 [4.3 - 10.5]	0.062	9.1 [5.4 - 12.3]	7.3 [4.4 - 11.1]	0.252
Moderate	1.3 [0.7 - 2.4]	1.1 [0.4 - 1.8]	0.032	1.6 [0.7 - 2.4]	1.0 [0.7 - 2.2]	0.239
Vigorous	0.1 [0 - 0.2]	0 [0 - 0.1]	0.033	0.1 [0 - 0.2]	0 [0 - 0.1]	0.072

PA, physical activity; MVPA, moderate and vigorous physical activity. Results expressed as median [interquartile range] for continuous variables and as number of participants (column percentage) for categorical variables. Statistical analysis by Kruskal-Wallis test for continuous variables and chi-square for categorical variables. Physical activity data assessed using the R-package GGIR version 1.5–9.

Supplementary table 5: multivariable analysis, objectively assessed physical activity by control group as defined by fasting plasma glucose, stratified by survey, CoLaus|PsyCoLaus study, Lausanne, Switzerland.

	Second survey (2014-2017)			Third survey (2018-2021)		
	Not controlled	**Controlled**	**p-value**	**Not controlled**	**Controlled**	**p-value**
Sample size	95	100		31	27	
Intensity of PA (min/day)						
Sedentary	761 ± 7	769 ± 7	0.403	756 ± 14	770 ± 15	0.527
Light	78 ± 4	69 ± 4	0.184	85 ± 9	71 ± 9	0.317
Moderate	15 ± 1	13 ± 1	0.509	18 ± 3	15 ± 3	0.528
Vigorous	1 ± 1	1 ± 1	0.394	1 ± 1	1 ± 1	0.370
At least 150 minutes MVPA per week	1 (ref)	0.85 (0.34 - 2.14)	0.727	1 (ref)	0.39 (0.07 - 2.07)	0.268
Intensity of PA (% of daily time)						
Sedentary	89.3 ± 0.6	90.4 ± 0.6	0.212	88.2 ± 1.3	90.0 ± 1.3	0.353
Light	8.9 ± 0.5	8.0 ± 0.5	0.177	9.6 ± 0.9	8.2 ± 1.0	0.316
Moderate	1.7 ± 0.1	1.5 ± 0.1	0.501	2.0 ± 0.3	1.7 ± 0.4	0.581
Vigorous	0.2 ± 0.1	0.1 ± 0.1	0.432	0.2 ± 0.1	0.1 ± 0.1	0.395

PA, physical activity; MVPA, moderate and vigorous physical activity. Results are expressed as mean ± sem for continuous variables and as odds ratio and (95% confidence interval) for categorical variables. Statistical analysis by analysis of variance for continuous variables and by logistic regression for categorical variables, adjusted for sex (male, female), age (continuous), BMI categories (normal, overweight, obese), smoking status (never, former, current), educational level (low, medium, high). Physical activity data assessed using the R-package GGIR version 1.5–9.

Supplementary table 6: bivariate analysis, objectively assessed physical activity by diabetes control group as defined by glycated haemoglobin, stratified by survey, CoLaus|PsyCoLaus study, Lausanne, Switzerland.

	Second survey (2014-2017)			Third survey (2018-2021)		
	Not controlled	Controlled	p-value	Not controlled	Controlled	p-value
Sample size	123	76		95	56	
Intensity of PA (min/day)						
Sedentary	626 [532 - 697]	638 [569 - 731]	0.151	600 [509 - 693]	603 [520 - 687]	0.742
Light	89 [65 - 121]	81 [59 - 110]	0.113	90 [63 - 112]	82 [70 - 100]	0.455
Moderate	106 [62 - 162]	89 [54 - 134]	0.140	123 [63 - 166]	102 [53 - 151]	0.552
Vigorous	0 [0 - 1]	0 [0 - 1]	0.139	0 [0 - 2]	0 [0 - 2]	0.843
At least 150 minutes MVPA per week (%)	116 (94.3)	71 (93.4)	0.798	87 (91.6)	51 (91.1)	0.914
Intensity of PA (% of daily time)						
Sedentary	75.0 [68.2 - 83.1]	79.0 [72.0 - 85.2]	0.082	73.9 [66.3 - 83.9]	75.5 [68.4 - 82.3]	0.726
Light	11.0 [8.9 - 13.7]	9.9 [7.1 - 13.2]	0.074	11.2 [8.0 - 13.2]	10.1 [8.5 - 12.6]	0.520
Moderate	12.5 [7.9 - 19.6]	10.3 [7.2 - 16.7]	0.106	14.6 [7.6 - 19.4]	12.3 [7.6 - 17.7]	0.540
Vigorous	0 [0 - 0.2]	0 [0 - 0.1]	0.144	0 [0 - 0.2]	0 [0 - 0.2]	0.777

PA, physical activity; MVPA, moderate and vigorous physical activity. Results expressed as median [interquartile range] for continuous variables and as number of participants (column percentage) for categorical variables. Statistical analysis by Kruskal-Wallis test for continuous variables and chi-square for categorical variables. Physical activity data assessed using the GENEActiv macro file 'General physical activity' version 1.9.

Supplementary table 7: bivariate analysis, objectively assessed physical activity by diabetes control group as defined by glycated haemoglobin, stratified by survey, CoLaus|PsyCoLaus study, Lausanne, Switzerland.

	Second survey (2014-2017)			Third survey (2018-2021)		
	Not controlled	Controlled	p-value	Not controlled	Controlled	p-value
Sample size	119	76		38	20	
Intensity of PA (min/day)						
Sedentary	752 [719 - 812]	770 [722 - 827]	0.210	764 [727 - 803]	742 [706 - 819]	0.612
Light	69 [40 - 105]	60 [35 - 85]	0.146	77 [41 - 106]	68 [45 - 97]	0.935
Moderate	10 [5 - 19]	9 [4 - 17]	0.344	13 [6 - 22]	10 [7 - 17]	0.731
Vigorous	1 [0 - 1]	0 [0 - 1]	0.317	1 [0 - 2]	0 [0 - 1]	0.185
At least 150 minutes MVPA per week (%)	20 (16.8)	12 (15.8)	0.852	10 (26.3)	4 (20.0)	0.593
Intensity of PA (% of daily time)						
Sedentary	90.4 [85.5 - 94.3]	92.1 [87.6 - 95.1]	0.172	89.6 [85.5 - 94.1]	91.3 [87.1 - 93.5]	0.806
Light	7.9 [5.1 - 12.1]	6.9 [4.3 - 10.1]	0.116	8.6 [5.0 - 12.5]	7.6 [5.4 - 11.0]	0.909
Moderate	1.2 [0.6 - 2.2]	1.1 [0.4 - 2.0]	0.324	1.5 [0.7 - 2.4]	1.1 [0.8 - 2.0]	0.659
Vigorous	0.1 [0 - 0.2]	0 [0 - 0.2]	0.113	0.1 [0 - 0.2]	0.1 [0 - 0.1]	0.191

PA, physical activity; MVPA, moderate and vigorous physical activity. Results expressed as median [interquartile range] for continuous variables and as number of participants (column percentage) for categorical variables. Statistical analysis by Kruskal-Wallis test for continuous variables and chi-square for categorical variables. Physical activity data assessed using the R-package GGIR version 1.5–9.

Supplementary table 8: multivariable analysis, objectively assessed physical activity by control group as defined by glycated haemoglobin, stratified by survey, CoLaus|PsyCoLaus study, Lausanne, Switzerland.

	Second survey (2014-2017)			Third survey (2018-2021)		
	Not controlled	Controlled	p-value	Not controlled	Controlled	p-value
Sample size	119	76		38	20	
Intensity of PA (min/day)						
Sedentary	761 ± 6	770 ± 8	0.353	766 ± 12	756 ± 17	0.664
Light	76 ± 4	68 ± 5	0.221	76 ± 8	84 ± 11	0.570
Moderate	13 ± 1	15 ± 1	0.494	16 ± 3	18 ± 4	0.614
Vigorous	1 ± 1	1 ± 1	0.974	1 ± 1	1 ± 1	0.238
At least 150 minutes MVPA per week	1 (ref)	1.31 (0.53 - 3.28)	0.560	1 (ref)	0.62 (0.11 - 3.42)	0.586
Intensity of PA (% of daily time)						
Sedentary	89.5 ± 0.5	90.3 ± 0.7	0.392	89.4 ± 1.1	88.3 ± 1.6	0.571
Light	8.8 ± 0.4	7.9 ± 0.5	0.199	8.6 ± 0.8	9.5 ± 1.2	0.554
Moderate	1.5 ± 0.1	1.7 ± 0.2	0.484	1.8 ± 0.3	2.1 ± 0.4	0.580
Vigorous	0.1 ± 0.1	0.1 ± 0.1	0.982	0.2 ± 0.1	0.1 ± 0.1	0.228

PA, physical activity; MVPA, moderate and vigorous physical activity. Results are expressed as mean ± sem for continuous variables and as odds ratio and (95% confidence interval) for categorical variables. Statistical analysis by analysis of variance for continuous variables and by logistic regression for categorical variables, adjusted for sex (male, female), age (continuous), BMI categories (normal, overweight, obese), smoking status (never, former, current), educational level (low, medium, high). Physical activity data assessed using the R-package GGIR version 1.5–9.

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ASSOCIATION BETWEEN PHYSICAL ACTIVITY AND DIABETES CONTROL: MULTIPLE CROSS-SECTIONAL STUDIES AND A PROSPECTIVE STUDY IN A POPULATION-BASED, SWISS COHORT

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Note: The following files were submitted by the author for peer review, but cannot be converted to PDF. You must view these files (e.g. movies) online.	
Annex 1.R	

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ASSOCIATION BETWEEN PHYSICAL ACTIVITY AND DIABETES CONTROL: MULTIPLE CROSS-SECTIONAL STUDIES AND A PROSPECTIVE STUDY IN A POPULATION-BASED, SWISS COHORT

Running title: Physical activity and diabetes in Switzerland

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Abstract

Introduction: physical activity (PA) is recommended in type 2 diabetes mellitus (T2DM) patients to improve their glycaemic control. We aimed to assess PA levels among participants with controlled and uncontrolled T2DM.

Research design and methods: three cross-sectional analyses of a prospective cohort conducted in Lausanne, Switzerland. PA levels (sedentary, light, moderate and vigorous) were either self-reported via questionnaire (first and second survey) or objectively assessed using accelerometry (second and third survey). T2DM control was defined as glycaemia <7.0 mmol/L or glycated haemoglobin <6.5% (48 mmol/mol).

Results: data from 195 (30.3% women), 199 (30.1% women) and 151 (44.4% women) participants with T2DM were analysed in the first (2009-2012), second (2014-2017) and third (2018-2021) surveys. Approximately half of the participants did not have controlled glycaemia. Using subjective data, over 90% (first survey) and 75% (second survey) of participants reported moderate and vigorous PA >150 min/week. After multivariable adjustment, no differences were found regarding all types of self-reported PA levels between controlled and uncontrolled participants. Objective assessment of PA led to considerable differences according to the software used: 90% and 20% of participants with moderate and vigorous PA >150 min/week, respectively. After multivariable adjustment, no differences were found for all PA levels between controlled and uncontrolled participants, irrespective of the analytical procedure used. Using glycated haemoglobin, almost two-thirds of participants were considered as uncontrolled, and no differences were found for objectively assessed PA between controlled and uncontrolled participants.

Conclusions: no differences in PA levels were found between participants with controlled and uncontrolled T2DM.

Abstract word count: 250

Keywords: physical activity; diabetes; control; epidemiology

STRENGTHS AND LIMITATIONS OF THIS STUDY

- Physical activity levels were assessed using accelerometer.
- Diabetes control was assessed using both fasting plasma glucose and glycated haemoglobin.
- Study was conducted in a single location; hence, generalizability might be an issue.
- Possible selection bias exists as only motivated participants accepted to wear the accelerometer.

INTRODUCTION

Diabetes mellitus affects 537 million adults in the world, 90% of whom have type 2 diabetes mellitus (T2DM). It is predicted that this number of people with diabetes will increase to 783 million by 2045. Diabetes also has a financial cost estimated at USD 966 billion dollars, representing 9% of total adult health spending. [1]

Besides quitting smoking and adopting a healthy diet, physical activity (PA) is recommended in all patients with T2DM to improve their glycaemic control, insulin action, lipid levels and blood pressure [2], thus reducing the risk of cardiovascular disease. Simple activity such as walking 30 minutes per day can promote weight loss and improve glycaemic control [3]. More structured exercise programs are more effective to reduce insulin resistance in T2DM [4]. Exercise programs can be focused on aerobic, resistance or combined training, leading to significant improvements in HbA1c levels [5]. Still, it has been reported that patients with T2DM seldom adhere to the recommended amounts of PA. Indeed, barriers such as old age, female sex, lack of motivation, feeling of obligation, depression, and fatigue, can affect adhesion to recommended PA [6]. For instance, in the EUROASPIRE IV and V studies, over half of patients with cardiovascular disease (CVD) and self-reported diabetes did not intend to do regular planned PA, and only one quarter (26%) did [7].

In Switzerland, it was estimated that, in 2021, 389,600 people aged between 20 and 79 years lived with diabetes, and 1,249,700 were affected by impaired glucose tolerance, with health costs amounting to $4.9 billion [8]. Still, the level of PA among people with T2DM and its impact on T2DM control have never been assessed.

Hence, we aimed to assess the effect of subjectively and objectively measured PA levels in subjects treated for T2DM according to diabetes control, using data from a population-based study.

MATERIALS AND METHODS

Participants

The CoLaus|PsyCoLaus study is a population-based prospective study assessing the clinical, biological, and genetic determinants of cardiovascular disease aged 35 to 75 years at baseline, living in the city of Lausanne, Switzerland [9]. In each survey, participants answered questionnaires, underwent a clinical examination and blood samples were drawn for analyses. Recruitment began in June 2003 and ended in May 2006. The first follow-up was performed between April 2009 and September 2012; the second follow-up was performed between May 2014 and April 2017, and the third follow-up was performed between April 2018 and May 2021. For more details, see www.colaus-psycolaus.ch.

Self-reported physical activity

Subjective PA was assessed using the Physical Activity Frequency Questionnaire (PAFQ). This self-reported questionnaire has been validated in the population of Geneva, Switzerland, and assesses the type and duration of 70 kinds of (non)professional activities and sports during the previous week. Sedentary status was defined as spending more than 90% of daily energy in activities below moderate- and high-intensity (defined as requiring at least 4 times the basal metabolic rate, BMR) [10]. BMR multiples are close to Metabolic Equivalent of Task (MET) multiples, although MET multiples do not consider participant sex, age, or height.

For the purpose of this study, each type of activity was categorized into sedentary behaviour (SB, <2 metabolic equivalent of tasks - METs), light physical activity (LPA, 2 to <3 METs), moderate physical activity (MPA, 3-6 METs) and vigorous physical activity (VPA, >6 METs) according to the compendium of physical activities [11]. Total PA was defined as the sum of LPA, MPA and VPA. For each item of the PAFQ, the time spent per week was computed as average hours per day multiplied by the number of days when the activity was performed. For each item category (i.e., corresponding to SB, LPA, MPA or VPA), the times were summed up and divided by 7 to estimate an average daily time.

We chose to include sedentary behaviour in the analysis as we have previously shown that it is associated with an increased risk of developing T2DM [12].

Accelerometry-assessed physical activity

Physical activity was objectively assessed using a wrist-worn triaxial accelerometer (GENEActiv, Activinsights Ltd, United Kingdom, www.activinsights.com). These devices are the same that have been used in the UK biobank study [13], weigh 16 g, and allow continuous monitoring of PA for a maximum of 45 days. The devices were pre-programmed with a 50 Hz sampling frequency and subsequently attached to the participants' right wrist. Participants were requested to wear the device continuously for 14 days in their free-living conditions.

Raw accelerometry data were downloaded using the GENEActiv software version 2.9 (GENEActiv, Activinsights Ltd, United Kingdom) and transformed into 1-minute epoch files. Data were analysed using the GENEActiv Excel macro file 'General physical activity' version 1.9, which had been previously validated [14]. A valid day was defined as ≥10 h (i.e., 600 min-epoch) and ≥8 h (i.e., 480 min-epoch) of diurnal wear-time on weekdays and weekend days, respectively. The Excel macro file can be provided upon request.

A second analysis was performed on the raw accelerometry data using the R-package GGIR version 1.5–9 (http://cran.r-project.org) [15] with the thresholds defined by [16], i.e. an acceleration between 85 and 180 milli-g to define light PA, between 181 and 437 milli-g to define moderate PA, and >437 milli-g to define vigorous PA. The code used to analyse the data is provided in **Annex 1**.

Participants were considered as complying with the recommendations if the weekly amount of MPA and VPA exceeded 150 minutes, as per European Society of Cardiology/ European Association for the Study of Diabetes (ESC/EASD) guidelines [2].

Diabetes assessment

Participants were asked whether they had been told they had diabetes and, if the answer was positive, if they were taking any medication (including insulin) to treat their diabetes. Participants were considered as presenting with treated diabetes if they reported taking any antidiabetic drug. Diabetes control was defined as a fasting plasma glucose <7 mmol/L; a second analysis was conducted using diabetes control defined as a glycated haemoglobin <6.5% (48 mmol/mol).

Blood was drawn in the fasting state and biological assays were performed by the Centre Hospitalier Universitaire Vaudois Clinical Laboratory on fresh blood samples within 2

hours of blood collection. The following analytical procedures (with maximum inter and intra-batch CVs) were used: glucose by glucose hexokinase (1.6%-0.8%). In the second and third follow-ups, glycated haemoglobin levels were also measured by high performance liquid chromatography (HPCL) using Bio-Rad, D-10TM system, with measurement range 3.8% (18 mmol/mol) to 18.5% (179 mmol/mol).

Eligibility and exclusion criteria

All participants reporting being treated for diabetes were eligible for the study. Participants were excluded if they lacked PA data.

Covariates

Participants were queried regarding their personal and family history of cardiovascular risk factors, medical treatment, and socio-economic status. Educational level was categorized into low (mandatory or apprenticeship), medium (high school) and high (university). Smoking status was categorized into never, former, and current.

Body weight and height were measured with participants barefoot and in light indoor clothes. Body weight was measured in kilograms to the nearest 100 g using a Seca® scale (Hamburg, Germany). Height was measured to the nearest 5 mm using a Seca® (Hamburg, Germany) height gauge. Body mass index (BMI) was computed and categorized into normal (<25 kg/m^2), overweight (≥25 and <30 kg/m^2) and obese (≥30 kg/m^2).

Blood pressure was measured using an Omron® HEM-907 automated oscillometric sphygmomanometer after at least a 10-minute rest in a seated position, and the average of the last two measurements was used. Hypertension was defined by a SBP ≥ 140 mm Hg or a DBP ≥ 90 mm Hg or presence of antihypertensive drug treatment.

Patient and Public Involvement

It was not possible to involve patients or the public in the design, or conduct, or reporting, or dissemination plans of our research.

Statistical analysis

Statistical analyses were performed separately for each study period using Stata version 18.0 for windows (Stata Corp, College Station, Texas, USA). Descriptive results were expressed as number of participants (percentage) for categorical variables and as average standard deviation or median and [interquartile range] for continuous variables. Bivariate

analyses were performed using chi-square or Fisher's exact test for categorical variables and Student's t-test, analysis of variance (ANOVA) or Kruskal-Wallis nonparametric test for continuous variables. Multivariable analysis of continuous data was performed using ANOVA and results were expressed as adjusted mean±standard error of the mean (sem). Multivariable analysis of categorical data was performed using logistic regression and results were expressed as odds ratio (95% confidence interval). Multivariable analyses were conducted adjusting for sex (male, female), age (continuous), BMI categories (normal, overweight, obese), smoking status (never, former, current), educational level (low, medium, high).

A sensitivity analysis was conducted using multivariable linear regression adjusting for the same covariates to assess the association between PA and fasting plasma glucose or glycated hemoglobin. Results were expressed as standardized beta coefficients.

Statistical significance was assessed for a two-sided test with $p<0.05$.

RESULTS

Characteristics of participants

The selection procedure of the participants for the first, second and third follow-ups is summarized in **figure 1** and the characteristics of the participants according to adequate or inadequate control of diabetes stratified by survey are provided in **supplementary table 1**. Overall, one half of the participants treated for diabetes did not achieve adequate control. There were no consistent differences between controlled and uncontrolled participants, except that in the second follow-up, controlled participants were older and more frequently smokers.

Sedentary behaviour and physical activity levels according to diabetes control as per fasting plasma glucose

The bivariate analysis of reported PA levels between controlled and uncontrolled participants for the first and the second follow-ups are presented in **supplementary table 2**. Overall, over 90% and 75% of participants were compliant with the 150 min/week of MPA+VPA in the first and second surveys, respectively. Participants spent half of their time in SB and very little in VPA. No differences in PA (in absolute time or as percentage of day) were found between controlled and uncontrolled participants, and similar findings were obtained after multivariable adjustment (**table 1**).

Table 1: multivariable analysis, self-reported physical activity by control group, stratified by survey, CoLaus|PsyCoLaus study, Lausanne, Switzerland.

	First survey (2009-2012)			Second survey (2014-2017)		
	Not controlled	**Controlled**	**p-value**	**Not controlled**	**Controlled**	**p-value**
Sample size	121	74		52	48	
Intensity of PA (min/day)						
Sedentary	527 ± 15	542 ± 19	0.543	525 ± 25	556 ± 26	0.395
Light	197 ± 10	166 ± 13	0.056	204 ± 16	176 ± 16	0.237
Moderate	186 ± 11	191 ± 15	0.819	181 ± 17	185 ± 18	0.864
Vigorous	32 ± 8	46 ± 10	0.250	43 ± 10	26 ± 11	0.262
At least 150 minutes MVPA per week	1 (ref)	NC		1 (ref)	0.85 (0.35 - 2.09)	0.731 §
Intensity of PA (% of daily time)						
Sedentary	56 ± 1.5	57.3 ± 2	0.608	54.8 ± 2.4	58.8 ± 2.5	0.257
Light	20.9 ± 1	17.7 ± 1.3	0.057	21.4 ± 1.6	18.8 ± 1.7	0.275
Moderate	19.7 ± 1.2	20.2 ± 1.5	0.798	19.3 ± 1.9	19.6 ± 1.9	0.291
Vigorous	3.4 ± 0.8	4.8 ± 1	0.260	4.6 ± 1	2.8 ± 1.1	0.257

PA, physical activity; MVPA, moderate and vigorous physical activity. Results are expressed as mean ± sem for continuous variables and as odds ratio and (95% confidence interval) for categorical variables. Statistical analysis by analysis of variance for continuous variables and by logistic regression for categorical variables, adjusted for sex (male, female), age (continuous), BMI categories (normal, overweight, obese), smoking status (never, former, current), educational level (low, medium, high). NC, not computable. § n=76 as several variables were dropped due to collinearity.

The results of the bivariate analysis of the objectively assessed PA levels using the GENEActiv macro between controlled and uncontrolled participants for the second and third follow-ups are presented in **supplementary table 3**. Overall, over 90% of participants were compliant with the 150 min/week of MPA+VPA. Participants spent three quarters of their time in SB; conversely, they spent almost two hours per day on MPA. In the second survey, uncontrolled participants had higher levels and percentages of LPA and MPA, and a lower level and percentage of SB. In the third survey, no difference was found between controlled and uncontrolled participants . After multivariable adjustment, no significant differences were observed (**table 2**).

Table 2: multivariable analysis, objectively assessed physical activity by control group as defined using fasting plasma glucose, stratified by survey, CoLaus|PsyCoLaus study, Lausanne, Switzerland.

	Second survey (2014-2017)			Third survey (2018-2021)		
	Not controlled	**Controlled**	**p-value**	**Not controlled**	**Controlled**	**p-value**
Sample size	97	102		79	72	
Intensity of PA (min/day)						
Sedentary	609 ± 12	634 ± 11	0.131	601 ± 14	591 ± 15	0.634
Light	97 ± 4	86 ± 4	0.028	92 ± 4	83 ± 4	0.138
Moderate	122 ± 7	106 ± 7	0.124	122 ± 9	119 ± 9	0.798
Vigorous	1 ± 1	1 ± 1	0.684	1 ± 1	1 ± 1	0.476
At least 150 minutes MVPA per week	1 (ref)	0.94 (0.23 - 3.77)	0.925	1 (ref)	1.45 (0.39 - 5.42)	0.576
Intensity of PA (% of daily time)						
Sedentary	73.8 ± 1.1	77.1 ± 1.1	0.035	74.3 ± 1.2	74.7 ± 1.3	0.812
Light	11.7 ± 0.4	10.2 ± 0.4	0.011	11.1 ± 0.4	10.3 ± 0.4	0.280
Moderate	14.4 ± 0.8	12.5 ± 0.8	0.105	14.5 ± 1.1	14.7 ± 1.1	0.897
Vigorous	0.2 ± 0.1	0.1 ± 0.1	0.679	0.1 ± 0.1	0.2 ± 0.1	0.232

PA, physical activity; MVPA, moderate and vigorous physical activity. Results are expressed as mean ± sem for continuous variables and as odds ratio and (95% confidence interval) for categorical variables. Statistical analysis by analysis of variance for continuous variables and by logistic regression for categorical variables, adjusted for sex (male, female), age (continuous), BMI categories (normal, overweight, obese), smoking status (never, former, current), educational level (low, medium, high). Physical activity data assessed using the GENEActiv macro file 'General physical activity' version 1.9.

Supplementary table 4 shows the bivariate analysis between controlled and uncontrolled participants of follow-ups 2 and 3, for objectively assessed PA, using the R-package GGIR . Overall, less than 25% of participants were compliant with the 150 min/week of MPA+VPA. Participants spent approximately one-quarter of an hour per day in MPA, and 90% of their time in SB. In the second survey, uncontrolled participants had higher levels and percentages of LPA and MPA, and a lower level and percentage of SB. After multivariable adjustment, no significant differences were observed (**supplementary table 5**).

The results of the sensitivity analysis using multivariable linear regression are provided in **supplementary tables 6 to 8**. Besides a significant negative association between LPA and glucose levels in the second follow-up for PA assessed by the MACRO procedure, which was not confirmed in the third follow-up, no other association between PA levels and glucose levels was found.

Sedentary behaviour and physical activity levels according to diabetes control as per glycated haemoglobin

The results of the bivariate analysis of the objectively assessed PA levels using the GENEActiv macro between controlled and uncontrolled participants for the second and the third follow-ups are presented in **supplementary table 9**. Almost two-thirds of participants were considered as uncontrolled. No differences were found between controlled and uncontrolled participants in bivariate and multivariable analyses (**table 3**).

Table 3: multivariable analysis, objectively assessed physical activity by control group as defined by glycated haemoglobin, stratified by survey, CoLaus|PsyCoLaus study, Lausanne, Switzerland.

	Second survey (2014-2017)			Third survey (2018-2021)		
	Not controlled	**Controlled**	**p-value**	**Not controlled**	**Controlled**	**p-value**
Sample size	123	76		95	56	
Intensity of PA (min/day)						
Sedentary	613 ± 10	636 ± 13	0.172	599 ± 13	592 ± 17	0.736
Light	94 ± 3	87 ± 4	0.216	89 ± 4	85 ± 5	0.543
Moderate	118 ± 6	106 ± 8	0.253	123 ± 8	118 ± 10	0.725
Vigorous	1 ± 1	1 ± 1	0.978	1 ± 1	1 ± 1	0.445
At least 150 minutes MVPA per week	1 (ref)	1.54 (0.41 - 5.79)	0.525	1 (ref)	1.11 (0.29 - 4.33)	0.879
Intensity of PA (% of daily time)						
Sedentary	74.6 ± 1.0	76.9 ± 1.2	0.143	74.4 ± 1.1	74.8 ± 1.5	0.821
Light	11.3 ± 0.3	10.4 ± 0.4	0.108	10.8 ± 0.4	10.5 ± 0.5	0.798
Moderate	14.0 ± 0.7	12.6 ± 0.9	0.225	14.7 ± 0.9	14.5 ± 1.2	0.884
Vigorous	0.1 ± 0.1	0.1 ± 0.1	0.925	0.1 ± 0.1	0.2 ± 0.1	0.394

PA, physical activity; MVPA, moderate and vigorous physical activity. Results are expressed as mean ± sem for continuous variables and as odds ratio and (95% confidence interval) for categorical variables. Statistical analysis by analysis of variance for continuous variables and by logistic regression for categorical variables, adjusted for sex (male, female), age (continuous), BMI categories (normal, overweight, obese), smoking status (never, former, current), educational level (low, medium, high). Physical activity data assessed using the GENEActiv macro file 'General physical activity' version 1.9.

The results of the bivariate and multivariable analysis of the objectively assessed PA levels using the R-package GGIR between controlled and uncontrolled participants for the second and the third follow-ups are presented in **supplementary table 10** (bivariate) and **supplementary table 11** (multivariable). Almost two-thirds of participants were considered as uncontrolled. No differences were found between controlled and uncontrolled participants in bivariate and multivariable analyses.

The results of the sensitivity analysis using multivariable linear regression are provided in **supplementary tables 12 and 13**. No significant association between PA levels and glycated hemoglobin was found.

DISCUSSION

Our results show that over half of participants treated for type 2 diabetes are not controlled. They also show that neither self-reported nor objectively assessed PA levels differ according to diabetes control.

Characteristics of participants

Overall, participants with controlled T2DM represented less than half of the participants in each of the three follow-ups. These values are lower than those reported in most European countries [17 18]. The reasons for such a low control are not easily identifiable: no differences were found between controlled and uncontrolled participants for almost all covariates analysed, and a previous study showed no differences in dietary intakes [19]. Hence, the factors associated to T2DM control may be a less effective health care or differences in PA levels, which will be detailed in the next section. Overall, our results indicate that over half of treated diabetics do not achieve adequate control in this Swiss population-based sample.

Sedentary behaviour and physical activity levels according to diabetes control

PA is a cost-saving treatment [20 21]. Patients with T2DM who regularly participate in aerobic exercise have a better control of their disease [22]. According to Swiss and international guidelines, it is recommended to spend 150 min/week doing moderate to vigorous PA [23].

In our study, participants with T2DM reported over 150 minutes per day of MPA. Our findings suggest that most participants with T2DM comply with PA recommendations, although a reporting bias cannot be excluded. Conversely, the results of the objectively assessed PA differed considerably according to the analytical method applied. According to the GENEActiv macro, almost all participants treated for T2DM were compliant with current PA recommendations, while according to the R-package GGIR this percentage was less than 25%. These differences between analytical methods have been reported previously [24] and raise the importance of standardization of PA accelerometry measurements [25].

After multivariable adjustment, no differences were found between controlled and uncontrolled participants regarding all PA levels, either as absolute time or as % of day. Our findings agree with a study conducted in Poland, where no differences in both subjectively and objectively assessed PA levels were found between controlled and uncontrolled participants [26]. Conversely, our findings do not replicate those of two other studies, which showed significant improvement in glycaemic control in participants with T2DM when regular PA was part of a healthy lifestyle [27 28]. Possible explanations include the methods used to categorize participants. For instance, both studies used self-filled questionnaire to categorize participants into active and inactive, while ours used both subjective and objective PA assessment. It is likely that the relatively small sample size of our study led to a low statistical power, and we cannot exclude an indication bias, participants with uncontrolled T2DM being recommended more frequently to exercise than those who are controlled.

PA levels differed considerably according to the methodology used. The differences between reported and objectively assessed PA are known [29], and the differences in PA levels according to the software used to process the accelerometry data have also been detected previously [24]. Overall, our results indicate that the method to assess PA might considerably impact the associations between PA and cardiometabolic risk factors. Hence, care should be taken when comparing findings from studies that used different software to assess PA.

Female sex, older age, comorbidities such as obesity and depression, lack of motivation, and social influence have been suggested to decrease adherence to PA [30]. It would thus be useful to consider these barriers in subjects with T2DM when prescribing regular PA [6] and consider routine activities as domestic chores to increase PA [31].

Implications for clinical practice

Overall, our results suggest that people with diabetes exhibit the same PA behaviour irrespective of their fasting glucose or HbA1c levels. As PA is part of the management of T2DM [2], more emphasis should be put by clinicians to motivate their patients to be more active, different types of PA being effective [5]. Still, doctors might not have either the time or the knowledge [32] to adequately advise their patients regarding PA. Hence, postgraduate training regarding PA prescription is advised [33].

Strengths and limitations

The major strengths of this study is the use of both subjectively and objectively assessed PA. It used two different software to analyse PA and two different criteria (fasting plasma glucose and glycated haemoglobin) to define T2DM. The results were replicated in two time points and a population-based sample was used.

This study also has some limitations. First, the study was conducted in a single location, and results might not be extrapolated to other settings, although similar findings were obtained elsewhere [26]. Second, a possible selection bias might have occurred, as more motivated participants may accept to wear the accelerometer more easily. Hence, it is likely that the amounts of PA might be overestimated, but not the comparisons between controlled and uncontrolled participants. Third, the cross-sectional design of this study cannot address the question whether effective PA levels can efficiently help manage diabetes. Still, our results are similar to those reported elsewhere [34], and suggest that PA levels should be implemented among people with diabetes. Finally, the amounts of light, moderate and vigorous PA differed considerably according to the analytical procedure applied. This issue has already been discussed [24] and recommendations have been issued [24 35]. Further, the results between controlled and uncontrolled participants were identical irrespective of the analytical procedure applied.

Conclusion

In this population-based study focusing on participants treated for T2DM, no differences were found between controlled and uncontrolled T2DM regarding self-reported or objectively assessed PA levels.

CONTRIBUTORY STATEMENT

Gaël Vonlanthen: investigation; formal analysis, visualisation; writing - original draft. Pedro Marques-Vidal: conceptualization; data curation; formal analysis; writing - review & editing; supervision. Pedro Marques-Vidal had full access to the data and is the guarantor of the study.

COMPETING INTERESTS

The authors report no conflict of interest.

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DATA SHARING STATEMENT

The CoLaus|PsyCoLaus cohort data used in this study cannot be fully shared as they contain potentially sensitive patient information. As discussed with the competent authority, the Research Ethic Committee of the Canton of Vaud, transferring or directly sharing this data would be a violation of the Swiss legislation aiming to protect the personal rights of participants. Non-identifiable, individual-level data are available for interested researchers, who meet the criteria for access to confidential data sharing, from the CoLaus Datacenter (CHUV, Lausanne, Switzerland). Instructions for gaining access to the CoLaus data used in this study are available at https://www.colaus-psycolaus.ch/professionals/how-to-collaborate/.

ETHICAL STATEMENT

The institutional Ethics Committee of the University of Lausanne, which afterwards became the Ethics Commission of Canton Vaud (www.cer-vd.ch) approved the baseline CoLaus study (reference 16/03). The approval was renewed for the first (reference 33/09), the second (reference 26/14) and the third (reference PB_2018-00040) follow-ups. The approval

for the entire CoLaus|PsyCoLaus study was confirmed in 2021 (reference PB_2018-00038, 239/09). The full decisions of the CER-VD can be obtained from the authors upon request. The study was performed in agreement with the Helsinki declaration and its former amendments, and in accordance with the applicable Swiss legislation (LRH 810.30). All participants gave their signed informed consent before entering the study.

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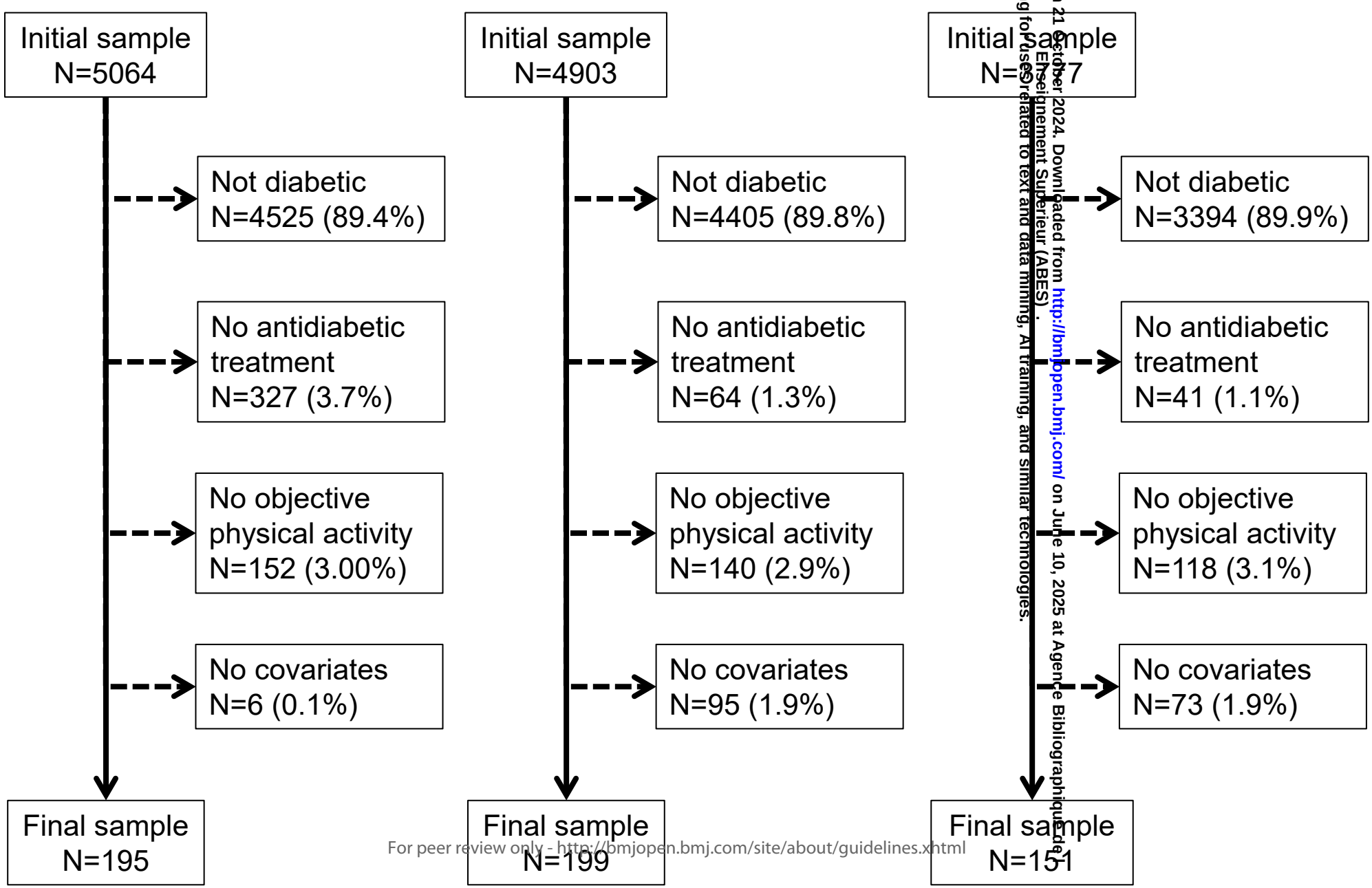
FIGURE LEGENDS

Figure 1: selection procedure for the first, second and third follow-ups, CoLaus|PsyColaus study, Lausanne, Switzerland.



Supplementary information

Table 1: characteristics of participants according to diabetes control as per fasting plasma glucose, stratified by survey, CoLaus|PsyColaus study, Lausanne, Switzerland.

	First survey (2009-2012)			Second survey (2014-2017)			Third survey (2018-2021)		
	Not controlled	Controlled	p-value	Not controlled	Controlled	p-value	Not controlled	Controlled	p-value
Sample size	121	74		97	102			72	
Women (%)	37 (30.6)	22 (29.7)	1.000	28 (28.9)	32 (31.4)	0.758	(40.5)	35 (48.6)	0.330
Age (years)	65.1 ± 8.8	65.9 ± 8.4	0.519	66.6 ± 8.7	69.5 ± 8.8	0.020	8.7	68.1 ± 8.7	0.652
Swiss born (%)	85 (70.3)	43 (58.1)	0.090	59 (60.8)	67 (65.7)	0.556	69.6)	42 (58.3)	0.175
Education (%)			0.212			0.589			1.000
High	11 (9.1)	13 (17.6)		12 (12.4)	12 (11.9)		11.4)	8 (11.1)	
Middle	29 (24.0)	18 (24.3)		24 (24.7)	19 (18.8)		18 (22.8)	17 (23.6)	
Low	81 (66.9)	43 (58.1)		61 (62.9)	70 (69.3)		52 (65.8)	47 (65.3)	
BMI (kg/m^2)	30.5 ± 5.6	29.4 ± 4.1	0.161	30.5 ± 4.9	30.6 ± 5.1	0.924	29.8 ± 4.6	29.0 ± 5.6	0.378
BMI categories (%)			0.711			1.000			0.319
Normal	17 (14.1)	10 (13.5)		11 (11.5)	12 (11.8)		11 (13.9)	15 (20.8)	
Overweight	50 (41.3)	35 (47.3)		37 (38.5)	39 (38.2)		33 (41.8)	33 (45.8)	
Obese	54 (44.6)	29 (39.2)		48 (50.0)	51 (50.0)		35 (44.3)	24 (33.3)	
Smoking categories (%)			0.770			0.022			0.950
Never	37 (30.6)	25 (33.8)		26 (26.8)	39 (38.2)		29 (36.7)	28 (38.9)	
Former	65 (53.7)	40 (54.1)		57 (58.8)	40 (39.2)		38 (48.1)	34 (47.2)	
Current	19 (15.7)	9 (12.2)		14 (14.4)	23 (22.6)		12 (15.2)	10 (13.9)	
Hypertension (%)	99 (81.8)	55 (74.3)	0.277	76 (78.4)	80 (78.4)	1.000	67 (84.8)	57 (79.2)	0.401
Hypolipidemic ttt (%)	67 (55.4)	51 (68.9)	0.071						
History of CVD (%)	18 (14.9)	12 (16.2)	0.839	18 (18.6)	20 (19.6)	0.859	16 (20.3)	13 (18.1)	0.837

BMI, body mass index; CVD, cardiovascular disease; ttt, treatment. Results expressed as mean ± standard deviation for continuous variables or as number of participants (percentage) for categorical variables. Statistical analysis by student's t-test or chi-square test.

Supplementary table 2: bivariate analysis, self-reported physical activity by diabetes control group as defined by fasting plasma glucose, stratified by survey, CoLaus|PsyCoLaus study, Lausanne, Switzerland.

	First survey (2009-2012)			Second survey (2014-2017)		
	Not controlled	**Controlled**	**p-value**	**Not controlled**	**Controlled**	**p-value**
Sample size	121	74		52	48	
Intensity of PA (min/day)						
Sedentary	522 [394 - 660]	557 [449 - 651]	0.379	555 [405 - 665]	532 [469 - 648]	0.637
Light	185 [107 - 272]	156 [109 - 243]	0.128	168 [125 - 249]	157 [123 - 242]	0.567
Moderate	164 [95 - 249]	155 [107 - 265]	0.862	143 [105 - 246]	161 [104 - 221]	0.992
Vigorous	0.7 [0 - 4]	0.8 [0 - 4.5]	0.995	18 [0 - 46]	15 [0 - 55]	0.997
At least 150 minutes MVPA per week	118 (97.5)	73 (98.7)	§	51 (78.5)	45 (76.3)	0.270
Intensity of PA (% of daily time)						
Sedentary	57.2 [42.4 - 68.8]	59.4 [46.8 - 68.4]	0.418	60.1 [44.6 - 68.0]	58.0 [48.3 - 68.0]	0.551
Light	19.3 [11.2 - 29.7]	16.6 [12.0 - 24.5]	0.108	18.5 [13.8 - 26.7]	17.7 [12.8 - 26.6]	0.801
Moderate	17.2 [10.7 - 25.8]	16.2 [11.2 - 26.9]	0.823	15.0 [10.3 - 26.8]	15.7 [11.4 - 24.2]	0.866
Vigorous	6.0 [0 - 37.0]	6.0 [0 - 39.0]	0.980	1.9 [0 - 5.2]	1.4 [0 - 6.0]	0.963

PA, physical activity; MVPA, moderate and vigorous physical activity. Results expressed as median [interquartile range] for continuous variables and as number of participants (column percentage) for categorical variables. Statistical analysis by Kruskal-Wallis test for continuous variables and chi-square or Fisher's exact test (§) for categorical variables.

Supplementary table 3: bivariate analysis, objectively assessed physical activity by diabetes control group as defined by fasting plasma glucose, stratified by survey, CoLaus|PsyCoLaus study, Lausanne, Switzerland.

	Second survey (2014-2017)			Third survey (2018-2021)		
	Not controlled	Controlled	p-value	Not controlled	Controlled	p-value
Sample size	97	102		79	72	
Intensity of PA (min/day)						
Sedentary	624 [522 - 691]	640 [561 - 734]	0.061	625 [515 - 693]	588 [503 - 690]	0.341
Light	92 [69 - 124]	83 [58 - 111]	0.024	87 [65 - 115]	83 [68 - 102]	0.378
Moderate	108 [65 - 165]	91 [54 - 134]	0.057	117 [56 - 161]	111 [60 - 160]	0.780
Vigorous	0 [0 - 1]	0 [0 - 1]	0.021	0 [0 - 2]	0 [0 - 2]	0.683
At least 150 minutes MVPA per week (%)	93 (95.9)	94 (92.2)	0.271	71 (89.9)	67 (93.1)	0.486
Intensity of PA (% of daily time)						
Sedentary	74.7 [67.0 - 82.6]	79.2 [72.1 - 85.1]	0.011	75.7 [68.1 - 84.9]	74.5 [66.7 - 82.3]	0.587
Light	11.1 [9.1 - 14.1]	9.8 [7.5 - 13.0]	0.008	11 [8.0 - 13.1]	10.7 [8.4 - 12.9]	0.631
Moderate	12.5 [8.3 - 20.0]	10.3 [7.3 - 16.4]	0.039	14.1 [6.9 - 18.8]	14.0 [8.4 - 18.9]	0.479
Vigorous	0.1 [0 - 0.2]	0 [0 - 0.1]	0.021	0 [0 - 0.2]	0 [0 - 0.2]	0.582

PA, physical activity; MVPA, moderate and vigorous physical activity. Results expressed as median [interquartile range] for continuous variables and as number of participants (column percentage) for categorical variables. Statistical analysis by Kruskal-Wallis test for continuous variables and chi-square or Fisher's exact test (§) for categorical variables. Physical activity data assessed using the GENEActiv macro file 'General physical activity' version 1.9.

Supplementary table 4: bivariate analysis, objectively assessed physical activity by diabetes control group as defined by fasting plasma glucose, stratified by survey, CoLaus|PsyCoLaus study, Lausanne, Switzerland.

	Second survey (2014-2017)			Third survey (2018-2021)		
	Not controlled	**Controlled**	**p-value**	**Not controlled**	**Controlled**	**p-value**
Sample size	95	100		31	27	
Intensity of PA (min/day)						
Sedentary	750 [708 - 811]	770 [722 - 822]	0.123	768 [725 - 809]	742 [706 - 821]	0.591
Light	72 [43 - 107]	60 [35 - 89]	0.076	81 [43 - 106]	66 [40 - 105]	0.198
Moderate	11 [6 - 22]	9 [3 - 16]	0.039	13 [6 - 22]	9 [6 - 19]	0.239
Vigorous	1 [0 - 1]	0 [0 - 1]	0.041	1 [0 - 2]	0 [0 - 1]	0.080
At least 150 minutes MVPA per week	19 (20.0)	13 (13.0)	0.187	8 (25.8)	6 (22.2)	0.750
Intensity of PA (% of daily time)						
Sedentary	90.2 [85 - 94.1]	92.1 [87.8 - 95.1]	0.057	89.1 [85.5 - 94.0]	91.6 [86.6 - 95.0]	0.233
Light	8.2 [5.3 - 12.2]	6.8 [4.3 - 10.5]	0.062	9.1 [5.4 - 12.3]	7.3 [4.4 - 11.1]	0.252
Moderate	1.3 [0.7 - 2.4]	1.1 [0.4 - 1.8]	0.032	1.6 [0.7 - 2.4]	1.0 [0.7 - 2.2]	0.239
Vigorous	0.1 [0 - 0.2]	0 [0 - 0.1]	0.033	0.1 [0 - 0.2]	0 [0 - 0.1]	0.072

PA, physical activity; MVPA, moderate and vigorous physical activity. Results expressed as median [interquartile range] for continuous variables and as number of participants (column percentage) for categorical variables. Statistical analysis by Kruskal-Wallis test for continuous variables and chi-square for categorical variables. Physical activity data assessed using the R-package GGIR version 1.5–9.

Supplementary table 5: multivariable analysis, objectively assessed physical activity by control group as defined by fasting plasma glucose, stratified by survey, CoLaus|PsyCoLaus study, Lausanne, Switzerland.

	Second survey (2014-2017)			Third survey (2018-2021)		
	Not controlled	**Controlled**	**p-value**	**Not controlled**	**Controlled**	**p-value**
Sample size	95	100		31	27	
Intensity of PA (min/day)						
Sedentary	761 ± 7	769 ± 7	0.403	756 ± 14	770 ± 15	0.527
Light	78 ± 4	69 ± 4	0.184	85 ± 9	71 ± 9	0.317
Moderate	15 ± 1	13 ± 1	0.509	18 ± 3	15 ± 3	0.528
Vigorous	1 ± 1	1 ± 1	0.394	1 ± 1	1 ± 1	0.370
At least 150 minutes MVPA per week	1 (ref)	0.85 (0.34 - 2.14)	0.727	1 (ref)	0.39 (0.07 - 2.07)	0.268
Intensity of PA (% of daily time)						
Sedentary	89.3 ± 0.6	90.4 ± 0.6	0.212	88.2 ± 1.3	90.0 ± 1.3	0.353
Light	8.9 ± 0.5	8.0 ± 0.5	0.177	9.6 ± 0.9	8.2 ± 1.0	0.316
Moderate	1.7 ± 0.1	1.5 ± 0.1	0.501	2.0 ± 0.3	1.7 ± 0.4	0.581
Vigorous	0.2 ± 0.1	0.1 ± 0.1	0.432	0.2 ± 0.1	0.1 ± 0.1	0.395

PA, physical activity; MVPA, moderate and vigorous physical activity. Results are expressed as mean ± sem for continuous variables and as odds ratio and (95% confidence interval) for categorical variables. Statistical analysis by analysis of variance for continuous variables and by logistic regression for categorical variables, adjusted for sex (male, female), age (continuous), BMI categories (normal, overweight, obese), smoking status (never, former, current), educational level (low, medium, high). Physical activity data assessed using the R-package GGIR version 1.5–9.

Table 1: multivariable analysis, self-reported physical activity by control group, stratified by survey, CoLaus|PsyCoLaus study, Lausanne, Switzerland.

	First survey (2009-2012)			Second survey (2014-2017)		
	Not controlled	**Controlled**	**p-value**	**Not controlled**	**Controlled**	**p-value**
Sample size	121	74		52	48	
Intensity of PA (min/day)						
Sedentary	527 ± 15	542 ± 19	0.543	525 ± 25	556 ± 26	0.395
Light	197 ± 10	166 ± 13	0.056	204 ± 16	176 ± 16	0.237
Moderate	186 ± 11	191 ± 15	0.819	181 ± 17	185 ± 18	0.864
Vigorous	32 ± 8	46 ± 10	0.250	43 ± 10	26 ± 11	0.262
At least 150 minutes MVPA per week	1 (ref)	NC		1 (ref)	0.85 (0.35 - 2.09)	0.731 §
Intensity of PA (% of daily time)						
Sedentary	56 ± 1.5	57.3 ± 2	0.608	54.8 ± 2.4	58.8 ± 2.5	0.257
Light	20.9 ± 1	17.7 ± 1.3	0.057	21.4 ± 1.6	18.8 ± 1.7	0.275
Moderate	19.7 ± 1.2	20.2 ± 1.5	0.798	19.3 ± 1.9	19.6 ± 1.9	0.291
Vigorous	3.4 ± 0.8	4.8 ± 1	0.260	4.6 ± 1	2.8 ± 1.1	0.257

PA, physical activity; MVPA, moderate and vigorous physical activity Results are expressed as standardized beta coefficients. Statistical analysis by linear regression adjusted for sex (male, female), age (continuous), BMI categories (normal, overweight, obese), smoking status (never, former, current), educational level (low, medium, high).

Supplementary table 6: multivariable analysis, association between self-reported physical activity and fasting plasma glucose, stratified by survey, CoLaus|PsyCoLaus study, Lausanne, Switzerland.

	First survey (2009-2012)	p-value	Second survey (2014-2017)	p-value
Sample size	195		100	
Intensity of PA (min/day)				
Sedentary	0.040	0.599	-0.080	0.455
Light	0.068	0.378	0.074	0.493
Moderate	0.003	0.968	0.070	0.517
Vigorous	-0.139	0.059	0.051	0.635
Intensity of PA (% of daily time)				
Sedentary	0.028	0.716	-0.120	0.271
Light	0.066	0.388	0.055	0.613
Moderate	0.003	0.972	0.083	0.439
Vigorous	-0.141	0.055	0.041	0.700

PA, physical activity; MVPA, moderate and vigorous physical activity. Results are expressed as standardized beta coefficients. Statistical analysis by linear regression adjusted for sex (male, female), age (continuous), BMI categories (normal, overweight, obese), smoking status (never, former, current), educational level (low, medium, high).

Supplementary table 7: multivariable analysis, association between objectively assessed physical activity and fasting plasma glucose, stratified by survey, CoLaus|PsyCoLaus study, Lausanne, Switzerland.

	Second survey (2014-2017)	p-value	Third survey (2018-2021)	p-value
Sample size	199		151	
Intensity of PA (min/day)				
Sedentary	-0.072	0.340	0.081	0.360
Light	0.203	0.005	0.126	0.152
Moderate	0.140	0.069	-0.051	0.589
Vigorous	0.012	0.871	-0.019	0.831
Intensity of PA (% of daily time)				
Sedentary	-0.145	0.061	0.021	0.827
Light	0.187	0.011	0.104	0.242
Moderate	0.103	0.188	-0.072	0.449
Vigorous	-0.007	0.928	-0.029	0.742

PA, physical activity; MVPA, moderate and vigorous physical activity. Results are expressed as standardized beta coefficients. Statistical analysis by linear regression adjusted for sex (male, female), age (continuous), BMI categories (normal, overweight, obese), smoking status (never, former, current), educational level (low, medium, high). Physical activity data assessed using the GENEActiv macro file 'General physical activity' version 1.9.

Supplementary table 8: multivariable analysis, association between objectively assessed physical activity and fasting plasma glucose, stratified by survey, CoLaus|PsyCoLaus study, Lausanne, Switzerland.

	Second survey (2014-2017)	p-value	Third survey (2018-2021)	p-value
Sample size	195		58	
Intensity of PA (min/day)				
Sedentary	-0.071	0.352	0.121	0.433
Light	0.154	0.052	-0.105	0.532
Moderate	0.078	0.339	-0.099	0.562
Vigorous	0.021	0.782	0.055	0.726
Intensity of PA (% of daily time)				
Sedentary	-0.141	0.080	0.256	0.102
Light	0.154	0.053	-0.101	0.547
Moderate	0.074	0.372	-0.100	0.557
Vigorous	0.012	0.880	0.067	0.670

PA, physical activity; MVPA, moderate and vigorous physical activity. Results are expressed as standardized beta coefficients. Statistical analysis by linear regression adjusted for sex (male, female), age (continuous), BMI categories (normal, overweight, obese), smoking status (never, former, current), educational level (low, medium, high). Physical activity data assessed using the R-package GGIR version 1.5–9.

Supplementary table 9: bivariate analysis, objectively assessed physical activity by diabetes control group as defined by glycated haemoglobin, stratified by survey, CoLaus|PsyCoLaus study, Lausanne, Switzerland.

	Second survey (2014-2017)			Third survey (2018-2021)		
	Not controlled	**Controlled**	**p-value**	**Not controlled**	**Controlled**	**p-value**
Sample size	123	76		95	56	
Intensity of PA (min/day)						
Sedentary	626 [532 - 697]	638 [569 - 731]	0.151	600 [509 - 693]	603 [520 - 687]	0.742
Light	89 [65 - 121]	81 [59 - 110]	0.113	90 [63 - 112]	82 [70 - 100]	0.455
Moderate	106 [62 - 162]	89 [54 - 134]	0.140	123 [63 - 166]	102 [53 - 151]	0.552
Vigorous	0 [0 - 1]	0 [0 - 1]	0.139	0 [0 - 2]	0 [0 - 2]	0.843
At least 150 minutes MVPA per week (%)	116 (94.3)	71 (93.4)	0.798	87 (91.6)	51 (91.1)	0.914
Intensity of PA (% of daily time)						
Sedentary	75.0 [68.2 - 83.1]	79.0 [72.0 - 85.2]	0.082	73.9 [66.3 - 83.9]	75.5 [68.4 - 82.3]	0.726
Light	11.0 [8.9 - 13.7]	9.9 [7.1 - 13.2]	0.074	11.2 [8.0 - 13.2]	10.1 [8.5 - 12.6]	0.520
Moderate	12.5 [7.9 - 19.6]	10.3 [7.2 - 16.7]	0.106	14.6 [7.6 - 19.4]	12.3 [7.6 - 17.7]	0.540
Vigorous	0 [0 - 0.2]	0 [0 - 0.1]	0.144	0 [0 - 0.2]	0 [0 - 0.2]	0.777

PA, physical activity; MVPA, moderate and vigorous physical activity. Results expressed as median [interquartile range] for continuous variables and as number of participants (column percentage) for categorical variables. Statistical analysis by Kruskal-Wallis test for continuous variables and chi-square for categorical variables. Physical activity data assessed using the GENEActiv macro file 'General physical activity' version 1.9.

Supplementary table 10: bivariate analysis, objectively assessed physical activity by diabetes control group as defined by glycated haemoglobin, stratified by survey, CoLaus|PsyCoLaus study, Lausanne, Switzerland.

	Second survey (2014-2017)			Third survey (2018-2021)		
	Not controlled	Controlled	p-value	Not controlled	Controlled	p-value
Sample size	119	76		38	20	
Intensity of PA (min/day)						
Sedentary	752 [719 - 812]	770 [722 - 827]	0.210	764 [727 - 803]	742 [706 - 819]	0.612
Light	69 [40 - 105]	60 [35 - 85]	0.146	77 [41 - 106]	68 [45 - 97]	0.935
Moderate	10 [5 - 19]	9 [4 - 17]	0.344	13 [6 - 22]	10 [7 - 17]	0.731
Vigorous	1 [0 - 1]	0 [0 - 1]	0.317	1 [0 - 2]	0 [0 - 1]	0.185
At least 150 minutes MVPA per week (%)	20 (16.8)	12 (15.8)	0.852	10 (26.3)	4 (20.0)	0.593
Intensity of PA (% of daily time)						
Sedentary	90.4 [85.5 - 94.3]	92.1 [87.6 - 95.1]	0.172	89.6 [85.5 - 94.1]	91.3 [87.1 - 93.5]	0.806
Light	7.9 [5.1 - 12.1]	6.9 [4.3 - 10.1]	0.116	8.6 [5.0 - 12.5]	7.6 [5.4 - 11.0]	0.909
Moderate	1.2 [0.6 - 2.2]	1.1 [0.4 - 2.0]	0.324	1.5 [0.7 - 2.4]	1.1 [0.8 - 2.0]	0.659
Vigorous	0.1 [0 - 0.2]	0 [0 - 0.2]	0.113	0.1 [0 - 0.2]	0.1 [0 - 0.1]	0.191

PA, physical activity; MVPA, moderate and vigorous physical activity. Results expressed as median [interquartile range] for continuous variables and as number of participants (column percentage) for categorical variables. Statistical analysis by Kruskal-Wallis test for continuous variables and chi-square for categorical variables. Physical activity data assessed using the R-package GGIR version 1.5–9.

Supplementary table 11: multivariable analysis, objectively assessed physical activity by control group as defined by glycated haemoglobin, stratified by survey, CoLaus|PsyCoLaus study, Lausanne, Switzerland.

	Second survey (2014-2017)			Third survey (2018-2021)		
	Not controlled	**Controlled**	**p-value**	**Not controlled**	**Controlled**	**p-value**
Sample size	119	76		38	20	
Intensity of PA (min/day)						
Sedentary	761 ± 6	770 ± 8	0.353	766 ± 12	756 ± 17	0.664
Light	76 ± 4	68 ± 5	0.221	76 ± 8	84 ± 11	0.570
Moderate	13 ± 1	15 ± 1	0.494	16 ± 3	18 ± 4	0.614
Vigorous	1 ± 1	1 ± 1	0.974	1 ± 1	1 ± 1	0.238
At least 150 minutes MVPA per week	1 (ref)	1.31 (0.53 - 3.28)	0.560	1 (ref)	0.62 (0.11 - 3.42)	0.586
Intensity of PA (% of daily time)						
Sedentary	89.5 ± 0.5	90.3 ± 0.7	0.392	89.4 ± 1.1	88.3 ± 1.6	0.571
Light	8.8 ± 0.4	7.9 ± 0.5	0.199	8.6 ± 0.8	9.5 ± 1.2	0.554
Moderate	1.5 ± 0.1	1.7 ± 0.2	0.484	1.8 ± 0.3	2.1 ± 0.4	0.580
Vigorous	0.1 ± 0.1	0.1 ± 0.1	0.982	0.2 ± 0.1	0.1 ± 0.1	0.228

PA, physical activity; MVPA, moderate and vigorous physical activity. Results are expressed as mean ± sem for continuous variables and as odds ratio and (95% confidence interval) for categorical variables. Statistical analysis by analysis of variance for continuous variables and by logistic regression for categorical variables, adjusted for sex (male, female), age (continuous), BMI categories (normal, overweight, obese), smoking status (never, former, current), educational level (low, medium, high). Physical activity data assessed using the R-package GGIR version 1.5–9.

Supplementary table 12: multivariable analysis, association between objectively assessed physical activity and glycated haemoglobin, stratified by survey, CoLaus|PsyCoLaus study, Lausanne, Switzerland.

	Second survey (2014-2017)	p-value	Third survey (2018-2021)	p-value
Sample size	199		151	
Intensity of PA (min/day)				
Sedentary	-0.072	0.340	0.081	0.360
Light	0.203	0.005	0.126	0.152
Moderate	0.140	0.069	-0.051	0.589
Vigorous	0.012	0.871	-0.019	0.831
Intensity of PA (% of daily time)				
Sedentary	-0.145	0.061	0.021	0.827
Light	0.187	0.011	0.104	0.242
Moderate	0.103	0.188	-0.072	0.449
Vigorous	-0.007	0.928	-0.029	0.742

PA, physical activity; MVPA, moderate and vigorous physical activity. Results are expressed as standardized beta coefficients. Statistical analysis by linear regression adjusted for sex (male, female), age (continuous), BMI categories (normal, overweight, obese), smoking status (never, former, current), educational level (low, medium, high). Physical activity data assessed using the GENEActiv macro file 'General physical activity' version 1.9.

Supplementary table 13: multivariable analysis, association between objectively assessed physical activity and glycated haemoglobin, stratified by survey, CoLaus|PsyCoLaus study, Lausanne, Switzerland.

	Second survey (2014-2017)	p-value	Third survey (2018-2021)	p-value
Sample size	195		58	
Intensity of PA (min/day)				
Sedentary	-0.071	0.352	0.121	0.433
Light	0.154	0.052	-0.105	0.532
Moderate	0.078	0.339	-0.099	0.562
Vigorous	0.021	0.782	0.055	0.726
Intensity of PA (% of daily time)				
Sedentary	-0.141	0.080	0.256	0.102
Light	0.154	0.053	-0.101	0.547
Moderate	0.074	0.372	-0.100	0.557
Vigorous	0.012	0.880	0.067	0.670

PA, physical activity; MVPA, moderate and vigorous physical activity. Results are expressed as standardized beta coefficients. Statistical analysis by linear regression adjusted for sex (male, female), age (continuous), BMI categories (normal, overweight, obese), smoking status (never, former, current), educational level (low, medium, high). Physical activity data assessed using the R-package GGIR version 1.5–9.