Acute Effects of Daily Life Spontaneous and Structured Physical Activity on Glycemia in Children with Type 1 Diabetes

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ABSTRACT

MELIN, A., E. LESPAGNOL, S. TAGOUGUI, J. DEREUMETZ, P. MOREL, S. BERTHOIN, C. PARENT, A. COQUART, C. STUCKENS, C. LEFEVRE, G. BAQUET, R. RABASA-LHORET, and E. HEYMAN. Acute Effects of Daily Life Spontaneous and Structured Physical Activity on Glycemia in Children with Type 1 Diabetes. *Med. Sci. Sports Exerc.*, Vol. 57, No. 9, pp. 1838–1851, 2025. **Objectives:** In type 1 diabetes, glycemia management is rendered complex through the confounding influence of spontaneous physical activity (PA), particularly frequent in children. We aim to understand the glycemic effects of self-reported PA and cumulative spontaneous PA in their everyday life, controlling for carbohydrate intake and insulin. **Methods:** In this 7-d observational study, 45 children/adolescents (21 females, 11.7 ± 3.4 yr) wore a continuous glucose monitoring system and accelerometer, completing diaries about PA, diet, and insulin. Types of PA included (i) self-reported PA and its characteristics (duration, subjective intensity) and conditions (previous sessions, timing and pre-exercise carbohydrate intake, insulin-on-board, glycemia), and (ii) spontaneous cumulative PA (accelerometry) adjusted for sedentary time. Linear mixed models were used with results expressed as the estimated coefficient "*e*." In cases of skewed continuous dependent outcomes containing a preponderance of zero % values, random-intercept binary logistic regressions were used with results expressed as odds ratios (OR). **Results:** Accumulating moderate-to-vigorous PA during the late afternoon ($e = -0.32$, $P = 0.039$) was associated with decreased concomitant time spent >13.9 mmol·L^{-1}. Time spent >10.0 mmol·L^{-1} during self-reported PA was lower when children consumed less high-glycemic-index carbohydrates the previous hour ($e = +0.49$, $P = 0.034$; albeit found only in one model out of two) or were physically active before the session (tendency: $e = -11.58$, $P < 0.07$). PA conditions were not significantly associated with hypoglycemia. Risk of spending some time <3.9 mmol·L^{-1} during sessions was higher in the case of longer PA duration (OR = 1.02, $P = 0.008$). Risk of nocturnal time <3.0 mmol·L^{-1} was greater when children performed longer duration structured PA (OR = 1.02, $P = 0.054$) or accumulated more afternoon vigorous-intensity PA (OR = 1.06, $P = 0.04$). **Conclusions:** Increasing spontaneous active behavior during the late afternoon could help reduce daytime spent >13.9 mmol·L^{-1}. There is a possibility that hyperglycemia during exercise could be limited by multiplying daily PA sessions or avoiding excessive pre-exercise carbohydrate intake. However, as only sessions characteristics, especially duration, predicted time <3.9 mmol·L^{-1} during PA and <3.0 mmol·L^{-1} the following night, simplified guidelines (not considering PA conditions) on hypoglycemic risk could be developed. **Key Words:** ACCELEROMETERY, CARBOHYDRATES, EXERCISE, HYPERGLYCEMIA, HYPOGLYCEMIA, MONITORING AMBULATORY

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In type 1 diabetes, being physically active can improve quality of life, physical fitness, body composition, lipid profile, and cardiac function (1–4). Encouraging active behavior from childhood is important in setting foundations for healthier lifestyles in adult life (5). However, many children with type 1 diabetes do not meet physical activity (PA) guidelines (6) and are less active than their nondiabetic peers (7). Risks of hypoglycemia and, albeit to a lesser extent, of hyperglycemia represent two main barriers to PA in children with type 1 diabetes (6).

Contrary to what happens in nondiabetic individuals, exogenous insulin in those with type 1 diabetes cannot be adjusted

once administered. As a result, PA can lead to hypoglycemia due to factors such as increased muscle glucose uptake alongside reduced hepatic glucose production, accelerated insulin absorption, enhanced insulin sensitivity during recovery, and nighttime glycogen store repletion. Conversely, PA may also result in hyperglycemia, particularly during high-intensity exercise (8,9), due to the impact of catecholamines on hepatic glucose production and of muscle lactate oxidation on spare blood glucose (10).

Studies have historically focused on exercise-induced hypoglycemia prevention (11), with limited consideration for the hyperglycemic risk (9). Such studies typically occurred in controlled laboratory settings (12–14). Laboratory conditions fail to capture the diversity of real-life PA scenarios, including the multiple possible variations and interaction of intensity, duration, timing, repeated bouts of exercise as well as glucose values, trends and possible insulin therapy adjustments, and/or snack intake.

Only a limited number of studies have examined the links between self-reported PA sessions and glycemic metrics in real-world settings. Some of these studies focused on standardized PA sessions, which did not fully capture the variety of daily-life PA situations. For instance, participants were randomly assigned to complete one of three video-guided exercises at home, totaling at least six sessions over a 4-wk observational period (15,16). To the best of our knowledge, only five studies have so far explored the effects of free-living (i.e., not study-assigned) self-reported PA sessions in adults (17–19) or adolescents (20,21) with type 1 diabetes. These studies suggest that a greater duration (17–19,21) or intensity (17) of exercise as well as lower glucose levels or higher insulin-on-board prior to exercise (17,19) may increase hypoglycemic risk during exercise (19) and the subsequent 24-h period (17,18,21).

Besides, the impact of everyday life PA on glycemia is confounded by the interference of accumulated spontaneous PA (i.e., not identified by the participant), and especially in childhood (e.g., getting up to go to the blackboard in class, playing at home) (22). Eight studies (five in adults [23–27], three in children/adolescents [28–30]), based on models including within- and between-participant effects, explored the association between glycemic outcomes and incrementing cumulative PA measured with activity trackers and expressed as a continuous outcome (i.e., not merely a simple comparison between glycemic metrics averaged across days classified into two or three categories of cumulative PA). They showed that longer time spent in moderate and/or vigorous PA (26–28,30) or total PA (23,27) increased hypoglycemic risk during the concomitant awake (27) and subsequent nocturnal (26–28,30) period, as well as decreased postprandial glucose levels of the first- (29) or last- (24) bolused meal of the day. However, these studies did not consider the confounding effect of sedentary time.

Dietary carbohydrates (CHO) are a major determinant of glycemia and one of the primary strategies offered to individuals for manage glycemia around exercise. Of the 13 studies on everyday life PA mentioned previously, only one controlled analysis using accurately recorded CHO intake (i.e., through food diaries rather than relying on CHO subjectively counted by the participant) (29). However, this study investigated only a limited 4-h period following breakfast. However, appetite and spontaneous energy intake are known to be influenced by exercise itself and its characteristics (31).

Moreover, the risk of hyperglycemia has been only rarely considered (15,18,25,29), with (i) no available data on the association between spontaneous accumulated PA and daytime or nighttime hyperglycemia and (ii) no information on hyperglycemia during self-reported PA sessions. Hyperglycemia during these periods could nonetheless have consequences on sports performance (32) or vascular complications (33) over the short or long term.

Our study aims to explore how the characteristics (intensity, duration) and conditions (e.g., number of previous sessions; timing; pre-exercise CHO intake, insulin on board, glycemia) of self-reported PA sessions in everyday life are associated with glycemic metrics during and after exercise in children living with type 1 diabetes. We also investigated the associations between objectively measured cumulative (i.e., including nonidentified spontaneous activities) moderate and/or vigorous PA as well as of sedentary time with both hypo- and hyperglycemic risks during several clinically relevant periods (e.g., daytime, postprandial, nighttime). In all the analyses, confounding factors such as participant characteristics, insulin, and food intake were considered.

METHODS

Study Design

This observational cross-sectional retrospective study (from 2016 to 2022) is part of a noninterventional educational therapeutic program (Data Protection and Freedom of Information, declaration 026-03-13-GC/VB). It was approved by the CERSTAPS (France) ethics committee (No. IRB00012476-2023-26-06-258) and was performed in accordance with the ethical standards as laid down in the 1964 Declaration of Helsinki and its later amendments or comparable ethical standards.

Participants

Fifty-eight children and adolescents (Fig. 1) attending the Pediatric Unit at Lille University Hospital (France) volunteered for this study. The inclusion criteria specified an age range of ≥4 and <19 yr, diagnosis of type 1 diabetes for >1 yr, and no change in insulin delivery method (i.e., multiple daily injections (MDI) or continuous subcutaneous insulin infusion (CSII)) over the previous 3 months. Children and their parents were orally informed that, after anonymization, their data could be used for research analyses and publication. Parents of children who did not routinely wear a CGM device gave their written informed consent for the insertion of the iPro2 (Enlite, Medtronic) sensor and the analysis of CGM data. Their children provided informed assent.

Procedures

At a first visit, we provided the equipment to be worn (accelerometer, continuous glucose monitoring (CGM) sensor for those without) and the diaries to be completed (PA, diet, insulin) during the 7 subsequent free-living days.

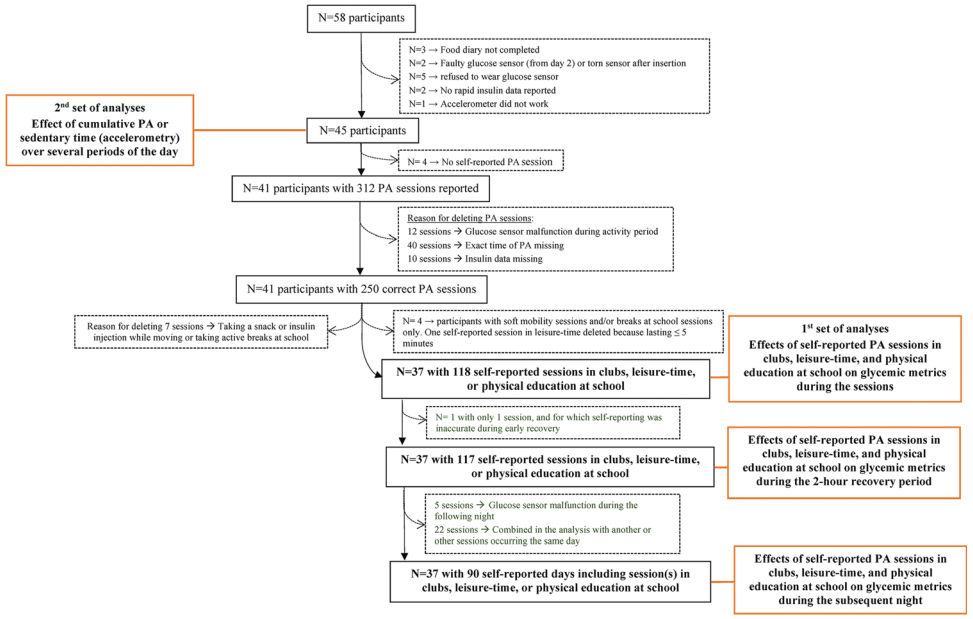

FIGURE 1—Trial profile.

CGM. For participants who did not use an intermittently scanned CGM sensor (value every 15 min) on a day-to-day basis (Table 1), a professional masked CGM sensor (Enlite iPro2, Medtronic; value every 5 min) was inserted, and they were asked to measure capillary blood glucose levels at least 4 times per day for subsequent sensor calibration. Glycemia changes during reported PA sessions as well as percentage times spent in hypoglycemia (<3.0 mmol·L^{-1} for level 1, <3.9 mmol·L^{-1} for level 2), normoglycemia (between 3.9 and 7.8 mmol·L^{-1} [34] or 3.9 and 10.0 mmol·L^{-1}), hyperglycemia (>10.0 mmol·L^{-1} for level 1, >13.9 mmol·L^{-1} for level 2), and glycemic variability (coefficient of variation) (35,36) over specific time periods (Supplemental Tables 1 and 2, Supplemental Digital Content, http://links.lww.com/MSS/D228) were calculated (Supplemental Table 2, Supplemental Digital Content, http://links.lww.com/MSS/D228). Only periods with at least 70% of CGM values were kept for analyses.

PA recordings. In the 7-d diary, children were helped by an adult to report scheduled (routinely or occasionally) and unscheduled PA sessions at sports clubs, in leisure time, and at school, as well as when moving around or during active breaks at school. They indicated the type of PA and its time, duration, and subjective intensity (light, moderate, or vigorous).

Participants wore a uniaxial accelerometer (ActiGraph, GT1M, epoch set at 5 s to better detect very short bouts of vigorous PA) on their right hip from the moment they woke up until bedtime (times recorded in the diary). For a day to be valid, the accelerometer had to be worn for at least 10 h per weekday or 8 h per weekend day (37,38). Data were analyzed using ActiLife software (version 6.13.3), excluding nonwear periods as defined by Troiano et al. (39) (i.e., at least 60 min of consecutive zeros, allowing for up to 2 min of nonzero interruptions) and using thresholds for activity levels (101–2295 accelerometer counts per minute as light intensity, 2296–4011 counts per minute as moderate intensity, ≥4012 counts per minute as vigorous intensity) and sedentary time (≤100 accelerometer counts per minute) from Evenson et al. (40). These thresholds were selected due to their validation in children through comparison with calorimetry in studies involving short epochs (15 s) and wide ranges of PA types (for a review, see Herman-Hansen et al. [41]). Accelerometry data were analyzed throughout the day as well as during specific periods including morning, afternoon, and late afternoon (Table 2). Moderate-to-vigorous PA (MVPA) was also analyzed during the aforementioned self-reported PA sessions.

Diet and insulin recordings. For each meal/snack, participants (assisted by an adult) recorded the time, type, and amount of food consumed, with the option of photographing the snack or the meal in its container (adding a second photo when the participant did not finish the meal) and/or of weighing the ingredients. During a follow-up appointment after the 7-d recordings period, participants and their parents were interviewed by research staff to meticulously gather additional details, such as brand names, fat content, cooking methods, and portion sizes. When participants did not photograph their meals or weigh the ingredients, portion sizes were estimated using the "SUIVIMAX" booklet containing standardized meal photographs. These detailed food diaries, cross-checked with meal photographs when available, enabled accurate estimation of both the quantity and quality of macronutrients consumed. Low and high glycemic index CHO values were determined for each meal/snack.

For each snack or meal taken, participants were instructed to record the doses and timing of rapid-acting insulin or bolus insulin administered. The diary included dedicated sections to log additional doses of rapid-acting insulin or bolus insulin given throughout the day, as well as any adjustments to long-acting insulin (though these were relatively infrequent) or basal rate changes for MDI or CSII users, respectively.

TABLE 1. Participant characteristics (n = 45).

	Mean ± SD (Min–Max)	Further Details
Anthropometric and demographic data		
Age (yr)	11.7 ± 3.4 (4.0–18.2)	<10 yr: n = 14, >10 yr: n = 31
Sex (boys/girls), n	24/21	
BMI (kg·m^{-2})	19.3 ± 4.3 (14.0–35.9)	
z-Score for BMI	0.4 ± 1.2 (−1.9–3.2)	Between +1 SD and +2 SD, overweight: n = 10, >+2 SD, obesity: n = 3
HbA_{1c} (%)	7.7 ± 1.0 (6.1–11.1)	<7.0: n = 11, <7.5: n = 21, >8.0: n = 16
HbA_{1c} (mmol·mol^{-1})	61.1 ± 11.5 (43.2–97.8)	
Diabetes duration (yr)	5.7 ± 3.8 (0.9–14.3)	>10.0: n = 7, <10.0: n = 38
Insulin delivery[a] (CSII/MDI), n	21/24	
Usual daily insulin dose (U·kg^{-1}·d^{-1})	1.0 ± 0.4 (0.3–2.4)	
CGM users in everyday life	n = 5	System used: FreeStyle Libre Flash, Abbott Diabetes Care
Gold score[b]	2.4 ± 1.3 (n = 38)	Score ≥4: n = 8
PWC_{170} (W·kg^{-1})	1.9 ± 0.5 (0.8–2.7) (n = 34)	
Weekly daytime (from the beginning to the end of the day) CGM data		
Mean sensor glucose (mmol·L^{-1})	9.4 ± 1.8 (5.7–14.2)	
% time <3.0 mmol·L^{-1}	2.2 ± 4.1 (0.0–18.0)	≥1% of time for n = 17
% time <3.9 mmol·L^{-1}	7.2 ± 7.9 (0.0–40.4)	≥4% of time for n = 25
% time between 3.9 and 10.0 mmol·L^{-1}	52.3 ± 14.9 (25.4–85.0)	≤70% of time for n = 38
% time >10.0 mmol·L^{-1}	40.5 ± 17.9 (1.4–72.2)	≥25% of time for n = 37
% time >13.9 mmol·L^{-1}	15.4 ± 11.5 (0.0–51.7)	≥5% of time for n = 36
Coefficient of variation (%)	35.2 ± 7.0 (22.6–56.9)	>36% for n = 18
Weekly nighttime (from 2 h post-dinner to breakfast the next day) CGM data		
Mean sensor glucose (mmol·L^{-1})	9.3 ± 2.4 (4.3–14.5)	
% time <3.0 mmol·L^{-1}	4.2 ± 8.7 (0.0–52.0)	≥1% of time for n = 20
% time <3.9 mmol·L^{-1}	10.2 ± 13.9 (0.0–61.3)	≥4% of time for n = 25
% time between 3.9 and 10.0 mmol·L^{-1}	49.0 ± 19.5 (10.9–89.2)	≤70% of time for n = 39
% time >10.0 mmol·L^{-1}	40.8 ± 24.3 (0.0–89.1)	≥25% of time for n = 32
% time >13.9 mmol·L^{-1}	15.6 ± 15.2 (0.0–53.3)	≥5% of time for n = 29
Coefficient of variation (%)	24.6 ± 7.6 (13.6–46.8)	>36% for n = 2
Objective usual PA (from 7-d accelerometery)		
Total time in MVPA (min·d^{-1})	52.9 ± 21.1 (24.4–102.2)	At least 60 min·d^{-1}, n = 12
Total time in MVPA (min per weekday)	51.5 ± 21.3 (18.9–99.4) (n = 42)	At least 60 min per weekday, n = 16
Total time in MVPA (min per weekend day)	48.9 ± 28.7 (8.6–114.9) (n = 43)	At least 60 min per weekend day, n = 12
Total time in light PA (min·d^{-1})	195.6 ± 74.8 (72.6–395.2)	
Total time in moderate PA (min·d^{-1})	33.5 ± 12.3 (16.7–69.2)	
Total time in vigorous PA (min·d^{-1})	16.1 ± 9.6 (0.4–40.5)	
Total sedentary time (min·d^{-1})	582.6 ± 106.1 (346.2–786.4)	
Total sedentary breaks (min·d^{-1})	125.1 ± 29.9 (45.6–396.2)	
Three main barriers to PA (BAPAD-1 score, 7-point Likert scale)[c]		
Fear of hypoglycemia	3.7 ± 2.1 (n = 40)	Score >4: n = 17
Fear of loss of diabetes control	2.8 ± 1.9 (n = 40)	Score >4: n = 9
Weather conditions	2.7 ± 1.8 (n = 38)	Score >4: n = 7

In the column displaying "Mean ± SD (min–max)," the number of subjects is indicated for outcomes where some data are lacking. The HbA_{1c} is the last one performed within the 3 months before the laboratory visit. Sex was self-reported.
[a] None closed-loop.
[b] Gold questionnaire hypoglycemia awareness score.
[c] BAPAD-1, the questionnaire on barriers to PA is rated on a scale of 1 to 7 (1 = extremely unlikely to 7 = extremely likely).
PWC_{170}, physical work capacity test at 170 bpm, as an indicator of aerobic fitness.

TABLE 2. Periods of the day considered for glycemic outcomes (dependent variables) and for PA/sedentary, insulin, and diet covariates used in the 2nd set of analyses.

Periods Considered for the Glycemic Outcomes (Dependent Variable)	Periods of the Day Considered for Cumulative PA and Sedentary Outcomes (Covariates)	Insulin Administration Considered (Covariate)	Dietary Intake Considered (Covariate)
Day	Day	Sum of long (or basal) and rapid-acting insulin during the same period as that for glycemic outcome	All CHO during the same period as that for glycemic outcome
Morning	Morning		
Afternoon	Afternoon		
Late afternoon	Late afternoon		
Lunch	Morning	Rapid-acting insulin during the same period as that for glycemic outcome	All CHO during the same period as that for glycemic outcome
Dinner	Afternoon		
Dinner	Late afternoon		
Subsequent night	Day	Sum of long (or basal) and rapid-acting insulin during subsequent night	All night CHO (including sum of low and high glycemic index CHO consumed during subsequent night + only low glycemic index CHO from dinner)
Subsequent night	Afternoon		
Subsequent night	Late afternoon		

Day, waking-up to bedtime; Subsequent night, from 2 h post-dinner to breakfast the next day; Lunch, from start of lunch to 2 h later; Dinner, from start of dinner to 2 h later; Morning, from waking up to start of lunch; Afternoon, from 1 h post-lunch to start of dinner; Late afternoon, from 5 PM to start of dinner.

Statistical Analyses

As this was a convenience sample retrospective analysis, we included all available participant data without calculating an *a priori* sample size. However, we found *a posteriori* good statistical power (e.g., 69% for the association between the duration of self-reported PA session and level 1 hypoglycemia during the session; 87% for the association between vigorous PA accumulated throughout the day on subsequent night level 2 hypoglycemia) for our significant effects (calculated using the "powerSim" function from the "Simr" package in R software). As expected, associations with a P value >0.1 exhibited low statistical power and should be interpreted as insufficient evidence to suggest an association.

Statistical analysis used IBM SPSS version 28.0. Linear mixed models or binary logistic regressions with random intercept were used to assess the association between free-living PA and glycemic metrics (Supplemental Table 2, dependent variables, Supplemental Digital Content, http://links.lww.com/MSS/D228), consistently controlling in all the models for food intake, insulin administration (Supplemental Tables 1 and 2, Supplemental Digital Content, http://links.lww.com/MSS/D228) and participant characteristics: age, children/adolescent ">10 vs <10 yr," sex, body mass index (BMI) z-score, diabetes duration, "MDI vs CSII" treatment method, usual daily insulin dose ($U \cdot kg^{-1} \cdot d^{-1}$), last HbA_{1c}, training level as reflected by average MVPA for a typical week ($min \cdot d^{-1}$) (42). In all models, a random participant intercept was included.

In the first set of analyses, we explored the associations between self-reported PA sessions and glycemic metrics during the session, during the 2 h post-session (early recovery) and from 2 h post-dinner to breakfast the next day (late recovery). PA sessions included only sports (clubs, physical education at school) and leisure-time sessions in the main analysis (Fig. 1). Explanatory variables added in the models included PA characteristics (in successive models i) duration and subjective intensity and ii) objectively measured time spent in MVPA, with accelerometry, during the session) as well as PA conditions (time, pre-exercise CHO intake, insulin-on-board, time elapsed from last bolus, pre-exercise glucose, CGM delta during the 30-min pre-exercise period, number of previous sessions in the same day; Supplemental Tables 1 and 4, Supplemental Digital Content, http://links.lww.com/MSS/D228).

In the second set of analyses, we explored the associations between cumulative PA and sedentary time (accelerometry recorded) over different periods of the day on concomitant or subsequent glycemic (CGM) outcomes (Table 2). Cumulative PA characteristics included in successive models were i) MVPA and sedentary time (43,44), ii) number of sedentary breaks (i.e., each interruption in sedentary time (accelerometer counts per minute > 100)) and sedentary time, iii) time spent in vigorous-intensity PA adjusted with light- and moderate-intensity PA (Supplemental Table 4, Supplemental Digital Content, http://links.lww.com/MSS/D228). In all models, CGM value at the start of the period considered for glycemic outcomes was included as a covariate.

The random-intercept binary logistic regressions were used in cases of skewed continuous dependent outcomes containing a preponderance of zero % values. These outcomes were transformed into categorical variables with two categories, that is, one category for 0% and the other for values greater than 0%.

Results are expressed as the estimated coefficient ("e") for both linear mixed models and binary logistic regressions, and for binary logistic regressions also as odds ratios (OR). For all the linear mixed model, residuals for both fixed and random effects were checked, and the assumption of normality appeared to be met (based on Q-Q plots). The hypothesis of no collinearity was checked using Variance Inflation Factor calculations. To account for repeated analyses, Bonferroni corrections were applied to P values based on the number of models focused on a same dependent outcome. After correction, $P \leq 0.05$ was considered statistically significant, and $P < 0.1$ was considered a tendency. These associations with significant P values or with tendency are explicitly presented in the results and addressed in the discussion only when their magnitude is deemed meaningful from real-word and physiological perspectives (45).

RESULTS

Participant characteristics are summarized in Table 1 and Supplemental Table 5 (Supplemental Digital Content, http://links.lww.com/MSS/D228). None were using hybrid closed loop systems. Participants averaged 52.9 ± 21.1 min of MVPA per day. Only 27% of the sample met the PA guidelines (i.e., to an average of 60 min of MVPA per day, over a week [46]). Of the 58 children/adolescents included in the study, 17 were excluded from the first set of analyses and 13 from the second set due to faulty glucose or accelerometers sensors and/or data missing in the diaries or, for the first of analyses, no self-reported PA sessions (Fig. 1). For the 40 participants who wore the iPro2 sensor, 82% of the days and nights were calibrated using at least four capillary glycemia per day and 15% using three capillary glycemia per day. All the data were used. Glycemic metrics obtained around self-reported PA sessions and during the day and nighttime periods studied are displayed in Supplemental Tables 6 and 7, respectively (Supplemental Digital Content, http://links.lww.com/MSS/D228). Table 3 gives details of characteristics and conditions for the 118 self-reported PA sessions, of which 5 were stopped due to participant-perceived hypoglycemia (Supplemental Table 8, Supplemental Digital Content, http://links.lww.com/MSS/D228). Magnitude of the associations between covariates and dependent variables that were significant or with a tendency is presented in Table 4.

First Set of Analyses on Self-Reported PA Sessions (N = 41)

Associations with self-reported PA session characteristics. Duration of self-reported sessions was a predictor of the probability of spending time <3.9 $mmol \cdot L^{-1}$ during exercise. However, their subjective intensity was not. Duration and MVPA of self-reported PA sessions were predictive (with a tendency or significantly, respectively) of time spent in level 2 hypoglycemia during the subsequent night, and this to a greater extent for MVPA (indicated by a higher estimated

TABLE 3. Conditions and characteristics of the 118 self-reported sessions in clubs, leisure-time, and physical education at school.

	Mean ± SD (Min–Max)	Further Details
Conditions of the sessions		
Pre-exercise glycemia (CGM value at the start of session) (mmol·L^{-1})	10.1 ± 4.3 (2.2–24.9)	<5.5 mmol·L^{-1} for 13 sessions (11%), <6.6 mmol·L^{-1} for 22 sessions (19%), >10.0 mmol·L^{-1} for 55 sessions (47%), >13.9 mmol·L^{-1} for 15 sessions (13%), >16.6 mmol·L^{-1} for 8 sessions (7%)
CGM delta during the 30-min pre-exercise period (mmol·L^{-1})	+0.2 ± 1.9 (–4.4 to +6.4)	Decreasing value for 55 sessions (47%)
Time from last bolus to start of exercise (min)	158.3 ± 162.0 (0.0–1020.0)	98 out of 118 sessions were performed in the postprandial state (i.e., ≤4 h from last meal with a bolus) (83%)
Insulin on board[a] at the start of the session (U)	0.112 ± 0.07 (0.019–0.45)	
High glycemic index CHO consumed in the hour before exercise (g)	6.6 ± 13.6 (0.0–79.2)	42 out of 118 sessions were performed after consuming some high glycemic index CHO 1 h before (36%), including on average 18.8 ± 17.2 g (min 1.5–max 79.2)
Morning (6:00 AM to 12:00 PM) vs afternoon (12:00 PM to bedtime)		84 out of 118 sessions were performed during the afternoon (71%)
Number of days including more than one session		18 d (concerns 12 children with a maximum of 4 sessions per day) (15%)
Characteristics of the sessions		
Duration of the sessions (min)	74.5 ± 41.1 (16.0–229.0)	>20 min for 114 sessions (97%), >30 min for 94 sessions (80%), >60 min for 55 sessions (47%), >90 min for 35 sessions (30%)
Total time in light intensity during the sessions (min)	26.2 ± 17.8 (0.1–17.8)	No sessions were exclusively light intensity
Total time in moderate intensity during the sessions (min)	8.5 ± 7.4 (0.0–43.0)	5 out of 110 sessions of moderate intensity did not have any vigorous intensity (5%)
Total time in vigorous intensity during the sessions (min)	9.5 ± 9.9 (0.0–26.9)	No sessions were exclusively vigorous intensity
Total time in MVPA during the sessions (min)	17.9 ± 15.0 (0.0–82.2)	>10 min for 71 sessions (60%), >20 min for 39 sessions (33%), >30 min for 19 sessions (16%), >45 min for 7 sessions (7%), >60 min for 2 sessions (2%)
Subjective intensity of the sessions		Of 118 sessions, intensity was self-reported as vigorous for 36 sessions (31%), moderate for 60 sessions (51%), and light for 22 sessions (19%)

[a] Calculated using [(∑ rapid-acting insulin in the 4 h before exercise × (1 – (time between exercise and bolus insulin/4)) + (basal insulin 4 to 3 h before exercise × 0.25 + basal insulin 3 to 4 h before exercise × 0.5 + basal insulin 3 to 2 h before exercise × 0.75 + basal insulin in the hour before exercise))/daily insulin dose in units]; for MDI users, we divided daily basal insulin by 24 h (47).

coefficient as in Table 4, lower Akaike and Bayesian Information Criteria, and greater sensitivity; Fig. 2A).

Time spent in hyperglycemia during exercise was not significantly associated with exercise characteristics (Supplemental Table 9, Supplemental Digital Content, http://links.lww.com/MSS/D228).

Longer time spent in MVPA during exercise was associated with higher glycemic variability during sessions and late recovery.

Associations with conditions of self-reported PA sessions. Low or high pre-exercise glycemia logically respectively predicted hypoglycemia or hyperglycemia (Fig. 2B) during exercise and early recovery (Supplemental Table 9, Supplemental Digital Content, http://links.lww.com/MSS/D228).

Higher initial glycemia was associated with a greater decrease in glycemia during exercise, whereas it was associated with a higher glycemia increase during early recovery (Fig. 3).

Starting PA a long time away from a bolus (tendency) or after consuming high-glycemic-index CHO (significant) in the previous hour was associated with a longer time >10.0 mmol·L^{-1} during exercise, but this was found only in one model out of two (Fig. 2B). Conversely, this hyperglycemic risk during exercise tended to be reduced if children did other PA sessions on the same day before the one in question (Fig. 2B). Neither pre-exercise high-glycemic-index CHO nor performing additional PA sessions was significantly associated with hypoglycemic risk.

Morning versus afternoon PA sessions were associated with increased level 1 hypoglycemia risk during early recovery (tendency), whereas it was significantly associated with a decrease in the risk of level 1 hyperglycemia (significant) and an increase in time in range (tendency; Supplemental Fig. 1, Supplemental Digital Content, http://links.lww.com/MSS/D228).

Second Set of Analyses on Associations with Objectively Measured Cumulative Moderate and/or Vigorous PA and of Sedentary Time (*N* = 45)

Accumulating more MVPA during the late afternoon was concomitantly associated with less time spent in level 2

TABLE 4. Magnitude of associations between dependent variables and covariates with significance or a tendency (1st and 2nd sets of analyses).

Magnitude of Change for the Explanatory Variable (Covariate)	Magnitude of the Effect on the Dependent Variable	*P* Value
Interpretation of linear mixed models results		
For a 30-min increase in the duration of the self-reported PA session	The mean coefficient of variation during exercise would increase by 3 percentage points	$P = 0.002$
For a 30-min increase in MVPA during the self-reported PA session	The mean coefficient of variation during exercise would increase by 8.6 percentage points	$P = 0.002$
For a 30-min increase in the duration of the self-reported PA session	The mean coefficient of variation during late recovery would increase by 2.4 percentage points	$P = 0.004$
For a 30-min increase in MVPA during the self-reported PA session	The mean coefficient of variation during late recovery would increase by 6.2 percentage points	$P = 0.03$
For a 2.78-mmol·L^{-1} increase in pre-exercise glycemia[a]	The mean Δ of glycemia during the self-reported PA session would decrease by 0.96 mmol·L^{-1}	$P = 0.002$
For a 2.78-mmol·L^{-1} increase in pre-exercise glycemia[a]	The mean Δ of glycemia during early recovery of the self-reported PA session would increase by 0.89 mmol·L^{-1}	$P = 0.006$
For a 180-min increase in time from last bolus to start of exercise[a]	The mean percentage of time spent >10.0 mmol·L^{-1} during the self-reported PA session would increase by 9.2 percentage points	$P = 0.052$
For a 180-min increase in time from last bolus to start of exercise[a]	The mean coefficient of variation during the self-reported PA session would decrease by 3.2 percentage points	$P = 0.07$
For a 15-g increase in high glycemic index CHO consumed during the hour before exercise[a]	The mean percentage of time spent >10.0 mmol·L^{-1} during the self-reported PA session would increase by 7.4 percentage points	$P = 0.034$
For a 15-g increase in high glycemic index CHO consumed during the hour before exercise[a]	The mean Δ of glycemia during the self-reported PA session would increase by 0.76 mmol·L^{-1}	$P = 0.07$
For a 5-U increase in insulin administered during early recovery of self-reported PA session[a]	The mean coefficient of variation during early recovery would decrease by 3.7 percentage points	$P = 0.046$
For one additional previous PA session during the same day[a]	The mean percentage of time spent >10.0 mmol·L^{-1} during the self-reported PA session would decrease by 11.6 percentage points	$P = 0.054$
For one additional previous PA session during the same day[a]	The mean percentage of time spent between 3.9 and 10.0 mmol·L^{-1} during the self-reported PA session would increase by 15.8 percentage points	$P = 0.04$
For one additional previous PA session during the same day[a]	The mean Δ of glycemia during the self-reported PA session would decrease by 1.39 mmol·L^{-1}	$P = 0.04$
For one additional previous PA session during the same day[a]	The mean percentage of time spent between 3.9 and 10.0 mmol·L^{-1} during early recovery would increase by 15.9 percentage points	$P = 0.06$
When the period of the day changes from afternoon to morning[a]	The mean percentage of time spent >10.0 mmol·L^{-1} during early recovery would decrease by 18.4 percentage points	$P = 0.034$
When the period of the day changes from afternoon to morning[a]	The mean percentage of time spent between 3.9 and 10.0 mmol·L^{-1} during early recovery would increase by 16.5 percentage points	$P = 0.07$
Accumulating 30 additional minutes of MVPA during the morning	The mean percentage time spent <3.9 mmol·L^{-1} during the morning would increase by 5.0 percentage points	$P = 0.03$
For a 5-U increase in insulin administered during the morning[b]	The mean percentage of time spent >13.9 mmol·L^{-1} during the morning would decrease by 5.5 percentage points	$P = 0.02$
For a 100-g increase in total CHO intake during lunch[b,c]	The mean percentage of time spent >10.0 mmol·L^{-1} during the postprandial lunch period would increase by 21.2 percentage points	$P = 0.08$
Accumulating 15 additional minutes of vigorous-intensity PA during the afternoon	The mean percentage of time spent between 3.9 and 7.8 mmol·L^{-1} during the afternoon would decrease by 9.1 percentage points	$P = 0.01$
Accumulating 60 additional minutes of sedentary time during the afternoon	The mean percentage of time spent >10.0 mmol·L^{-1} during the afternoon would increase by 4.6 percentage points	$P = 0.024$
Accumulating 60 additional minutes of sedentary time during the afternoon	The mean percentage of time spent between 3.9 and 7.8 mmol·L^{-1} during the afternoon would decrease by 4.2 percentage points	$P = 0.02$
Accumulating 60 additional minutes of sedentary time during the afternoon	The mean percentage of time spent between 3.9 and 10.0 mmol·L^{-1} during the afternoon would decrease by 4.2 percentage points	$P = 0.03$
Accumulating 60 additional minutes of sedentary time during the afternoon	The mean percentage of time spent >10.0 mmol·L^{-1} during the postprandial dinner period would increase by 4.2 percentage points	$P = 0.08$
Accumulating 30 additional minutes of MVPA during late afternoon	The mean percentage of time spent >13.9 mmol·L^{-1} during late afternoon would decrease by 9.6 percentage points	$P = 0.039$
Accumulating 60 additional minutes of sedentary time during late afternoon	The mean percentage of time spent <3.9 mmol·L^{-1} during late afternoon would increase by 2.4 percentage points	$P = 0.09$
Accumulating 15 additional minutes of vigorous-intensity PA during late afternoon	The mean percentage of time spent between 3.9 and 10.0 mmol·L^{-1} during the following night would decrease by 14.7 percentage points	$P = 0.08$

Continued next page

TABLE 4. *(Continued)*

Magnitude of Change for the Explanatory Variable (Covariate)	Magnitude of the Effect on the Dependent Variable	*P* Value
Accumulating 60 additional minutes of sedentary time during late afternoon	The mean percentage of time spent between 3.9 and 7.8 mmol·L^{-1} during the following night would decrease by 7.1 percentage points	$P = 0.01$
Accumulating 60 additional minutes of sedentary time during late afternoon	The mean percentage of time spent between 3.9 and 10.0 mmol·L^{-1} during the following night would decrease by 6.0 percentage points	$P = 0.045$
For a 5-yr increase in diabetes duration[a]	The mean percentage of time spent between 3.9 and 10.0 mmol·L^{-1} during the self-reported PA session would decrease by 17.5 percentage points	$P = 0.03$
For a 1-unit increase in BMI *z*-score[a]	The mean percentage of time spent between 3.9 and 10.0 mmol·L^{-1} during the self-reported PA session would increase by 12.7 percentage points	$P = 0.01$
For a 5-yr increase in diabetes duration[d]	The mean percentage of time spent >10.0 mmol·L^{-1} during the self-reported PA session would increase by 10.2 percentage points	$P = 0.08$
For a 1-unit increase in BMI *z*-score [a]	The mean percentage of time spent >10.0 mmol·L^{-1} during the self-reported PA session would decrease by 7.6 percentage points	$P = 0.04$
Interpretation of the results of binary logistic regressions with random intercepts: The magnitude of the effect is calculated based on an initial probability of spending time in the specific glycemic range, arbitrarily set at 20%		
For a 30-min increase in the duration of the self-reported PA session	The probability of spending some time <3.9 mmol·L^{-1} during exercise would increase to 34%	$P = 0.008$
For a 30-min increase in the total duration of all self-reported PA sessions throughout the day	The probability of spending some time <3.0 mmol·L^{-1} the following night would increase to 28%	$P = 0.054$
For a 30-min increase in the total sum of MVPA for all self-reported PA sessions throughout the day	The probability of spending some time <3.0 mmol·L^{-1} the following night would increase to 58%	$P = 0.04$
When the period of day changes from afternoon to morning	The probability of spending some time <3.9 mmol·L^{-1} during early recovery would increase to 47.7%	$P = 0.094$
Accumulating 15 additional minutes of vigorous-intensity PA during the day	The probability of spending some time <3.0 mmol·L^{-1} the following night would increase to 35%	$P = 0.021$
Accumulating 15 additional minutes of vigorous-intensity PA during the afternoon	The probability of spending some time <3.0 mmol·L^{-1} the following night would increase to 43%	$P = 0.024$
Accumulating 15 additional minutes of vigorous-intensity PA during late afternoon	The probability of spending some time <3.0 mmol·L^{-1} the following night would increase to 69%	$P = 0.009$
For a 100-g increase in total CHO during the following night[e]	If the initial probability of spending some time >13.9 mmol·L^{-1} during the following night is arbitrarily set at 20%, this probability would increase to 64.8%	$P = 0.04$
Interpretation of the results of multinomial logistic regression with random intercept		
Accumulating 60 additional minutes of sedentary time during the afternoon	If the initial probability of spending more than 2.16% (i.e., the median) of the time >13.9 mmol·L^{-1} during the afternoon is arbitrarily set at 20%, this probability would increase to 30%.	$P = 0.018$

This table presents the magnitude of associations for covariates that were significant or showed a tendency in the manuscript. The magnitude is calculated using changes in independent variables arbitrarily set at plausible values, determined based on real-life contexts and physiological considerations, rather than the 1-unit changes corresponding to estimated coefficients (*e*) from Supplemental Tables 9–12, http://links.lww.com/MSS/D228. The latter can be very small given the scale of the variables.

For binary logistic regressions with random intercepts, the reported magnitude reflects the change in the probability of being in a specific category, derived from the initial estimated coefficients (see Supplemental Tables 9–12, http://links.lww.com/MSS/D228) and assuming an initial fixed probability of 20%. For multinomial logistic regressions with a cumulative logit link and random intercept, the magnitude represents the change in the probability of being in category "3" (i.e., values above the sample median).

P values in the table correspond to the initial estimated coefficients presented in Supplemental Tables 9–12, http://links.lww.com/MSS/D228, and have been adjusted using the Bonferroni correction.

[a] Results are based on the model including the duration and subjective intensity of self-reported PA sessions as covariates. Comparable magnitudes were observed when using MVPA of self-reported PA sessions as the covariate (see Supplemental Table 9, http://links.lww.com/MSS/D228).

[b] Results are based on the model including MVPA and sedentary time as covariates. Comparable magnitudes were observed when using the number of sedentary breaks (adjusted for sedentary time) or vigorous-intensity PA (adjusted for light and moderate intensity PA) as covariates (see Supplemental Table 11, http://links.lww.com/MSS/D228).

[c] Total CHO was not significant when included in the model with vigorous intensity PA instead of "MVPA and sedentary time" as the "PA characteristics" covariate.

[d] Duration of diabetes was not significant when included in the model with MVPA instead of "exercise duration and subjective intensity" as the "PA characteristics" covariate.

[e] Results are based on the model with MVPA and sedentary time throughout the day as covariates. Comparable magnitudes and significance levels were observed when PA characteristics (as covariates) were assessed during the late afternoon. However, the association was not significant when PA characteristics were assessed during the afternoon (see Supplemental Table 11, http://links.lww.com/MSS/D228).

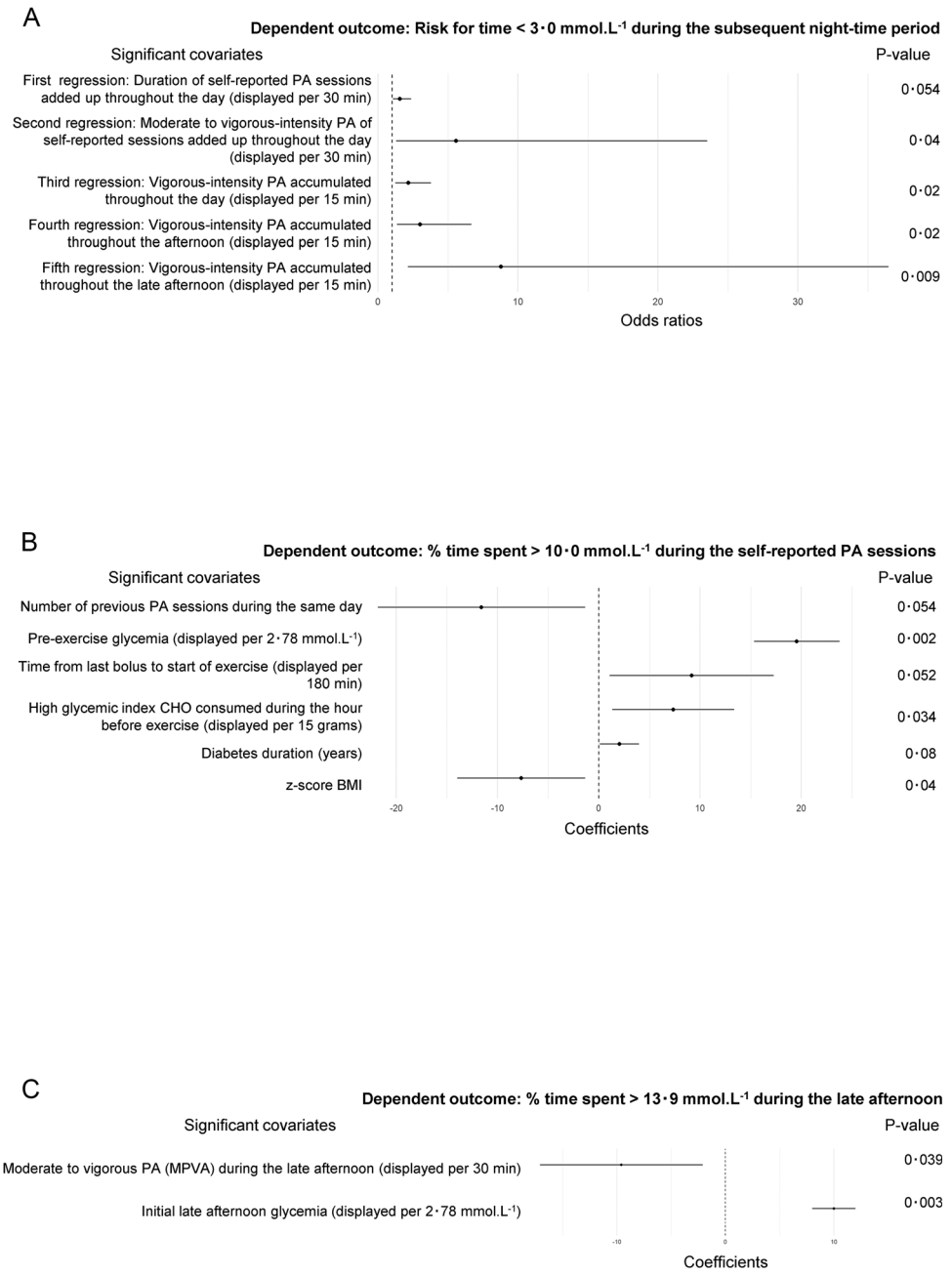

FIGURE 2—Plots of estimated coefficients or OR (and 95% CI) of explanatory covariates with significant effects in the estimated models of hyperglycemia during PA sessions, hyperglycemia during late afternoon, and hypoglycemia during subsequent nighttime periods. All the covariates with significant effects are displayed in panels A, B, and C. The other covariates were not significant. A, OR and confidence intervals of covariates with a significant effect on the risk for spending time spent <3.0 mmol·L^{-1} during subsequent nighttime periods in five different binary logistic regressions with random intercept. B, Estimated coefficients and confidence intervals of the covariates with a significant effect on percentage of time spent >10.0 mmol·L^{-1} during self-reported PA sessions in the model including duration and subjective intensity as the "exercise" covariates (linear model without random effects). C, Estimated coefficients and confidence intervals of the covariates with significant effects on percentage of time spent >13.9 mmol·L^{-1} during late afternoon (linear mixed model).

hyperglycemia (Fig. 2C), whereas increased sedentary time during the afternoon was associated with more time in level 2 hyperglycemia (Supplemental Table 11, Supplemental Digital Content, http://links.lww.com/MSS/D228).

Postprandial hyperglycemia was not significantly associated with previous accumulated PA or sedentary time.

We were not able to detect an association between nocturnal hypo- or hyperglycemia and accumulated previous-day MVPA. However, a longer time in vigorous PA accumulated during the day, afternoon, or late afternoon was associated with an increased probability of spending time in level 2 hypoglycemia during the subsequent night (Fig. 2A).

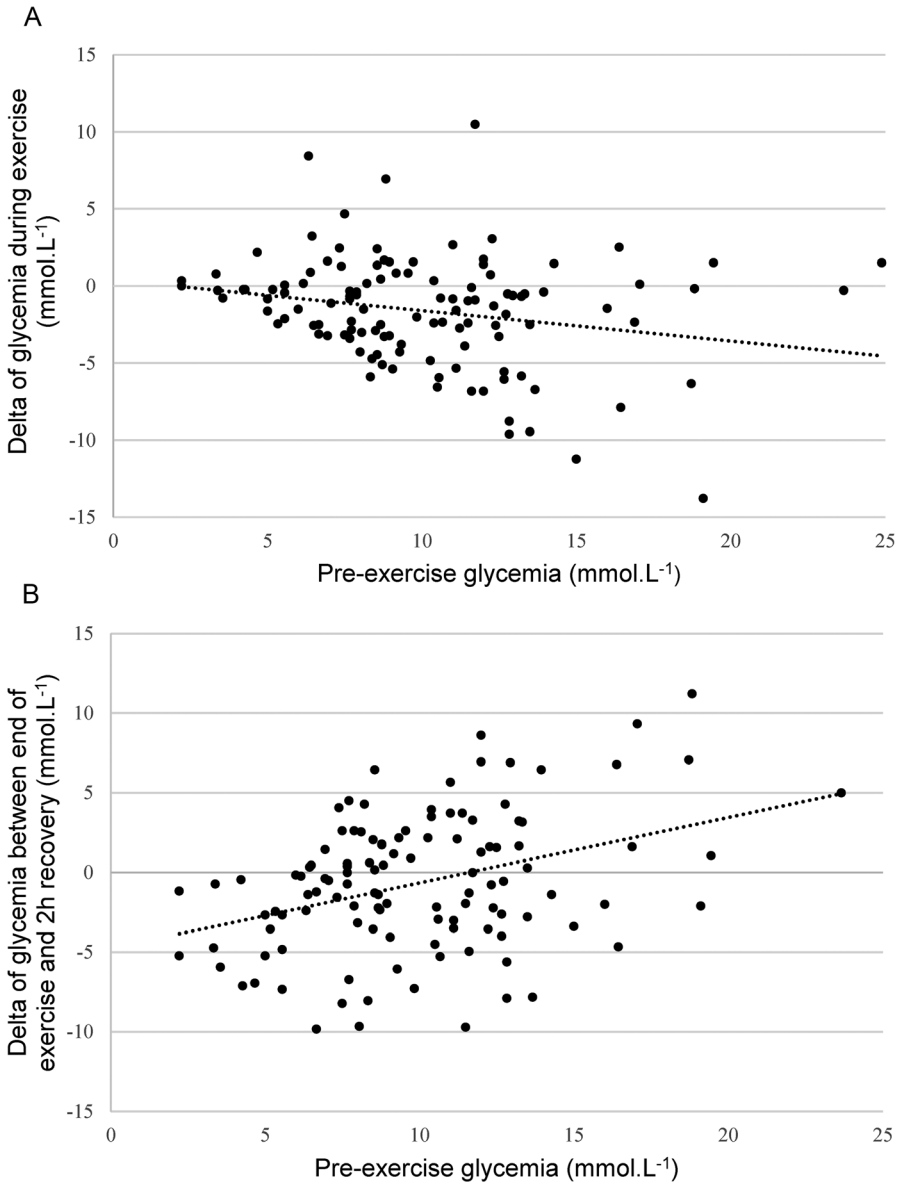

FIGURE 3—Delta of glycemia during self-reported PA sessions and during the 2 h of recovery after the sessions as a function of pre-exercise glycemia. A, Delta of glycemia during exercise (mmol·L^{-1}). B, Delta of glycemia between end of exercise and 2-h recovery (mmol·L^{-1}).

Sedentary breaks in sedentary time were not significantly associated with glycemic metrics.

Associations with Participant Characteristics in the First and Second Sets of Analyses

A higher diabetes duration was associated with less time in normoglycemia during self-reported PA sessions (Table 4). A higher BMI *z*-score was associated with more time in normoglycemia and less time in level 1 hyperglycemia during self-reported PA sessions (Table 4). A higher HbA_{1c} was associated with less time in normoglycemia and more time in hyperglycemia, whereas a higher usual daily insulin dose was associated with higher daytime and nighttime hypoglycemia risk. However, these associations were present only in some of the models. Other participant characteristics, including training level, were not substantially associated with glycemic metrics (Supplemental Tables 10 and 12, respectively, Supplemental Digital Content, http://links.lww.com/MSS/D228).

DISCUSSION

Despite the challenges of capturing the spontaneous nature of children's PA in real-life settings, this is the first observational study in everyday life to investigate the associations between both cumulative PA and self-reported PA sessions and the risk of hypoglycemia and hyperglycemia, while controlling for CHO intake, insulin administration, and sedentary time.

Importance of Considering Pre-Exercise Glycemia for Hypoglycemia and Hyperglycemia Risks during Exercise and Early Recovery But Not during Late Recovery. Beginning exercise with higher glycemia logically

predicted more hyperglycemia and less level 1 hypoglycemia during exercise and early recovery. We confirmed previous research (15,48) on the greater exercise-induced glucose decline in cases of higher pre-exercise glycemia. This phenomenon is probably related to the mass-action effect of glucose, stimulating muscle glucose uptake and use as well as inhibiting hepatic glucose production, even when circulating insulin levels are low (49). However, for the first time, we show that despite this bigger drop during exercise, glycemia increased more during early recovery in cases of higher pre-exercise glycemia. Thus, even if the glucose drop may be more pronounced during exercise for those using the strategy to increase glycemia in preparation for exercise (to avoid hypoglycemia), they can be reassured that glycemia is likely to rise again during recovery.

Hypoglycemic risk is more associated with PA characteristics than by pre-exercise CHO, insulin, or active behavior strategies. Prandial status and the timing of exercise are receiving increased attention in the literature as factors modulating the risk of hypoglycemia (50). To our knowledge, this is the first study to account for pre-exercise CHO intake in self-reported PA sessions conducted in everyday life. Taking CHO during the hour before the self-reported PA session, delaying exercise from the last insulin bolus, or multiplying the number of PA sessions before the one in question was not significantly associated with hypoglycemic risk.

Regarding exercise characteristics, a longer duration of self-reported PA sessions was associated with increased risk of time <3.9 $mmol \cdot L^{-1}$ during exercise (as previously reported [50]) and tended to be associated with increased risk of time spent <3.0 $mmol \cdot L^{-1}$ during the subsequent night. The latter was also significantly associated with a greater amount of MVPA accumulated during the self-reported PA sessions. However, we were not able to detect a significant association between subjective intensity of self-reported PA sessions and glycemic metrics.

In previous studies (17–20), objective intensity of self-reported PA sessions was not checked to guarantee they accurately reflected reality. Sherr et al. (21) and Morrison et al. (only study-assigned video exercises [16]) did not find any impact of mean session heart rate on post-exercise glycemic metrics, although mean heart rate does not give precise information on the respective times in light-intensity PA or MVPA. We found for the first time that objectively measured time in MVPA recorded via accelerometry during the self-reported PA sessions predicted nocturnal level 2 hypoglycemic risk with a stronger estimated magnitude compared with just looking at the duration of these sessions. To illustrate this, increasing the MVPA of self-reported sessions (added up over the day) by 30 min would increase the probability of spending some time <3.0 $mmol \cdot L^{-1}$ from 20% (for example) to 58% during the subsequent night, whereas a 30-min increase in duration of self-reported daytime PA sessions would increase the nocturnal level 2 hypoglycemic risk from 20% (for example) to 28%. It could therefore be clinically pertinent to prescribe the wearing of an activity tracker during a week in everyday life to objectively measure which structured PA sessions are associated with longer time in MVPA. These sessions should then require increased vigilance for nocturnal hypoglycemia prevention (e.g., reducing basal insulin and/or adding a bedtime snack). It is reassuring for children and their parents to focus specifically on MVPA accumulated during self-identified PA sessions and not on MVPA accumulated throughout the day. The latter, which includes spontaneous PA (e.g., soft mobility and other PA not identified by children) was indeed not a significant predictor of nocturnal hypoglycemic risk in the current study.

However, for children accumulating significant levels of vigorous-intensity PA throughout the afternoon or late afternoon, objectively detecting this type of PA with an activity tracker could still be relevant, considering its association with nocturnal level 2 hypoglycemia. In our study, children accumulated between 0 and 42 min of vigorous-intensity PA during late afternoons, with results showing that increasing by 15 min this type of PA would increase the probability of nocturnal level 2 hypoglycemia from 20% to 69%. All this information could be computed to guide insulin or CHO adaptation to minimize nocturnal hypoglycemic risk.

Implementing pre-exercise strategies based on CHO intake, insulin, or active behavior may conceivably have short-term effect on hyperglycemia. We were not able to detect significant associations between characteristics of self-reported PA sessions and hyperglycemia. Conversely, it is not impossible that consuming high-glycemic-index CHO in the hour before exercise (as in Vartak et al.'s laboratory study [51]) or exercising longer after the last meal with a bolus may increase time spent in level 1 hyperglycemia during exercise. Although pre-exercise CHO supplementation is a common strategy used by patients to prevent short-term hypoglycemia, our results did not support its effectiveness. These results suggest that careful consideration of the balance between hypoglycemic and hyperglycemic risks is crucial when deciding whether to consume pre-exercise CHO. This decision should probably be individualized based on the child's specific characteristics. For instance, in children with obesity, increasing lipid oxidation during exercise may be an important objective, and it has been shown that short-term hyperglycemia during exercise might impair this metabolic pathway (52). Similarly, avoiding hyperglycemia could be beneficial for young athletes prior to competition given the possible negative impact of hyperglycemia on performance (32). Interestingly, performing an additional PA session earlier on the same day may be helpful for these athletes, as our results suggest that a greater number of prior PA sessions are associated with less time spent in level 1 hyperglycemia during subsequent exercise.

In line with the latter result, accumulating more MVPA during the late afternoon was associated with a slightly decreased time spent in level 2 hyperglycemia during this period. For example, increasing cumulative MVPA by 30 min during late afternoon may decrease mean percent of time spent >13.9 $mmol \cdot L^{-1}$ by 9.6 percentage points. Thus, children suffering from serious hyperglycemia should be encouraged to increase spontaneous PA such as walking or cycling to and from school. Additionally, more sedentary time was associated with a greater risk of level 2 hyperglycemia during the afternoon.

Morning versus afternoon exercise may modulate hypo- and hyperglycemic risks in the short term. In our study of children/adolescents, morning compared with afternoon exercise (while controlling for time from the last bolused meal) tended to be associated with an increased risk of level 1 hypoglycemia and was significantly associated with decreased time in level 1 hyperglycemia during early recovery. This contrasts with the few studies in the literature only on adults and which found a protective effect of morning exercise on the risk of post-exercise hypoglycemia (53). The divergence in the impact of time of the day between children and adults may be due to the absence in children of an early-morning abrupt decrease in insulin sensitivity, as usually observed in adults (i.e., the dawn phenomenon caused by cortisol and growth hormone secretion) (54). Nevertheless, the protective effect of morning exercise in adults has still to be confirmed because the studies carried out to date could be biased by the use of a different prandial status for morning versus afternoon exercises (50,53).

Strengths and limitations. It is important to note that CGM devices estimate glycemia based on interstitial fluid measurements, and their accuracy depends on the equilibration between blood and interstitial compartments. This may take longer during rapid blood glucose changes, such as those occurring during exercise (55). Nevertheless, the literature suggests that the performance of iPro2 and Freestyle CGM devices remains adequate during exercise periods (55).

The results were obtained only from MDI and CSII users, with few children already using a CGM sensor in everyday life. This could limit extrapolation to the rapidly increasing number of hybrid closed-loop therapy users in the pediatric population. Nevertheless, accessibility to novel technologies is restricted to a limited number of children in the world depending on socioeconomic factors (56). The 7-d observation period may not adequately reflect participants' long-term habits regarding PA, diet, and insulin management. Recordings over a more extended period could provide fuller insights into behavior.

Our study was carried out in the everyday lives of our participants, involving minimal interference with their usual behavior. In addition, we attempted to fully take into account the main factors able to influence glycemia, including macronutrient intake. PA was recorded using both objective and subjective methods. This innovative methodology was designed as part of an exploratory approach to identify putative influencing factors that later can be validated through more controlled studies. In such an approach, a slightly higher type I error rate may be tolerated to ensure that no potentially crucial associations for the patient are overlooked (45). With this in mind, a moderate correction for multiple tests was used, which led to the identification of avenues for future research and hypotheses. Although our sample size appears reasonable, results with P values >0.1 lacked statistical power. A larger sample size would be required to verify whether these associations are genuinely negligible.

CONCLUSIONS

Overall, we found that neither timing and prandial state of structured PA nor the accumulation of MVPA bouts throughout the day significantly predicted the risk for level 2 hypoglycemia. However, this risk of clinically relevant hypoglycemia increased during the subsequent night proportionally to the duration of structured PA during the day. This prompts us to suggest that children who are at risk of nocturnal hypoglycemia should be encouraged to take into account the duration of PA as the key factor influencing this risk. This could help to lighten the mental burden for children and their families, especially as children tend to do more unplanned exercise at unpredictable times (22). However, as vigorous PA accumulated during the afternoon or late afternoon was also an important predictor of nocturnal level 2 hypoglycemia, the wearing of an activity tracker to better detect this type of activity, particularly when spontaneous, could still be recommended in very active children.

Concerning hyperglycemic risk, it is not impossible that the conditions under which the PA session was performed, such as taking high-glycemic-index CHO during the hour before PA, or extending the time since the last meal with an insulin bolus could have short-term negative effects on time spent >10.0 $mmol \cdot L^{-1}$ during exercise. On the contrary, the latter would perhaps be prevented by multiplying the number of PA sessions, a result that is difficult to achieve through conventional laboratory designs. Our results also suggest that level 2 hyperglycemia during the afternoon or late afternoon may be prevented by increasing spontaneous active behavior while limiting sedentary time.

Lastly, our results highlight distinct associations with glycemic metrics depending on how PA was assessed—whether through spontaneous objective measurement (i.e., with activity trackers) or through self-identified/reported PA sessions. The latter also showed specific associations based on either their characteristics or contextual conditions. The unique methodology employed in our study could serve as a reference for future research among different populations, enabling the individualization of daily-life PA guidelines to maximize health benefits.

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Contributors: E. H. designed the experiments. S. B. contributed to the design of the experiments. E. L., S. T., C. P., and E. H. conducted the experiments. E. H., A. M., C. P., A. C., G. B., and E. L. collected and analyzed the data. J. D. contributed to statistical analyses, and P.M. contributed to data and literature interpretation. C. S. and C. L. recruited participants. E. H. and A. M. wrote the first draft of the manuscript, which was reviewed and significantly revised by R. R. L. All other authors were also involved in reviewing the manuscript. E. H. is the guarantor of this work and, as such, had full access to all the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis.

No potential conflicts of interest relevant to this article were reported. The results of the study are presented clearly, honestly, and without fabrication, falsification, or inappropriate data manipulation. The results of the present study do not constitute endorsement by the American College of Sports Medicine.

Availability of data and material: The datasets generated analyzed during the current study are available in the https://www.data.gouv.fr/fr/ platform (https://doi.org/10.57745/YLKLQH).

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