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Objectively recorded physical activity and the association with gestational diabetes

K. Mørkrid[1,2], A. K. Jenum[3,4], S. Berntsen[5], L. Sletner[2,6], K. R. Richardsen[4,6], S. Vangen[6], I. Holme[7], K. I. Birkeland[1,2]

[1]Department of Endocrinology, Obesity and Preventive Medicine, Oslo University Hospital, Oslo, Norway, [2]Faculty of Medicine, Institute of Clinical Medicine, University of Oslo, Oslo, Norway, [3]Faculty of Medicine, Institute of Health and Society, Department of General Practice, University of Oslo, Oslo, Norway, [4]Faculty of Health Sciences; Oslo and Akershus University College of Applied Sciences, Oslo, Norway, [5]Faculty of Health and Sport Sciences, University of Agder, Kristiansand, Norway, [6]Norwegian Resource Centre for Women's Health, Department for Women's and Children's Health, Oslo University Hospital, Oslo, Norway, [7]Department of Biostatistics, Epidemiology and Health Economics, Oslo University Hospital, Oslo, Norway
Corresponding author: Kjersti Mørkrid, *PhD, Department of Endocrinology, Obesity and Preventive Medicine, Oslo University Hospital, PO Box 4959, Nydalen, N-0424 Oslo, Norway. Tel: +47 995 46 157, Fax: +47 22894250, E-mail: kjersti.morkrid@medisin.uio.no*

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The aim of this population-based study was to assess the association between objectively recorded physical activity (PA) in early gestation and gestational diabetes mellitus (GDM) identified at 28 weeks of gestation in a multiethnic cohort of healthy pregnant women in Oslo, Norway. In total, 759 women were included. In early gestation (<20 weeks), light-, moderate-, and vigorous-intensity PA and number of steps were objectively recorded (SenseWear™ Armband Pro3), and self-reported PA, demographics, and anthropometrics were collected. The 75-g oral glucose tolerance test was performed at 28 weeks of gestation. Women with GDM had fewer objectively recorded steps (mean 7964 steps/day vs 8879 steps/day, $P < 0.001$) and minutes of moderate-to-vigorous-intensity PA (median 62 min/day vs 75 min/day, $P = 0.004$) in early gestation than women without GDM. Additionally, 30% of women with GDM compared with 44% ($P < 0.001$) of women without GDM self-reported regular PA before pregnancy. The significant inverse association between objectively recorded steps per day in early gestation and GDM persisted after adjustment for ethnic origin, weeks of gestation, age, parity, pre-pregnancy BMI, early life socioeconomic position, and self-reported regular PA before pregnancy. The adjusted odds ratio for GDM decreased 19% per standard deviation (3159 steps) increase in objectively recorded steps per day ($P = 0.039$). Daily life PA in early gestation measured as steps/day was associated with lower risk of GDM.

Gestational diabetes mellitus (GDM) is an increasingly prevalent complication of pregnancy, which may lead to adverse effects for both the mother and her offspring (Metzger et al., 2010). GDM shares pathophysiological similarities with type 2 diabetes and increases the risk for this condition later in life (Buchanan et al., 2012). Advancing maternal age, ethnic origin, and family history of diabetes have been identified as risk factors, in addition to obesity. The prevention of GDM may yield substantial clinical and economic benefits (Roberts et al., 2013). An important component in the prevention of GDM may be the promotion of healthy maternal lifestyle factors, such as physical activity (PA).

PA is defined as any bodily movement produced by skeletal muscles (Caspersen et al., 1985). It influences insulin sensitivity and secretion both directly and indirectly (Hawley & Lessard, 2008; Roberts et al., 2013). PA may improve body composition and metabolism even in the absence of weight loss (InterAct, 2012; Thompson et al., 2012). Despite similar benefits of PA in pregnant and non-pregnant women (Gradmark et al., 2011), intervention studies promoting PA in mid-pregnancy have not convincingly demonstrated a preventive effect on GDM (Oostdam et al., 2012; Stafne et al., 2012). Higher levels of PA prior to and in early gestation are associated with lower risk for GDM (Tobias et al., 2011; Downs et al., 2012). However, neither the dose-response relationship nor the joint and independent effects of PA before and in early gestation on GDM are known (Mudd et al., 2013). Therefore, controversies exist regarding the preventive effect of PA on GDM.

PA is difficult to assess, and the dissimilarities between methods and definitions used hamper the understanding of the health effects of PA (Gaston & Cramp, 2011; Zhang & Ning, 2011; Matthews et al., 2012). Few studies have reported objectively recorded PA (Mudd et al., 2013), which allows assessment of the dose-response relationship between PA and GDM. PA levels based on self-reports are often overestimated and may hold recall and social desirability bias (Gaston & Cramp, 2011; Evenson et al., 2012; Pollard & Guell, 2012). Several studies have failed to address potential confounding

factors such as socioeconomic position (SEP), and conclusions must be drawn with care.

The association between SEP and GDM has been poorly assessed (Anna et al., 2008; Link & McKinlay, 2009; Cullinan et al., 2012), but a higher prevalence of type 2 diabetes is reported in groups with low SEP (Stringhini et al., 2012). Individuals with low SEP are less likely to participate in leisure time PA (Beenackers et al., 2012), and the effect of SEP on diabetes may be mediated partly through different levels of PA across social strata, in addition to complex mechanisms such as nutritional status, use of health services, and stress (Brown et al., 2004). Environmental factors in childhood have been found to have long-lasting effects on adult health (Gluckman et al., 2008; Dode & dos Santos, 2009) and put forward as an explanatory theory regarding susceptibility to diabetes in South Asians (Bhopal, 2013).

A higher prevalence of GDM has been reported among ethnic minority groups in Western countries, particularly among South Asian women (Anna et al., 2008; Jenum et al., 2012). Pregnant ethnic minority women have lower levels of PA compared with women from the host population (Evenson & Wen, 2010; Berntsen et al., 2012). Ethnic minority groups are often socially disadvantaged (Anna et al., 2008). SEP and/or PA may therefore be more important than ethnic origin in determining susceptibility for diabetes, and the concept of ethnicity as a primary determinant for diabetes may be questioned (Link & McKinlay, 2009).

The International Association for Diabetes in Pregnancy Study Groups (IADPSG) suggested new criteria for GDM (Metzger et al., 2010), which have been adopted by the World Health Organization (2013). The number of women diagnosed with GDM will increase significantly with the new criteria, and ethnic differences in the figures are reported (Metzger et al., 2010; Jenum et al., 2012; Sacks et al., 2012). To our knowledge, no studies have examined the impact of objectively recorded PA on GDM with the IADPSG criteria. The aim of the present study was to assess the association between objectively recorded PA in early gestation and GDM identified at 28 weeks of gestation.

Material and methods

Study population

The Stork Groruddalen Study was a population-based cohort study. Data collection was conducted at three public Child Health Clinics in Eastern Oslo, Norway, from May 6, 2008 to May 15, 2010 (Jenum et al., 2010). The Regional Ethics committee and The Norwegian Data Inspectorate approved the study protocol. The methods are described in detail elsewhere (Jenum et al., 2010, 2012). Women were eligible and were asked to participate in the study if they (a) lived in one of the three study districts; (b) planned to give birth at one of the two study hospitals; (c) were <20 weeks of gestation at inclusion; (d) could communicate in either Norwegian, Arabic, English, Sorani, Somali, Tamil, Turkish, Urdu, or Vietnamese; and (e) were able to provide written informed consent. Women with known diabetes or other diseases necessitating intensive hospital follow-up during pregnancy were excluded. Staff members were certified after training and assisted by professional translators if required. All women were offered the 75-g oral glucose tolerance test (OGTT) at 28 weeks of gestation.

Of the eligible participants, 823 (74%) healthy pregnant women were included in mean 15 weeks of gestation (Jenum et al., 2010). The cohort was considered fairly representative for women from the main ethnic groups living in the study area (Jenum et al., 2010, 2012). Seven hundred and seventy-two women attended the study at 28 weeks of gestation (Jenum et al., 2012), and 759 of them completed the OGTT. There were no significant differences in baseline characteristics between attendees and non-attendees at 28 weeks of gestation or between those with and without valid OGTT data (Jenum et al., 2012). The 759 women with valid OGTT data constituted the present study sample.

Demographics, SEP, and anthropometrics

Questionnaire data related to demographics and present and early life SEP were collected through interviews at inclusion (Jenum et al., 2010). Ethnic origin was defined by the country of birth of the participant or that of the participant's mother if the participant's mother was born outside Europe or North America (Jenum et al., 2012). Ethnic origin was categorized as follows: Western Europe, primarily women from Norway and Sweden/Denmark; South Asia, primarily from Pakistan and Sri Lanka; Middle East, primarily from Iraq, Turkey, and Morocco; and Others, from Africa (except North Africa), Eastern Europe, East Asia, and South and Central America.

Pre-pregnancy body weight was self-reported. Body height (fixed stadiometer) and weight (Tanita BC 418MA, Tokyo, Japan) were measured at inclusion. Body mass index (BMI, kg/m^2) was computed using body height at inclusion and body weight pre-pregnancy or at inclusion as stated.

Physical activity

Information about self-reported PA was collected with a questionnaire that was previously validated against a PA monitor (Brantsaeter et al., 2010). This information was collected during the face-to-face interviews at inclusion (Jenum et al., 2010). Self-reported regular PA was defined as moderately intensive activity for 30 min for ≥5 days/week, moderately intensive activity for 2.5 h/week over ≥3 days, vigorous-intensity activity for ≥20 min three times per week, or activity of both moderate and vigorous intensity (e.g., vigorous activity once per week and moderate activity twice per week). A self-reported regular PA history before pregnancy was reported with the response categories: "never," "<1 year," "1–5 years," "6–10 years," and ">10 years." Furthermore, with reference to the two time points (three months before pregnancy and the last seven days before inclusion), the women reported the number of minutes (if ≥10 min) they engaged in each of the following PA modes: running, bicycling, aerobic classes, dancing, ball games, swimming, and brisk walking. The response categories were "never," "1–3 times per month" (only for PA before pregnancy), "once per week," "twice per week," "3–6 times per week, and "daily." The total number of minutes of self-reported aerobic PA/week (all PA modes) three months before pregnancy and in early gestation were calculated separately.

PA was objectively recorded by the SenseWear™ Pro3 Armband. The data from the monitor were downloaded and analyzed with a software developed by the manufacturer (SenseWear Professional Research Software Version 6.1, BodyMedia Inc., Pittsburgh, Pennsylvania, USA) (Berntsen et al., 2012). The armband was affixed to the women's upper arm at the end of the interview at inclusion. In agreement with the interviewer, she was

instructed to wear the armband until a defined day (minimum of 4 days) (Matthews et al., 2012), only removing it for bathing/water activities. Data from women with a minimum of 1 day [defined as ≥19.2 h (80% of the day) of recorded data] were classified as valid. Multiple imputations were performed for women without valid data (see the Statistical analyses section). PA was characterized as light-intensity PA [1.5 to <3 metabolic equivalents (METs)], moderate-intensity PA (3–6 METs), and vigorous-intensity PA (>6 METs) (Berntsen et al., 2012). Average minutes per day of light-, moderate-, and vigorous-intensity PA in addition to moderate- and vigorous-intensity PA summarized into moderate-to-vigorous-intensity PA and number of steps per day are reported.

Gestational diabetes

Universal screening for GDM was performed at 28 weeks of gestation (Jenum et al., 2010). Fasting plasma glucose (FPG) and 2-h plasma glucose (PG) were measured on site in venous EDTA blood (HemoCue 201C, Angelholm, Sweden) (Jenum et al., 2012). GDM was diagnosed if FPG ≥ 5.1 mmol/L or 2-h PG ≥ 8.5 mmol/L (Metzger et al., 2010), according to a modification of the IADPSG criteria, as 1-h PG was not available. The GDM prevalence was 24% for Western Europeans, 42% for South Asians, and 37% for Middle Easterners (Jenum et al., 2012).

Statistical analyses

Differences between ethnic groups and between women with and without GDM were tested for significance using Fisher's exact test and Pearson's chi-square test for categorical variables, *t*-tests, and one-way ANOVA for normally distributed continuous variables and the Mann-Whitney U and Kruskal-Wallis tests for non-normally distributed continuous variables, with the Bonferroni correction for multiple testing. The data are presented as the number of women with the percentage, the mean, and standard deviation (SD) or the median and interquartile range, as appropriate. SPSS version 19 was used for all analyses (SPSS Inc., Chicago, Illinois, USA). The significance level was set as $P < 0.05$.

Valid objectively recorded PA data were obtained for 632 (83%) women, with a mean (SD) wearing time of 3.8 (1.3) days and 23.5 (0.6) h/day. The numbers of weekday and weekend day recordings did not differ between women with and without GDM. Sensitivity analyses of data from women with only 1 day and women with <3.8 days of wearing time were conducted to test the robustness of the findings. Missing value analyses of the variable steps, light-intensity PA, moderate-intensity PA, and vigorous-intensity PA were performed, followed by 20 multiple imputations using Markov chain Monte Carlo methods (Sterne et al., 2009). Variables with $P < 0.05$ from the missing value analysis, the covariates used in the final logistic regression model and GDM, were included in the multiple imputation model. The multiple imputations data (pooled set) were used in the logistic regression analyses, and the original data are presented in Fig. 1 and in Tables 1 and 2.

A principal component analysis was performed to obtain a score for early life SEP. One component was extracted in agreement with the scree plot and Kaiser's criterion, and it explained 55% of the variance. Cronbach's α was 0.44, reflecting that only three variables were included in the principal component analysis. The component was defined by three variables: highest parental occupational class in household, household crowding (room per persons), and ownership of car (factor loadings 0.708–0.769). A low score indicates poor early life SEP.

A directed acyclic graph was drawn prior to the regression analysis to identify potential confounders. In a timeline, ethnic origin was considered as a point of departure, followed by SEP. Pre-pregnancy BMI was addressed prior to PA and PA before

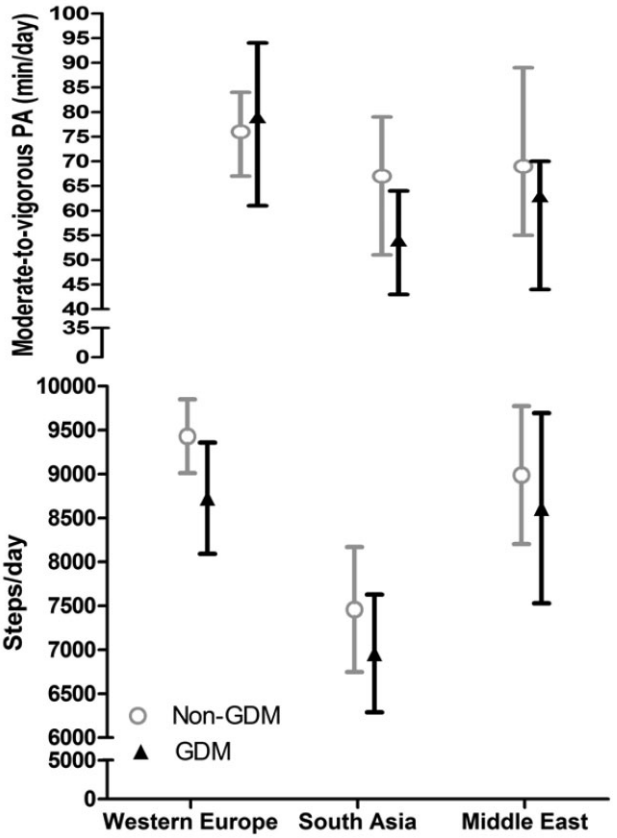

Fig. 1. Moderate-to-vigorous-intensity physical activity (PA) minutes per day [median, 95% confidence interval (CI)] and steps per day (mean, 95% CI) for the main ethnic groups. Significant difference between the non-gestational diabetes mellitus (non-GDM) and GDM women overall for steps (< 0.001) and moderate-to-vigorous-intensity PA (0.004), and for steps between the GDM women from South Asia and Middle East ($P = 0.031$) and South Asia and Western Europe ($P < 0.001$). Crude values.

pregnancy prior to PA in early gestation. Age and parity were included as covariates. The pregnancy stage might influence the level of PA, and the week of gestation at inclusion was therefore included. Bivariate logistic regression analyses were performed with GDM as the dependent variable and, in multiple logistic regression analyses, with PA as the main independent variable. For continuous covariates (age, gestational week, pre-pregnancy BMI, steps per day, moderate-to-vigorous-intensity PA minutes/day, and early life SEP), the regression coefficients (ORs) were standardized using SD for the whole population for each variable. The standardized OR therefore represents the per SD change in the predictor variable and enables comparison across variables with different measurement units.

The independent associations between each of the PA variables separately (objectively recorded steps per day, light-intensity PA minutes/day, and moderate-to-vigorous-intensity PA minutes/day in early gestation, self-reported aerobic PA ≥ 150 min/week in early gestation, regular PA before pregnancy and aerobic PA ≥ 150 min/week 3 months before pregnancy) and GDM were adjusted for ethnic origin, weeks of gestation, age, parity, and pre-pregnancy BMI. The association between objectively recorded moderate-to-vigorous-intensity PA minutes/day and GDM was adjusted for self-reported regular PA before pregnancy, early life SEP, and the covariates listed earlier (model 1). The same adjustments were performed for the association between objectively

Table 1. Baseline characteristics of the total cohort stratified into ethnic groups. Data are mean (SD) or *n* (%), unless otherwise stated

	Total *n* = 759		Western Europe *n* = 313, 41%		South Asia *n* = 188, 25%		Middle East *n* = 112, 15%		Others *n* = 146, 19%	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Weeks of gestation	15	3	14	2	16	4	15	3	16	4
Age (years)	29.9	4.8	30.9	4.5	28.7	4.5	29.4	5.4	29.4	5.1
Body height (cm)	163.7	6.7	167.4	5.6	160.0	5.6	161.2	5.5	162.3	6.9
Para ≥ 2*	151	20	35	11	48	26	35	31	33	23
BMI pre-pregnancy (kg/m^2)	24.6	4.8	24.6	4.8	23.7	4.1	25.9	5.1	24.6	5.3
BMI early gestation (kg/m^2)	25.3	4.9	25.3	4.8	24.3	4.1	26.9	5.4	25.5	5.3
Early life SEP score	0.01	0.99	0.76	0.67	−0.59	0.75	−0.53	0.79	−0.44	0.89
Objectively recorded steps per day	8582	3159	9250	2999	7232	3071	8850	2983	8533	3266
Objectively recorded light-intensity PA (min/day)	266	87	254	80	275	96	297	91	256	84
Objectively recorded moderate-intensity PA (min/day)†	68	59	76	56	58	63	66	53	68	63
Objectively recorded vigorous-intensity PA (min/day)†	0.2	1.0	0.3	1.8	0.0	0.8	0.0	0.5	0.1	0.8
	n	%	*n*	%	*n*	%	*n*	%	*n*	%
Low early life SEP	245	33	11	4	110	59	56	52	68	49
Medium early life SEP	248	33	99	32	61	33	40	37	48	34
High early life SEP	253	34	201	65	16	9	12	11	24	17
Primary education (<12 years)	216	29	41	13	59	31	62	56	54	37
Objectively recorded steps per day, 1000–6999	212	34	70	25	79	52	26	29	37	34
Objectively recorded steps per day, 7000–9999	228	36	107	38	46	30	32	36	43	40
Objectively recorded steps per day, ≥10 000	192	30	104	37	28	18	32	36	28	26
Objectively recorded MVPA, <60 min/day	253	40	92	33	77	50	37	41	47	44
Objectively recorded MVPA, 60–89 min/day	162	26	83	30	31	20	25	28	23	21
Objectively recorded MVPA, ≥90 min/day	217	34	106	38	45	29	28	31	38	35
Self-reported aerobic PA, ≥150 min/week	94	13	64	21	9	5	9	8	12	9
Self-reported not regular PA before pregnancy	446	61	143	47	129	71	83	75	91	65
Self-reported aerobic PA ≥ 150 min/week before pregnancy	288	39	140	46	59	32	38	35	51	36

*Number, %.

†Median, interquartile range. There are in total 127 women with missing objectively recorded PA data.

BMI, body mass index; MVPA, moderate-to-vigorous-intensity PA; PA, physical activity; SEP, socioeconomic position.

recorded steps per day and GDM (model 2). To assess the independent association between PA and GDM, early life SEP was subsequently included. The Nagelkerke R-square was calculated.

Results

The mean (SD) maternal age was 29.9 years (4.4 years), and the pre-pregnancy BMI was 24.6 kg/m^2 (4.8 kg/m^2) (Table 1). The mean gestational week for the objectively recorded PA in early gestation was 15 weeks (3 weeks). The mean number of objectively recorded steps per day in early gestation was 8582 steps (3159 steps), and 39% of the women self-reported regular PA before pregnancy. South Asians had lower mean values for objectively recorded steps per day and median moderate-to-vigorous-intensity PA minutes/day, and Middle Easterners had lower mean values for objectively recorded light-intensity PA minutes/day compared with Western Europeans ($P < 0.001$). South Asian and Middle Eastern women were less likely to self-report regular PA before pregnancy compared with Western European women ($P < 0.001$).

Women identified with GDM at 28 weeks of gestation had fewer objectively recorded mean steps per day and median moderate-to-vigorous-intensity PA minutes/day in early gestation compared with women without GDM ($P < 0.005$) (Table 2). Of the women with GDM, 71% self-reported no aerobic PA in early gestation compared with 60% of the women without GDM ($P = 0.003$). The women with GDM had a lower mean early life SEP score compared with the women without GDM ($P < 0.001$). South Asian women with GDM had lower mean values

Table 2. Characteristics for the women with and without gestational diabetes mellitus (GDM). Data are mean (SD) or *n* (%) unless otherwise stated

	Non-GDM *n* = 520, 68.5%		GDM *n* = 239, 31.5%		
	Mean	SD	Mean	SD	*P*‡
Weeks of gestation	15	4	15	3	0.994
Age (years)	29.7	4.7	30.2	5.1	0.167
Body height (cm)	164.0	6.7	163.1	6.6	0.087
Para ≥ 2*	92	18	59	25	0.017
BMI pre-pregnancy (kg/m^2)	23.9	4.3	26.0	5.6	<0.001
BMI early gestation (kg/m^2)	24.7	4.4	26.7	5.6	<0.001
Early life SEP score	0.11	0.99	−0.21	0.95	<0.001
Objectively recorded steps per day	8879	3255	7964	2857	<0.001
Objectively recorded light-intensity PA (min/day)	266	88	264	85	0.756
Objectively recorded MVPA (min/day)†	75	66	62	62	0.004§
	n	%	*n*	%	*P*¶
Primary education (<12 years)	136	26	80	33	0.027
Low early life SEP	147	30	98	42	<0.001
Objectively recorded steps per day, ≥10 000	149	35	43	21	<0.001
Objectively recorded MVPA, <60 min/day	154	36	99	48	0.002
Self-reported aerobic PA, ≥150 min/week	70	14	24	10	0.110
Self-reported not regular PA before pregnancy	283	56	163	70	<0.001
Self-reported aerobic PA ≥ 150 min/week before pregnancy	214	43	74	32	0.003

*Number, %.

†Median, interquartile range.

‡*t*-test.

§Mann-Whitney U-test.

¶Fisher's exact test. There are in total 127 women with missing objectively recorded PA data.

BMI, body mass index; MVPA, moderate-to-vigorous-intensity PA; PA, physical activity; SEP, socioeconomic position.

for objectively recorded steps per day compared with Middle Eastern ($P = 0.031$) and Western European women with GDM ($P < 0.001$) (Fig. 1).

Significant inverse associations between objectively recorded steps per day in early gestation and GDM, moderate-to-vigorous-intensity PA minutes/day in early gestation and GDM, and regular PA before pregnancy and GDM were found in bivariate logistic regression analyses (Table 3, Unadjusted). Controlling for wearing time did not change the results significantly (data not shown). After adjusting for ethnic origin, weeks of gestation, age, parity, and pre-pregnancy BMI, significant associations were found between objectively recorded steps per day in early gestation [OR per SD increase (SD = 3159 steps): 0.79, 95% confidence interval (CI): 0.65–0.97] and GDM, self-reported regular PA before pregnancy (OR: 0.66, 95% CI: 0.46–0.94) and GDM, and self-reported aerobic PA ≥ 150 min/week 3 months before pregnancy (OR: 0.69, 95% CI: 0.49–0.97) and GDM.

The significant inverse association between objectively recorded steps per day in early gestation and GDM remained after further adjustments for self-reported regular PA before pregnancy and early life SEP, and revealed that the OR for developing GDM at 28 weeks of gestation decreased 19% per SD increase in objectively recorded steps per day in early gestation (Table 3, Model 2). Additional adjustments for education level (≥12 years) or using education level (≥12 years) instead of early life SEP did not change the estimate for the association between objectively recorded steps per day in early gestation and GDM (data not shown).

With GDM as the outcome, the R-squared value increased from 0.10 in the model adjusted for only ethnic origin, weeks of gestation, age, parity, and pre-pregnancy BMI to 0.12 after additional adjustments for PA (steps per day and regular PA before pregnancy) and, finally, to 0.13 after further adjusting for early life SEP. PA and early life SEP therefore accounted for a moderate relative improvement (30%) in fit in the logistic regression model.

Discussion

In this population-based cohort study of pregnant women, we found that objectively recorded PA in early gestation (mean 15 weeks of gestation) was inversely associated with GDM identified at 28 weeks of gestation. To our knowledge, this is the first study to assess the association between objectively recorded PA in early gestation and GDM with the IADPSG criteria. We found that low PA levels, both before pregnancy and in early gestation, and poor early life SEP were associated with GDM. The inverse association between objectively recorded PA in early gestation and GDM was related to daily life PA, measured as steps/day.

Table 3. Odds ratios (ORs) for gestational diabetes in logistic regression analyses

	OR	95% CI		*P*
Unadjusted				
Ethnic origin				
South Asia	2.30	1.56	3.39	<0.001
Middle East	1.83	1.15	2.91	0.010
Others	1.37	0.88	2.12	0.161
Western Europe	1.00			
Early life SEP score*	0.73	0.62	0.85	<0.001
Objectively recorded MVPA*	0.83	0.69	0.98	0.032
Objectively recorded steps*	0.74	0.62	0.89	0.001
Self-reported regular PA before pregnancy				
Yes	0.55	0.40	0.77	<0.001
No	1.00			
Multiple Model 1 (with MVPA)†				
Ethnic origin				
South Asia	1.92	1.14	3.24	0.015
Middle East	1.13	0.66	1.94	0.678
Others	1.07	0.63	1.82	0.816
Western Europe	1.00			
Early life SEP score*	0.79	0.63	0.98	0.028
Objectively recorded MVPA*	1.02	0.85	1.23	0.840
Self-reported regular PA before pregnancy				
Yes	0.65	0.46	0.94	0.020
No	1.00			
Multiple Model 2 (with steps)†				
Ethnic origin				
South Asia	1.72	1.02	2.92	0.043
Middle East	1.14	0.64	2.03	0.667
Others	1.04	0.60	1.80	0.886
Western Europe	1.00			
Early life SEP score*	0.79	0.64	0.98	0.032
Objectively recorded steps*	0.81	0.66	0.99	0.039
Self-reported regular PA before pregnancy				
Yes	0.69	0.48	0.99	0.046
No	1.00			

*Numbers for continuous variables give OR per 1 SD.

†Adjusted for gestational week, age, parity, pre-pregnancy body mass index plus the covariates listed.

CI, confidence interval; MVPA, moderate-to-vigorous-intensity PA; PA, physical activity; SEP, socioeconomic position.

The number of objectively recorded steps per day in early gestation was inversely associated with the risk of GDM even after adjustments for pre-pregnancy BMI, self-reported regular PA before pregnancy, and early life SEP. The adjusted odds ratio for developing GDM decreased by 19% for each 3159 objectively recorded steps per day increase. Glucose uptake by skeletal muscles is improved and proteins involved in insulin signal transduction are altered for up to 48 h after a PA session (Zhang & Ning, 2011; Roberts et al., 2013). Additionally, small breaks during sedentary periods have positive effects on the metabolic profile and insulin action (Cooper et al., 2012; Tudor-Locke & Schuna, 2012). Previous studies have found that light-to-moderate-intensity PA in early gestation is associated with a lower risk for GDM (Tobias et al., 2011; Mudd et al., 2013). We did not find any significant association between light-intensity PA and GDM. The number of steps might be a measure of total daily life PA, as it does not differentiate between leisure time, occupational, and other types of PA nor intensity levels. Information about the total amount of PA can be difficult to collect through questionnaires due to the respondents' conceptualization of PA, recall difficulties, and other factors (Gaston & Cramp, 2011; Evenson et al., 2012; Pollard & Guell, 2012). Objectively recorded steps appear to be a robust measure that captures information about total daily life PA, which might be important for the prevention of GDM (Hawley & Lessard, 2008; Gradmark et al., 2011).

Self-reported regular PA for less than 1 year prior to pregnancy was associated with a lower risk for GDM. The importance of PA before pregnancy in the prevention of GDM has also been reported by others (Tobias et al., 2011; Cooper et al., 2012; Mudd et al., 2013). The long-term preventive effect of PA may be related to altered body weight and/or body composition, with a relative decrease in fat mass and an increase in lean muscle mass (Zhang & Ning, 2011; Thompson et al., 2012). Women who are insulin sensitive before pregnancy may be more capable of handling pregnancy-induced insulin resistance with adequate β-cell compensation (Buchanan et al., 2012). Studies have shown that a modest increase in habitual PA may profoundly affect an individual's glucose tolerance (Thompson et al., 2012; Roberts et al., 2013). The association between self-reported regular PA before pregnancy and GDM persisted even after adjustments for pre-pregnancy BMI, indicating that PA has long-term positive effects beyond the benefit of lower BMI (InterAct, 2012; Thompson et al., 2012).

International recommendations state that all adults, even pregnant women, should perform PA of moderate intensity for at least 30 min on most, if not all, days of the week (Mudd et al., 2013). Moderate-intensity PA in bouts of at least 10 min is recommended. Moderate-to-vigorous-intensity PA has been reported to improve health outcomes outside pregnancy (Beenackers et al., 2012). In the present study, self-reported aerobic PA for at least 150 min/week 3 months before pregnancy was inversely associated with the risk for developing GDM, but this association was not significant after adjustments. Only 13% of the women self-reported aerobic PA for at least 150 min/week in early gestation, and this variable may therefore not discriminate the consequence of inactivity appropriately. Objectively recorded moderate-to-vigorous-intensity PA minutes/day in early gestation was also not significantly associated with the risk of GDM after adjustments. Possible explanations for the non-significant effect of exercise on GDM reported from intervention studies include poor adherence to the interventions, the content or delivery of the intervention itself and that the second trimester might be too late to achieve an effect (Oostdam et al., 2012; Stafne et al., 2012). However, PA including activities of daily life without vigorous intensity may be beneficial for glucose

homeostasis, not only through an increase in insulin sensitivity but also for β-cell function (Hawley & Lessard, 2008; Roberts et al., 2013). In accordance with studies assessing type 2 diabetes (Tobias et al., 2011; Cooper et al., 2012; Tudor-Locke & Schuna, 2012), a greater amount of daily life PA, i.e., objectively recorded steps, was associated with reduced risk for GDM.

Early life SEP was inversely associated with GDM. This is in agreement with other studies showing an effect of early environment on adult health (Brown et al., 2004; Gluckman et al., 2008; Dode & dos Santos, 2009). Recognized risk factors of type 2 diabetes, including low birth weight, short stature, and greater adult weight, are associated with the SEP of the parents (Dode & dos Santos, 2009), and thus, early life SEP. However, studies assessing the effect of SEP on the risk of developing GDM have reported inconsistent findings (Anna et al., 2008; Dode & dos Santos, 2009; Link & McKinlay, 2009; Cullinan et al., 2012). We found that early life SEP, assessed with a more specific and robust measure, was inversely associated with the risk of GDM even after adjustments for education, whereas no independent association was seen between education level and GDM. This may reflect that the timing of exposure is relevant (Gluckman et al., 2008) and that early life SEP might be of foremost importance for GDM.

Asian women are more insulin resistant than Western Europeans, with a reduced β-cell insulin response at the same BMI (Golden et al., 2012; Morkrid et al., 2012). Ethnic minority women from South Asia have been reported to have a higher GDM prevalence compared with the majority of the population (Anna et al., 2008; Jenum et al., 2012). Consistent with theories explaining the susceptibility for diabetes in South Asians (Bhopal, 2013), both reduced early life SEP and low levels of PA explain a significant proportion of their increased risk for GDM. It might also be in concert with the hypothesis stating that if there is a mismatch between the intrauterine environment, where the prenatal programming occurs, and the actual environment, increased susceptibility to obesity and diabetes might develop in the offspring (Gluckman et al., 2008).

The present study reports unique information regarding objectively recorded PA and early life SEP, which were not previously assessed in relation to GDM. The strengths of the study are its prospective design and the high participation rates across the ethnic groups (Jenum et al., 2012). The sample is considered fairly representative for the largest ethnic groups included and should therefore be relevant to other countries with ethnic minority populations originating from the same regions.

The limitations of the study include lack of the 1-h PG value included in the diagnosis, as the Stork Groruddalen Study was planned before the release of the IADPSG criteria. However, the majority of women identified with GDM using the IADPSG criteria were identified based on the FPG value (Sacks et al., 2012). With the 1-h PG value, the number of women identified with GDM might have been higher, and thus, the power to identify significant associations would increase. The early life SEP score was identified through a principal component analysis, but only three variables were included in the analysis; thus, the reported Cronbach's α value is low. However, when using the three variables separately, similar gradients were found, and the patterns across the ethnic groups were comparable. The required number of hours per day and number of days wearing an accelerometer to reliably record valid estimates of mean PA levels depend on the study design and purpose, and there is no consensus (Matthews et al., 2012). The objectively recorded information is only a snapshot of the participant's PA behavior and may not be a representative of their habitual PA level. In the present study, a valid measurement of PA was defined as ≥19.2 h of objectively recorded data during 1 day. There were 127 (17%) women that did not meet this criterion. The results from the complete case analysis and the multiple imputations for missing at random showed similar findings, and data were therefore most likely missing completely at random (Sterne et al., 2009). Participants' compliance with the methods to objectively record PA in large-scale studies may be a challenge, and despite our request that participants wear the armband for 4–7 days, the mean recording duration was 3.8 days. Perhaps an even greater challenge is to perform such recordings among women from South Asia due to their traditional dress with tight sleeves and large family gatherings (greetings with physical body contact) (Pollard & Guell, 2012). There is no consensus regarding the lower threshold value for light-intensity PA. We used ≥1.5 METs, which might have included modes of sedentary behavior. Only 52% of the women had objectively recorded vigorous PA, and there was no difference in this proportion between women with and without GDM. Objectively recorded moderate-intensity PA and vigorous-intensity PA were both inversely associated with the risk of GDM and therefore combined. The objectively recorded minutes of moderate-to-vigorous-intensity PA are the total duration and are not restricted to bouts of least 10 min at a time, as recommended in the guidelines. This may partly explain the disparity between the minutes of objectively recorded moderate-to-vigorous-intensity PA and self-reported aerobic PA. Self-reported PA data are known to hold bias (Gaston & Cramp, 2011; Pollard & Guell, 2012). The questionnaires used in the present study have been validated and were translated into the eight languages primarily spoken in the district (Jenum et al., 2010). The questions did not capture information regarding household or occupational activities. There might be measurement errors due to conceptual and cultural factors related to PA (Hunt & Bhopal, 2004). However, when the objectively recorded and self-reported PA data were compared, the patterns were similar across ethnic groups and among women with and without GDM.

To conclude, objectively recorded PA in early gestation was inversely associated with the risk of developing GDM at 28 weeks of gestation even after adjusting for self-reported regular PA before pregnancy. The inverse association between objectively recorded PA in early gestation and GDM was related to daily life PA measured as steps.

Perspectives

The present study demonstrated that both objectively recorded PA in early gestation and self-reported regular PA before pregnancy were associated with GDM. A novel finding was that the inverse association between objectively recorded PA in early gestation and the risk of GDM identified at 28 weeks of gestation was related to the number of steps. These results indicate that even daily life PA may have a protective effect against GDM. Pregnant women should be encouraged to walk and be informed that it might prevent adverse pregnancy outcomes such as GDM.

Key words: Activity monitor, gestational diabetes mellitus, ethnic difference, pregnancy, socioeconomic factors.

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