Protocol

Measuring 24-hour Movement Profiles During Pregnancy: Protocol for the 24MOVE Prospective Cohort Study

Elizabeth Ryan[1], MD; Alex Asera[1], MPH; Kelley Pettee Gabriel[2], MS, PhD; Rachel Manber[3], PhD; Charles P Quesenberry[1], PhD; Lyndsay A Avalos[1], MPH, PhD; Monique M Hedderson[1], MPH, PhD; Sylvia E Badon[1], MS, PhD

[1]Division of Research, Kaiser Permanente Northern California, Pleasanton, CA, United States

[2]Department of Epidemiology, University of Alabama at Birmingham, Birmingham, AL, United States

[3]Department of Psychiatry and Behavioral Sciences, Standford University School of Medicine, Stanford, CA, United States

Corresponding Author:
Sylvia E Badon, MS, PhD
Division of Research
Kaiser Permanente Northern California
4480 Hacienda Dr
Pleasanton, CA, 94588
United States
Phone: 1 5108913638
Fax: 1 5108913638
Email: sylvia.e.badon@kp.org

Abstract

Background: Physical activity (PA) during the waking period and sleep during pregnancy may mitigate the increased risk for adverse pregnancy outcomes posed by gestational diabetes mellitus (GDM) and excessive gestational weight gain (GWG) in pregnant individuals with pre-pregnancy overweight and obesity. Recent studies have conceptualized PA, sedentary behavior, and sleep as part of a 24-hour movement framework; however, there is a gap in the knowledge about the relationship between 24-hour movement and pregnancy outcomes.

Objective: This paper describes the study protocol for the 24MOVE study, a prospective cohort study that examines associations between 24-hour movement profiles across pregnancy and maternal glucose tolerance, GWG, and infant birthweight.

Methods: Participants (N=306) were recruited from a large, integrated health care delivery system at 10 weeks' gestation. In early (10-12 weeks), mid- (20-22 weeks), and late (33-35 weeks) pregnancy, all eligible individuals with a pre-pregnancy BMI of ≥25 kg/m2 completed online surveys collecting information about sociodemographic characteristics and pregnancy symptoms and behaviors, including sleep quality. Participants concurrently wore a research-grade accelerometer for 24 hours per day for 7 consecutive days to capture movement, sedentary behavior, and sleep data. Data from accelerometry will be processed to create 24-hour movement profiles. Pregnancy outcomes will be ascertained from electronic health records (EHRs). We will use compositional data analysis (CoDA) methods, modeling associations of reallocations of time from one component behavior to another at various timepoints with outcomes.

Results: Recruitment began on March 19, 2023, and ended on September 11, 2024. Enrollment was completed on September 19, 2024. Data collection was completed in April 2025. Over an 18-month recruitment period, 2035 individuals were invited to participate, and of those, 306 (15%) eligible participants were enrolled in this study. The enrolled cohort had a median age of 33 (quintile 1 [Q1]-quintile 3 [Q3] 30-36) years and a median BMI of 28.8 (Q1-Q3 26.9-32.7) kg/m². Most participants had private insurance (n=266, 86.9%) and were multiparous (n=232, 75.8%). Analyses are in progress.

Conclusions: The 24MOVE study is designed to address gaps in our knowledge of the impact of 24-hour movement during pregnancy on maternal glucose metabolism, GWG, and other risk factors for childhood obesity, such as a high birthweight. Data from this study will also serve as a rich resource for future investigations of 24-hour movement profiles and behavior substitutions and other perinatal mental and physical health outcomes.

International Registered Report Identifier (IRRID): DERR1-10.2196/72828

Introduction

A high maternal pre-pregnancy BMI, gestational diabetes mellitus (GDM), and excessive gestational weight gain (GWG; value above the Institute of Medicine recommendations [1]) are prevalent pregnancy conditions that contribute to an in utero environment of overnutrition, leading to significant short- and long-term health ramifications for pregnant people and their children, including increased risks for obesity and diabetes [2-11]. Pregnant individuals with both obesity and excessive GWG have the highest risks of adverse pregnancy outcomes [12], and their children are also at greater risk of childhood obesity [13-15] and a greater BMI [16] in adulthood compared to children exposed to a normal weight and GWG within recommendations in utero.

Physical activity (PA) during the waking period and sleep during pregnancy may mitigate the increased risk for adverse pregnancy and health outcomes posed by GDM and excessive GWG in pregnant individuals with a high pre-pregnancy BMI. When studied as individual behaviors, regular moderate- to vigorous-intensity PA during pregnancy, light-intensity PA, less sedentary behavior, and adequate sleep are associated with pregnancy-specific health benefits [17], including lowering the risk of GDM [18-25], abnormal glucose tolerance [26-29], and excessive GWG [30-36]. Moderate-to vigorous-intensity PA is also associated with a lower risk of large for gestational age (LGA) birthweight [37]. In addition, emerging evidence suggests that sleep regularity, including consistent timing of sleep and wake periods, may be important for optimal health outcomes in adults [38].

Given that PA, sedentary behavior, and sleep are interrelated behaviors in the context of a 24-hour day, recent studies have conceptualized these behaviors as part of a 24-hour movement framework [39,40]. Informed by associations of 24-hour movement profiles and individual component behaviors with physical and mental health outcomes in the general adult population, Canada [41] and Thailand [42] have released "24-Hour Movement Guidelines for Adults," and Australia is in the process of incorporating a 24-hour approach for their next set of "Physical Activity and Sedentary Guidelines for Adults" [43]. In the United States, the most recent PA guidelines [44] include the recommendation to "sit less, move more, implying that for individuals initiating or increasing PA, replacing sedentary behavior with PA is a beneficial behavior change. Recent research has also highlighted the importance of integrating 24-hour movement guidance with dietary recommendations to support more holistic public health strategies [45]. These recommendations recognize the importance of considering the balance of behaviors in the 24-hour day, as well as behavior change as a replacement of one behavior for another in the context of the 24-hour day, but do not provide specific guidelines during pregnancy, a time when behavior change is common.

Initial studies on 24-hour movement in pregnancy suggest behavior reallocations to maintain or increase moderate- to vigorous-intensity PA may be beneficial for reducing pregnancy-induced increases in cardiometabolic biomarkers [46,47], improving body composition [46,48], and improving cardiorespiratory fitness [48]. In addition, one study found that reallocating time from sleep or sedentary behavior to light-intensity PA in early pregnancy may be beneficial for improving body composition and cardiometabolic biomarkers in late pregnancy [46]. However, these studies have all been exploratory and focused on risk factors for adverse outcomes. Larger, more representative, and longitudinal studies designed to address research questions on 24-hour movement and pregnancy outcomes, rather than risk factors, are needed to guide recommendations in this population.

As previous studies have all been exploratory, the impact of 24-hour movement during pregnancy on maternal glucose metabolism, GWG, and LGA birthweight remains uncertain. To address crucial knowledge gaps, studies with concurrent measurement of sedentary behavior, PA, and sleep throughout pregnancy are essential for informing recommendations and interventions to promote a healthy 24-hour day during pregnancy and optimal pregnancy outcomes.

This paper describes the study protocol for the 24MOVE study, a prospective cohort study that seeks to fill these knowledge gaps by examining associations between 24-hour movement profiles across pregnancy and maternal glucose tolerance, GWG, and infant birthweight. The aims of this study are to (1) examine relationships of 24-hour movement profiles in early and midpregnancy with maternal glucose tolerance in midpregnancy; (2) examine relationships of 24-hour movement profiles in early, mid-, and late pregnancy with GWG, and (3) examine relationships of 24-hour movement profiles in early, mid-, and late pregnancy with infant birthweight.

Methods

Study Setting

This study is currently being conducted within Kaiser Permanente Northern California (KPNC), an integrated health care delivery system providing care for more than 66,000 pregnancies (40,000 live births) annually in Northern California. KPNC health plan members are covered by employer-sponsored insurance plans, the California Insurance Exchange, Medicare, and Medicaid. KPNC membership represents the diverse population of the Northern California region in terms of demographic, ethnic, and socioeconomic characteristics, except with respect to income, where members underrepresent the poor and the wealthy [49]. Leveraging the KPNC's electronic health records (EHRs), participants were identified and recruited from three KPNC medical centers: Oakland, Walnut Creek, and South Sacramento. The Oakland, Walnut Creek, and South Sacramento medical centers represent urban, suburban, and semirural regions

across Northern California, providing a geographically and socioeconomically diverse sample.

Ethical Considerations

All study procedures were reviewed and approved by the KPNC Institutional Review Board (IRB approval number 1998165). Written informed consent was obtained from all participants prior to study enrollment, including consent for use of their data in future analyses. Participants were informed that participation was voluntary and that they could withdraw from the study at any time. All data used in this study were deidentified prior to analysis in order to protect participant privacy and confidentiality. No identifiable personal health information was used in analyses or shared outside the study team. Participants received compensation as follows:

- A US $75 gift card at each of the three study timepoints (early, mid-, and late pregnancy) after completing the study surveys and returning the accelerometer
- A US $25 gift card at each timepoint for completing three time-use and three diet surveys
- A US $20 gift card after completing the feedback survey at the late pregnancy timepoint

Overview of the Study Design

This prospective cohort study identified newly confirmed pregnancies among KPNC members with pre-pregnancy overweight or obesity through the KPNC's EHRs. Identified individuals were invited to participate in this study via letter and email invitations. Eligible participants who provided written informed consent completed surveys (copies of study surveys are available in Multimedia Appendix 1) wore an accelerometer on their nondominant wrist for 24 hours per day for 7 days and participated in daily short sleep surveys at three timepoints in pregnancy (early, mid-, and late). During select days of activity and sleep monitoring, participants received links for additional surveys on 24-hour time use and diet. At the late pregnancy timepoint, participants also received an additional survey asking for feedback on their experience in the study, including their motivation for participating, any problems or issues they experienced with any aspect of the study, and suggestions for future research questions that are important to them. Pregnancy outcomes were ascertained from the EHRs.

Recruitment

Eligible KPNC members at 10 weeks' gestation (10 weeks 0 days to 10 weeks 6 days) were identified weekly from the EHRs. Identified members received an invitation letter by mail, including a link to an online eligibility survey, administered via Research Electronic Data Capture (REDCap), to confirm eligibility for the study. After completing the eligibility survey, eligible individuals who chose to participate in the study proceeded to complete informed consent. In cases of nonresponse to the mailed letter invitation after a week, an email study invitation was sent from the study email address. If there was still no response to the email after a week, a research assistant followed up once by phone. Members who did not respond to any of these invitations were not contacted further. Those who initiated but did not complete the baseline survey received two reminders via email through REDCap (1 reminder per week) after initiating the survey. If the survey was not completed after the reminders were sent, the individual was not contacted further.

Eligibility Criteria

As summarized in Table 1, potential participants were identified using initial EHR criteria, and eligibility was confirmed with an online eligibility survey.

Table 1. Eligibility criteria for the 24MOVE study.

Eligibility criterion	EHRs[a]	Eligibility survey
KPNC[b] membership	X[c]	X
Currently pregnant	X	X
Receiving care at Kaiser Permanente Oakland, South Sacramento, or the Walnut Creek Medical Center	X	—[d]
Singleton pregnancy	X	X
≤12 weeks' gestation (10 weeks 0 days to 12 weeks 6 days)	X	X
Age ≥18 years	X	X
Pre-pregnancy BMI ≥25 kg/m² (based on closest weight measured within 12 months prior to pregnancy)	X	—
No diabetes diagnosis in the 12 months before pregnancy	X[e]	X
Not currently on bed rest or activity restriction (to exclude those with extreme limitations on their PA[f])	—	X
No diagnosis or treatment of a sleep disorder in the 12 months before pregnancy (to exclude those with disrupted sleep patterns)	X[g]	X
No clinically significant insomnia symptoms (Insomnia Severity Index [50,51] <15, to exclude those with disrupted sleep patterns)	—	X

[a]EHR: electronic health record.

[b]KPNC: Kaiser Permanente Northern California.

[c]Applicable.

[d]Not applicable.

[e]Identified using the KPNC Diabetes Registry [52]

[f]PA: physical activity.

[g]Identified using International Classification of Diseases (ICD) codes F51 and G47.

Overview of Data Collection

At each of the three data collection timepoints—early pregnancy (10 weeks 0 days to 12 weeks 6 days), midpregnancy (20 weeks 0 days to 22 weeks 6 days), and late pregnancy (33 weeks 0 days to 35 weeks 6 days)—participants completed a set of surveys administered through REDCap (copies of study surveys are available in Multimedia Appendix 1), wore a Centrepoint Insight accelerometer (ActiGraph) on their nondominant wrist for 24 hours per day for 7 days, and participated in short daily sleep surveys. The surveys at each timepoint covered a broad range of topics, including PA levels, pregnancy-related symptoms, substance use, perceived social support, depressive and anxiety symptoms, perceived stress levels, quality of life, and sociodemographic characteristics (Table 2). At the early pregnancy timepoint, participants additionally reported whether it was their first pregnancy, the number of children currently residing with them, the birthdate of each child, their typical waking times on weekdays and weekends since the beginning of pregnancy, their gender identity, their racial and ethnic identities, educational attainment, the total annual household income, the number of individuals supported by this income, marital status, and wrist size. Participants' address and contact information were confirmed, by phone or as part of the online survey, at each study timepoint. After survey completion at each timepoint, accelerometers were mailed to participants, along with a prepaid return envelope. Participants were provided detailed written instructions on how to properly wear, care for, and return the accelerometer, including a frequently asked question (FAQ) section covering common concerns. Participants received a link to a Consensus Sleep Diary via a text message at their usual wake time (as indicated on the early pregnancy survey) for 7 consecutive days during the accelerometer wear period. If typical wake times were not provided by a participant, surveys were sent at 8:00 AM by default. On 3 random days during the 7-day period of accelerometer wear, participants received links via email for additional surveys for 24-hour recall of time use and diet. After delivery, maternal glucose tolerance–screening results, GWG, and infant birthweight will be abstracted from prenatal care and delivery records in the EHRs.

Table 2. Overview of data collection at each study timepoint.

Measure	Instrument	Study data collection timepoint		
		Early pregnancy (10-12 weeks' gestation)	Midpregnancy (20-22 weeks' gestation)	Late pregnancy (33-35 weeks' gestation)
24-hour movements				
24-hour accelerometry	Centrepoint Insight watch	X[a] (7 consecutive days)	X (7 consecutive days)	X (7 consecutive days)
In-bed duration, sleep duration, sleep quality, napping	Consensus Sleep Diary [53]	X (7 consecutive days)	X (7 consecutive days)	X (7 consecutive days)
PA[b] and sedentary behavior	Modified PPAQ[c] [54]	X	X	X
Time use	ACT24[d] [55]	X (3 random days)	X (3 random days)	X (3 random days)
PA before pregnancy	Stanford Leisure-Time Activity Categorical Item (L-Cat) [56,57]	X	__[e]	—
Usual weekday/weekend wakeup times	—	X	—	—
Pregnancy symptoms and behaviors				
Nausea and vomiting	Modified PUQE[f] index [58]	X	X	X
Tobacco, alcohol, and marijuana use	—	X	X	X
Diet	ASA24[g] [59]	X (3 random days)	X (3 random days)	X (3 random days)
Mental health and social support during pregnancy				
Perceived social support	Multidimensional Scale of Perceived Social Support [60,61]	X	X	X
Perceived stress	PSS-10[h] [62]	X	X	X
Depressive symptoms	PHQ-8[i] [63]	X	X	X
Anxiety symptoms	GAD-7[j] [64]	X	X	X
Quality of life	QOL-GRAV[k] [65]	X	X	X
Sociodemographic characteristics				
Gravidity, number of children living with the participant, birthdates of those children	—	X	—	—
Gender identity	—	X	—	—
Racial and ethnic identities	—	X	—	—
Education	—	X	—	—
Employment status	—	X	X	X
Household income, number of people supported by this income	—	X	—	—
Marital status	—	X	—	—

[a]Applicable.

[b]PA: physical activity.

[c]PPAQ: Pregnancy Physical Activity Questionnaire.

[d]ACT24: Activities Collected over Time over 24 hours.

[e]Not applicable.

[f]PUQE: Pregnancy-Unique Quantification of Emesis and Nausea.

[g]ASA24: Automated Self-Administered 24-Hour Dietary Assessment.

[h]PSS-10: 10-item Perceived Stress Scale.

[i]PHQ-8: 8-item Patient Health Questionnaire.

[j]GAD-7: 7-item General Anxiety Disorder Scale.

[k]QOL-GRAV: Quality of Life Gravidarum questionnaire.

Data Processing and Creation of 24-hour Movement Profiles Using Accelerometer Data

Accelerometer Wear Time

Raw accelerometer data will be sampled at 32 Hz, downloaded using the Centrepoint software platform (ActiGraph), and processed with R (R Foundation for Statistical Computing) [66]. Vector magnitude counts, summarized for each minute (60-second epoch) of data collection, will be extracted. Nonwear time will be identified using the Choi algorithm [67-69], where nonwear is defined as an interval of ≥90 consecutive minutes with 0 vector magnitude counts/minute, allowing up to 2 minutes of nonzero counts during the 30-minute window before or after that interval. Any nonzero vector magnitude counts (except within the allowed short intervals) will be considered wear time. Valid accelerometer data will be defined as ≥10 hours of waking wear time in a 24-hour period for ≥4 days.

Sleep Opportunity Period

The Tracy bed rest algorithm will be used to estimate sleep opportunity periods [70]. Uniaxial counts, summarized for each minute (60-second epoch) of data collection, will be extracted. Wear time will be divided into 60-minute time blocks; counts per minute will be averaged for each block. The algorithm, using a 4-step decision tree process, identifies transition times for getting in and out of bed, with thresholds of 400 counts per minute for getting in bed and 1500 counts per minute for getting out of bed. Minutes between identified in-bed and out-of-bed times will be classified as the sleep opportunity period and the remaining minutes as wake time. The duration of the sleep opportunity period for each 24-hour period will be calculated and averaged across valid days, with daily averages for sleep opportunity period duration considered as exposures in the 24-hour movement framework. Daytime naps will be separately reported via the Consensus Sleep Diary and will be considered as an additional component of 24-hour movement profiles in secondary analyses. We will also use self-reported measures of sleep quality from sleep diaries as potential effect modifiers in analyses.

Light-Intensity PA, Moderate- to Vigorous-Intensity PA, and Sedentary Behavior

We will use the 2-regression algorithms developed by Hibbing et al [71] to categorize the waking period by intensity. Raw acceleration data for each second of identified waking wear time (1-second epochs) will be extracted. Each 1-second epoch will be classified as sedentary or at least light-intensity PA. Sedentary 1-second epochs will be assigned a metabolic equivalent of task (MET) value of 1.25 METs. Epochs classified as light- or higher-intensity PA will be further categorized as continuous walk/run or intermittent activity, regression equations will predict a MET value for each 1-second epoch, and then MET values will be averaged over each minute. Minutes of waking wear time will then be classified as sedentary (≤1.5 METs), light intensity (1.6-2.9 METs), or moderate to vigorous intensity (≥3 METs). Daily averages for light-intensity PA duration, moderate- to vigorous-intensity PA duration, and sedentary behavior duration will be calculated by summing the times per day and averaging across valid days.

24-hour Movement Profiles

Participants' 24-hour movement profiles will be created by normalizing the sleep opportunity period, sedentary behavior, light-intensity PA, and moderate- to vigorous-intensity PA durations to a 24-hour period.

Survey Data: 24-hour Movement

Self-Reported PA and Sedentary Behavior

The self-reported PA and sedentary behavior levels of participants will be assessed using the Pregnancy Physical Activity Questionnaire (PPAQ) [54]. The PPAQ was developed based on commonly reported physical activities in pregnant women and is a validated tool for assessing PA levels during pregnancy [54]. We used a modified version of the PPAQ that expands on leisure time behaviors to include additional activities (eg, weightlifting, yoga/Pilates/stretching, and team sports). We will use the PPAQ to provide contextual information about activity domains to complement accelerometer data. In scoring, activities reported will be matched to their assigned MET values, which will then be summed across categories to calculate total MET-hours per week or day by intensity of behavior and by domain.

24-hour Time Use

The Activities Collected over Time over 24 hours (ACT24) [55] instrument will be used to collect detailed data on each participant's activities over the previous 24-hour day, including PA, sedentary behavior, and sleep. The ACT24 is a valid tool for accurately capturing time spent in the previous day's activities across multiple intensities and domains [55,72,73]. Data from the ACT24 will complement accelerometer data by providing contextual information on the types of activities and domains not captured by movement sensors alone.

Survey Data: Pregnancy Symptoms and Additional Behaviors

Pregnancy Nausea and Vomiting Symptoms

The modified Pregnancy-Unique Quantification of Emesis and Nausea (PUQE) index is a validated tool for measuring the severity of nausea and vomiting during pregnancy [58,74]. It assesses the frequency and intensity of nausea and vomiting and their impact on daily life. Responses are summed to obtain a total score ranging from 3 to 15, with a higher score indicating more severe nausea and vomiting symptoms during pregnancy.

Diet

The Automated Self-Administered 24-Hour Dietary Assessment (ASA24) is a web-based recall tool for collecting detailed dietary intake data over a 24-hour period that has been validated for estimating dietary intake in multiple populations [59,75,76]. The ASA24 generates comprehensive reports and analysis files

on nutrient intake and food group consumption based on user inputs.

Survey Data: Mental Health and Social Support During Pregnancy

Perceived Social Support

The Multidimensional Scale of Perceived Social Support [60,61] measures perceived support from family, friends, and significant others. It is a widely validated and reliable tool across various populations [60,61,77]. The scale consists of 12 questions scored on a 7-point Likert scale ranging from 1 (very strongly disagree) to 7 (very strongly agree). Scores are calculated for overall social support and within each subscale (family, friends, significant other). Calculated scores range from 1 to 7, with higher scores indicating greater perceived social support.

Perceived Stress

The 10-item Perceived Stress Scale (PSS-10) [62] is the most widely used psychological instrument for measuring the perception of stress and has been validated in diverse populations and in perinatal women [78]. Scores range from 0 to 40, with 14 or greater signifying moderate-to-severe perceived stress.

Depressive Symptoms

Depressive symptoms will be measured using the 8-item Patient Health Questionnaire (PHQ-8) [63]. The PHQ-8 has been validated in many studies as an instrument for screening for depression, with high sensitivity (>88%) and specificity (>88%) in obstetric patients [63,79]. The PHQ-8 is also a valid tool to establish depression severity and outcome [80]. The 8-question screener scores range from 0 to 24. A score of 1-4 suggests minimal depression; 5-9, mild depression; 10-14, moderate depression; 15-19, moderately severe depression; and 20-24, severe depression.

Anxiety Symptoms

The 7-item General Anxiety Disorder Scale (GAD-7) [64] has been validated in prenatal populations and will be used to measure anxiety symptoms [64,81]. Scores range from 0 to 21, and scores of 10-21 are categorized as clinically significant anxiety symptoms.

Pregnancy-Related Quality of Life

The Quality of Life Gravidarum questionnaire (QOL-GRAV) is a validated tool for assessing the well-being of pregnant women across physical, emotional, and social aspects [1,65]. Overall scores range from 15 to 35, with a lower score reflecting a higher quality of life during pregnancy.

Pregnancy Outcomes

Pregnancy outcomes, including glucose tolerance, GWG, and infant birthweight, will be identified from EHR data. The KPNC maintains a virtual data warehouse where data from EHRs are aggregated on a daily basis with rigorous quality control and standardization of data for consistency and accuracy across multiple data sources. Outcomes will be extracted from this database.

Maternal Glucose Tolerance

GDM screening at the KPNC consists of a 50 g glucose challenge test for all pregnant patients. If the glucose challenge test results are abnormal ($\geq$140 mg/dL), a subsequent 100 g, 3-hour oral glucose tolerance test is administered. GDM will be diagnosed according to Carpenter-Coustan criteria [82]. Glucose tolerance–screening results and GDM diagnoses will be abstracted from the EHRs. Glucose challenge test results (continuous glucose levels and dichotomized as normal [<140 mg/dL] vs abnormal [$\geq$140 mg/dL]) will be examined as outcomes in the main analyses. In exploratory analyses, we will examine the GDM diagnosis as an outcome.

Gestational Weight Gain

Weight measurements will be taken and recorded during each prenatal visit in the EHRs. The total GWG will be calculated as the difference between the final pregnancy weight predelivery (within 3 weeks of delivery) and the pre-pregnancy weight (the most recent clinically measured pre-pregnancy weight within 6 months before the last menstrual period or for women lacking a measured pre-pregnancy weight, the earliest clinically measured pregnancy weight before 10 weeks' gestation). We will use standardized GWG-for-gestational age charts to calculate GWG z-scores to account for the correlation between the GWG and the gestational age at delivery [83,84]. GWG z-scores will be used as continuous outcomes in the main analyses. The average weekly trimester-specific GWG for the second and third trimesters will also be calculated. The trimester-specific GWG will be categorized using Institute of Medicine recommendations (below, within, or above recommendations) [85]. We will examine the trimester-specific GWG as a continuous outcome, stratified by pre-pregnancy BMI category, and as a categorical outcome.

Infant Birthweight

The birthweight is measured at the time of delivery and recorded in the EHR. We will use gestational age data from the EHR in conjunction with national sex-specific birthweight curves to identify birthweight-for-gestational age z-scores and the LGA birthweight [86]. We will examine birthweight as a continuous outcome in the main analyses. In exploratory analyses, we will examine the LGA birthweight as an outcome.

Sample Size

Given a sample size of 300, there is sufficient power (0.80) to detect an additional 2.1%-2.4% in the proportion of variance in glucose-screening results, GWG, and birthweight explained by the duration of each behavior (sleep, sedentary behavior, light-intensity PA, or moderate- to vigorous-intensity PA) across the expected ranges in R^2 for a set of confounders (5%-20%; 15 confounders assumed, α=.05, F-test). In exploratory analyses, the minimum detectable relative risk of GDM, excessive GWG, and LGA per 1 SD increase in a component behavior is 1.70, 1.12, and 1.60, respectively (power=0.80, α=.05, 2-sided test).

Planned Statistical Analyses

We will use a compositional data analysis (CoDA) approach for all analyses. We will apply isometric log-ratio transformations to normalized 24-hour movement profiles (the

proportion of the 24-hour day spent in the sleep opportunity period, sedentary behavior, light-intensity PA, and moderate-to vigorous-intensity PA) to obtain three transformed variables that capture the codependence and collinearity between these behaviors [87-89]. To examine how hypothetical behavior substitutions within the 24-hour day during pregnancy impact outcomes, we will use a compositional isotemporal substitution approach [90] to model the predicted change in pregnancy outcomes when reallocating up to 60 minutes of time from one component behavior to another at various timepoints. We will assess associations of hypothetical behavior substitutions in early and midpregnancy with glucose tolerance outcomes (aim 1); in early, mid-, and late pregnancy with GWG outcomes (aim 2); and in early, mid-, and late pregnancy with birthweight outcomes (aim 3).

We will use linear regression models to model relationships with continuous outcomes (glucose challenge test results, GWG, birthweight) and log-binomial regression models to model relationships with dichotomous outcomes (abnormal glucose challenge test results, GDM diagnosis, GWG above recommendations, LGA birthweight). All models will be adjusted for a priori–identified confounding variables (eg, maternal age, race and ethnicity, education, income, employment, pre-pregnancy BMI, parity, diet, depression and anxiety symptoms, stress, smoking and alcohol use, and severity of nausea and vomiting). We will assess potential multicollinearity using variance inflation factors and exclude covariates from the models, as necessary. Departures from linearity will be addressed by the addition of higher order (eg, quadratic) terms. Departures from model assumptions will be assessed via diagnostic plots of weighted residuals. Missing data will be assessed, and if necessary, missing data in covariates and outcomes will be handled using standard multiple imputation methods for longitudinal data analysis, namely multivariate imputation by chained equations (MICE), which has also been referred to as fully conditional specification (FCS).
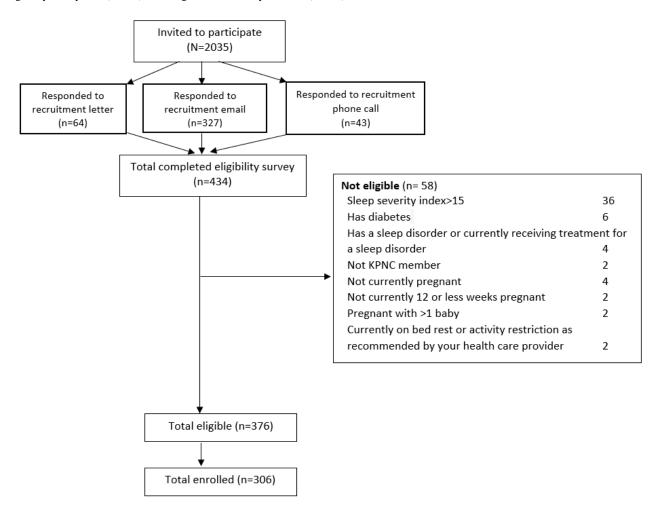
Results

Study Timeline

Recruitment began on March 19, 2023, and ended on September 11, 2024. Enrollment was completed on September 19, 2024. Data collection was completed in April 2025.

Recruited Cohort

Over an 18-month recruitment period, we invited 2035 KPNC members to participate in this study (Figure 1). Responses to the invitation were received via recruitment emails (n=327, 16.1%), recruitment letters (n=64, 3.1%), and recruitment phone calls (n=43, 2.1%). Of those invited, 434 (21.3%) individuals completed the eligibility survey, and 376 (86.6%) met the eligibility criteria. The most prevalent reason for ineligibility was clinically significant insomnia symptoms (n=36, 8.3%). A total of 306 (81.4%) participants consented to participate in the study and were enrolled.

Figure 1. Summary of recruitment for the 24MOVE study. In total, 2035 participants were invited to participate, 434 (21.3%) responded and completed an eligibility survey, 376 (86.6%) were eligible for the study, and 306 (81.4%) were enrolled. KPNC: Kaiser Permanente Northern California.

Enrolled participants had a median age of 33 (quintile 1 [Q1]-quintile 3 [Q3] 30-36) years with a median pre-pregnancy BMI of 28.8 (Q1-Q3 26.9-32.7) kg/m^2 (Tables 3 and 4). Among the 306 participants, 129 (42.2%) were non-Hispanic White, 61 (19.9%) were Hispanic, 48 (15.7%) were Asian, and 24 (7.8%) were non-Hispanic Black. Most participants had private insurance (n=266; 86.9%) and were multiparous (n=232; 75.8%). Pre-pregnancy anxiety and depression had a prevalence of 19%-22% (n=58-68), while hypertension and diabetes were uncommon (reported by 0-12, 0%-4%, participants). Comparing sociodemographic and pre-pregnancy health characteristics between invited participants and the subset that were eligible and enrolled in this study, the enrolled cohort underrepresented non-Hispanic Black, Asian, and Hispanic participants and those with Medicaid insurance compared to the invited group. Other characteristics (age, parity, and pre-pregnancy health) were similar between the invited and enrolled participants.

Table 3. Comparison of sociodemographic characteristics between subsets of participants invited to the 24MOVE study.

Characteristics	Invited (N=2035)	Completed eligibility survey (n=434)	Eligible (n=376)	Enrolled (n=306)
Age (years), median (Q1[a]-Q3[b])	32 (28-35)	33 (30-36)	33 (30-36)	33 (30-36)
Race and ethnicity, n (%)				
Asian	424 (20.8)	70 (16.1)	61 (16.2)	50 (16.3)
Non-Hispanic Black	283 (13.9)	41 (9.4)	33 (8.8)	25 (8.2)
Hispanic	497 (24.4)	100 (23.0)	82 (21.8)	61 (19.9)
Multiracial	170 (8.4)	42 (9.7)	35 (9.3)	30 (9.8)
Non-Hispanic White	560 (27.5)	158 (36.4)	147 (39.1)	128 (41.8)
Other	63 (3.1)	12 (2.7)	9 (2.3)	4 (1.3)
Missing	38 (1.9)	11 (2.5)	9 (2.3)	8 (2.6)
Medicaid insurance, n (%)				
Insured	333 (16.4)	44 (10.1)	36 (9.6)	28 (9.2)
Missing	90 (4.4)	18 (4.1)	13 (3.5)	12 (3.9)
Nulliparous, n (%)				
Yes	316 (15.5)	67 (15.4)	58 (15.4)	45 (14.7)
Missing	145 (7.1)	34 (7.8)	32 (8.5)	27 (8.8)

[a]Q1: quintile 1.

[b]Q3: quintile 3.

Table 4. Comparison of pre-pregnancy health characteristics between subsets of participants invited to the 24MOVE study.

Characteristics	Invited (N=2035)	Completed eligibility survey (n=434)	Eligible (n=376)	Enrolled (n=306)
BMI (kg/m^2), median (Q1[a]-Q3[b])	30.4 (27.4-34.9)	29.2 (27.0-33.5)	29.1 (26.9-33.1)	28.8 (26.9-32.7)
Anxiety diagnosis, n (%)	396 (19.5)	101 (23.3)	89 (23.7)	68 (22.2)
Depression diagnosis, n (%)	339 (16.7)	88 (20.3)	72 (19.1)	57 (18.6)
Hypertension diagnosis, n (%)	95 (4.7)	19 (4.4)	15 (4.0)	12 (3.9)
Diabetes diagnosis, n (%)	11 (0.5)	2 (0.5)	1 (0.3)	1 (0.3)

[a]Q1: quintile 1.

[b]Q3: quintile 3.

Discussion

Summary

The 24MOVE study is designed to address gaps in our knowledge regarding the impact of 24-hour movement during pregnancy on maternal glucose metabolism, GWG, and other risk factors for childhood obesity, such as a high birthweight. Data from this study will serve as a rich resource for future investigations of 24-hour movement profiles and behavior substitutions and perinatal mental and physical health outcomes, in addition to the aims of this study. As a growing number of countries release "24-Hour Movement Guidelines for Adults," the results from this study will contribute to the body of literature that will guide future 24-hour movement guidelines for pregnant individuals.

Strengths and Limitations

Strengths of the 24MOVE study include prospective data collection using wearable devices and self-reported measures for all component behaviors during the 24-hour day at multiple timepoints across pregnancy, allowing for the assessment of the duration, intensity, and domain of PA and sedentary behavior and the duration and quality of sleep, including napping. In addition, all data collection is remote, and outcomes are ascertained from EHRs, decreasing the participant burden. Our planned statistical analysis approach using CoDA addresses limitations of conventional statistical approaches, including all mutually exclusive component behaviors of the 24-hour day [91-94]. We will also assess a variety of important confounders and covariates in our data collection and include them in analysis models, as well as assess and address missing data using statistical approaches to maximize available data.

Several potential limitations should also be considered. Although more than 50% of our enrolled study cohort are participants from minoritized racial and ethnic groups, these groups are underrepresented compared to those invited to participate in the study. In addition, those with Medicaid insurance (a proxy for low income) are also underrepresented in the enrolled cohort. Our cohort may not be representative of pregnancies with pre-pregnancy overweight or obesity across the United States. We did not collect data on whether the pregnancy was planned, which may influence pregnancy-related behaviors and outcomes. Although we attempted to minimize the participant burden as much as possible by streamlining surveys and accelerometer protocols, there is a risk of participant fatigue due to multiple data collection modalities over the three timepoints of data collection. During follow-up data collection, we monitored participant engagement and loss to follow-up, amending study procedures to address identified issues if necessary. We will also carefully consider representativeness and loss to follow-up in our analyses and apply appropriate statistical methods to mitigate some of these concerns.

Dissemination of Results

Results from the 24MOVE study will be disseminated widely via publication in peer-reviewed journals and presentations at national and international conferences.

Conclusion

The 24MOVE study seeks to enhance our understanding of how 24-hour movement throughout pregnancy influences maternal glucose regulation, the GWG, and key risk factors for childhood obesity, including a high birthweight. Furthermore, the study will offer a comprehensive data resource for future research on movement patterns, behavioral changes, and associations with perinatal mental and physical health outcomes.

Data Availability

Deidentified individual participant data and supporting documentation will be made publicly available in a data repository upon publication, in accordance with funder requirements. The code used for statistical analyses will be provided as a supplement to the published manuscript or made available in the same repository.

Authors' Contributions

ER led project administration, coordinated data collection, wrote the initial draft, and reviewed and edited the manuscript. AA handled data curation and reviewed and edited the manuscript. CPQ contributed to the methodology and reviewed and edited the manuscript. KPG, RM, LAA, and MMH contributed to conceptualization, funding acquisition, and reviewed and edited the manuscript. SEB led the study's conceptualization, methodology, supervision, and funding acquisition; contributed to writing the initial draft; and reviewed and edited the manuscript.

Conflicts of Interest

None declared.

Multimedia Appendix 1

First trimester survey and feedback survey.
[PDF File (Adobe PDF File), 320 KB-Multimedia Appendix 1]

References

1. Brekke M, Berg RC, Amro A, Glavin K, Haugland T. Quality of life instruments and their psychometric properties for use in parents during pregnancy and the postpartum period: a systematic scoping review. Health Qual Life Outcomes. Jul 09, 2022;20(1):107. [FREE Full text] [doi: 10.1186/s12955-022-02011-y] [Medline: 35810315]
2. Catalano PM, Ehrenberg HM. The short- and long-term implications of maternal obesity on the mother and her offspring. BJOG. Oct 2006;113(10):1126-1133. [FREE Full text] [doi: 10.1111/j.1471-0528.2006.00989.x] [Medline: 16827826]
3. Torloni MR, Betrán AP, Horta BL, Nakamura MU, Atallah AN, Moron AF, et al. Prepregnancy BMI and the risk of gestational diabetes: a systematic review of the literature with meta-analysis. Obes Rev. Mar 2009;10(2):194-203. [doi: 10.1111/j.1467-789X.2008.00541.x] [Medline: 19055539]
4. Sridhar SB, Darbinian J, Ehrlich SF, Markman MA, Gunderson EP, Ferrara A, et al. Maternal gestational weight gain and offspring risk for childhood overweight or obesity. Am J Obstet Gynecol. Sep 2014;211(3):259.e1-259.e8. [FREE Full text] [doi: 10.1016/j.ajog.2014.02.030] [Medline: 24735804]
5. Rogozińska E, Zamora J, Marlin N, Betrán AP, Astrup A, Bogaerts A, et al. International Weight Management in Pregnancy (i-WIP) Collaborative Group. Gestational weight gain outside the Institute of Medicine recommendations and adverse pregnancy outcomes: analysis using individual participant data from randomised trials. BMC Pregnancy Childbirth. Sep 02, 2019;19(1):322. [FREE Full text] [doi: 10.1186/s12884-019-2472-7] [Medline: 31477075]

6.   Bellamy L, Casas J, Hingorani AD, Williams D. Type 2 diabetes mellitus after gestational diabetes: a systematic review and meta-analysis. Lancet. May 23, 2009;373(9677):1773-1779. [doi: 10.1016/S0140-6736(09)60731-5] [Medline: 19465232]

7.   Kim C, Newton KM, Knopp RH. Gestational diabetes and the incidence of type 2 diabetes: a systematic review. Diabetes Care. Oct 2002;25(10):1862-1868. [FREE Full text] [doi: 10.2337/diacare.25.10.1862] [Medline: 12351492]

8.   Langer O, Yogev Y, Most O, Xenakis EMJ. Gestational diabetes: the consequences of not treating. Am J Obstet Gynecol. Apr 2005;192(4):989-997. [FREE Full text] [doi: 10.1016/j.ajog.2004.11.039] [Medline: 15846171]

9.   Fraser A, Lawlor DA. Long-term health outcomes in offspring born to women with diabetes in pregnancy. Curr Diab Rep. Mar 25, 2014;14(5):489. [FREE Full text] [doi: 10.1007/s11892-014-0489-x] [Medline: 24664798]

10. Clausen TD, Mathiesen ER, Hansen T, Pedersen O, Jensen DM, Lauenborg J, et al. High prevalence of type 2 diabetes and pre-diabetes in adult offspring of women with gestational diabetes mellitus or type 1 diabetes: the role of intrauterine hyperglycemia. Diabetes Care. Mar 2008;31(2):340-346. [doi: 10.2337/dc07-1596] [Medline: 18000174]

11. Li S, Zhu Y, Yeung E, Chavarro JE, Yuan C, Field AE, et al. Offspring risk of obesity in childhood, adolescence and adulthood in relation to gestational diabetes mellitus: a sex-specific association. Int J Epidemiol. Oct 01, 2017;46(5):1533-1541. [FREE Full text] [doi: 10.1093/ije/dyx151] [Medline: 29024955]

12. Santos S, Voerman E, Amiano P, Barros H, Beilin LJ, Bergström A, et al. Impact of maternal body mass index and gestational weight gain on pregnancy complications: an individual participant data meta-analysis of European, North American and Australian cohorts. BJOG. Jul 2019;126(8):984-995. [FREE Full text] [doi: 10.1111/1471-0528.15661] [Medline: 30786138]

13. Voerman E, Santos S, Patro Golab B, Amiano P, Ballester F, Barros H, et al. Maternal body mass index, gestational weight gain, and the risk of overweight and obesity across childhood: an individual participant data meta-analysis. PLoS Med. Mar 2019;16(2):e1002744. [FREE Full text] [doi: 10.1371/journal.pmed.1002744] [Medline: 30742624]

14. Jharap VV, Santos S, Steegers EAP, Jaddoe VWV, Gaillard R. Associations of maternal obesity and excessive weight gain during pregnancy with subcutaneous fat mass in infancy. Early Hum Dev. May 2017;108:23-28. [FREE Full text] [doi: 10.1016/j.earlhumdev.2017.03.006] [Medline: 28364636]

15. Hillier TA, Pedula KL, Vesco KK, Oshiro CES, Ogasawara KK. Impact of maternal glucose and gestational weight gain on child obesity over the first decade of life in normal birth weight infants. Matern Child Health J. Aug 2016;20(8):1559-1568. [FREE Full text] [doi: 10.1007/s10995-016-1955-7] [Medline: 27154523]

16. Stuebe AM, Forman MR, Michels KB. Maternal-recalled gestational weight gain, pre-pregnancy body mass index, and obesity in the daughter. Int J Obes (Lond). Jul 2009;33(7):743-752. [FREE Full text] [doi: 10.1038/ijo.2009.101] [Medline: 19528964]

17. Physical Activity Guidelines Advisory Committee. Section F, chapter 8. Women who are pregnant or postpartum. U.S. Department of Health and Human Services. 2018. URL: https://odphp.health.gov/sites/default/files/2019-09/14_F-8_Women_Who_are_Pregnant_or_Postpartum.pdf [accessed 2025-07-30]

18. Tobias DK, Zhang C, van Dam RM, Bowers K, Hu FB. Physical activity before and during pregnancy and risk of gestational diabetes mellitus: a meta-analysis. Diabetes Care. Jan 2011;34(1):223-229. [FREE Full text] [doi: 10.2337/dc10-1368] [Medline: 20876206]

19. Aune D, Sen A, Henriksen T, Saugstad OD, Tonstad S. Physical activity and the risk of gestational diabetes mellitus: a systematic review and dose-response meta-analysis of epidemiological studies. Eur J Epidemiol. Oct 2016;31(10):967-997. [FREE Full text] [doi: 10.1007/s10654-016-0176-0] [Medline: 27485519]

20. Sanabria-Martínez G, García-Hermoso A, Poyatos-León R, Álvarez-Bueno C, Sánchez-López M, Martínez-Vizcaíno V. Effectiveness of physical activity interventions on preventing gestational diabetes mellitus and excessive maternal weight gain: a meta-analysis. BJOG. Aug 2015;122(9):1167-1174. [FREE Full text] [doi: 10.1111/1471-0528.13429] [Medline: 26036300]

21. Facco FL, Kramer J, Ho KH, Zee PC, Grobman WA. Sleep disturbances in pregnancy. Obstet Gynecol. Jan 2010;115(1):77-83. [doi: 10.1097/AOG.0b013e3181c4f8ec] [Medline: 20027038]

22. Qiu C, Enquobahrie D, Frederick IO, Abetew D, Williams MA. Glucose intolerance and gestational diabetes risk in relation to sleep duration and snoring during pregnancy: a pilot study. BMC Womens Health. May 14, 2010;10:17. [FREE Full text] [doi: 10.1186/1472-6874-10-17] [Medline: 20470416]

23. Reutrakul S, Anothaisintawee T, Herring SJ, Balserak BI, Marc I, Thakkinstian A. Short sleep duration and hyperglycemia in pregnancy: aggregate and individual patient data meta-analysis. Sleep Med Rev. Aug 2018;40:31-42. [doi: 10.1016/j.smrv.2017.09.003] [Medline: 29103944]

24. Leng J, Liu G, Zhang C, Xin S, Chen F, Li B, et al. Physical activity, sedentary behaviors and risk of gestational diabetes mellitus: a population-based cross-sectional study in Tianjin, China. Eur J Endocrinol. Jun 2016;174(6):763-773. [FREE Full text] [doi: 10.1530/EJE-15-1103] [Medline: 26966174]

25. Zhang C, Solomon CG, Manson JE, Hu FB. A prospective study of pregravid physical activity and sedentary behaviors in relation to the risk for gestational diabetes mellitus. Arch Intern Med. Mar 13, 2006;166(5):543-548. [FREE Full text] [doi: 10.1001/archinte.166.5.543] [Medline: 16534041]

26. Tinius RA, Cahill AG, Cade WT. Low-intensity physical activity is associated with lower maternal systemic inflammation during late pregnancy. J Obes Weight Loss Ther. Jun 2017;7(3):343. [FREE Full text] [doi: 10.4172/2165-7904.1000343] [Medline: 28856070]

27.   Hawkins M, Pekow P, Chasan-Taber L. Physical activity, sedentary behavior, and C-reactive protein in pregnancy. Med
       Sci Sports Exerc. Mar 2014;46(2):284-292. [FREE Full text] [doi: 10.1249/MSS.0b013e3182a44767] [Medline: 23860417]
28.   Lowe LP, Metzger BE, Lowe WL, Dyer AR, McDade TW, McIntyre HD, et al. HAPO Study Cooperative Research Group.
       Inflammatory mediators and glucose in pregnancy: results from a subset of the Hyperglycemia and Adverse Pregnancy
       Outcome (HAPO) study. J Clin Endocrinol Metab. Dec 2010;95(12):5427-5434. [FREE Full text] [doi: 10.1210/jc.2010-1662]
       [Medline: 20843942]
29.   Gollenberg AL, Pekow P, Bertone-Johnson ER, Freedson PS, Markenson G, Chasan-Taber L. Sedentary behaviors and
       abnormal glucose tolerance among pregnant Latina women. Med Sci Sports Exerc. Jun 2010;42(6):1079-1085. [FREE Full
       text] [doi: 10.1249/MSS.0b013e3181c6dec8] [Medline: 19997024]
30.   Wang J, Wen D, Liu X, Liu Y. Impact of exercise on maternal gestational weight gain: an updated meta-analysis of
       randomized controlled trials. Medicine (Baltimore). Jul 2019;98(27):e16199. [FREE Full text] [doi:
       10.1097/MD.0000000000016199] [Medline: 31277127]
31.   Ruchat S, Mottola MF, Skow RJ, Nagpal TS, Meah VL, James M, et al. Effectiveness of exercise interventions in the
       prevention of excessive gestational weight gain and postpartum weight retention: a systematic review and meta-analysis.
       Br J Sports Med. Nov 2018;52(21):1347-1356. [FREE Full text] [doi: 10.1136/bjsports-2018-099399] [Medline: 30337461]
32.   Restall A, Taylor RS, Thompson JMD, Flower D, Dekker GA, Kenny LC, et al. Risk factors for excessive gestational
       weight gain in a healthy, nulliparous cohort. J Obes. 2014;2014:148391. [FREE Full text] [doi: 10.1155/2014/148391]
       [Medline: 24995130]
33.   Cohen TR, Plourde H, Koski KG. Use of the Pregnancy Physical Activity Questionnaire (PPAQ) to identify behaviours
       associated with appropriate gestational weight gain during pregnancy. J Phys Act Health. Sep 2013;10(7):1000-1007.
       [FREE Full text] [doi: 10.1123/jpah.10.7.1000] [Medline: 23132834]
34.   Hill C, Lipsky LM, Betts GM, Siega-Riz AM, Nansel TR. A prospective study of the relationship of sleep quality and
       duration with gestational weight gain and fat gain. J Womens Health (Larchmt). Mar 2021;30(3):405-411. [FREE Full text]
       [doi: 10.1089/jwh.2020.8306] [Medline: 32945728]
35.   Hawkins MS, Pokutnaya DY, Bodnar LM, Levine MD, Buysse DJ, Davis EM, et al. The association between
       multidimensional sleep health and gestational weight gain. Paediatr Perinat Epidemiol. Sep 2023;37(7):586-595. [FREE
       Full text] [doi: 10.1111/ppe.13004] [Medline: 37641423]
36.   Wallace MK, Jones MA, Whitaker K, Barone Gibbs B. Patterns of physical activity and sedentary behavior before and
       during pregnancy and cardiometabolic outcomes. Midwifery. Nov 2022;114:103452. [FREE Full text] [doi:
       10.1016/j.midw.2022.103452] [Medline: 35969919]
37.   Wiebe HW, Boulé NG, Chari R, Davenport MH. The effect of supervised prenatal exercise on fetal growth: a meta-analysis.
       Obstet Gynecol. May 2015;125(5):1185-1194. [doi: 10.1097/AOG.0000000000000801] [Medline: 25932847]
38.   Ohayon M, Wickwire EM, Hirshkowitz M, Albert SM, Avidan A, Daly FJ, et al. National Sleep Foundation's sleep quality
       recommendations: first report. Sleep Health. Mar 2017;3(1):6-19. [FREE Full text] [doi: 10.1016/j.sleh.2016.11.006]
       [Medline: 28346153]
39.   Rosenberger ME, Fulton JE, Buman MP, Troiano RP, Grandner MA, Buchner DM, et al. The 24-hour activity cycle: a new
       paradigm for physical activity. Med Sci Sports Exerc. Mar 2019;51(3):454-464. [FREE Full text] [doi:
       10.1249/MSS.0000000000001811] [Medline: 30339658]
40.   Janssen I, Clarke AE, Carson V, Chaput J, Giangregorio LM, Kho ME, et al. A systematic review of compositional data
       analysis studies examining associations between sleep, sedentary behaviour, and physical activity with health outcomes in
       adults. Appl Physiol Nutr Metab. Oct 2020;45(10 (Suppl. 2)):S248-S257. [FREE Full text] [doi: 10.1139/apnm-2020-0160]
       [Medline: 33054342]
41.   Ross R, Chaput J, Giangregorio LM, Janssen I, Saunders TJ, Kho ME, et al. Canadian 24-hour movement guidelines for
       adults aged 18-64 years and adults aged 65 years or older: an integration of physical activity, sedentary behaviour, and
       sleep. Appl Physiol Nutr Metab. Oct 2020;45(10 (Suppl. 2)):S57-S102. [FREE Full text] [doi: 10.1139/apnm-2020-0467]
       [Medline: 33054332]
42.   Khamput T, Phuangkrampun M, Sangsumritpol W, Thongbo T, Sianglee S, Kaeyai T. Thailand recommendations on
       physical activity, non-sedentary lifestyles, and sleeping. Division of Physical Activity and Health MoPH. 2017.
43.   Draft 24-hour movement guidelines for adults. Australian Government Department of Health. 2023. URL: https:/
       /consultations.health.gov.au/national-preventive-health-taskforce/draft-24-hour-movement-recommendations/ [accessed
       2025-07-30]
44.   U.S. Department of Health and Human Services. U.S. Physical Activity Guidelines for Americans, 2nd edition. Washington,
       DC. U.S. Department of Health and Human Services; 2018.
45.   Fournier E, Łuszczki E, Isacco L, Chanséaume-Bussiere E, Gryson C, Chambrier C, et al. Toward an integrated consideration
       of 24 h movement guidelines and nutritional recommendations. Nutrients. Apr 27, 2023;15(9):2109. [FREE Full text] [doi:
       10.3390/nu15092109] [Medline: 37432285]
46.   Sandborg J, Migueles JH, Söderström E, Blomberg M, Henriksson P, Löf M. Physical activity, body composition, and
       cardiometabolic health during pregnancy: a compositional data approach. Med Sci Sports Exerc. Dec 01,
       2022;54(12):2054-2063. [FREE Full text] [doi: 10.1249/MSS.0000000000002996] [Medline: 36069838]

47. Badon S, Ferrara A, Gabriel K, avalos L, Hedderson M. 24-hour movement in early pregnancy and late pregnancy cardiometabolic biomarkers. Med Sci Sports Exercise. 2022;54(9S):84. [doi: 10.1249/01.mss.0000876080.45440.d4]

48. Oviedo-Caro MA, Bueno-Antequera J, Munguía-Izquierdo D. Associations of 24-hours activity composition with adiposity and cardiorespiratory fitness: the PregnActive project. Scand J Med Sci Sports. Mar 2020;30(2):295-302. [FREE Full text] [doi: 10.1111/sms.13566] [Medline: 31593623]

49. Gordon NP. Similarity of adult Kaiser Permanente members to the adult population in Kaiser Permanente's Northern California service area: comparisons based on the 2017/2018 cycle of the California health interview survey. Kaiser Permanente Northern California Division of Research. Nov 8, 2020. URL: https://divisionofresearch.kaiserpermanente.org/projects/memberhealthsurvey/SiteCollectionDocuments/compare_kp_ncal_chis2017-18.pdf [accessed 2025-07-30]

50. Bastien CH, Vallières A, Morin CM. Validation of the Insomnia Severity Index as an outcome measure for insomnia research. Sleep Med. Jul 2001;2(4):297-307. [Medline: 11438246]

51. Morin CM, Belleville G, Bélanger L, Ivers H. The Insomnia Severity Index: psychometric indicators to detect insomnia cases and evaluate treatment response. Sleep. May 01, 2011;34(5):601-608. [FREE Full text] [Medline: 21532953]

52. Schmittdiel JA, Uratsu CS, Fireman BH, Selby JV. The effectiveness of diabetes care management in managed care. Am J Manag Care. May 2009;15(5):295-301. [FREE Full text] [Medline: 19435397]

53. Carney CE, Buysse DJ, Ancoli-Israel S, Edinger JD, Krystal AD, Lichstein KL, et al. The Consensus Sleep Diary: standardizing prospective sleep self-monitoring. Sleep. Mar 01, 2012;35(2):287-302. [FREE Full text] [doi: 10.5665/sleep.1642] [Medline: 22294820]

54. Chasan-Taber L, Schmidt MD, Roberts DE, Hosmer D, Markenson G, Freedson PS. Development and validation of a Pregnancy Physical Activity Questionnaire. Med Sci Sports Exerc. Oct 2004;36(10):1750-1760. [FREE Full text] [doi: 10.1249/01.mss.0000142303.49306.0d] [Medline: 15595297]

55. Keadle SK, Patel S, Berrigan D, Christopher CN, Huang J, Saint-Maurice PF, et al. Validation of ACT24 Version 2.0 for estimating behavioral domains, active and sedentary time. Med Sci Sports Exerc. Jun 01, 2023;55(6):1054-1062. [FREE Full text] [doi: 10.1249/MSS.0000000000003135] [Medline: 36719650]

56. Kiernan M, Schoffman DE, Lee K, Brown SD, Fair JM, Perri MG, et al. The Stanford Leisure-Time Activity Categorical Item (L-Cat): a single categorical item sensitive to physical activity changes in overweight/obese women. Int J Obes (Lond). Dec 2013;37(12):1597-1602. [FREE Full text] [doi: 10.1038/ijo.2013.36] [Medline: 23588625]

57. Ross KM, Leahey TM, Kiernan M. Validation of the Stanford Leisure-Time Activity Categorical Item (L-Cat) using armband activity monitor data. Obes Sci Pract. Jun 2018;4(3):276-282. [FREE Full text] [doi: 10.1002/osp4.155] [Medline: 29951218]

58. Lacasse A, Rey E, Ferreira E, Morin C, Bérard A. Validity of a modified Pregnancy-Unique Quantification of Emesis and Nausea (PUQE) scoring index to assess severity of nausea and vomiting of pregnancy. Am J Obstet Gynecol. Jan 2008;198(1):71.e1-71.e7. [doi: 10.1016/j.ajog.2007.05.051] [Medline: 18166311]

59. Zimmerman TP, Hull SG, McNutt S, Mittl B, Islam N, Guenther PM, et al. Challenges in converting an interviewer-administered food probe database to self-administration in the National Cancer Institute automated self-administered 24-hour recall (ASA24). J Food Compost Anal. Dec 01, 2009;22(Supplement 1):S48-S51. [FREE Full text] [doi: 10.1016/j.jfca.2009.02.003] [Medline: 20161418]

60. Dahlem NW, Zimet GD, Walker RR. The Multidimensional Scale of Perceived Social Support: a confirmation study. J Clin Psychol. Nov 1991;47(6):756-761. [FREE Full text] [doi: 10.1002/1097-4679(199111)47:6<756::aid-jclp2270470605>3.0.co;2-l] [Medline: 1757578]

61. Zimet GD, Powell SS, Farley GK, Werkman S, Berkoff KA. Psychometric characteristics of the Multidimensional Scale of Perceived Social Support. J Pers Assess. 1990;55(3-4):610-617. [FREE Full text] [doi: 10.1080/00223891.1990.9674095] [Medline: 2280326]

62. Cohen S, Kamarck T, Mermelstein R. A global measure of perceived stress. J Health Soc Behav. Dec 1983;24(4):385-396. [FREE Full text] [doi: 10.2307/2136404]

63. Kroenke K, Strine TW, Spitzer RL, Williams JBW, Berry JT, Mokdad AH. The PHQ-8 as a measure of current depression in the general population. J Affect Disord. May 2009;114(1-3):163-173. [doi: 10.1016/j.jad.2008.06.026] [Medline: 18752852]

64. Spitzer RL, Kroenke K, Williams JBW, Löwe B. A brief measure for assessing generalized anxiety disorder: the GAD-7. Arch Intern Med. May 22, 2006;166(10):1092-1097. [FREE Full text] [doi: 10.1001/archinte.166.10.1092] [Medline: 16717171]

65. Vachkova E, Jezek S, Mares J, Moravcova M. The evaluation of the psychometric properties of a specific quality of life questionnaire for physiological pregnancy. Health Qual Life Outcomes. Dec 23, 2013;11:214. [FREE Full text] [doi: 10.1186/1477-7525-11-214] [Medline: 24365336]

66. R Core Team. R: A language and environment for statistical computing. In: R Foundation for Statistical Computing. Vienna, Austria. R Foundation for Statistical Computing; 2021.

67. Choi L, Liu Z, Matthews CE, Buchowski MS. Validation of accelerometer wear and nonwear time classification algorithm. Med Sci Sports Exerc. Mar 2011;43(2):357-364. [FREE Full text] [doi: 10.1249/MSS.0b013e3181ed61a3] [Medline: 20581716]

68. Choi L, Ward SC, Schnelle JF, Buchowski MS. Assessment of wear/nonwear time classification algorithms for triaxial accelerometer. Med Sci Sports Exerc. Oct 2012;44(10):2009-2016. [FREE Full text] [doi: 10.1249/MSS.0b013e318258cb36] [Medline: 22525772]

69. Ehrlich SF, Casteel AJ, Crouter SE, Hibbing PR, Hedderson MM, Brown SD, et al. Alternative wear-time estimation methods compared to traditional diary logs for wrist-worn ActiGraph accelerometers in pregnant women. J Meas Phys Behav. Jul 2020;3(2):110-117. [FREE Full text] [doi: 10.1123/jmpb.2019-0049] [Medline: 33997656]

70. Tracy JD, Acra S, Chen KY, Buchowski MS. Identifying bedrest using 24-h waist or wrist accelerometry in adults. PLoS One. 2018;13(3):e0194461. [FREE Full text] [doi: 10.1371/journal.pone.0194461] [Medline: 29570740]

71. Hibbing PR, Lamunion SR, Kaplan AS, Crouter SE. Estimating energy expenditure with ActiGraph GT9X inertial measurement unit. Med Sci Sports Exerc. May 2018;50(5):1093-1102. [FREE Full text] [doi: 10.1249/MSS.0000000000001532] [Medline: 29271847]

72. Matthews CE, Kozey Keadle S, Moore SC, Schoeller DS, Carroll RJ, Troiano RP, et al. Measurement of active and sedentary behavior in context of large epidemiologic studies. Med Sci Sports Exerc. Mar 2018;50(2):266-276. [FREE Full text] [doi: 10.1249/MSS.0000000000001428] [Medline: 28930863]

73. Matthews CE, Patel S, Saint-Maurice PF, Loftfield E, Keadle SK, Chen KY, et al. Physical activity levels (PAL) in US adults-2019. Med Sci Sports Exerc. May 01, 2023;55(5):884-891. [FREE Full text] [doi: 10.1249/MSS.0000000000003102] [Medline: 36729673]

74. Lacasse A, Rey E, Ferreira E, Morin C, Bérard A. Nausea and vomiting of pregnancy: what about quality of life? BJOG. Dec 2008;115(12):1484-1493. [doi: 10.1111/j.1471-0528.2008.01891.x] [Medline: 18752585]

75. Subar AF, Kirkpatrick SI, Mittl B, Zimmerman TP, Thompson FE, Bingley C, et al. The Automated Self-Administered 24-hour dietary recall (ASA24): a resource for researchers, clinicians, and educators from the National Cancer Institute. J Acad Nutr Diet. Aug 2012;112(8):1134-1137. [FREE Full text] [doi: 10.1016/j.jand.2012.04.016] [Medline: 22704899]

76. Kirkpatrick SI, Subar AF, Douglass D, Zimmerman TP, Thompson FE, Kahle LL, et al. Performance of the Automated Self-Administered 24-hour recall relative to a measure of true intakes and to an interviewer-administered 24-h recall. Am J Clin Nutr. Jul 2014;100(1):233-240. [FREE Full text] [doi: 10.3945/ajcn.114.083238] [Medline: 24787491]

77. Canty-Mitchell J, Zimet GD. Psychometric properties of the Multidimensional Scale of Perceived Social Support in urban adolescents. Am J Community Psychol. Jul 2000;28(3):391-400. [FREE Full text] [doi: 10.1023/A:1005109522457] [Medline: 10945123]

78. Solivan AE, Xiong X, Harville EW, Buekens P. Measurement of perceived stress among pregnant women: a comparison of two different instruments. Matern Child Health J. Feb 5, 2015;19(9):1910-1915. [FREE Full text] [doi: 10.1007/s10995-015-1710-5] [Medline: 25652063]

79. Spitzer RL, Williams JB, Kroenke K, Hornyak R, McMurray J. Validity and utility of the PRIME-MD patient health questionnaire in assessment of 3000 obstetric-gynecologic patients: the PRIME-MD Patient Health Questionnaire Obstetrics-Gynecology Study. Am J Obstet Gynecol. Oct 2000;183(3):759-769. [FREE Full text] [doi: 10.1067/mob.2000.106580] [Medline: 10992206]

80. Kroenke K, Spitzer RL, Williams JB. The PHQ-9: validity of a brief depression severity measure. J Gen Intern Med. Oct 2001;16(9):606-613. [FREE Full text] [doi: 10.1046/j.1525-1497.2001.016009606.x] [Medline: 11556941]

81. Simpson W, Glazer M, Michalski N, Steiner M, Frey BN. Comparative efficacy of the Generalized Anxiety Disorder 7-item scale and the Edinburgh Postnatal Depression Scale as screening tools for generalized anxiety disorder in pregnancy and the postpartum period. Can J Psychiatry. Aug 2014;59(8):434-440. [FREE Full text] [doi: 10.1177/070674371405900806] [Medline: 25161068]

82. Carpenter MW, Coustan DR. Criteria for screening tests for gestational diabetes. Am J Obstet Gynecol. Dec 01, 1982;144(7):768-773. [FREE Full text] [doi: 10.1016/0002-9378(82)90349-0] [Medline: 7148898]

83. Hutcheon J, Platt R, Abrams B, Himes K, Simhan H, Bodnar L. A weight-gain-for-gestational-age z score chart for the assessment of maternal weight gain in pregnancy. Am J Clin Nutr. May 2013;97(5):1062-1067. [FREE Full text] [doi: 10.3945/ajcn.112.051706] [Medline: 23466397]

84. Bodnar L, Johansson K, Himes K, Khodyakov D, Abrams B, Parisi S, et al. Gestational weight gain below recommendations and adverse maternal and child health outcomes for pregnancies with overweight or obesity: a United States cohort study. Am J Clin Nutr. Oct 2024;120(3):638-647. [FREE Full text] [doi: 10.1016/j.ajcnut.2024.06.011] [Medline: 38942117]

85. Committee to Reexamine IOM Pregnancy Weight Guidelines. Rasmussen KM, Yaktine AL, editors. Weight Gain During Pregnancy: Reexamining the Guidelines. Washington DC. National Academies Press; 2009.

86. Aris IM, Kleinman KP, Belfort MB, Kaimal A, Oken E. A 2017 US reference for singleton birth weight percentiles using obstetric estimates of gestation. Pediatrics. Jul 2019;144(1):e20190076. [FREE Full text] [doi: 10.1542/peds.2019-0076] [Medline: 31201230]

87. Pawlowsky-Glahn V, Egozcue J, Tolosana-Delgado R. Modeling and Analysis of Compositional Data. Chichester, UK. John Wiley & Sons; 2015.

88. Dumuid D, Stanford TE, Martin-Fernández J-A, Pedišić Ž, Maher CA, Lewis LK, et al. Compositional data analysis for physical activity, sedentary time and sleep research. Stat Methods Med Res. Dec 30, 2018;27(12):3726-3738. [FREE Full text] [doi: 10.1177/0962280217710835] [Medline: 28555522]

89.   Aitchinson J. The Statistical Analysis of Compositional Data. London. Blackburn Press; 2003.

90.   Dumuid D, Pedišić Ž, Stanford TE, Martín-Fernández J-A, Hron K, Maher CA, et al. The compositional isotemporal substitution model: a method for estimating changes in a health outcome for reallocation of time between sleep, physical activity and sedentary behaviour. Stat Methods Med Res. Mar 20, 2019;28(3):846-857. [doi: 10.1177/0962280217737805] [Medline: 29157152]

91.   Zeljko P. Measurement issues and poor adjustments for physical activity and sleep undermine sedentary behavior research. Kinesiology. 2014;46:135-146. [FREE Full text]

92.   Pearson K. Mathematical contributions to the theory of evolution. On a form of spurious correlation which may arise when indices are used in the measurement of organs. Proc R Soc Lond. Jan 31, 1997;60(359-367):489-498. [FREE Full text] [doi: 10.1098/rspl.1896.0076]

93.   Maher C, Olds T, Mire E, Katzmarzyk PT. Reconsidering the sedentary behaviour paradigm. PLoS One. 2014;9(1):e86403. [FREE Full text] [doi: 10.1371/journal.pone.0086403] [Medline: 24454968]

94.   Perrin A. Mobile technology and home broadband 2021. Pew Research Center. 2021. URL: https://www.pewresearch.org/internet/2021/06/03/mobile-technology-and-home-broadband-2021/ [accessed 2025-07-30]

Abbreviations

ACT24: Activities Collected over Time over 24 hours
ASA24: Automated Self-Administered 24-hour Dietary Assessment
CoDA: compositional data analysis
EHR: electronic health record
GAD-7: 7-item Generalized Anxiety Disorder Scale
GDM: gestational diabetes mellitus
GWG: gestational weight gain
KPNC: Kaiser Permanente Northern California
LGA: large for gestational age
MET: metabolic equivalent of task
PA: physical activity
PHQ-8: 8-item Patient Health Questionnaire
PPAQ: Pregnancy Physical Activity Questionnaire
PSS-10: 10-item Perceived Stress Scale
PUQE: Pregnancy-Unique Quantification of Emesis and Nausea
Q1: quintile 1
Q3: quintile 3
QOL-GRAV: Quality of Life Gravidarum questionnaire
REDCap: Research Electronic Data Capture

XSL•FO
RenderX