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Original Research

Associations Between Maternal Screen Time Duration, Gestational Weight Gain, and Small-for-Gestational-Age Infants: A Retrospective Clinical Study

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Abstract

Background: Screen use is a common sedentary behavior that may influence gestational weight gain (GWG) and fetal growth through metabolic and sleep-related pathways. However, evidence regarding dose–response relationships, nonlinear thresholds, effect modification by pre-pregnancy body mass index (BMI), and mediation by inadequate GWG remains limited. We aimed to assess the association between maternal screen time and deviations in GWG and small-for-gestational-age (SGA) birth, and to examine dose–response relationships, BMI-related effect modification, and the mediating role of inadequate GWG. **Methods:** We retrospectively analyzed data of 8162 women in a single-center (2019–2024). Average daily screen time was obtained from questionnaires administered during mid-to-late pregnancy, and outcomes were categorized into three groups according to Institute of Medicine (IOM) guidelines and SGA defined by INTERGROWTH-21st. Multinomial and binomial logistic regression models, adjusted for confounders using multiple imputation, were used to evaluate linear trends, with screen time modeled both as a continuous variable and in quartiles. Restricted cubic splines were applied to characterize dose-response relationships, and BMI-stratified interaction analyses were performed to evaluate effect modification. Causal mediation analysis under the counterfactual framework (with bootstrap sampling) was used to estimate the indirect effect attributable to inadequate GWG, with additional sensitivity analyses and E-value calculations. **Results:** For each additional hour per day of screen time, the adjusted odds ratios (aORs) for inadequate and excessive GWG were 1.06 and 1.13, respectively (both $p < 0.01$). Restricted cubic spline analyses showed a clear dose-response relationship, with excessive GWG exhibiting a nonlinear increase at higher exposure levels ($p\_nonlin = 0.012$, aOR ≈ 3). The risk of SGA increased with longer screen time (aOR = 1.08), with an aOR of 1.41 for Q4 versus Q1 (both $p < 0.001$), and restricted cubic spline analyses suggested mild nonlinearity ($p\_nonlin = 0.029$). Pre-pregnancy BMI showed evidence of effect modification ($p\_int < 0.05$). Mediation analysis under the counterfactual framework indicated that inadequate GWG explained approximately 38% of the statistical association between screen time and SGA. Sensitivity analyses yielded consistent results, with E-values around 1.3–1.5 and all lower bounds >1.20. **Conclusion:** Longer screen time was associated with an increased risk of abnormal GWG and SGA, with nonlinearity at high exposure levels and heterogeneity by pre-pregnancy BMI. Prenatal care should routinely record and limit screen time exposure, alongside interventions to reduce sedentary behavior, increase physical activity, and improve sleep. Prevention of inadequate GWG should be prioritized to reduce SGA risk, while targeted strategies to prevent excessive GWG are warranted among women with obesity. For practical implementation, a provisional cutoff of ≥4 h/day (approximately the upper quartile range in this cohort) may be used to flag high exposure for targeted counseling, with ≤2 h/day serving as a reference level. These thresholds are exploratory and require external validation.

Keywords: pregnant women; screen time; gestational weight gain; small-for-gestational-age

1. Introduction

Gestational weight gain (GWG) and fetal growth are key determinants of perinatal outcomes, and deviations from the recommended range are associated with cesarean delivery, postpartum weight retention, and metabolic abnormalities in offspring [1,2]. Small-for-gestational-age (SGA) infants are associated with increased perinatal morbidity and long-term cardiometabolic risk [3]. From a lifestyle perspective, screen use has become the predominant sedentary behavior among people of reproductive age and is accompanied by poorer diet quality, shortened sleep duration, and increased emotional burden. These factors may influence gestational weight trajectories and placental function through imbalances between energy intake and expenditure, as well as through circadian rhythm disruption [4,5]. In prenatal management in China, assessment and intervention for sedentary behavior lack operational indicators. Screen time, as a quantifiable and modifiable behavioral variable, has practical value for incorporation into routine clinical management [6]. Surveys in China indicate that screen exposure among pregnant women is relatively common. For example, a multi-province study in 2015 showed that 62.6% of pregnant women used mobile phone screens for >1 h/day, and the median (M) daily smartphone use among women in early pregnancy was approximately 5

h [7,8]. Existing evidence has largely focused on sedentary behavior or sleep, while studies examining screen time during pregnancy remain limited. In fact, most available studies are cross-sectional, with coarse exposure categorization, limited assessment of dose-response relationships on a continuous scale, and insufficient characterization of nonlinear thresholds [9]. Most studies target a single outcome, and simultaneous evaluation of GWG and SGA in the same population is uncommon, limiting the availability to establish an evidence chain linking maternal weight change to fetal growth [10,11]. Whether inadequate GWG plays a mediating role between screen time and fetal growth has not been quantified, and whether pre-pregnancy body mass index (BMI) modifies the strength of this association remains to be determined [11]. These evidence gaps limit the translation of screen-related behaviors into clinical risk stratification and behavioral recommendations. In this single-center retrospective cohort study, electronic medical records and follow-up questionnaires were used to construct exposure indicators of maternal screen time during pregnancy. Associations with categories of GWG and SGA were evaluated using multivariable models to control confounders. Dose-response relationships on a continuous scale were assessed using restricted cubic splines. Effect modification by pre-pregnancy BMI was examined, and the mediating role of inadequate GWG was quantified using causal mediation analysis. The results suggest that these associations are stable and clinically meaningful, with excessive GWG showing an accelerated increase at high exposure levels. Part of the association may be explained by the pathway of inadequate GWG, providing evidence for incorporating screen time into risk assessment and behavioral interventions in prenatal care.

2. Materials and Methods

2.1 Study Design

This single-center retrospective cohort study was based on the hospital's electronic medical records and prenatal outpatient follow-up questionnaire database. The study period was from January 1, 2019, to December 31, 2024. The study population comprised pregnant women who delivered at the hospital during this period and completed the lifestyle questionnaire in mid-to-late pregnancy. The study protocol was reviewed and approved by the Ethics Committee of our hospital (approval number: [2025] Research No. [232]). Written informed consent was waived, and all personal identifiers were anonymized before analysis.

2.2 Study Participants and Sample Source

Study participants were obtained from the obstetric delivery registration and perinatal management system of our hospital. We included women who delivered in our hospital and completed the pregnancy lifestyle questionnaire at least once during mid-pregnancy (24–28 weeks) or late pregnancy (32–36 weeks), with average daily screen time recorded. The inclusion criteria were as follows: age 18–45 years; singleton pregnancy; gestational age at first prenatal registration <14 weeks; and delivery in our hospital with complete maternal and infant outcome data. The exclusion criteria were as follows: multiple pregnancies; stillbirth; major congenital structural malformations; pre-pregnancy diagnosis of type 1 or type 2 diabetes; pre-pregnancy chronic hypertension; chronic kidney disease stage 3 or higher; long-term systemic glucocorticoid therapy; and missing key variables or records deemed unreliable after data quality control. Data quality control included range restrictions and logical consistency checks. For example, screen time was limited to 0–16 h/day, with values outside this range treated as missing. For variables such as weight, gestational age, and birth weight, records outside physiologically plausible ranges or logically inconsistent were cross-checked against original medical records; if they could not be corrected, they were classified as abnormal and excluded. During the study period, a total of 10,985 deliveries were recorded in our hospital, and 8162 cases were retained for analysis after applying the above criteria. Exclusions included 295 multiple pregnancies, 165 stillbirths, 122 major malformations, 1425 cases with missing screen time, 612 missing pre-pregnancy weight or delivery weight, 132 with pre-pregnancy diabetes or chronic hypertension, and 72 with abnormal values.

2.3 Assessment of Maternal Screen Time Exposure During Pregnancy

Screen time was obtained from the standardized "Pregnancy Lifestyle Questionnaire" administered at our hospital, which was self-administered by the participants at 24–28 weeks and 32–36 weeks and subsequently verified by medical staff. The core item of the questionnaire was: "In the past 7 days, on average, how many hours per day did you spend on screen time on a mobile phone, tablet, computer, or television? (unit: h, one decimal place)." The study defined the record at 24–28 weeks as the primary exposure. If this was missing, the record at 32–36 weeks was used. When data were available at both time points, the arithmetic mean of the two was calculated. Screen time values were restricted to between 0 and 16 h/day, and values outside this range were regarded as invalid and treated as missing. In the main analysis, screen time was modeled as a continuous variable (per additional 1 h/day), and in sensitivity analyses, it was categorized into quartiles for validation.

2.4 Covariates and Potential Confounders

Covariates were obtained from electronic medical records or the same questionnaire and selected based on a prior causal diagram. All covariates were uniformly adjusted in the main models, including the following: maternal age (years, continuous); pre-pregnancy BMI (kg/m^2,

analyzed as both continuous and categorical); parity (nulliparous/multiparous); years of education (≤12 years, 13–16 years, ≥17 years); smoking during pregnancy (yes/no); passive smoking (yes/no); physical activity during pregnancy (metabolic equivalent minutes/week calculated from the short form of the International Physical Activity Questionnaire (IPAQ), categorized as low <600, moderate 600–3000, and high >3000) [12]; diet quality score (10-point scale, constructed based intake/frequency of fruits, vegetables, whole grains, fish, red meat, sugar-sweetened beverages, nuts, dairy products, fried foods, and late-night snacks, with higher scores indicating higher quality) [13]; mode of conception (natural/assisted reproduction); and prenatal depressive symptoms (Patient Health Questionnaire-9 (PHQ-9) score, continuous) [14]. Pregnancy complications (gestational diabetes and gestational hypertension) were not included in the main models to avoid adjustment for post-exposure variables that may lie on the causal pathway from exposure and outcomes.

2.5 Outcome Definitions

2.5.1 GWG

Pre-pregnancy weight was obtained from self-reported values at the first prenatal visit, and weight during pregnancy was recorded at each outpatient visit using electronic scales (accurate to 0.1 kg). Total GWG was calculated as the difference between the last weight measured within 7 days before delivery and the pre-pregnancy weight. According to the 2009 Institute of Medicine (IOM) guidelines and stratified by pre-pregnancy BMI, adequate GWG was defined as follows: for pre-pregnancy BMI <18.5 kg/m^2, adequate weight gain 12.5–18.0 kg; for 18.5–24.9 kg/m^2, adequate weight gain 11.5–16.0 kg; for 25.0–29.9 kg/m^2, adequate weight gain 7.0–11.5 kg; and for ≥30.0 kg/m^2, adequate weight gain 5.0–9.0 kg [15]. Weight gain below the lower limit was classified as inadequate GWG, weight gain above the upper limit as excessive GWG, and weight gain within the range as adequate GWG.

2.5.2 SGA

SGA was defined according to the INTERGROWTH-21st newborn anthropometric standards as birth weight adjusted for gestational age and sex below the 10th percentile [16]. Gestational age was determined based on the last menstrual period, corrected by a first-trimester ultrasound, and birth weight was measured in the delivery room using calibrated electronic scales (accurate to 10 g). Only singleton live births were included in the assessment of SGA.

2.6 Statistical Analysis

2.6.1 Descriptive and Baseline Comparisons

Participants were grouped into quartiles according to screen time. Continuous variables are expressed as mean ± standard deviation (SD) or M (interquartile range, IQR), and categorical variables are expressed as frequency and percentage. Between-group comparisons were performed using one-way analysis of variance (ANOVA) for normally distributed variables, the Kruskal-Wallis test for non-normally distributed variables, and the chi-squared test for categorical variables. All tests were two-sided, and statistical significance was defined as $p < 0.05$.

2.6.2 Main Effect Models: Screen Time and GWG

After adequate GWG was established as the reference category, multinomial logistic regression models were constructed to estimate odds ratios (ORs) and 95% CIs for the associations between screen time and inadequate and excessive GWG. Screen time was entered into the models as a continuous variable, with effects reported per additional 1 hour/day, and as a categorical into quartiles for trend analyses. Models were adjusted for covariates listed in Section 2.4, with additional adjustment for gestational age at visit and mode of conception in the sensitivity analyses. Robust standard errors were used to calculate CIs.

2.6.3 Main Effect Models: Screen Time and SGA

Binomial logistic regression was used to estimate ORs and 95% CIs for the association between screen time and the risk of SGA. To avoid artificially blocking a potential mediating pathway prior to mediation analysis, GWG was not adjusted for in the main association models. In additional models, GWG was introduced as a three-category variable with adequate GWG as the reference to examine changes in the estimated direct association. Adjustment for the remaining covariates was consistent with that described in Section 2.6.2.

2.6.4 Dose–Response and Nonlinearity Modeling

In the models for both GWG and SGA, restricted cubic splines were applied to model screen time to characterize the continuous dose–response relationship and test potential nonlinearity. To balance model flexibility and robustness while reducing the risk of overfitting, the main analysis used 3 knots, placed at the 10th, 50th, and 90th percentiles of screen time, based on its distribution, to ensure adequate data support across intervals and to mitigate curve instability at the extremes. The reference value was set at 2 h/day, selected as a low exposure level to facilitate clinical interpretation. Wald test p values for the overall association and the nonlinear component were reported, and adjusted dose-response curves with 95% CIs were plotted.

2.6.5 Effect Modification Test: Pre-Pregnancy BMI Stratification

Pre-pregnancy BMI was stratified into <18.5, 18.5–24.9, 25.0–29.9, and ≥30.0 kg/m^2. Primary association models were fitted separately within each stratum, and within-stratum estimates were reported. Concurrently, an interaction term of screen time × BMI strata was added to

the overall model, and the Wald test was used to evaluate multiplicative interaction. To reduce instability within strata, screen time was modelled as a continuous variable in the interaction analyses.

2.6.6 Mediation Analysis: the Role of GWG in the Association Between Screen Time and SGA

CMA based on the counterfactual framework (CF) framework was performed, with inadequate GWG (yes/no) as the mediator variable. A logistic regression model was constructed for the exposure → mediator association, and a second logistic regression model for exposure + mediator → outcome. Both models were adjusted for the covariates in section 2.4. The natural direct effect (NDE), natural indirect effect (NIE), and total effect (TE), along with their 95% CIs, were estimated using nonparametric bootstrapping with asymmetric distributions (1000 repetitions), and the proportion mediated was calculated. The identification assumptions for the mediation analysis included no unmeasured confounding between exposure and mediator, exposure and outcome, or mediator and outcome; no exposure-induced mediator-outcome confounding; and correct model specification. Screen time at 24–28 weeks was used as the exposure in the primary analysis to ensure the correct temporal ordering.

2.6.7 Sensitivity Analysis and Handling of Missing Data

Three sensitivity analyses were pre-specified: (1) exclusion of participants whose activities were restricted in mid-to-late pregnancy due to threatened preterm labor, premature rupture of membranes (PROM), or physician-advised bed rest; (2) restriction of the analysis to term deliveries (gestational age ≥37 weeks); and (3) replacement of the continuous exposure with quartile-categorized screen time, with repetition all main models. Missing covariates were handled using multiple imputation by chained equations, with 20 imputations and 10 iterations. The imputation model included the exposure, outcomes, and all covariates. Imputed values of screen time were restricted to the range of 0–16 h/day. All regression analyses were based on the pooled imputed datasets and estimates of coefficients and variances were combined using the Rubin's rules. Complete-case analyses were performed as a sensitivity analysis to assess robustness.

2.7 Bias Control and Quality Assurance

Regarding information bias control, screen time was collected using a standardized questionnaire item within fixed gestational-age windows, weight was measured using calibrated electronic scales, and birth weight was recorded on site by midwives. In terms of selection bias control, only singleton deliveries with prenatal records established at Peking University First Hospital, and completed follow-up questionnaires were included to reduce systematic differences caused by referral and loss to follow-up. In terms of confounding control, the minimally sufficient set of covariates was determined a priori based on the causal diagram and was consistently adjusted for in all main models. For data quality assurance, double independent data entry verification, logical consistency checks, and outlier identification were performed. In cases of conflicting records, the original scanned medical records were used as the reference standard.

3. Results

3.1 Baseline Characteristics of Study Participants

A total of 8162 pregnant women were included in the study. After grouping by screen time quartiles, each group comprised approximately 2040 participants. With increasing screen time, maternal age, physical activity level, and diet quality score gradually decreased, whereas pre-pregnancy BMI, the proportion of overweight/obese women, the proportion of passive smokers, and PHQ-9 score progressively increased. In addition, the proportions of multiparous women, higher education level, and those who had undergone assisted reproduction decreased (all $p < 0.001$). No statistically significant between-group differences were observed for active smoking during pregnancy or gestational age at questionnaire administration (both $p > 0.05$) (Table 1).

3.2 Screen Time and GWG

Using multinomial logistic regression and after adjustment for major confounders, each additional 1 h/day of maternal screen time during pregnancy was associated with increased odds of both inadequate (aOR = 1.06) and excessive GWG (aOR = 1.13) (both $p < 0.01$). In analysis by screen time quartiles, from Q1 to Q4, the aORs for both inadequate and excessive GWG showed a stepwise increase, with statistically significant linear trends for both outcomes (both $p\_trend < 0.01$) (Table 2). Multinomial logistic regression with restricted cubic splines showed dose-response relationships between screen time and the odds of both inadequate and excessive GWG ($p\_overall < 0.001$ for both outcomes). The association with inadequate GWG was approximately linear ($p\_nonlin = 0.168$), whereas the association with excessive GWG showed a marked increase at higher exposure levels and became steeper at the upper range of screen time, with the aOR reaching approximately 3, suggesting a nonlinear association ($p\_nonlin = 0.012$), (Fig. 1).

3.3 Screen Time and SGA

Using binomial logistic regression, after adjusting for confounders, for each additional 1 h/day of maternal screen time during pregnancy, the odds of SGA increased (aOR = 1.08, $p < 0.001$). In analyses by screen time quartiles, from Q1 to Q4, the odds of SGA showed a stepwise increase, with the highest odds observed in Q4 (aOR = 1.41), and statistically significant linear trend was identified, indicati-

Table 1. Baseline characteristics of participants by quartiles of screen time.

Variable	Q1(0.0 ≤ × ≤ 1.9)	Q2(1.9 < × ≤ 2.9)	Q3(2.9 < × ≤ 4.3)	Q4(4.3 < × ≤ 16.0)	Total	Test statistic	*p*-value
Sample size (N)	2041	2040	2040	2041	8162	—	—
Age (years, $\bar{x} \pm s$)	31.62 ± 4.24	31.08 ± 4.31	30.57 ± 4.44	30.09 ± 4.53	30.84 ± 4.38	F = 46.119	<0.001
Pre-pregnancy BMI (kg/m^2, $\bar{x} \pm s$)	22.45 ± 3.04	22.71 ± 3.13	23.01 ± 3.28	23.41 ± 3.43	22.90 ± 3.22	F = 33.437	<0.001
Pre-pregnancy BMI categories (n, %)						χ^2 = 57.709	<0.001
— <18.5	(234) 11.46	(220) 10.78	(200) 9.80	(182) 8.92	(836) 10.24	—	—
— 18.5–24.9	(1404) 68.79	(1387) 67.99	(1353) 66.32	(1312) 64.28	(5456) 66.85	—	—
— 25.0–29.9	(345) 16.90	(370) 18.14	(392) 19.22	(416) 20.38	(1523) 18.66	—	—
— ≥30.0	(58) 2.84	(63) 3.09	(95) 4.66	(131) 6.42	(347) 4.25	—	—
Parity (multiparous, %)	51.76	49.12	47.06	44.38	48.08	χ^2 = 23.813	<0.001
Years of education (%)						χ^2 = 25.266	<0.001
— ≤12 years	21.36	23.48	25.39	27.83	24.52	—	—
— 13–16 years	56.72	55.14	54.18	52.31	54.59	—	—
— ≥17 years	21.92	21.38	20.43	19.86	20.89	—	—
Smoking during pregnancy (yes, %)	0.44	0.59	0.69	0.93	0.66	χ^2 = 3.950	0.267
Passive smoking (yes, %)	21.76	24.02	27.15	30.18	25.78	χ^2 = 43.280	<0.001
Physical activity (MET-minutes/week, M [IQR])	1785 [990–2680]	1560 [860–2365]	1290 [680–2005]	1035 [520–1740]	1410 [740–2220]	H = 158.437	<0.001
Physical activity categories (%)						χ^2 = 205.736	<0.001
— Low	18.27	23.29	28.62	34.09	26.07	—	—
— Moderate	51.07	52.5	50.34	49.44	50.83	—	—
— High	30.66	24.21	21.04	16.47	23.09	—	—
Diet quality score (points, $\bar{x} \pm s$)	6.94 ± 1.21	6.72 ± 1.24	6.43 ± 1.31	6.09 ± 1.36	6.54 ± 1.28	F = 168.598	<0.001
Mode of conception (assisted reproduction, %)	7.88	6.36	5.23	4.23	5.93	χ^2 = 27.242	<0.001
PHQ-9 score (points, M [IQR])	2 [1–4]	3 [1–5]	3 [2–5]	4 [2–6]	3 [2–5]	H = 64.812	<0.001
Gestational age at questionnaire (weeks, $\bar{x} \pm s$)	27.82 ± 1.93	27.78 ± 1.95	27.76 ± 1.97	27.73 ± 1.98	27.77 ± 1.96	F = 0.759	0.518
Screen time (h/day, M [IQR])	1.30 [0.8–1.8]	2.40 [2.1–2.7]	3.60 [3.2–3.9]	5.10 [4.5–6.1]	2.90 [1.9–4.3]	—	—

Note: Screen time was the grouping variable; between-group comparisons were not applicable, and the columns for statistics are marked with "—".

BMI, body mass index; MET, metabolic equivalent of task; PHQ-9, Patient Health Questionnaire-9; M, median; IQR, interquartile range.

Table 2. Multinomial logistic regression: aORs for screen time and inadequate and excessive GWG.

Exposure level	Inadequate GWG vs. adequate (aOR, 95% CI, *p*-value)	Excessive GWG vs. adequate (aOR, 95% CI, *p*-value)	Linear trend *p*_trend (inadequate/excessive)
Per additional 1 hour/day (continuous)	1.06 (1.03–1.09), 0.003	1.13 (1.09–1.18), <0.001	—
Q1 (reference)	1.00 (reference)	1.00 (reference)	—
Q2	1.07 (0.95–1.20), 0.272	1.19 (1.07–1.32), 0.002	—
Q3	1.15 (1.02–1.30), 0.021	1.35 (1.22–1.49), <0.001	—
Q4	1.26 (1.10–1.44), 0.001	1.57 (1.38–1.78), <0.001	0.002/<0.001

Note: Age, pre-pregnancy BMI (continuous), parity, years of education, smoking during pregnancy, passive smoking, physical activity (continuous), diet quality score, mode of conception, and PHQ-9 score were uniformly adjusted for.
aOR, adjusted odds ratio; GWG, gestational weight gain.

Table 3. Logistic regression: aORs for the association between screen time and odds of SGA.

Exposure level	SGA (aOR, 95% CI, *p*-value)	Linear trend *p*_trend
Per additional 1 hour/day (continuous)	1.08 (1.05–1.12), <0.001	—
Q1 (reference)	1.00 (reference)	—
Q2	1.12 (0.99–1.26), 0.068	—
Q3	1.22 (1.08–1.38), 0.001	—
Q4	1.41 (1.24–1.62), <0.001	<0.001

Note: Covariate adjustment was the same as that in Table 2; GWG was not adjusted for in the main model to avoid blocking the mediation pathway. SGA was defined according to the INTERGROWTH-21st standards as birth weight < the 10th percentile adjusted for gestational age and sex.
SGA, small-for-gestational-age.

ng a stable dose-response relationship (p_trend < 0.001) (Table 3). Logistic regression with restricted cubic splines showed a significant positive dose-response relationship between screen time and the odds of SGA (p_overall < 0.001). Mild nonlinearity was observed at high exposure levels (p_nonlin = 0.029) (Fig. 2).

3.4 Effect Modification: Stratified Analysis by Pre-Pregnancy BMI

Stratified multinomial and binomial logistic regression with interaction terms showed that the associations between screen time and all three outcomes were modified by pre-pregnancy BMI (all p_int < 0.05). Among women with BMI <18.5 kg/m^2, the positive associations between increasing screen time, inadequate GWG, and the odds of SGA were more pronounced. In contrast, among women with BMI ≥30.0 kg/m^2, the association with excessive GWG was the strongest (Fig. 3).

3.5 Mediation Analysis: the Role of Inadequate GWG in the Association Between Screen Time and SGA

Using CMA, it was estimated that for each additional 1 h/day of maternal screen time during pregnancy, the total estimated association with SGA was TE = 1.08, the natural direct effect was NDE = 1.06, and the natural indirect effect was NIE = 1.03 (all $p < 0.05$). Approximately 38.41% of the total association was statistically attributable to inadequate GWG under the assumptions of the counterfactual framework (Table 4).

NDE and NIE are standard nomenclature in the counterfactual mediation framework and denote the statistical decomposition of the total association into indirect components. In this observational context, they do not, in themselves, imply causal direction.

3.6 Sensitivity Analysis

Sensitivity analyses refitting multinomial (GWG) and binomial (SGA) logistic regression showed that, regardless of whether excluding women with activity restriction in mid-to-late pregnancy or restricting the analysis to term deliveries, the magnitude of the associations between each additional 1 hour/day of screen time with inadequate GWG, excessive GWG, and SGA (aOR about 1.04–1.05, 1.11–1.12, and 1.06–1.07, respectively) and their statistical significance (all $p < 0.05$) were consistent with those observed in the main models. Because the continuous-variable specification estimates the average log-linear effect across the full exposure range, and because restriction of the analytic sample may narrow the exposure distribution, a modest attenuation of effect estimates relative to the main models is expected in the presence of mild nonlinearity. After categorizing exposure into quartiles, the odds in the high-exposure group (Q4) were more pronounced, and all outcomes continued to show robust dose-response trends (all p_trend < 0.01) (Table 5). E-value sensitivity analyses showed that unmeasured confounding would need to be moderately associated with both the exposure and the outcomes to fully account for the observed associations. The E-value for the

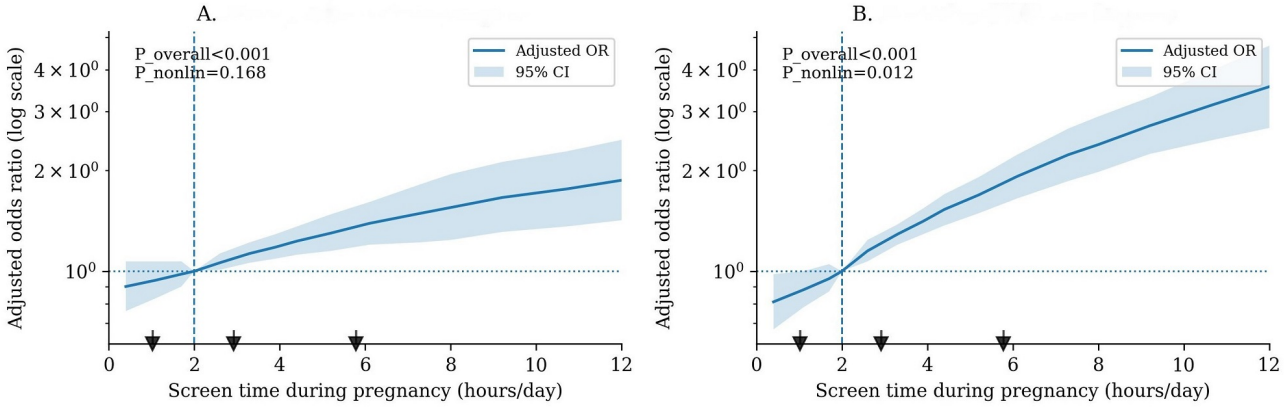

Fig. 1. Dose-response relationship between screen time and inadequate and excessive GWG. (A) Inadequate vs. adequate GWG. (B) Excessive vs. adequate GWG. Restricted cubic spline models based on multinomial logistic regression were used (3 knots at the 10th, 50th, and 90th percentiles). The solid line shows the aOR and the shaded area indicates the 95% CI (log scale). The reference is 2 h/day (vertical dashed line; aOR = 1), and the horizontal dashed line indicates aOR = 1. Knot locations are marked on the x-axis. *p*_overall and *p*_nonlin are shown; covariate adjustment is described in the Methods section.

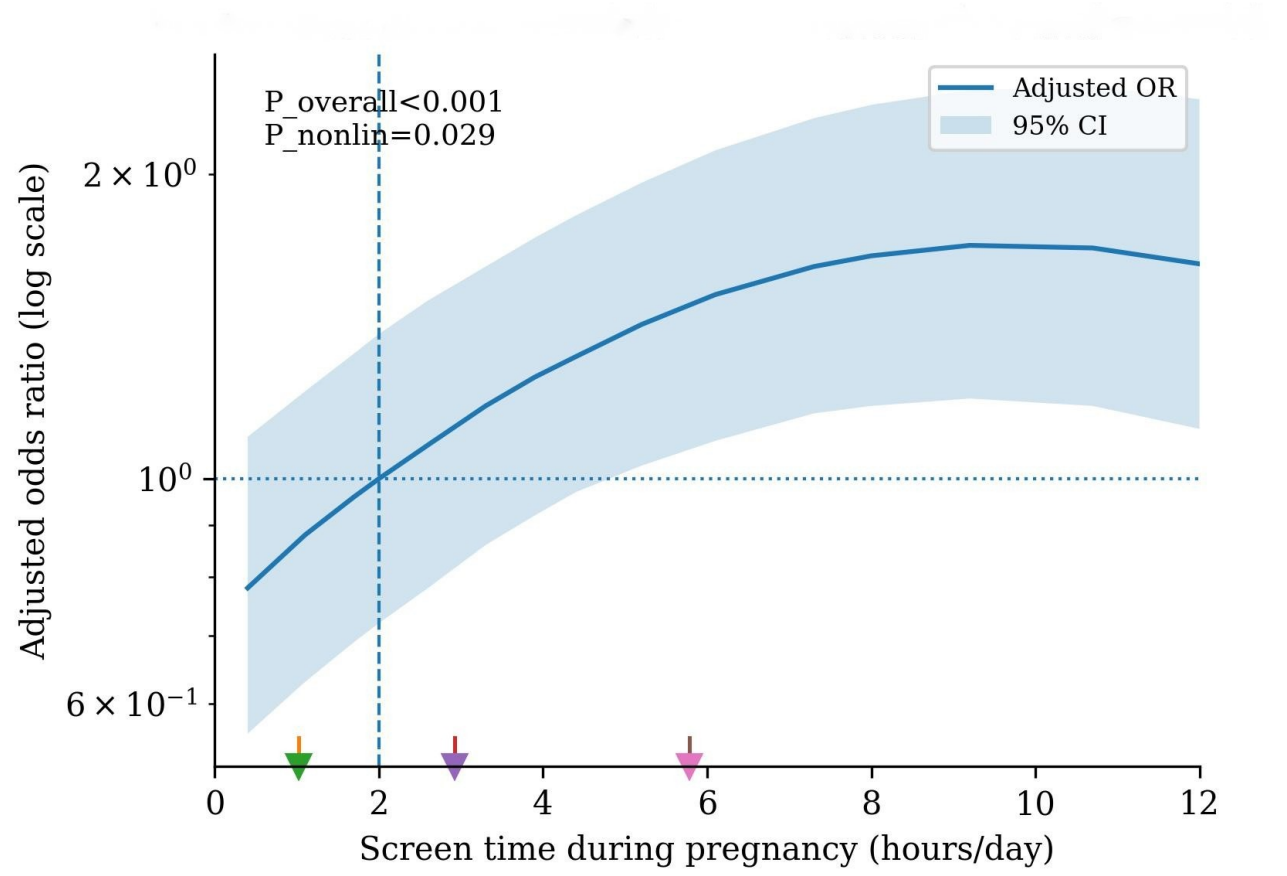

Fig. 2. Dose–response relationship between screen time and odds of SGA. Restricted cubic spline models from logistic regression were used (3 knots at the 10th, 50th, and 90th percentiles). The solid line shows the aOR and the shaded area indicates the 95% CI (log scale). The reference is 2 h/day (vertical dashed line; aOR = 1), and the horizontal dashed line indicates aOR = 1. Knot locations are marked on the x-axis. *p*_overall and *p*_nonlin are shown; covariate adjustment is described in the Methods section.

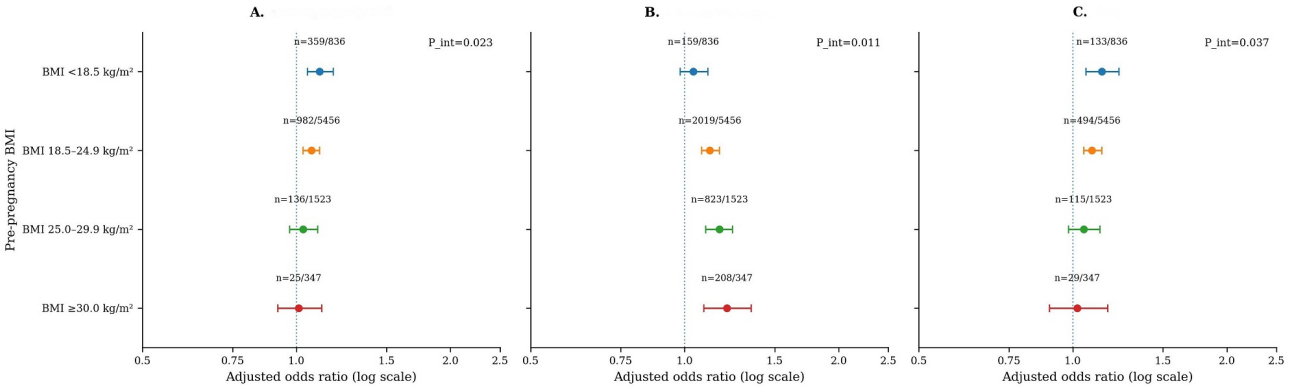

Fig. 3. Stratified associations between screen time and GWG and SGA by pre-pregnancy BMI. (A) Inadequate gestational weight gain; (B) excessive gestational weight gain; and (C) small-for-gestational-age birth. Points represent adjusted odds ratios, and horizontal lines represent 95% confidence intervals. Note: aORs are adjusted for the same covariates as in the main models; P_int is the Wald test for multiplicative interaction.

Table 4. Estimated direct association, indirect association, and proportion mediated of screen time with SGA.

Association type	Estimate (OR)	95% CI	*p*-value	Proportion mediated (%)
Natural direct association (NDE)	1.06	1.02–1.10	0.004	—
Natural indirect association (NIE)	1.03	1.01–1.05	0.012	—
Total association (TE)	1.08	1.05–1.12	<0.001	—
Proportion mediated (PM, %)	—	—	—	38.41

Note: Exposure was screen time at 24–28 weeks; the mediator was "inadequate GWG (yes/no)"; all models were adjusted for the covariates in the main models. The terms "natural direct" and "natural indirect" are standard statistical terminology within the counterfactual mediation framework and do not imply established causality in an observational design.

total association with SGA was 1.37, whereas the E-values for inadequate and excessive GWG were 1.31 and 1.51, respectively; the corresponding lower-bound E-values were all greater than 1.20 (Fig. 4).

4. Discussion

In this retrospective cohort of 8162 Chinese pregnant women, longer daily screen time was associated with increased odds of both inadequate and excessive GWG and a higher risk of SGA infants in a dose–response manner. These associations were robust across continuous and quartile-based specifications, persisted after comprehensive covariate adjustment, and showed nonlinear acceleration at higher exposure levels for excessive GWG. Pre-pregnancy BMI modified the strength of these associations, and the statistical decomposition suggested that inadequate GWG may partially explain the association between screen time and SGA.

Regarding GWG, each additional hour per day of screen time was associated with a 6% increase in the odds of inadequate GWG and a 13% increase in the odds of excessive GWG. The restricted cubic spline for excessive GWG revealed a marked increase beyond approximately 4 h/day, with the odds approaching threefold increase at the highest exposure levels (p_nonlin = 0.012). This nonlinear acceleration has not been reported previously and may have direct clinical relevance by identifying an exposure range beyond which risk escalates disproportionately. In contrast, the association with inadequate GWG was approximately linear. Prior observational studies have primarily focused on linear relationships between overall sedentary behavior and excessive GWG, with limited and inconsistent evidence regarding inadequate GWG [17]. A systematic review by Hamann et al. (2022) [17] found that, although most studies suggested an inverse association between physical activity and excessive GWG, not all findings reached statistical significance, and few studies addressed inadequate GWG at all. The present study extends this evidence by simultaneously demonstrating the cumulative associations of both forms of abnormal GWG within a single cohort using continuous dose–response modeling.

Regarding fetal growth, screen time was consistently positively associated with SGA infants (aOR = 1.08 per h/day; Q4 vs. Q1 aOR = 1.41), with a mild nonlinear inflection at high exposure levels (p_nonlin = 0.029). Previous literature has predominantly examined related behaviors such as sleep duration or physical activity [18], and few studies examining screen-related behaviors have employed dichotomous exposure classifications, which do not capture

Table 5. Summary of sensitivity analyses: comparison of main associations across different scenarios.

Sensitivity scenario	Inadequate GWG aOR (95% CI, *p*-value)	Excessive GWG aOR (95% CI, *p*-value)	SGA aOR (95% CI, *p*-value)
Excluding women with activity restriction in mid-to-late pregnancy	1.05 (1.02–1.09), 0.006	1.12 (1.08–1.17), <0.001	1.07 (1.03–1.11), 0.001
Restricting to term deliveries (gestational age ≥37 weeks)	1.04 (1.01–1.08), $p = 0.014$	1.11 (1.07–1.16), <0.001	1.06 (1.02–1.10), 0.004
Exposure categorized into quartiles: Q2 vs. Q1	1.07 (0.95–1.20), $p = 0.272$	1.19 (1.07–1.32), 0.002	1.12 (0.99–1.26), 0.068
Exposure categorized into quartiles: Q3 vs. Q1	1.15 (1.02–1.30), $p = 0.021$	1.35 (1.22–1.49), <0.001	1.22 (1.08–1.38), 0.001
Exposure categorized into quartiles: Q4 vs. Q1 (including *p*_trend)	1.26 (1.10–1.44), 0.001; *p*_trend = 0.002	1.57 (1.38–1.78), <0.001; *p*_trend < 0.001	1.41 (1.24–1.62), <0.001; *p*_trend < 0.001

Note: aOR represents the estimate of the main model "per + 1 hour/day"; *p*_trend is also reported for the quartile scenarios; all model covariates were the same as in the main model.

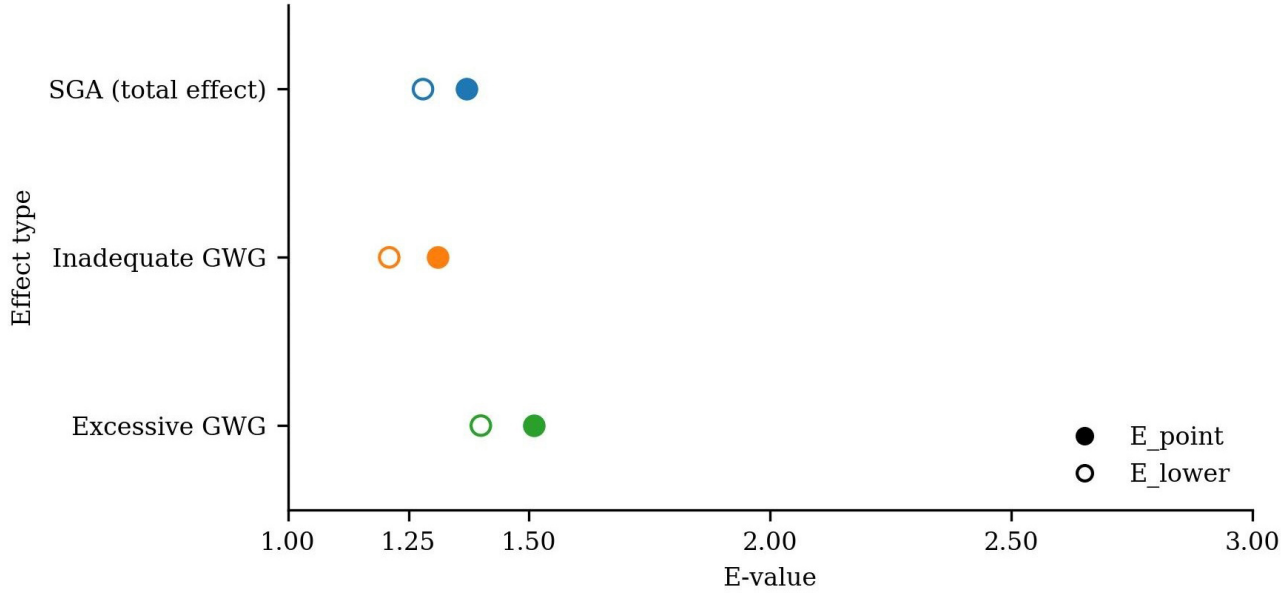

Fig. 4. E-values for unmeasured confounding in the associations between screen time and study outcomes. Note: E-values quantify the minimum strength of association with both exposure and outcome that an unmeasured confounder would need to fully explain away the observed effect; E_lower is based on the lower bound of the 95% CI.

risk variation across the full exposure spectrum [19]. Under the assumptions of the counterfactual mediation framework, approximately 38% of the total association between screen time and SGA was statistically attributable to inadequate GWG, whereas the remaining component was independent of GWG and remained statistically significant after adjustment. This proportion should be interpreted as an approximation contingent on model specification rather than a precise causal decomposition. Nonetheless, the direction and significance of both components were consistent across the sensitivity analyses. Few prior studies have simultaneously estimated both components within a single analytical framework [20], and these findings provide a basis for hypothesis generation regarding the relative contributions of weight-related and non-weight-related pathways.

Pre-pregnancy BMI showed clear effect modification (all $p\_int < 0.05$). Among women with a low BMI, who have limited metabolic reserves and are more susceptible to negative energy balance [21,22], the associations with inadequate GWG and SGA were amplified. Among women with obesity, in whom higher baseline insulin resistance and chronic inflammation may be exacerbated by prolonged sedentary behavior [23], the association with excessive GWG was most prominent. These findings support differentiated weight management strategies according to BMI category in prenatal care.

Several plausible but unverified mechanisms may underlie the observed associations, none of which were directly measured in this study. Higher screen time was accompanied by lower physical activity, poorer diet quality, and higher depressive symptom scores at baseline, a constellation consistent with energy imbalance. Sedentary behavior may reduce total daily energy expenditure [24], and screen-related reward cues may promote snacking and selection of energy-dense foods [25]. From a circadian disruption perspective, nighttime screen use has been linked to shortened sleep and melatonin suppression [26], which may impair insulin sensitivity and, independently of GWG, constrain placental perfusion and nutrient transport [27,28]. These mechanisms remain speculative and require prospective investigation using objective measurements of sleep, circadian markers, and dietary intake.

This study has several strengths, including a large sample size, continuous dose–response modeling using restricted cubic splines, simultaneous evaluation of bidirectional GWG abnormalities and SGA, formal mediation decomposition, and comprehensive covariate adjustment guided by a prespecified causal diagram. The choice of the 2009 IOM criteria for GWG classification is supported by recent evidence in Chinese populations. Zhang et al. (2021) [29] demonstrated that Chinese-specific GWG recommendations were comparable to the IOM 2009 guidelines in predicting adverse outcomes; Gong et al. (2023) [30] found that the IOM criteria were more suitable for identifying inadequate GWG; and Jiang et al. (2023) [31] confirmed their applicability in underweight women. The E-values of 1.31–1.51, in the context of adjustment for ten major confounders, indicate that a residual confounder of at least moderate strength would be needed to fully explain the observed associations.

Limitations

Several limitations should be acknowledged. The single-center, tertiary hospital design may limit generalizability. Screen time was self-reported using a 7-day recall questionnaire and lacked objective validation. The questionnaire did not differentiate screen use by device type, content, purpose, or timing, such as work-related versus leisure use or daytime versus pre-sleep use. These distinct patterns of screen exposure may have different effects on maternal health and pregnancy outcomes, which could not be evaluated in the present study. However, any resulting misclassification, including that attributable to social desirability bias, which is likely limited given the absence of strong social stigma surrounding screen use during pregnancy in China, would be nondifferential and would be expected to bias estimates toward the null rather than inflate the observed associations. Screen time was recorded only in mid-to late pregnancy and therefore could not capture full trimester-specific trajectories. Pre-pregnancy weight was self-reported, and the use of OR may slightly overestimate the magnitude of association for common outcomes. The BMI $\geq$30.0 kg/m^2 stratum (n = 347) limits the precision of stratum-specific estimates; however, the formal interaction test is not contingent on within-stratum estimate stability. The mediation analysis relies on unverifiable identification assumptions, and the proportion mediated should be interpreted as an approximation. Residual confounding and reverse causality cannot be fully excluded.

5. Conclusion

Maternal screen time during pregnancy was positively associated with both bidirectional abnormal GWG and with the odds of SGA infants. These associations strengthened with cumulative exposure, with a steeper increase in the risk of excessive GWG at higher exposure levels. A portion of the association with SGA was statistically attributable to inadequate GWG, while additional associations remained independent of GWG, consistent with hypothesized mechanisms related to sleep and circadian rhythm disruption. Pre-pregnancy BMI modified the strength of the association, with underweight women more likely to experience inadequate GWG and SGA, whereas women with obesity showed a stronger association with excessive GWG. Screen time is a modifiable behavior and should be incorporated into risk stratification and preventive interventions in prenatal care together with monitoring of GWG and sleep management. Differentiated strategies should be implemented according to pre-pregnancy BMI to reduce adverse pregnancy outcomes. For practical implementation, a provisional cutoff of $\geq$4 h/day (approximately the upper quartile range in this cohort) may be used to flag high exposure for targeted counseling, with $\leq$2 h/day used as a reference for counseling. These thresholds are exploratory and require external validation.

Availability of Data and Materials

The data and materials used and analyzed during the current study are available from the corresponding author on reasonable request.

Author Contributions

CZ and WS designed the research study. CZ and WS performed the research. CZ analyzed the data. Both authors contributed to editorial changes in the manuscript. Both authors read and approved the final manuscript. Both authors have participated sufficiently in the work and agreed to be accountable for all aspects of the work.

Ethics Approval and Consent to Participate

The study was conducted in accordance with the Declaration of Helsinki. The study protocol was reviewed and approved by the Biomedical Research Ethics Committee of Peking University First Hospital (approval number: [2025] Research No. [232]). The requirement for written informed

consent was waived by the ethics committee because of the retrospective nature of the study. All personal identifiers were removed before analysis.

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Conflicts of Interest

The authors declare no conflicts of interest.

Declaration of AI and AI-Assisted Technologies in the Writing Process

During the preparation of this manuscript, ChatGPT-3.5 was used to check spelling and grammar. The authors subsequently reviewed and edited the content as needed and take full responsibility for the content of the publication.

References

[1] Goldstein RF, Abell SK, Ranasinha S, Misso M, Boyle JA, Black MH, et al. Association of Gestational Weight Gain With Maternal and Infant Outcomes: A Systematic Review and Meta-analysis. JAMA. 2017; 317: 2207–2225. https://doi.org/10.1001/jama.2017.3635

[2] Wen J, Lv A, Aihemaitijiang S, Li H, Zhou Y, Liu J. The association of maternal gestational weight gain with cardiometabolic risk factors in offspring: a systematic review and meta-analysis. Nutrition Reviews. 2025; 83: e106–e115. https://doi.org/10.1093/nutrit/nuae027

[3] Fung C, Zinkhan E. Short- and Long-Term Implications of Small for Gestational Age. Obstetrics and Gynecology Clinics of North America. 2021; 48: 311–323. https://doi.org/10.1016/j.ogc.2021.02.004

[4] Moitra P, Madan J. Impact of screen time during COVID-19 on eating habits, physical activity, sleep, and depression symptoms: A cross-sectional study in Indian adolescents. PloS One. 2022; 17: e0264951. https://doi.org/10.1371/journal.pone.0264951

[5] Hasan MK. Balancing screen time during pregnancy: implications for maternal and fetal health. AJOG Global Reports. 2025; 5: 100422. https://doi.org/10.1016/j.xagr.2024.100422

[6] Mok KC, Liu M, Wang X. The physical activity and sedentary behavior among pregnant women in Macao: A cross-sectional study. PloS One. 2025; 20: e0318352. https://doi.org/10.1371/journal.pone.0318352

[7] Xu X, Liu D, Rao Y, Zeng H, Zhang F, Wang L, et al. Prolonged Screen Viewing Times and Sociodemographic Factors among Pregnant Women: A Cross-Sectional Survey in China. International Journal of Environmental Research and Public Health. 2018; 15: 403. https://doi.org/10.3390/ijerph15030403

[8] Yang Q, Wang Q, Zhang H, Zheng D, Tang S. Association of electronic screen exposure with depression among women in early pregnancy: a cross-sectional study. Reproductive Health. 2024; 21: 127. https://doi.org/10.1186/s12978-024-01869-z

[9] Kracht CL, Redman LM, Bellando J, Krukowski RA, Andres A. Association between maternal and infant screen time with child growth and development: A longitudinal study. Pediatric Obesity. 2023; 18: e13033. https://doi.org/10.1111/ijpo.13033

[10] Fazzi C, Saunders DH, Linton K, Norman JE, Reynolds RM. Sedentary behaviours during pregnancy: a systematic review. International Journal of Behavioral Nutrition and Physical Activity. 2017; 14: 32. https://doi.org/10.1186/s12966-017-0485-z

[11] Josey MJ, McCullough LE, Hoyo C, Williams-DeVane C. Overall gestational weight gain mediates the relationship between maternal and child obesity. BMC Public Health. 2019; 19: 1062. https://doi.org/10.1186/s12889-019-7349-1

[12] Hagströmer M, Oja P, Sjöström M. The International Physical Activity Questionnaire (IPAQ): a study of concurrent and construct validity. Public Health Nutrition. 2006; 9: 755–762. https://doi.org/10.1079/phn2005898

[13] Bromage S, Batis C, Bhupathiraju SN, Fawzi WW, Fung TT, Li Y, et al. Development and Validation of a Novel Food-Based Global Diet Quality Score (GDQS). The Journal of Nutrition. 2021; 151: 75S–92S. https://doi.org/10.1093/jn/nxab244

[14] Wang L, Kroenke K, Stump TE, Monahan PO. Screening for perinatal depression with the Patient Health Questionnaire depression scale (PHQ-9): A systematic review and meta-analysis. General Hospital Psychiatry. 2021; 68: 74–82. https://doi.org/10.1016/j.genhosppsych.2020.12.007

[15] Institute of Medicine (US) and National Research Council (US) Committee to Reexamine IOM Pregnancy Weight Guidelines. Weight Gain During Pregnancy: Reexamining the Guidelines. Weight Gain During Pregnancy. Washington (DC): National Academies Press (US); 2009. https://doi.org/10.17226/12584

[16] Villar J, Cheikh Ismail L, Victora CG, Ohuma EO, Bertino E, Altman DG, et al. International standards for newborn weight, length, and head circumference by gestational age and sex: the Newborn Cross-Sectional Study of the INTERGROWTH-21st Project. The Lancet. 2014; 384: 857–868. https://doi.org/10.1016/S0140-6736(14)60932-6

[17] Hamann V, Deruelle P, Enaux C, Deguen S, Kihal-Talantikite W. Physical activity and gestational weight gain: a systematic review of observational studies. BMC Public Health. 2022; 22: 1951. https://doi.org/10.1186/s12889-022-14324-0

[18] Warland J, Dorrian J, Morrison JL, O'Brien LM. Maternal sleep during pregnancy and poor fetal outcomes: A scoping review of the literature with meta-analysis. Sleep Medicine Reviews. 2018; 41: 197–219. https://doi.org/10.1016/j.smrv.2018.03.004

[19] Kwon S, Armstrong B, Wetoska N, Capan S. Screen Time, Sociodemographic Factors, and Psychological Well-Being Among Young Children. JAMA Network Open. 2024; 7: e2354488. https://doi.org/10.1001/jamanetworkopen.2023.54488

[20] Malta MB, Neves PAR, Lourenço BH, Benício MHDA, Werneck GL, Castro MC, et al. Leisure-time physical activity in Amazonian pregnant women and offspring birth weight: A prospective cohort study. PloS One. 2022; 17: e0265164. https://doi.org/10.1371/journal.pone.0265164

[21] Montvignier Monnet A, Savoy D, Préaubert L, Hoffmann P, Bétry C. In Underweight Women, Insufficient Gestational Weight Gain Is Associated with Adverse Obstetric Outcomes. Nutrients. 2023; 15: 57. https://doi.org/10.3390/nu15010057

[22] Aoyama S, Haruna M, Yonezawa K, Tahara-Sasagawa E, Usui Y, Ohori R, et al. Factors Associated With Inadequate Gestational Weight Gain: A Prospective Multicenter Cohort Study. Nursing and Health Sciences. 2025; 27: e70047. https://doi.org/10.1111/nhs.70047

[23] Brunner K, Linder T, Klaritsch P, Tura A, Windsperger K, Göbl C. The Impact of Overweight and Obesity on Pregnancy: A Narrative Review of Physiological Consequences, Risks and Challenges in Prenatal Care, and Early Intervention Strategies. Current Diabetes Reports. 2025; 25: 30. https://doi.org/10.1007/s11892-025-01585-3

[24] Higgins S, Pomeroy A, Bates LC, Paterson C, Barone Gibbs B, Pontzer H, et al. Sedentary behavior and cardiovascular disease risk: An evolutionary perspective. Frontiers in Physiology. 2022; 13: 962791. https://doi.org/10.3389/fphys.2022.962791

[25] Harris JL, Bargh JA, Brownell KD. Priming effects of television food advertising on eating behavior. Health Psychology. 2009; 28: 404–413. https://doi.org/10.1037/a0014399

[26] Meléndez-Fernández OH, Liu JA, Nelson RJ. Circadian Rhythms Disrupted by Light at Night and Mistimed Food Intake Alter Hormonal Rhythms and Metabolism. International Journal of Molecular Sciences. 2023; 24: 3392. https://doi.org/10.3390/ijms24043392

[27] Perumal N, Gernand AD. Nutrition during Pregnancy and Birth Outcomes. Annals of Nutrition and Metabolism. 2025; 81: 19–32. https://doi.org/10.1159/000541205

[28] Valenzuela-Melgarejo FJ, Lagunas C, Carmona-Pastén F, Jara-Medina K, Delgado G. Supraphysiological Role of Melatonin Over Vascular Dysfunction of Pregnancy, a New Therapeutic Agent? Frontiers in Physiology. 2021; 12: 767684. https://doi.org/10.3389/fphys.2021.767684

[29] Zhang CX, Lai JQ, Liu KY, Yang NH, Zeng G, Mao LM, et al. Optimal gestational weight gain in Chinese pregnant women by Chinese-specific BMI categories: a multicentre prospective cohort study. Public Health Nutrition. 2021; 24: 3210–3220. https://doi.org/10.1017/S1368980021001622

[30] Gong X, Wu T, Zhang L, You Y, Wei H, Zuo X, et al. Comparison of the 2009 Institute of Medicine and 2021 Chinese guidelines for gestational weight gain: A retrospective population-based cohort study. International Journal of Gynaecology and Obstetrics. 2023; 162: 1033–1041. https://doi.org/10.1002/ijgo.14788

[31] Jiang H, Jia Y, Wang X, Zhang C, Li Y, Wang H. Evaluating the application of the 2009 Institute of Medicine gestational weight gain guidelines on pregnant Chinese women. Global Health Action. 2023; 16: 2213494. https://doi.org/10.1080/16549716.2023.2213494