Optimal 24-hour movement behaviour compositions across trimesters and risk of hypertensive disorders of pregnancy: the Pregnancy 24/7 cohort study

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ABSTRACT

Objectives Hypertensive disorders of pregnancy (HDP) are primary antecedents of maternal cardiovascular morbidity during and after pregnancy. Despite evidence that 24-hour movement behaviours, including moderate-to-vigorous and light-intensity physical activity (MVPA, LPA), sedentary behaviour (SED) and sleep, relate to cardiovascular disease risk, associations with HDP are unknown. This study identified optimal 24-hour behavioural compositions across pregnancy associated with lower HDP risk.

Methods The Pregnancy 24/7 cohort study (N=500) quantified 24-hour movement behaviours in each trimester (10^0–12^6, 20^0–22^6 and 32^0–34^6 weeks gestation) and examined associations with HDP. Participants were enrolled between 2021–2024 from three US study sites. Movement behaviours were quantified from 7-day × 24-hour monitor wear using the activPAL3 micro (MVPA, LPA and SED) and Actiwatch Spectrum Plus (sleep). HDP (gestational hypertension and pre-eclampsia) was abstracted from medical records. Compositional binomial regression models predicted HDP risk based on isometric log-ratio transformation of 24-hour movement behaviours. Optimal overlapping behavioural compositions were identified by aggregating up to three repeated assessments of 24-hour data.

Results Among 470 participants with complete data, 86 (18.3%) developed HDP. The optimal overlapping daily composition (0–5th percentile) associated with the lowest HDP risk (7.2%) consisted of 5.9 (5.5–6.6) hours SED, 7.9 (6.4–8.9) hours LPA, 7 (2–22) minutes MVPA and 10.1 (8.5–11.3) hours sleep. Risk increased exponentially among participants with more than 10 hours/day of SED or less than 5 hours/day of LPA.

Conclusion SED and LPA were the strongest modifiable predictors of HDP, independent of trimester. These findings inform behavioural intervention targets to reduce the risk of HDP.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Randomised clinical trials provide evidence that engaging in moderate-to-vigorous physical activity (MVPA) during pregnancy reduces the risk of hypertensive disorders of pregnancy (HDP). Observational studies also suggest that sleep disorders are associated with an increased risk of HDP. However, less is known about how lower-intensity movement behaviours, including high sedentary behaviour (SED) and low light-intensity physical activity (LPA), relate to HDP.

WHAT THIS STUDY ADDS

⇒ Using device-based methodology, this study rigorously assessed 24-hour movement behaviours (MVPA, LPA, SED and sleep) in each trimester of pregnancy and examined associations with HDP in 470 participants. Higher sedentary behaviour (>10 hours/day) and lower LPA (<5 hours/day) were associated with exponentially higher risk of developing HDP, independent of trimester.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ Future research is needed to test whether behaviour change interventions that replace SED with LPA across pregnancy can reduce the risk of HDP and improve maternal cardiovascular health.

INTRODUCTION

Pregnancy is a biologically unique period where sex-specific risk factors, including hypertensive disorders of pregnancy (HDP), contribute to the development of severe maternal and infant morbidity as well as subsequent maternal cardiovascular disease (CVD).[1 2] HDP, including new onset gestational hypertension, pre-eclampsia, eclampsia and superimposed pre-eclampsia, complicates approximately one in seven pregnancies.[3] Globally, HDP are leading causes of pregnancy-related morbidity and mortality,[4] representing a significant public health challenge. Robust epidemiological evidence demonstrates that individuals who develop HDP have increased hypertension, ischaemic heart disease, cerebrovascular disease and cardiovascular death anywhere from 1 to 40 years after childbirth.[5 6] Thus, HDPs are prevalent and a critical target for CVD risk mitigation.

Identifying modifiable behavioural factors associated with HDP could help prevent these conditions and their long-term risks. Randomised controlled trials demonstrate that moderate-to-vigorous intensity physical activity (MVPA) training reduces HDP risk,[7 8] yet less than 25% of pregnant people meet the guidelines of at least 150 min per week of moderate

intensity aerobic activity across pregnancy.[9 10] Given the short- and long-term risks of HDP, limited therapeutic options and low participation in MVPA, it is essential to identify *additional* modifiable factors that could reduce the risk of HDP. Recent evidence links lower-intensity movement behaviours, including sedentary behaviour (SED),[11] light-intensity physical activity (LPA)[12] and sleep,[13] to CVD and its risk factors in the general adult population. However, little is known about how these lower intensity behaviours during pregnancy relate to HDP.[14]

There is increasing recognition that studying lower-intensity behaviours requires examining the full 24-hour movement profile, including MVPA, LPA, SED and sleep, to fully understand associations with health.[15] Compositional data analysis has emerged as a strong analytical framework,[16 17] including the clinically relevant 'Goldilocks' approach, which identifies the optimal distribution of daily movement behaviours for health.[18 19] This approach is ideally suited to examine the composition of 24-hour movement behaviours across pregnancy trimesters with risk of HDP. The Pregnancy 24/7 study was designed to address the major research gaps regarding 24-hour movement behaviours and HDP. Study objectives were to identify optimal 24-hour time-use compositions in each trimester and across pregnancy associated with reduced risk of HDP, informing evidence-based recommendations during pregnancy.

METHODS

Study design, setting and population

Details of the prospective Pregnancy 24/7 cohort study (NCT04749849), including design, eligibility criteria, recruitment and power analysis have been previously described in a study by Whitaker *et al*.[20] Briefly, N=500 participants were enrolled between 2021–2024 from three US study sites (Iowa City, Iowa; Pittsburgh, Pennsylvania; and Morgantown, West Virginia) and completed study assessments in each trimester of pregnancy (10^0–12^6, 20^0–22^6 and 32^0–34^6 weeks gestation).

This paper follows the guidelines outlined in the CHAMP (Checklist for Statistical Assessment of Medical Papers)[21] and recommended reporting practices for compositional data analysis.[16] For analysis, participants were required to have ≥1 day of valid 24-hour monitor wear[22] and a live birth. Participants were excluded if they experienced a miscarriage before 20 weeks of gestation, stillbirth or lacked HDP data.

Exposure: device-based assessment of 24-hour movement behaviour

MVPA, LPA, SED and sleep were measured using two monitors to align with standards for field-based assessments of each behaviour.[23 24] Physical activity (MVPA and LPA) and SED were assessed using the thigh-worn activPAL3 micro (PAL Technologies, Glasgow, Scotland, UK). Sleep was assessed using the wrist-worn Actiwatch Spectrum Plus (Philips Respironics, Bend, Oregon, USA). Participants were instructed to wear both devices concurrently for seven full days in each trimester while completing a non-wear/sleep diary. SED was calculated using sitting events during waking hours; LPA (upright time <3.0 metabolic equivalents (METs)) and MVPA (≥3.0 METs) were estimated using 30-second averaged MET values during standing and stepping events. MET-based estimates were selected due to prior work demonstrating higher agreement with the ActiGraph GT3X compared with step-based metrics.[25] Time designated as sleep was identified using a hierarchical process of inputs from the Actiwatch and diary (preferred approach), then activPAL data if needed. Sleep included intervals representing sleep-related behaviours (ie, waking behaviour where the participant is attempting to fall asleep or return to sleep) for the primary rest interval and any naps. A valid day was defined as 83% wear per day (20 out of 24 hours) with ≥500 steps per day, including at least one stepping minute during waking time.[22] Data integration from both devices was completed using a custom R package, pregnancy247,[26] with data standardised to 1440 min; see online supplemental material S1 for processing details.

Outcome: hypertensive disorders of pregnancy

HDP were abstracted from medical charts by a trained staff member and reviewed for accuracy by a second staff member. All identified events and a random 10% sample without events were adjudicated at each study site by maternal-fetal medicine subspecialists or an obstetrician. HDP included gestational hypertension and all cases of pre-eclampsia using American College of Obstetricians and Gynecologists clinical guidelines[27] (online supplemental table S1) or clinical diagnosis from medical chart abstraction.

Covariates

Participants self-reported their age, race and ethnicity, parity and education level at the baseline study visit. Prepregnancy weight was abstracted from medical charts. If missing from medical charts (n=21), self-reported prepregnancy weight from the baseline study visit was used. Height was measured during the first study visit in duplicate on a wall mounted stadiometer, with a third measure taken if the first two assessments differed by more than 0.5 cm. The two closest height measures were averaged and used with prepregnancy weight to calculate prepregnancy body mass index (BMI).

Statistical analysis

Statistical analyses were conducted using R (V.4.5.0). The four-part compositional data (MVPA, LPA, SED, sleep) representing 24-hour movement behaviours were transformed using isometric log-ratio (ILR) coordinates (compositions package, V.2.0–8).[28] Binomial generalised linear models predicted HDP risk separately for each trimester, adjusted for study site, age, race, ethnicity, parity, education and prepregnancy BMI (online supplemental figure S1). Assumptions were checked using the performance package (V.0.13.0), and all fitted models were used to identify clinically relevant time-use compositions.

Geometric means for 24-hour movement composition across trimesters were obtained using linear mixed models with ILR coordinates as the dependent variable in long 'stacked' format, participant as random intercept and trimester as fixed effect. Values for each trimester were back-transformed from the model-estimated ILR coordinates.[29]

To identify optimal time-use compositions associated with a lower risk of HDP, a 24-hour composition grid was created using 10-minute increments within observed sample behavioural ranges (truncated at ±3 SD). Predicted risks for each composition in the grid were obtained from adjusted models using the emmeans package (V.1.11.2). All compositions in the predictive grid were ranked, and the best-performing zones (0–5%, 5–10%, 10–15%, 15–20% and 20–25%) were estimated to offer a broader acceptable time-use range. Reference zones (47.5–52.5% and 95–100%) were used as contrasts to quantify the potential benefits of the proposed zones compared with a typical and worst-case scenario.[30] After observing similar patterns across trimesters, an overlap analysis was performed between the trimester-specific optimal zones, and the compositional centre

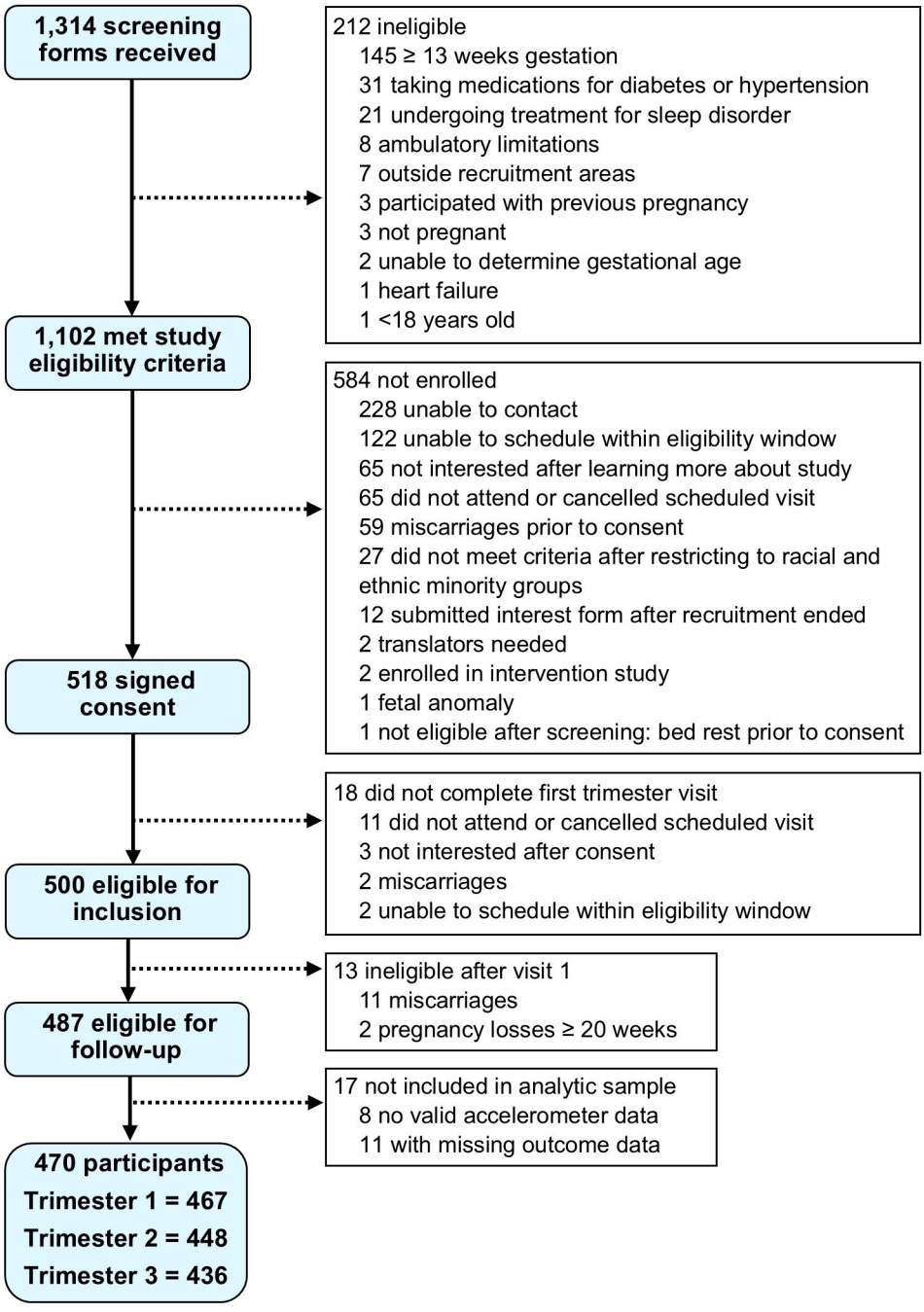

Figure 1 Pregnancy 24/7 cohort study flow diagram.

of this overlapping region was defined as the 'Goldilocks Day' recommendation,[31] representing an integrated time-use profile that minimises HDP risk across all trimesters and provides a simple public health recommendation. Average risk was calculated as the unweighted mean across trimesters, and relative risk reductions (point estimates from bootstrap medians) with 95% CIs were estimated via parametric bootstrap (10 000 iterations) for comparisons with median and worst zone compositions.

Since SED and LPA emerged as the primary behaviours associated with HDP, an additional 24-hour composition grid was constructed for each trimester, fixing MVPA and sleep at their overall geometric means across all trimesters. Grids from all trimesters were pooled, and the best performing zones with the lowest predicted risk were identified from this aggregated dataset. The geometric centre of these pooled risk zones was calculated, providing a simplified recommendation for SED-LPA balance. In addition, exponential models (growth for SED and decay for LPA) were fitted using non-linear least squares on pooled trimester data within observed behavioural ranges to quantify risk patterns.

Sensitivity and exploratory analysis

Demographic characteristics were compared between included and excluded participants to assess the representativeness of the analytical sample. Sensitivity analyses assessed the robustness of compositional associations after excluding participants with <5 valid wear days (n=6), >1500 min/day wear time (n=3), twin pregnancies (n=5) or chronic hypertension (n=13). In exploratory analysis, statistical interactions between prepregnancy BMI and ILR coordinates were tested to examine whether associations varied by BMI.

Table 1 Descriptive sociodemographic and clinical characteristics, Pregnancy 24/7 cohort study

Variables	N=470
Age, mean±SD	30.7±4.5
BMI, mean±SD	27.3±6.5
Race, n (%)	
White	412 (87.7)
Black or African American	21 (4.5)
Asian	22 (4.7)
Native Hawaiian or Other Pacific Islander	2 (0.4)
Multiple races	13 (2.8)
Ethnicity, n (%)	
Hispanic	20 (4.3)
Non-Hispanic	450 (95.7)
Education, n (%)	
High school	47 (10.0)
Some college or associate degree	60 (12.8)
College degree	162 (34.5)
Post-college degree	201 (42.8)
Annual household income, n (%)	
<US$50 000	75 (16.0)
US$50 000–149 999	265 (56.4)
>US$ 150 000	118 (25.1)
Do not know/refused	12 (2.6)
Parity, n (%)	
Nulliparous (0)	199 (42.3)
Parous (≥1)	271 (57.7)
Insurance, n (%)	
Private	397 (84.5)
Medicaid/Medicare	70 (14.9)
None or do not know	3 (0.6)
Study site, n (%)	
Iowa	240 (51.1)
Pittsburgh	116 (24.7)
West Virginia	114 (24.3)
HDP, n (%)	86 (18.3)
Gestational hypertension	57 (12.1)
Pre-eclampsia	28 (6.0)
Superimposed pre-eclampsia	1 (0.2)

Values are presented as mean ± SD or frequency (percentage). Multiple races include individuals who selected more than one racial category.
BMI, body mass index; HDP, hypertensive disorders of pregnancy.

Table 2 Geometric means of 24-hour movement behaviour compositions across pregnancy trimesters

24-hour movement behaviours (min/day)	Trimester 1 n=467	Trimester 2 n=448	Trimester 3 n=436
SED	613.6	600.7	615.6
LPA	254.9	284.8	277.0
MVPA	20.4	21.5	18.5
Sleep	551.0	533.0	528.9

Values represent estimated marginal means back-transformed from linear mixed models with 24-hour movement composition (ILR coordinates) as dependent variable and participant as random intercept. Sleep includes all sleep-related behaviours and also includes daytime naps. All compositions sum to 1440 min (24 hours) per day. Sample sizes reflect participants with valid accelerometer data for each trimester.
ILR, isometric log-ratio; LPA, light-intensity physical activity; MVPA, moderate-to-vigorous physical activity; SED, sedentary behaviour.

Patient and public involvement

This study did not involve patients or members of the public in the planning, design, data collection, analysis or interpretation of results.

Equity, diversity and inclusion

Participants were recruited across three study centres to enhance diversity and generalisability, with nearly 20% identifying with a race or ethnicity other than non-Hispanic white and 23% residing in rural areas. The author team consists of 12 women and 5 men across several US institutions and disciplines.

RESULTS

As reported in figure 1, 500 participants completed the first trimester visit and received monitors. The final analytical sample included 467, 448 and 436 participants from the first, second and third trimester evaluations, respectively, representing 470 unique participants contributing data in at least one trimester.

Participant characteristics are presented in table 1. HDP was diagnosed in 18.3%, most commonly as gestational hypertension (12.1%), followed by pre-eclampsia (6.0%), and superimposed pre-eclampsia (0.2%). Participants were diagnosed with HDP at 37.5±3.1 weeks of gestation (range 23–41 weeks), with 97.7% of cases diagnosed after the third trimester wear period, meaning temporality of exposure prior to outcome was nearly always established. Participant characteristics were comparable among those included (n=470) and excluded (n=30) from analysis (online supplemental table S2).

Participants wore the accelerometers for an average of 1437 of 1440 min per day across all trimesters (online supplemental table S3). Table 2 presents back-transformed geometric means of 24-hour movement behaviours across pregnancy trimesters. The trimester×ILR composition interaction was statistically significant ($F(4, 3584)=9.00$, $p<0.001$), but absolute differences across trimesters were modest. SED, LPA, MVPA and sleep varied within approximately 15, 30, 3 and 22 min/day, respectively. These differences represent 0.2–2.1% of daily time, suggesting relatively stable behavioural patterns throughout pregnancy despite statistical significance. Variation matrix analysis (online supplemental table S4) showed that SED and sleep demonstrated the strongest compositional co-dependence (variation <0.05), while MVPA exhibited the greatest independence from other activities (variation >0.45). Results from unadjusted and adjusted models examining the association between the overall 24-hour behavioural composition and HDP and analysis of individual behavioural components (relative to remaining components) are provided in online supplemental tables S5,S6. Sensitivity analyses were consistent with primary analyses (online supplemental table S7). Interactions between 24-hour movement behaviours and prepregnancy BMI were not significant, indicating that associations did not vary by BMI (online supplemental table S8).

Figure 2 presents predicted HDP risk in each trimester according to time spent in each behavioural component based on the 24-hour compositional grids (online supplemental table S9). Visual interpretation of locally estimated scatterplot smoothing (LOESS) curves applied to the 24-hour compositional grids showed that SED and LPA were the most consistent predictors across trimesters, with risk increasing for higher SED and decreasing for higher LPA.

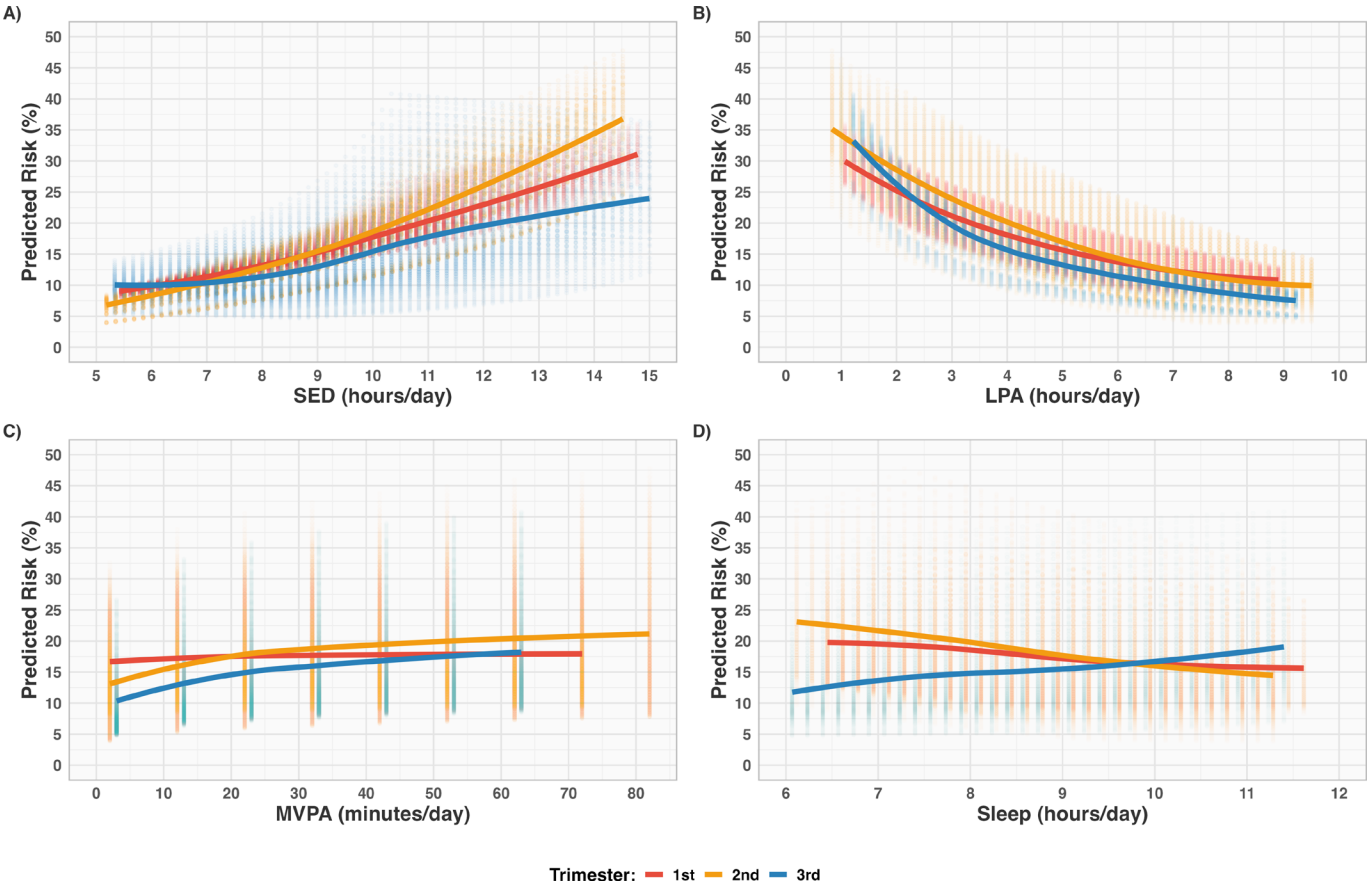

Figure 2 LOESS curves of predicted risk of hypertensive disorders of pregnancy across theoretical 24-hour time-use compositions, stratified by trimester. Panels show: (A) sedentary behaviour, (B) light physical activity, (C) moderate-to-vigorous physical activity and (D) sleep (all sleep-related behaviours, including naps). Each point represents a unique theoretical composition within physiologically plausible ranges, generated at 10-minute intervals. LPA, light-intensity physical activity; LOESS, locally estimated scatterplot smoothing; MVPA, moderate-to-vigorous physical activity; SED, sedentary behaviour.

In contrast, MVPA and sleep showed no clear trends within observed ranges and had high variability.

Descriptive summaries of the overlapping optimal time-use compositions (ie, 'Goldilocks Day') across risk percentile bands are presented in table 3. The behavioural profiles associated with the lowest predicted HDP risk (0–5%) were characterised by low SED (geometric centre: 5.93 hours/day), high LPA (7.87 hours/day), low MVPA (7.00 min/day) and long sleep (10.08 hours/day). As risk percentiles increased, a compositional shift was observed, with the median and worst-case scenarios showing substantially higher SED (9.98 and 13.83 hours/day) and lower LPA time (4.93 and 1.48 hours/day). Notably, mean predicted HDP risk increased progressively across percentile bands, from 7.2% (0–5% band) to 15.6% (median band) and 34.5% (≥95% band). This represents relative risk reductions of 54.0% (95% CI 50.6% to 57.2%) and 79.2% (95% CI 77.8%

Table 3 Overlapping 24-hour behavioural compositions for the best and reference percentile zones of predicted risk

Percentile band	SED (hours/day)	LPA (hours/day)	MVPA (min/day)	Sleep (hours/day)	Average risk (%)	RRR from median zone (47.5–52.5%)	RRR from worst zone (≥95%)
Best							
0–5%	5.93 (5.45–6.62)	7.87 (6.40–8.90)	7 (2–22)	10.08 (8.45–11.28)	7.2	54.0 (50.6 to 57.2)	79.2 (77.8 to 80.5)
5–10%	6.57 (5.78–7.28)	7.52 (5.90–8.90)	14 (2–42)	9.68 (7.78–11.28)	8.6	44.8 (40.8 to 48.7)	75.0 (73.4 to 76.6)
10–15%	6.98 (6.12–7.78)	7.28 (5.40–8.90)	21 (2–62)	9.38 (7.28–11.28)	9.5	38.9 (34.5 to 43.1)	72.3 (70.5 to 74.0)
15–20%	7.45 (6.45–8.28)	7.03 (4.90–8.90)	22 (2–62)	9.17 (6.78–11.28)	10.4	33.7 (29.0 to 38.3)	70.0 (68.1 to 71.8)
20–25%	7.88 (6.95–8.62)	6.87 (4.73–8.90)	22 (2–62)	8.90 (6.45–11.28)	11.1	28.8 (23.8 to 33.7)	67.7 (65.7 to 69.7)
Reference							
47.5–52.5%	9.98 (8.45–11.12)	4.93 (3.07–6.73)	22 (2–62)	8.73 (6.45–11.28)	15.6	–	54.7 (51.9 to 57.4)
≥95%	13.83 (12.12–14.45)	1.48 (1.23–2.07)	37 (12–62)	8.07 (6.45–9.78)	34.5	–	–

Values represent geometric centres (minimum–maximum ranges) of overlapping compositions within each percentile band. Average risk represents the mean predicted probability (%) of hypertensive disorders of pregnancy across all three trimesters for compositions within each band. RRR (with bootstrap 95% CIs) represents relative risk reduction compared with a reference composition.
LPA, light physical activity; MVPA, moderate-to-vigorous physical activity; RRR, relative risk reduction; SED, sedentary behaviour.

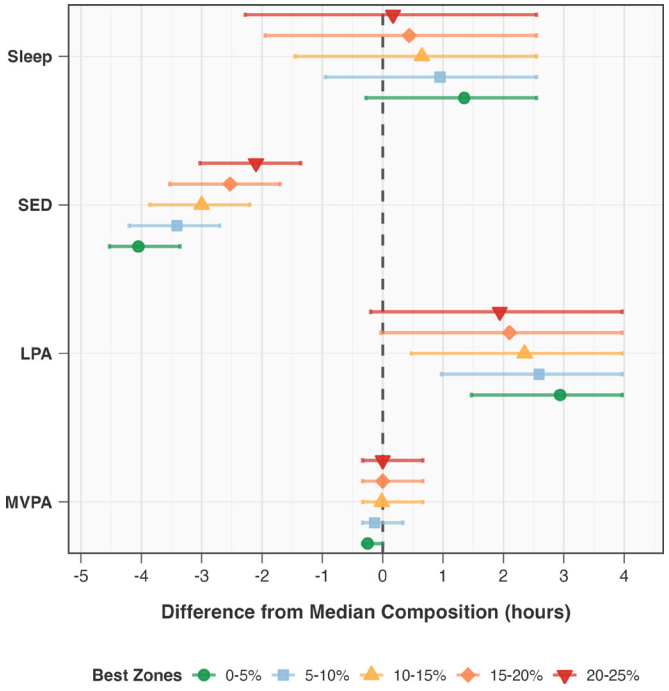

Figure 3 Time differences between the best-performing overlapping zones and the median reference. Each point represents the difference between the geometric centre of each optimal zone and the median composition (47.5–52.5%). Horizontal bars show the range of differences (minimum–maximum) within each percentile band relative to the median reference. LPA, light physical activity; MVPA, moderate-to-vigorous physical activity; SED, sedentary behaviour.

to 80.5%) when comparing the optimal zone to the median and worst-case zones, respectively.

Figure 3 presents the differences between optimal and reference time-use compositions. Compared with median compositions (47.5–52.5%), the geometric centres of all optimal zones consistently showed lower SED (ranging from −2.10 to −4.05 hours/day) paired with greater LPA (+1.94 to +2.94 hours/day). In contrast, MVPA and sleep showed minimal and inconsistent differences from median composition (47.5–52.5% percentile band), with ranges that frequently crossed zero, reinforcing that these components were not primary drivers of risk reduction.

Table 4 presents the optimal time-use compositions when reallocating time exclusively between SED and LPA, with MVPA and sleep fixed at their geometric means across all trimesters (which approximated guidelines levels of these behaviours). The compositional centre of the lowest-risk zone (0–5%) comprised 5.72 hours/day SED and 8.98 hours/day LPA, associated with 8.4% HDP risk. This represented a 45.5% (95% CI 41.5% to 49.3%) relative risk reduction compared with the median composition (9.57 hours SED, 5.13 hours LPA; 15.4% risk) and 75.1% (95% CI 73.4% to 76.6%) reduction compared with the worst-case scenario (13.45 hours SED, 1.25 hours LPA; 33.6% risk). The trend between time in SED or LPA and predicted HDP risk followed clear exponential patterns (figure 4), with models showing excellent fit (R^2=0.96). Details of model outputs are provided in online supplemental table S10. For SED, the growth rate parameter (b=0.26; 95% CI 0.22 to 0.30) indicates that each additional hour/day is associated with a 30% multiplicative increase in risk (e^ 0.26=1.30), doubling approximately every 2.7 hours of SED. LPA displayed a mirror, inverse association, with an exponential decay rate of similar magnitude (b=0.26; 95% CI 0.22 to 0.30), where each additional hour/day reduces risk by 23% (e^ −0.26=0.77). The increase in risk with SED becomes particularly steep beyond 10 hours/day. Conversely, the benefits of LPA are most pronounced when increasing from very low levels (1–2 hours/day) to moderate levels (4–5 hours/day), reducing risk from approximately 30% to 15%.

DISCUSSION

This study examined 24-hour movement behaviours in each trimester using device-based measurement and compositional data analysis to describe associations with HDP in a multisite pregnancy cohort. When holding MVPA and sleep constant at median levels consistent with guidelines, SED and LPA remained strongly associated with HDP, independent of trimester. A behavioural composition characterised by 8 hours/day of SED and 7 hours/day of LPA was associated with a meaningfully lower predicted risk of HDP compared with referent and higher risk compositions. Risk increased exponentially when SED exceeded 10 hours/day and LPA was lower than 5 hours/day. These findings indicate that replacing SED with LPA across pregnancy trimesters may be an effective intervention strategy to reduce the risk of HDP and provide quantitative guidance for behavioural targets.

Table 4 Optimal time-use compositions from sedentary–light physical activity substitution analysis with other components fixed

Percentile band	SED (hours/day)	LPA (hours/day)	MVPA (min/day)	Sleep (hours/day)	Average risk (%)	RRR from median zone (47.5–52.5%)	RRR from worst zone (≥95%)
Best							
0–5%	5.72 (5.35–6.12)	8.98 (8.58–9.35)	20	9	8.4	45.5 (41.5 to 49.3)	75.1 (73.4 to 76.6)
5–10%	6.15 (5.85–6.45)	8.55 (8.25–8.85)	20	9	9.0	41.2 (37.0 to 45.3)	73.1 (71.4 to 74.8)
10–15%	6.57 (6.33–6.95)	8.13 (7.75–8.37)	20	9	9.7	37.2 (32.7 to 41.5)	71.3 (69.4 to 73.1)
15–20%	6.98 (6.68–7.28)	7.72 (7.42–8.02)	20	9	10.3	32.9 (28.1 to 37.5)	69.3 (67.4 to 71.2)
20–25%	7.35 (7.17–7.62)	7.35 (7.08–7.53)	20	9	10.9	29.0 (23.9 to 33.8)	67.5 (65.4 to 69.5)
Reference							
47.5–52.5%	9.57 (9.45–9.67)	5.13 (5.03–5.25)	20	9	15.4	–	54.3 (51.5 to 57.0)
≥95%	13.45 (13.0–13.85)	1.25 (0.85–1.70)	20	9	33.6	–	–

Values represent the geometric centres (minimum–maximum ranges) within each risk percentile band. Risk estimates were obtained from exponential models fitted to pooled trimester data. MVPA (20 min/day) and time in bed (9 hours/day) were fixed at their geometric means across all trimesters. Average risk refers to the mean predicted probability (%) of hypertensive disorders of pregnancy across all three trimesters for compositions within each band. RRR (with bootstrap 95% CIs) represents relative risk reduction compared with a reference composition.
LPA, light physical activity; MVPA, moderate-to-vigorous physical activity; RRR, relative risk reduction; SED, sedentary behaviour.

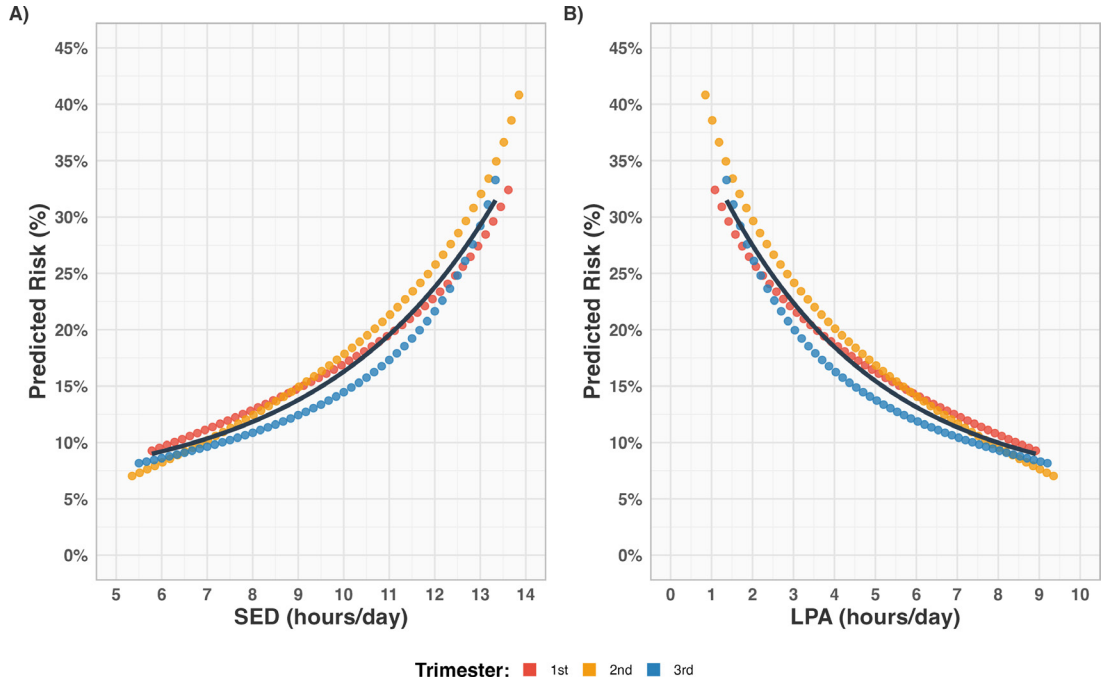

Figure 4 Predicted risk of hypertensive disorders of pregnancy across the substitution spectrum between sedentary behaviour and light physical activity, with other components fixed. Points represent theoretical time-use compositions generated at 10-minute increments. Black lines represent exponential models fitted to pooled trimester data within observed behavioural ranges. LPA, light physical activity; SED, sedentary behaviour.

While there are currently no quantitative SED or LPA guidelines during pregnancy, the Canadian 24-hour movement guidelines for adults recommend accumulating at least 150 min per week of MVPA, several hours of LPA including standing, limiting SED to 8 hours or less, and getting 7–9 hours of sleep.[32] Our findings align with these guidelines for SED, but suggest a higher level of LPA may be needed to reduce HDP risk. MVPA and sleep had limited associations with HDP, but on average our sample met both guidelines.

This is the first large prospective cohort using device-based methodology to quantify 24-hour movement behaviours in each trimester of pregnancy and examine associations with HDP. While there are no directly comparable studies, others have identified associations between 24-hour movement behaviours in pregnancy and cardiometabolic risk factors.[33 34] For example, Sandborg and colleagues[34] examined the associations of 24-hour movement behaviours with cardiometabolic health in early and late pregnancy, finding reallocation of time from SED to LPA in early pregnancy was non-significantly associated with 1.40 mm Hg and 2.63 mm Hg lower systolic and diastolic blood pressure, respectively. These results align with our findings, where compositions with lower SED and higher LPA were associated with lower risk of HDP.

More studies have examined isolated associations of individual 24-hour behaviours with health outcomes in pregnancy. An American Heart Association Science Advisory summarising existing evidence examining SED and LPA during pregnancy and cardiovascular health[14] identified only one study reporting associations of SED and LPA with HDP. The MoM Health Study[35] found that compared with the referent low SED trajectory (7.8 hours/day), the high SED trajectory (10.9 hours/day) had 3.59 (95% CI 0.65 to 19.95) higher odds of developing HDP. A significant inverse association was observed for lower intensity LPA (ie, 'standing'), while no association was observed between MVPA and HDP. This study was limited by a small sample (n=105) and few HDP events (n=13), yet these data are consistent with current study findings. Taken together, this replication provides compelling evidence that SED and LPA are novel contributors to HDP risk.

We found limited evidence of an association between MVPA and HDP. While two meta-analyses of randomised exercise intervention trials report a 39–56% reduced risk of gestational hypertension,[7 8] the evidence supporting the efficacy of exercise interventions on pre-eclampsia is mixed, with null or beneficial findings.[7 8] When considering the observational evidence, our findings align with others reporting no association between MVPA and HDP.[35 36] Our study answers the call for larger observational studies with objective monitoring to clarify these associations, concluding that SED and LPA are stronger predictors of HDP than MVPA.

We also found no evidence of an association between sleep duration and HDP, after accounting for other 24-hour movement behaviours. Although other observational studies report associations between poor sleep and HDP, results are based on participants with sleep disorders,[37 38] thus findings are not comparable to our sample. In addition, our lack of findings may be due in part to how sleep was conceptualised in our compositional data analysis as duration of sleep-related behaviours (ie, time in bed). This fails to account for the multidimensional nature of sleep,[39] and it is possible that other dimensions such as sleep quality and regularity may be more important than duration when examining associations with HDP.

Strengths and limitations

Strengths of this study include the large, multisite longitudinal cohort study design with repeated assessments of rigorous, device-based measures of 24-hour movement behaviours in each trimester of pregnancy. Retention rates were >90% across pregnancy trimesters and 97% of participants had ≥5 days of valid monitor wear. In addition, assessment of HDP was abstracted and verified by trained research staff in 98% of the sample

and then adjudicated by each site physician, ensuring a robust outcome measure.

While compositional isometric log-ratio transformation yields less intuitive results than traditional regression, our novel overlapping 'Goldilocks' approach provides clinically interpretable recommendations that remained consistent across pregnancy. However, it is important to recognise that the optimal compositions identified are constrained by observed behavioural ranges and may not generalise to populations with different patterns. While standing (static and active) is often included in LPA in compositional analysis as we have done,[16] future studies should examine the role of static standing and HDP separately. Further, this study may have been insufficiently powered to examine associations stratified by prepregnancy BMI, lacked a comprehensive assessment of diet and included a high proportion of white participants with higher education and income levels; thus, additional studies are needed to address these limitations.

Research implications

When considering all 24-hour movement behaviours, we found lower HDP risk in pregnant participants with lower SED (less than 10 hours per day) and higher LPA (5 or more hours per day) across pregnancy trimesters. To achieve the greatest reduction in HDP risk, it may be necessary to limit SED to 8 hours per day with concurrent increases in LPA to 7 hours per day. Our robust findings strongly support future research interventions testing the efficacy of reducing SED and increasing LPA to reduce the risk of HDP and related long-term cardiovascular risk.

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