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Heat Exposure, Preterm Birth, and the Role of Greenness in Australia

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IMPORTANCE Preterm birth (PTB) is associated with adverse health outcomes. The outcomes of heat exposure during pregnancy and the moderating association of greenness with PTB remain understudied.

OBJECTIVE To investigate associations between heat exposure, greenness, and PTB, as well as interactions between these factors.

DESIGN, SETTING, AND PARTICIPANTS Included in this cohort study were births occurring in Sydney, New South Wales, Australia, between 2000 and 2020, retrieved from New South Wales Midwives Data Collection. Participants with incomplete or missing data on their residential address or those who resided outside of New South Wales during their pregnancy were excluded. Data were analyzed from March to October 2023.

EXPOSURES Greenness measured using normalized difference vegetation index (NDVI) and tree cover derived from satellite images. Daily extreme heat and nighttime extreme heat were defined as above the 95th percentile of community- and trimester-specific daily mean temperatures and nighttime temperatures.

MAIN OUTCOMES AND MEASURES Logistic regression models estimated the independent association of extreme heat with PTB, adjusting for individual- and area-level covariates, season of conception, and long-term trend. An interaction term between extreme heat exposure and greenness was included to explore potential modification. With a significant interaction observed, the number of preventable heat-associated PTBs that were associated with greenness was estimated.

RESULTS A total of 1 225 722 births (median [IQR] age, 39 [38-40] weeks; 631 005 male [51.5%]) were included in the analysis, including 63 144 PTBs (median [IQR] age, 35 [34-36] weeks; 34 822 male [55.1%]). Compared with those without heat exposure, exposure to daily extreme heat and nighttime extreme heat in the third trimester was associated with increased risks of PTB, with an adjusted odds ratio (OR) of 1.61 (95% CI, 1.55-1.67) and 1.51 (95% CI, 1.46-1.56]), respectively (PTB rates: exposed, 4615 of 61 338 [7.5%] vs unexposed, 56 440 of 1 162 295 [4.9%] for daily extreme heat and 4332 of 61 337 [7.1%] vs 56 723 of 1 162 296 [4.9%] for nighttime extreme heat). Disparities in associations between extreme heat exposure and PTB were observed, with lower odds of PTB among pregnant individuals residing in greener areas. The associations between extreme heat exposure and PTB could be mitigated significantly by higher greenness. Improving NDVI and tree cover could reduce daily extreme heat-associated PTB by 13.7% (95% CI, 2.3%-15.1%) and 20.9% (95% CI, 5.8%-31.5%), respectively. For nighttime extreme heat-associated PTB, reductions were 13.0% (0.2%-15.4%) and 17.2% (4.1%-27.0%), respectively.

CONCLUSIONS AND RELEVANCE Results of this large birth cohort study suggest that extreme heat exposure was adversely associated with PTB, with greenness playing a moderating role. Increasing greenness levels in residential communities could prevent heat-associated PTBs. These findings emphasize the importance of integrating heat mitigation strategies and improving green space in urban planning and public health interventions.

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Supplemental content

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Preterm birth (PTB) is a significant global health concern and a leading cause of neonatal and infant mortality, contributing to long-term health complications and substantial economic costs.[1] PTB is defined as childbirth occurring before 37 completed weeks of gestation. It accounts for a substantial proportion of infant deaths worldwide and poses challenges for health care systems and families alike.[2] Understanding the factors that contribute to PTB and exploring potential interventions are crucial for reducing its incidence and improving child health outcomes.[3]

The phenomenon of global warming has led to an increasing number of extreme heat events. Heat exposure poses various risks to human health, including exhaustion, heatstroke, cardiovascular and respiratory disorders, and increased mortality.[4] From January 30 to February 6, 2011, New South Wales, Australia was affected by an exceptional heat wave. This resulted in an increase in emergency department visits and ambulance callouts, as well as an increase in all-cause mortality.[5] There has been increasing but still limited epidemiological evidence linking prenatal temperatures with birth outcomes.[6]

Emerging evidence suggests that nighttime temperature, particularly extreme nighttime heat, significantly impacts health,[7] including sleep and rest.[8] Sleep quality and duration affect various aspects of health, and disturbances in these factors may have consequences for pregnancy outcomes.[9-11] High nighttime temperatures can disrupt circadian rhythms and entrainment, potentially affecting blood pressure, especially in vulnerable people like pregnant individuals.[12] Blood pressure follows diurnal patterns, including sleep-related elevations, and high maternal blood pressure is linked to increased adverse birth outcomes.[13] Few studies have explored associations between nocturnal temperature extremes and birth outcomes.[14] Given the projected increase in extreme temperatures, it is crucial to assess the potential impacts on birth outcomes and strategies to mitigate risks.[15]

Greenness, defined as the presence of vegetation and access to green spaces, has been widely discussed as beneficial for multiple health outcomes.[16] Greenness offers various advantages, including regulating temperature, improving air quality, reducing stress, and promoting physical activity.[17] Investigating the potential synergistic interactions of heat exposure and greenness on birth outcomes could provide practical insights into the design of healthier living environments.[18]

Against this background, this study aimed to (1) investigate the association of trimester-specific heat exposures with PTB, (2) explore potential disparities in the associations between heat exposure and PTB by greenness, as well as interactions between the 2 factors, and (3) quantify the number of PTBs associated with heat exposure and the potential reduction achievable through improving greenness.

Key Points

Question Is heat exposure during pregnancy associated with preterm birth, and what role does greenness play in this association?

Findings In this large cohort study of pregnant individual-offspring pairs in Sydney, New South Wales, Australia (1 225 722 singleton live births included), significant positive associations were found between exposure to extreme heat during the third trimester and increased odds of preterm births. Importantly, significant interactions were observed between heat exposure and greenness, suggesting that a substantial proportion of heat-associated preterm births could be prevented by enhancing greenness in residential communities.

Meaning Enhancing greenness in residential communities could potentially mitigate the adverse association of heat exposure with preterm birth, highlighting the importance of integrating heat mitigation strategies and improving green space in urban planning and public health interventions.

Methods

This cohort study was approved by the Human Research Ethics Committee at Monash University, Melbourne, Australia. Informed consent was not required owing to the use of deidentified patient data. This study followed the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) reporting guidelines.

Study Setting and Sample

Data on birth outcomes and pregnant individual's information were collected in Australia from the New South Wales Midwives Data Collection from January 1, 2000, to December 31, 2020. Details of data used in this study were previously described.[19] Briefly, the data included information about pregnant individuals (eg, age, country of birth, residential address at delivery, smoking status during pregnancy, and medical conditions like gestational diabetes and hypertension) and infant information (eg, infant's sex, gestational week). Our study area was restricted to the Greater Sydney region to enhance the focus on an urban area, and participants with incomplete or missing data on their residential address or who resided outside of New South Wales during their pregnancy were excluded. In this study, participant race and ethnicity data were not gathered as this information was not provided by the data provider.

The residential addresses of the pregnant women were geocoded to Statistical Areas Level 2 (SA2) with a median (IQR) area of 8.3×10^6 m^2 (4.7×10^6-15.0×10^6 m^2) (eFigure 2 in Supplement 1); SA2 geographic zones were designed by the Australian Bureau of Statistics to represent communities that interact socially and economically.

Heat Exposure

We used reanalyzed meteorological data, specifically the European Centre for Medium-Range Weather Forecasts Reanalysis, version 5 (ERA5). ERA5 provides extensive and continuous coverage meteorological variables across a large geographic area, offering complete representation in our study area in New South Wales at a spatial resolution of 0.1°. Previous evaluations have confirmed its satisfactory performance when compared with weather station observations.[20] Additionally, we conducted further validation to ensure the accuracy and reliability of the ERA5 hourly data specifically acquired for New South Wales (eMethods 1 in Supplement 1). Given that maternal residential addresses were collected at the SA2 level, temperatures were calculated by averaging the gridded temperature values within the boundaries of each SA2 area.

Next, we calculated the daily mean temperature by averaging the 24-hour values. To capture nighttime temperature associated with heat exposure, we defined the nighttime period as 20:00 PM to 07:00 AM, aligning with the approach adopted in previous studies.[21] Using the daily temperature values, we derived the mean and nocturnal temperature for each gestational week by averaging the temperature over every 7-day period. Then we estimated mean temperature and nighttime temperature for each trimester by averaging the weekly values: trimester 1 (1-12 weeks), trimester 2 (13-27 weeks), and trimester 3 (28-44 weeks).

Due to the absence of a standardized and consistent definition for temperature extremes, previous studies have used various percentiles of temperature to define extreme heat based on the temperature distribution.[21-23] We defined daily extreme heat and nighttime extreme heat as above the 95th percentile of the location- and trimester-specific daily mean and nighttime temperatures.

Exposure to Greenness

To evaluate the overall greenness level, we used the normalized difference vegetation index (NDVI) from Moderate Resolution Imaging Spectroradiometer (MODIS) vegetation indices (MOD13Q1.061). For a more comprehensive description of data processing, we refer readers to our previous study.[24] Briefly, we obtained 16-day NDVI data and applied a water mask to eliminate negative NDVI values. To present the total greenness within each residential community (ie, SA2), we calculated yearly maximum NDVI by aggregating the gridded NDVI data.

Furthermore, we used an additional greenness indicator, specifically the tree cover, which was extracted from MODIS vegetation continuous fields product (MOD44B.006). Generated yearly, this product provides a subpixel-level presentation of 3 components: percentage tree cover, nontree vegetation cover, and bare. In our analysis, we focused on calculating the percentage of tree cover within residential communities. Both datasets have a spatial resolution of 250 m, covering the period from 2000 to current.

Built-Up Surfaces

To consider the influence of urbanization on our study's findings, we incorporated an urbanization indicator derived from the Global Human Settlement Layer (GHSL). We obtained 100-m spatial resolution data from the GHSL built-up surface dataset for the years 2000, 2005, 2010, 2015, and 2020. We calculated the yearly built-up fraction within each residential community by matching the data to the nearest available year. Given the negative associations between greenness cover and built-up surface cover (eFigure 3 in Supplement 1), we aimed to explore how variations in greenness within different urban environments could influence the association between extreme heat exposure and PTB.

Covariates

Potential confounders were considered, including infant sex, smoking during pregnancy, the pregnant individual's medical status (ie, gestational diabetes, hypertension), age at birth, country of birth, previous pregnancies, area level socioeconomic status and population density, conception season, and year of birth.

Statistical Analysis

We conducted 2 stages of analysis. In the first stage, we examined the individual associations of trimester-specific exposure to mean temperature extremes and nighttime temperature extremes with PTB. In the second stage, we explored the interactions between extreme heat exposure and greenness in association with PTB. Based on our hypothesis, we anticipated a significant interaction. Thus, we calculated the potential preventable PTB associated with improved greenness. All analyses were conducted in RStudio, version 4.2.2 (Posit, PBC).Data were analyzed from March to October 2023.

Association of Heat Exposure With PTB

Associations between 2 temperature extreme metrics and PTB were evaluated using generalized linear regression models (GLMs) with a logit link function to estimate odds ratios (OR) and 95% CIs, comparing the odds of PTB between those exposed and unexposed to heat. Models were adjusted for individual- and area-level covariates, season of conception, and year of birth. Sensitivity analyses were conducted by rerunning the models. A detailed description is available in eMethods 2 in Supplement 1.

To further explore the association between extreme heat exposure and PTB, we conducted stratified analyses based on the level of greenness within urban environment (eFigure 4 in Supplement 1). Specifically, we first categorized the residential communities (ie, SA2) into 2 groups: highly or moderately urbanized areas according to the built-up surface fractions. We then assessed associations between extreme heat exposure and PTB across different levels of greenness, measured by NDVI and tree cover separately within each subgroup.

Interactions Between Heat Exposure and Greenness

Furthermore, we incorporated an interaction term between extreme heat exposure and greenness in GLM to explore potential interactions between these 2 factors in association with PTB. If the estimates for the interaction term were found to be statistically significant (2-sided *P* value <.05), it indicated the association between extreme heat exposure and PTB was modified by the levels of greenness. This suggested that the amplifying association of extreme heat exposure with PTB may vary depending on the level of greenness in the urban environment.

Table 1. General Characteristics of Study Participants

Characteristic	Preterm birth (n = 63 144)	Term birth (n = 1 162 578)	Total (N = 1 225 722)
Gestational age, median (IQR), wk	35 (34-36)	39 (38-40)	39 (38-40)
Pregnant individual's age, mean (SD), y	31.07 (5.7)	30.87 (5.3)	30.88 (5.3)
Previous pregnancies, No. (%)	32 094 (50.9)	646 011 (55.6)	678 105 (55.4)
Pregnant individual born in Australia, No. (%)	28 440 (60.4)	506 516 (58.5)	534 956 (58.6)
Season of conception, No. (%)			
Spring	16 231 (25.7)	288 346 (24.8)	304 577 (24.9)
Summer	15 729 (24.9)	292 289 (25.1)	308 018 (24.1)
Autumn	15 605 (24.7)	288 601 (24.8)	304 206 (24.8)
Winter	15 579 (24.7)	293 342 (25.2)	308 921 (25.2)
Smoked during pregnancy, No. (%)	8157 (13.0)	88 294 (7.6)	96 451 (7.9)
IRSAD scores, No. (%)			
High, most advantaged	24 218 (38.4)	492 129 (42.3)	516 347 (42.1)
Medium	17 675 (28.0)	317 288 (27.3)	334 963 (27.3)
Low	21 224 (33.6)	352 862 (30.4)	374 086 (30.5)
Pregnant individual's medical condition, No. (%)			
Chronic hypertension	1492 (2.3)	8059 (0.7)	9551 (0.8)
Gestational diabetes	6703 (10.6)	92 738 (8.0)	99 441 (8.1)

Abbreviation: IRSAD, Index of Relative Socio-Economic Advantage/Disadvantage.

Table 2. Distribution of Trimester-Specific Daily Mean Temperature and Nighttime Temperature Among All Participants

Trimester	Mean (SD)	IQR	95th percentile
Daily mean temperature, °C			
1st trimester	17.2 (4.1)	13.5-20.9	23.0
2nd trimester	17.2 (3.8)	13.8-20.7	22.7
3rd trimester	17.2 (4.1)	13.5-20.9	23.0
Nighttime mean temperature, °C			
1st trimester	15.0 (4.1)	11.4-18.7	20.7
2nd trimester	14.9 (3.9)	11.6-18.5	20.5
3rd trimester	14.9 (4.1)	11.3-18.6	20.7

We then proceeded to estimate the number of preventable heat-associated PTBs associated with greenness ($AC_{preventable}$). To do this, we compared the heat-associated PTB under 2 scenarios: (1) a counterfactual scenario where greenness was absent (we assessed the association of extreme heat exposure with PTB and determined the number of heat-associated PTB [AC_{heat}]) and (2) a realistic scenario where greenness existed but was spatially uneven (we determined the number of heat-associated PTB considering the presence of greenness [$AC_{heat:green}$]). The difference between these 2 values represented the potential number of PTB that could be prevented by the presence of greenness (equations listed in the eMethods 3 in Supplement 1).

Finally, we repeated these calculations to estimate the potential reduction in heat-associated PTB under an ideal scenario where greenness was improved. Specifically, we considered 2 scenarios: (1) higher NDVI at the 75th percentile and (2) increased tree cover with a 30% coverage.[25]

Results

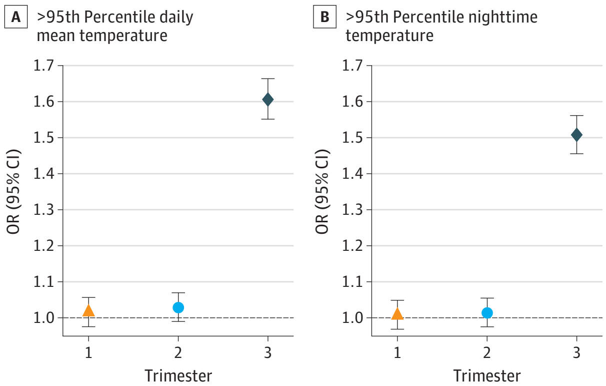
Characteristics of the Participants

Of 1 264 370 live births, we narrowed the study participants to 1 225 722 (96.9%) singleton births (median [IQR] age, 39 [38-40] weeks; 631 005 male [51.5%]; 594 717 female [48.5%]) delivered at 20 to 44 complete gestational weeks (eFigure 1 in Supplement 1). Of the total singleton live births, 5.15% (63 144) were PTBs (median [IQR] age, 35 [34-36] weeks; 34 822 male [55.2%]; 28 322 female [44.9%]). The characteristics of preterm and term births are summarized in **Table 1**. The mean (SD) age of all participants was 31 (5.3) years, with slightly older ages observed among pregnant individuals who had PTB. A larger proportion of PTBs occurred in pregnant individuals who reported smoking during pregnancy (PTB, 8157 [13.0%] vs term, 88 294 [7.6%]). The distribution of conception season did not show a significant difference between the 2 groups (eTable 1 in Supplement 1). Regarding the greenness exposure, the mean (SD) level of tree cover was 17.0% (11.3%), and the mean (SD) NDVI value was 0.58 (0.11) for all participants. **Table 2** indicates the distributions of daily mean temperature and nighttime temperature in each trimester of pregnancy among all participants. The characters of subgroups by trimester-specific extreme heat exposure (with vs without) are summarized in eTable 2 in Supplement 1 and the distribution patterns were consistent.

Associations Between Heat Exposure and PTB

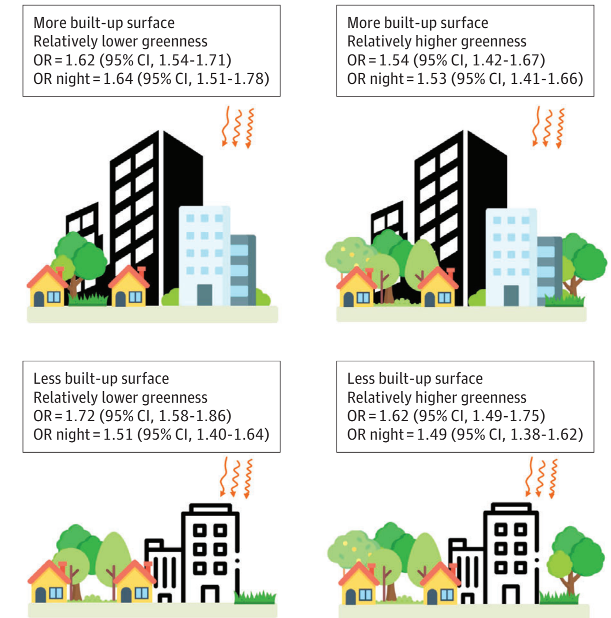
Figure 1 presents the adjusted ORs and corresponding 95% CIs for the association between extreme heat exposure,

Figure 1. Adjusted Odds Ratios (ORs) of Extreme Heat Exposure, Specifically Daily Mean Temperature Extreme and Nighttime Temperature Extreme, on Preterm Birth in Each Trimester of Pregnancy



Models were adjusted for baby's sex, maternal age at birth, previous pregnancies, pregnant individual's country of birth, smoking during pregnancy, medical status during pregnancy, area level socioeconomic status, area level population density, conception season, and year of birth.

Figure 2. Stratified Analysis by Area Built-Up Surface Fraction and Greenness Level



Adjusted odds ratios (ORs) of extreme heat exposure in the third trimester, specifically extreme daily mean and nighttime temperatures, on preterm birth. Models were adjusted for baby's sex, maternal age at birth, previous pregnancies, pregnant individual's country of birth, smoking during pregnancy, medical status during pregnancy, area level socioeconomic status, area level population density, conception season, and year of birth.

including extreme daily mean and nighttime temperatures, and the risk of PTB in each trimester. Notably, positive associations were observed between PTB and extreme daily mean temperature in the third trimester, with an adjusted OR of 1.61 (95% CI, 1.55-1.67; PTB rates: exposed, 4615 of 61 338 [7.5%] vs unexposed, 56 440 of 1 162 295 [4.9%] for daily extreme heat). Similarly, a magnitude of 1.51 (95% CI, 1.46-1.56) was observed for extreme nighttime temperatures in the third trimester (4332 of 61 337 [7.1%] vs 56 723 of 1 162 296 [4.9%] for nighttime extreme heat). Importantly, sensitivity analyses (eTable 3 in Supplement 1) revealed no substantial changes in these findings. In the following results, we specifically report the exposure and associations observed in the third trimester, as significant associations were found exclusively during this period. Unless otherwise specified, the term *exposure* refers to exposure in the third trimester.

When stratifying the analysis by area built-up surface fraction and greenness, positive associations between extreme heat exposure and PTB were observed in each subgroup (**Figure 2** and eFigures 5 and 6 in Supplement 1). The results remained consistent for nighttime extreme heat. Although no significant difference was observed, there was an increased association observed between extreme heat exposure and PTB in pregnant women exposed to lower levels of greenness (eFigures 5 and 6 in Supplement 1).

Preventable Heat-Associated PTB by Greenness

We observed significant interactions between extreme heat exposure and greenness level on PTB, suggesting that the impact of extreme heat exposure varies depending on the level of greenness in urban areas (eTable 4 in Supplement 1). When tree cover was absent, a substantial number of PTBs (5223; 95% CI, 4535-5824) could be associated with extreme daily mean temperatures during the third trimester. Similarly, in the absence of NDVI, the number of PTBs associated with extreme daily mean temperature was 6744 (95% CI, 4597-8030).

By increasing greenness, a significant proportion of these PTBs could be prevented (**Table 3**). Current levels of NDVI could prevent 926 heat-associated PTBs (95% CI, 107-1209), accounting for 13.7% (95% CI, 2.3%-15.1%). Current level of tree cover could prevent 1089 heat-associated PTBs (95% CI, 265-1838), accounting for 20.9% (95% CI, 5.8%-31.6%). Additionally, NDVI and tree cover act as moderators in the associations between nighttime temperature extreme heat and PTB, with the potential to prevent 861 associated PTBs (95% CI, 9-1197) through NDVI and 916 associated PTBs (95% CI, 193-1574) through tree cover. Improved NDVI resulted in reductions of 12.98% (95% CI, 0.2%-15.4%) in nighttime extreme heat-associated PTB, whereas increased tree cover showed reductions of 17.2% (4.1%-27.0%).

Increasing greenness to higher levels would lead to a higher number of preventable PTBs, with 38.2% of heat-associated PTBs (95% CI, 10.1%-61.2%) being prevented by improving tree cover to 30% and 21.8% (95% CI, 3.5%-25.5%) preventable by improving NDVI to the 75th percentile. Similarly, 34.1% of nighttime heat-associated PTBs (95% CI, 10.1%-61.2%) could be prevented by improving tree cover to 30% and 19.8% (95% CI, 4.9%-23.3%) prevented by improving NDVI to the 75th percentile (eTable 5 in Supplement 1). These findings highlight the potential of increasing greenness as a preventive measure to reduce the impact of extreme heat exposure on PTB.

Table 3. Number of Heat-Associated and Preventable Heat-Associated Preterm Births (PTBs) by Greenness and the Preventable Fractions

Variable	Heat-associated PTBs, No. (95% CI)	Preventable heat-associated PTBs, No. (95% CI)	Preventable fraction, % (95% CI)
Daily mean temperature			
Interaction with NDVI	6744 (4597-8030)	926 (107-1209)	13.73 (2.33-15.06)
Interaction with tree cover	5223 (4535-5824)	1089 (265-1838)	20.85 (5.84-31.56)
Nighttime temperature			
Interaction with NDVI	6633 (4816-7750)	861 (9-1197)	12.98 (0.19-15.44)
Interaction with tree cover	5316 (4720-5839)	916 (193-1574)	17.23 (4.09-26.96)

Abbreviation: NDVI, normalized difference vegetation index.

Discussion

In this cohort study, we found that the susceptible exposure window for both daily extreme heat and nighttime extreme heat was primarily in the third trimester of pregnancy, which aligns with the findings of previous studies indicating a stronger association between extreme heat exposure and PTB during late pregnancy.[21,26] Although previous research has mainly focused on the impact of daily mean temperature extremes, our study also highlights the significance of nighttime extreme heat, which has received relatively less attention.

As far as we know, only 2 studies[14,21] conducted in China have explored the association between nighttime temperature extremes and PTB, and both reported positive associations. For instance, Zhang et al[21] found that extreme heat exposure during the third trimester was strongly associated with PTB, with an adjusted OR of 1.90 (95% CI, 1.66-2.18). However, another study[14] observed a susceptible heat extreme window during the second trimester, with an adjusted OR of 1.01 (95% CI, 1.00-1.02). This variation in findings indicated the need for further studies examining the associations between nighttime temperature extremes exposure and PTB to enhance understanding of their impacts.

Heat exposure during pregnancy can lead to maternal dehydration and increased body temperature, potentially triggering physiological responses.[27] Although no studies have been conducted in pregnant women, animal studies suggest that elevated body temperature can increased production of oxytocin and prostaglandins,[28] which stimulate uterine contractions and potentially contribute to PTB.[29,30] Heat exposure also induces oxidative stress and inflammation,[31] which are associated with adverse pregnancy outcomes.[32] Oxidative stress may impair placental function,[33] affecting fetal growth and development. Additionally, heat stress disrupts maternal sleep patterns,[34] leading to sleep disturbances and chronic maternal stress, both of which are linked to an increased risk of PTB.[35]

Regarding nighttime extreme heat, pathways linking this exposure to PTB risk remain less explored. Disrupted sleep and increased maternal discomfort during hot nights could contribute to adverse pregnancy outcomes.[36] Sleep disturbances increase PTB risk,[9] and nighttime temperature extremes can disrupt sleep patterns, potential leading to physiological consequences.

The role of greenness in moderating the association between extreme heat exposure and PTB highlights important pathways in this interaction. Our findings demonstrated that higher levels of greenness, measured by indicators like NDVI and tree cover, were associated with a decreased risk of PTB in the presence of extreme heat. Previous research on this specific interaction is limited, with few studies examining disparity based on residential greenness.

For instance, a recent study[37] in North Carolina identified a significant PTB heat risk in urbanized regions with low greenness, suggesting that greenness acted as a modifier in the associations between heat exposure and health outcomes. Similarly, a study[38] in California found positive interactions between heat waves and low NDVI-based greenness for PTB. However, a study[39] in South Korea did not find a significant difference of associations between heat and PTB based on residential greenness. These discrepancies may be attributed to regional characteristics (ie, climate zone), mitigation measures (ie, air conditioning usage), variations in greenness metrics, behaviors related to actual use of green space, and complex interactions among factors.

Greenness offers various benefits that can mitigate the adverse impacts of heat on maternal health. For instance, increasing tree coverage in urban areas has been shown to reduce the urban heat island and lower ambient temperatures, leading to improved thermal comfort. In European cities, it has been estimated that increasing tree coverage to 30% could cool cities by an average of 0.4 °C and prevent 1.84% of summer deaths.[25] Moreover, the presence of greenness in residential environments may encourage physical activity, which is associated with positive pregnancy outcomes.[40] Greenness also contributes to reducing stress, improved air quality, and improved overall well-being, potentially buffering the impact of heat on pregnancy outcomes.[41]

Strengths and Limitations

Strengths of this study include its large birth cohort size, which enhances the statistical power and generalizability of the findings. The use of comprehensive data from the New South Wales Midwives Data Collection allowed for detailed assessment of individual- and area-level covariates, controlling for potential confounders. The study's focus on both daily extreme heat and nighttime extreme heat provided a more comprehensive understanding of the association between extreme heat exposure and PTB, with a particular emphasis on the less explored nighttime temperature exposure. Additionally, the examination of the moderating role of greenness in this association added a novel and important dimension to the study, highlighting the potential for preventive strategies through improving greenness in residential areas.

Our study also has several limitations. First, the lack of detailed phenotyping of PTB subtypes in our dataset hindered the ability to distinguish differences in underlying mechanisms, such as medically indicated vs spontaneous preterm birth.[42] Second, although we objectively measured greenness exposure using tree cover and NDVI at a community level, this approach did not capture intracommunity variations. These measures reflected general vegetation levels but did not characterize other features of urban greenspace that may be relevant to physical activity of pregnant individuals such as accessibility and quality. Third, although we used location-specific cutoff points to define extreme heat exposure, accounting for individuals' adaptation to their local climatic conditions, the definition of heat was relatively crude. There was potential misclassification bias in extreme heat exposure assignment, for instance, the differences in exposure duration during the third trimester. Considering a range of more comprehensive heat metrics could be beneficial.[43]

Conclusions

This extensive birth cohort study found positive associations between extreme heat exposure during the third trimester and PTB. Greenness in residential areas moderated this association. Increasing greenness could prevent heat-associated PTBs. These findings highlight the importance of considering heat exposure and greenness to reduce PTB risks. Further interventions should prioritize urban green to mitigate detrimental impacts of heat.

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Concept and design: Ye, Guo, Huang, Li.
Acquisition, analysis, or interpretation of data: Ye, Guo, Zhang, Abramson, Li.
Drafting of the manuscript: Ye, Guo.
Critical review of the manuscript for important intellectual content: All authors.
Statistical analysis: Ye, Guo, Huang, Zhang.
Obtained funding: Guo, Li.
Administrative, technical, or material support: Ye, Guo, Huang, Li.
Supervision: Guo, Abramson, Li.

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