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Temperature and Child & Adolescent Mental health Service Use - A Time-Series Population-Based Study

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Abstract

Background

Increasing evidence links exposure to extreme heat with adverse mental health outcomes. However, few studies have examined specific impacts on children and adolescents or community care.

Methods

We conducted a time-series population-based study using electronic health records from children and adolescents (aged 3-17 years) in contact with South London and Maudsley NHS Foundation Trust from 2008-2019. We analysed daily counts of mental health-related inpatient admissions, emergency department (ED) visits, referrals, and appointments in relation to maximum daily temperature during summer months (June-August), using quasi-Poisson regression combined with distributed lag non-linear models (lags 0-14 days). We also investigated effect modification by residential air pollution ($PM_{2.5}$ and NO_2) and greenspace (NDVI).

Findings

During the study period 16,579 inpatient admissions, 7,152 ED visits, 3,415,517 referrals, and 98,766 appointments took place. Overall, extreme heat (99th percentile, 32.3°C) was associated with reduced ED visits (RR = 0.56, 95% CI: 0.35-0.90) and appointments (RR = 0.80, 95% CI: 0.67-0.95). However, for those with neurodevelopmental conditions, inpatient admissions (RR = 1.47, 95% CI:1.07-2.04) and referrals (RR = 1.005, 95% CI: 1.003-1.007) increased. Extreme heat was also associated with increased ED visits for those exposed to high $PM_{2.5}$ (RR = 16.13, 95% CI: 1.39–186.65) and increased referrals for those exposed to low greenspace (RR = 1.003, 95% CI: 1.000–1.005).

Interpretation

Associations between temperature and mental health service use by young people are heterogeneous. While extreme heat may reduce service need or utilisation overall, it could increase vulnerability for children and adolescents with neurodevelopmental conditions and exposed to high $PM_{2.5}$ or low greenspace levels.

Funding

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Introduction

Almost two-thirds of mental disorders develop by age 25, with the peak onset at 14-15 years[1]. Mental health problems in children and adolescents are increasing globally, including in the UK, thereby increasing the burden on Child and Adolescent Mental Health Services (CAMHS) and widening treatment gaps[2,3]. Young people are also one of the demographics considered especially vulnerable to the impacts of climate change, which can impact mental health through a range of pathways, including increased temperatures[4-6].

Increasing evidence shows that high and anomalously hot temperatures, increasingly likely under climate change, are associated with higher rates of suicide, mental health-related emergency department (ED) visits, and psychiatric hospitalisation[4,7]. Many of these studies include children and adolescents but few focus on this population, and there is not a clear consensus as to whether heat impacts young people in the same way as adults [8-11]. Although some studies have found stronger associations between elevated temperatures and hospital visits in children and young people under 25[10-12], others have reported weaker associations[9,13]. A recent study of children and young people in Australia (<25 years) also reported increased risk of hospital admissions at high temperatures[14]. We are not aware of any UK-based study evaluating the associations between heat and mental-health admissions or ED visits in children.

Outpatient care, reflected in metrics such as referrals and appointments, is the patient setting most frequently accessed by children and adolescents[15] and reflects a broad spectrum of symptom severity, making it an important indicator of mental health and health service impacts across the population. Yet, we are only aware of two studies of temperature and outpatient and community care for young people, one finding higher temperatures to be associated with support seeking via a crisis textline[16], and one finding elevated temperatures to be associated with mental health-related hospital visits (including outpatient appointments) in 6-25 year olds, most strongly in children (age 6-11).[12]

There is also increasing evidence that high temperatures and air pollution exposure can synergistically amplify the risk of mental and other health outcomes[17] and that greenspace can be protective against heat-related mental health risks[18,19]. However, evidence in children and adolescents is limited.

This study aimed to address these gaps by (i) evaluating the association between temperature, extreme heat, and a range of outpatient and inpatient mental health service use outcomes in children and adolescents (<18), and (ii) exploring effect modification by air pollution and residential greenspace, using electronic health records from a large south London mental health trust. We hypothesised that extreme heat and higher temperatures would be associated with higher service use, and that this

would be mitigated by greenspace exposure. This is the first study, as far as we are aware, to analyse associations between temperature and engagement with Child and Adolescent Mental Health Services (CAMHS) or to investigate interactions with other environmental factors in this age group.

Results

Across children and adolescents engaged with SLaM, there were 16,579 inpatient admissions, 7,152 emergency department visits, 3,415,517 referrals, and 98,766 appointments during the summer season between 2008-2019 (1104 days) (counts and daily descriptive statistics can be found in Table 1). The mean averaged maximum daily temperature during the study period was 22.49°C, ranging from 12.9°C to 36.5°C (descriptive statistics of all environmental variables are found in Table 2).

Table 1: Counts of mental health service use during summer season in SLaM (2008 - 2019)

		Total (1104 days)	Daily		
Condition	**Outcome**	**Count**	**Mean**	**Median**	**IQR**
All	Inpatient admissions	16579	15.0	15.0	4.0
	Emergency department visits	7152	6.5	6.0	5.0
	Referrals	3415517	3093.8	3316.0	318.3
	Appointments	98766	89.5	102.0	140.0
Mood and anxiety disorders	Inpatient admissions	8456	7.7	7.0	4.0
	Emergency department visits	2291	2.1	2.0	2.0
	Referrals	886642	803.1	865.5	136.5
	Appointments	40618	36.8	41.0	58.0
Neurodevelopmental conditions	Inpatient admissions	3264	3.0	3.0	2.0
	Emergency department visits	2740	2.5	2.0	3.0
	Referrals	1602210	1451.3	1593.5	353.5
	Appointments	29166	26.4	28.0	43.0
- ADHD	Inpatient admissions	532	0.5	0.0	1.0
	Emergency department visits	1684	1.5	1.0	1.0
	Referrals	971061	879.6	939.0	165.8
	Appointments	14478	13.1	13.0	21.0
- ASD	Inpatient admissions	2732	2.5	3.0	2.0
	Emergency department visits	1056	1.0	1.0	2.0
	Referrals	631149	571.7	665.0	224.3
	Appointments	14688	13.3	13.0	22.0

ADHD: Attention Deficit/ Hyperactivity Disorder
ASD: Autism Spectrum Disorder
ICD codes (Condition): Mood (affective) and anxiety (Neurotic, stress-related, and somatoform) disorders- F30-F39, F40-F48; Neurodevelopmental conditions- F84 (ASD), F90 (ADHD)

Table 2: Descriptive summaries for environmental covariates during summer season in SLaM (2008 - 2019)

Environmental variables	Mean	SD	Minimum	Median	IQR	Maximum
Maximum Temperature (°C)	22.5	3.5	12.9	22.1	4.4	36.5
Mean Temperature (°C)	17.8	2.6	11.1	17.7	3.5	27.7
Normalised Differential Vegetation Index (NDVI)	0.16	0.023	0.10	0.16	0.02	0.19
Nitrogen dioxides (NO_2) (µg/m³)	31.5	9.5	8.3	30.8	13.3	64.9
Particulate Matter > 2.5µm ($PM_{2.5}$) (µg/m³)	11.0	3.9	5.1	10.1	4.0	33.7
Precipitation (mm)	1.8	4.4	0.00	0.05	1.5	42.9
Relative Humidity (%)	71.5	8.6	45.2	70.7	11.8	96.4
Surface pressure (hectopascals/ hPa)	100854.7	630.5	98652.9	100901.1	834.1	102611.2

Relative Risks (RR) for mental health service use in children and adolescents exposed to extreme heat (maximum temperature at the 99th percentile, 32.3°C), relative to the median temperature (22.1°C), are shown in Table 3, and cumulative exposure-response curves showing the association between maximum temperature and service use outcomes (centred at the median temperature) can be seen in Figure 2. Inpatient admissions showed a U-shaped association with temperature (Figure 2.a), increasing at low and high temperatures, however the association at the 99th percentile of temperature (32.3°C) was below 1 and not significant (RR: 0.975; 95% CI: 0.875-1.086). The lag-response association with extreme heat (Figure S1a, supplementary information) showed reduced risk for the first 5 days followed by slightly increased risk. This association differed by diagnosis (Figure 3.a), with a significant positive association evident in neurodevelopmental disorders (RR at 32.3°C: 1.474; 95% CI: 1.067-2.038) but not mood and anxiety disorders (RR at 32.3°C: 1.055; 95% CI: 0.908-1.227).

ED visits showed an inverse U-shaped relationship with temperature (Figure 2.b), significantly decreasing at high temperatures (RR at 32.3°C: 0.557; 95% CI: 0.345-0.898). Lag-response patterns suggested this effect was most pronounced in the first 8 days before decaying up to 14 days (Supplementary Figure S1.b). In those with mood and anxiety disorders, ED visits were significantly less likely at 32.3°C (RR at 32.3°C: 0.151; 95% CI: 0.068-0.334), with little apparent association in those with NDD (Figure 3.b)

Referrals (Figure 2.c) showed little evidence of an overall association with temperature (cumulative RR at 32.3°C: 1.001, 95% CI: 0.998–1.002). Lag-specific estimates were negative at days 2–6, although these associations were not statistically significant, and were positive at other lags (Figure S2.c). However, this relationship differed by diagnosis (Figure 3.c) with higher rates of referral for NDDs at high temperatures (RR at 32.3°C: 1.005; 95% CI: 1.003-1.007) and lower rates of referrals for mood and anxiety disorders at high temperatures (RR at 32.3°C: 0.996; 95% CI: 0.992-0.999).

Appointments were negatively associated with temperature (Figure 2.d), decreasing at higher temperatures (RR at 32.3°C: 0.798; 95% CI: 0.672-0.946) which appeared to be a delayed effect emerging after 5 days and persisting up to 14 days (Figure S1.d). Appointments were lower at high temperatures for both mood and anxiety disorders and NDDs, but the association was stronger in mood and anxiety disorders (Figure 3.d).

Table 3: Relative Risks (RR) and 95% Confidence Interval (95% CIs) of the association between extreme heat and mental health service use in children and adolescents (<18)

	Relative risk of extreme heat	LL (95% CI)	UL (95% CI)
Inpatient Admissions			
All diagnoses	0.975	0.875	1.086
Neurodevelopmental conditions	**1.474**	**1.067**	**2.038**
Mood and anxiety disorder	1.055	0.908	1.227
Emergency department (ED) visits			
All diagnoses	**0.557**	**0.345**	**0.898**
Neurodevelopmental conditions	1.069	0.509	2.245
Mood and anxiety disorder	**0.151**	**0.068**	**0.334**
Referrals			
All diagnoses	1.001	0.998	1.003
Neurodevelopmental conditions	**1.005**	**1.003**	**1.007**
Mood and anxiety disorder	**0.996**	**0.992**	**0.999**
Appointments			
All diagnoses	**0.798**	**0.672**	**0.946**
Neurodevelopmental conditions	0.896	0.684	1.173
Mood and anxiety disorder	**0.748**	**0.601**	**0.930**

The point estimates were derived at the 99th Percentile of summer temperature (32.3ºC), compared to the median temperature of 22·1ºC, for all children and adolescents in contact with mental health services, with a mood and anxiety disorder diagnoses (F30-48) and with a neurodevelopmental disorder diagnosis (F84 and F90).

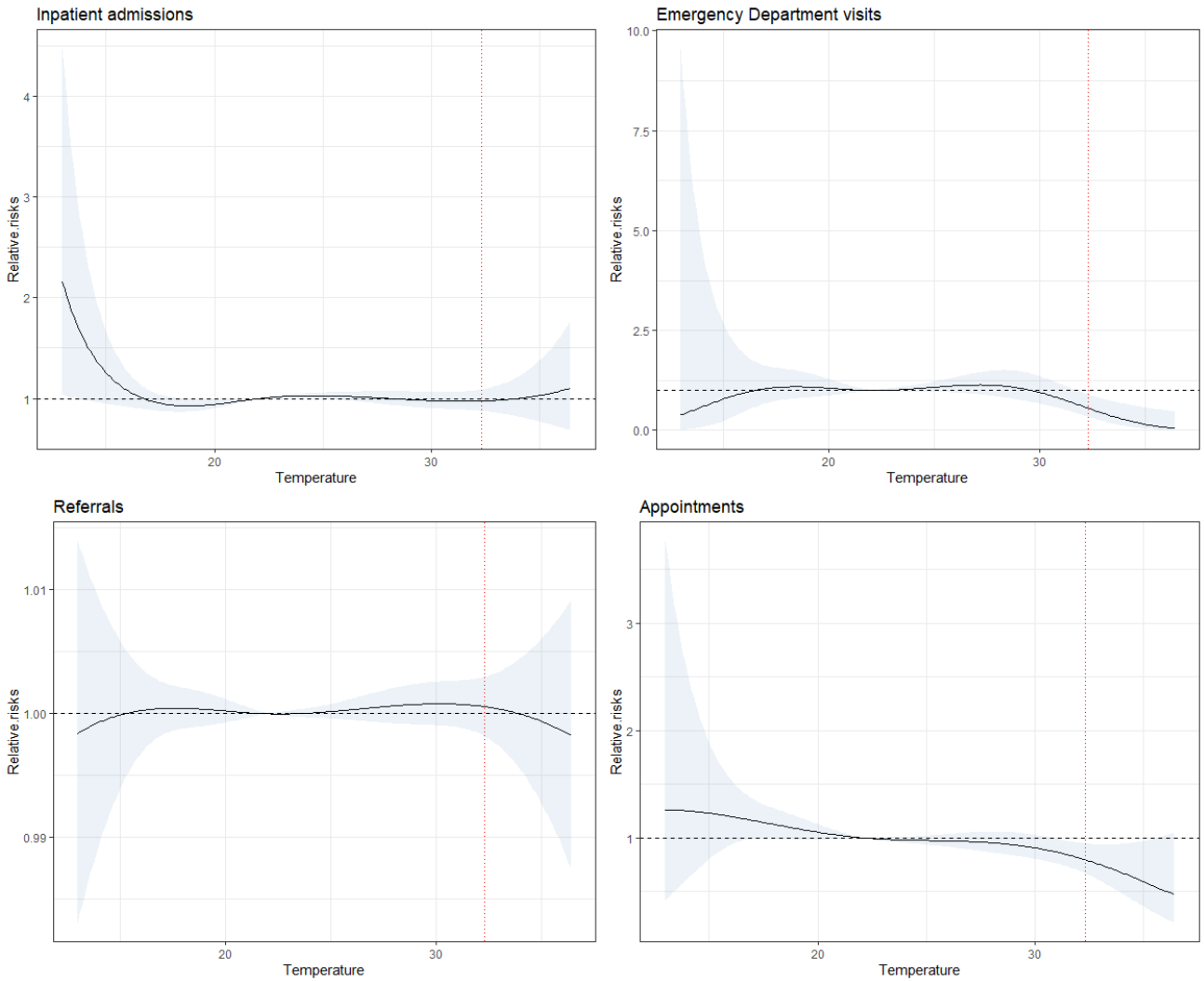


Figure 2: Cumulative overall exposure-response for temperature-mental health service use associations in children and adolescents (<18), with 95% confidence intervals. The curve is centred at the median maximum temperature (22.1ºC). The dotted vertical red line is the 99th percentile of summer temperature (32.3ºC).

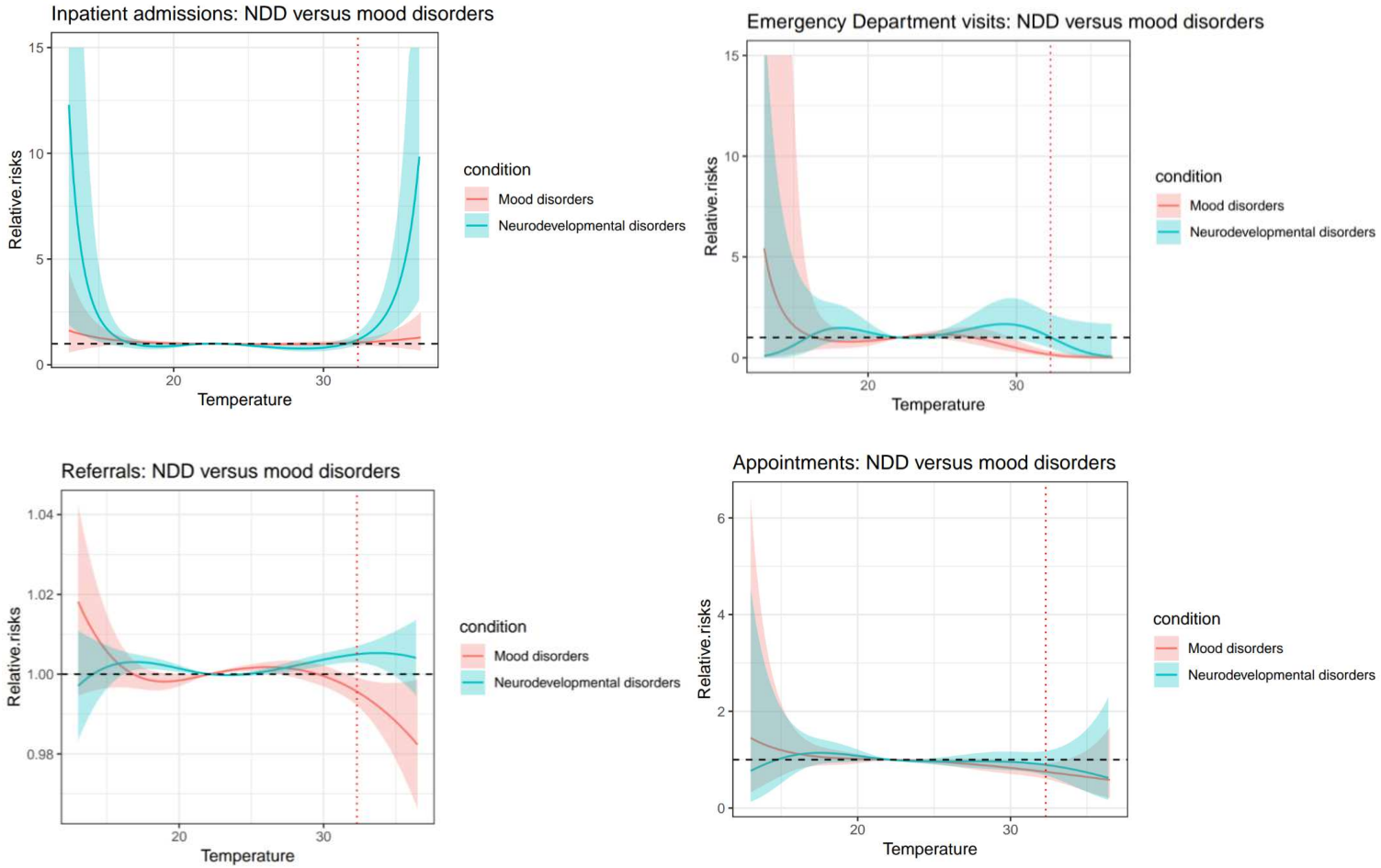


Figure 3: Cumulative overall exposure-response for temperature-mental health service use association in children and adolescents (<18) with mood and anxiety disorders (shaded in blue, F30-48) and with neurodevelopmental disorders (shaded in red, F84 and F90), with 95% confidence intervals. The curve is centred at the median maximum temperature (22.1ºC). The dotted vertical red line is the 99th Percentile of summer temperature (32.3ºC). Note: in Figures 3.a and 3.b (Inpatient admissions and Emergency Department visits), the Y-axis has been capped at maximum Y = 15 to aid perceptibility.

$PM_{2.5}$ significantly interacted with temperature (Table 4) to influence inpatient admissions and ED visits (Figures 4a and 4b), with those exposed to high $PM_{2.5}$ experiencing significantly elevated risk of ED visits at high temperatures (RR at 32.3°C: 16.128; 95% CI: 1.393-186.652). $PM_{2.5}$ was associated with slightly elevated risk of inpatient admissions at lower temperatures, but risk did not significantly differ under extreme heat conditions (Table 4, Figure 4a). High NO_2 exposure corresponded to lower risk of appointments at low and high temperatures (Figure 4c), but significant differences in risk under extreme heat were not evident (Table 4).

Greenspace also significantly modified the association between temperature and referrals (Figure 5). Rates of referrals were significantly increased under extreme heat for those with low greenspace exposure (RR at 32.3°C: 1.003; 95% CI: 1.001-1.005) but not for high greenspace exposure (RR at 32.3°C: 0.994; 0.981-1.001).

For children and adolescents with neurodevelopmental conditions, attributable risk analysis (Table 5) showed that the 10 days of extreme heat (>= 32.3°C) observed in the study were associated with an excess 615.34 inpatient admissions (attributable fraction: 18.9%; 95% eCI: 6.9%-28.3%) and 6384.20 referrals (0.4%; 95% eCI: -1.0% - 1.8%), relative to minimum risk temperatures of 28.6°C and 13°C, respectively.

In sensitivity analyses applying mean temperature as the exposure metric, similar exposure-response curves were observed (Figure S2). Similar patterns of association were also observed including additional knots at the 50^{th}, 75^{th}, and 90^{th} percentile of maximum temperature (Figure S3) and estimating the impact of temperature over a 7-day or 21-day lag period also did not substantially alter findings (Figures S4 and S5).

Table 4: Modification effect of pollution and residential greenness on extreme heat and mental service use

	Inpatient admissions		
Effect Modifier	**P value (interaction)**	**Low exposure - RR for extreme heat (32.3ºC)**	**High exposure - RR for extreme heat (32.3ºC)**
$PM_{2.5}$	0.043	0.899 (0.800-1.016)	0.629 (0.342-1.159)
	Emergency department visits		
Effect Modifier	**P value (interaction)**	**Low exposure - RR for extreme heat (32.3ºC)**	**High exposure - RR for extreme heat (32.3ºC)**
$PM_{2.5}$	0.040	0.483 (0.283- 0.826)	16.128 (1.393-186.652)
	Appointments		
Effect Modifier	**P value (interaction)**	**Low exposure - RR for extreme heat (32.3ºC)**	**High exposure - RR for extreme heat (32.3ºC)**
NO_2	0.007	0.901 (0.738-1.101)	0.730 (0.521-1.023)
	Referrals		
Effect Modifier	**P value (interaction)**	**Low exposure - RR for extreme heat (32.3ºC)**	**High exposure - RR for extreme heat (32.3ºC)**
Greenspace (NDVI)	<0.001	1.003 (1.001-1.005)	0.994 (0.981-1.001)
The relative risks of extreme heat at the 99th percentile (32.3ºC) with 95% Confidence Intervals. Relative risks were centred at the median temperature (22.1 ºC). High $PM_{2·5:} \geq 12·5$ μg/m³, Low $PM_{2·5}$: <12·5 μg/m³; High NO_2: ≥ 37.5 μg/m³, Low NO_2: < 37.5 μg/m ³; High residential greenness (NDVI): ≥ 0·176, Low: < 0·176.			

Table 5: Attributable risk of extreme heat on mental health service use by children and adolescents with neurodevelopmental disorders (NDD)

Outcome	**Relative risk of extreme heat (95% CI)**	**Attributable risk (empirical Confidence Interval)**	
		Attributable number	**Attributable Fraction**
Inpatient admissions	1.474 (1.067 - 2.038)	615.341 (236.757 - 925.783)	0.189 (0.069 - 0.283)
Referrals	1.005 (1.003 - 1.007)	6384.20 (-15334.12 – 19857.40)	0.004 (-0.0102 - 0.0182)
The relative risks of extreme heat at the 99th percentile (32.3ºC) with 95% Confidence Intervals. Relative risks were centred at the respective minimum risk temperatures for inpatient admissions (28.6ºC) and referrals (13ºC) in this group.			

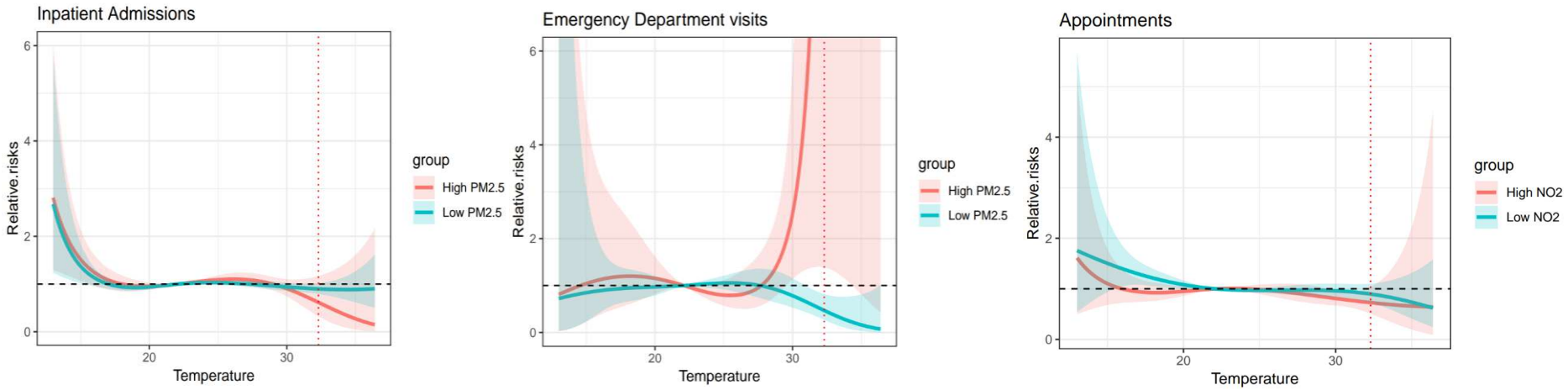


Figure 4: Cumulative overall exposure-response for associations between temperature and A) Inpatient admissions, B) Emergency Department visits, and C) Appointments, in children and adolescents (<18) with low air pollution exposure (shaded in blue) and high air pollution exposure (shaded in red), with 95% confidence intervals. The curve is centred at the median maximum temperature (22.1ºC). The dotted vertical red line is the 99th Percentile of summer temperature (32.3ºC). Note: in Figure 4.b (Emergency Department visits), the visible confidence interval for high $PM_{2.5}$ has been capped at maximum Y = 6 to aid perceptibility.

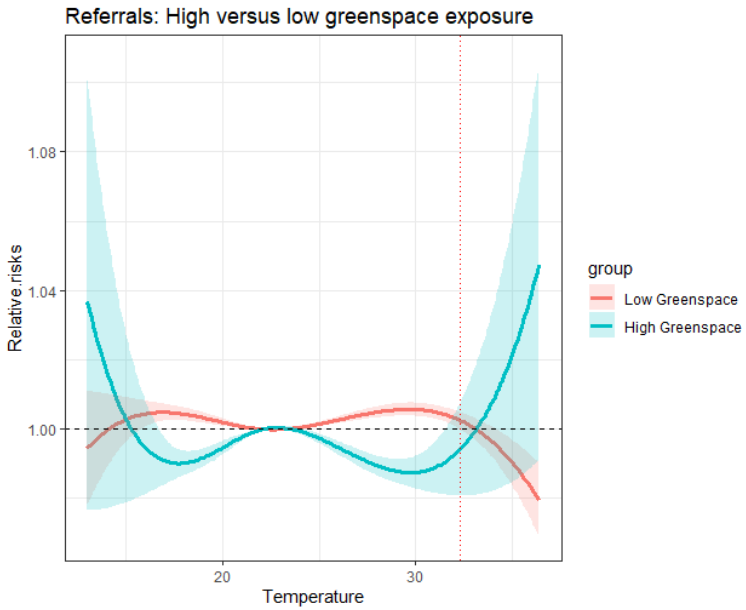


Figure 5: Cumulative overall exposure-response for association between temperature and mental health referrals in children and adolescents (<18) with high residential greenspace exposure (shaded in blue) and low residential greenspace exposure (shaded in red), with 95% confidence intervals. The curve is centred at the median maximum temperature (22.1ºC). The dotted vertical red line is the 99th Percentile of summer temperature (32.3ºC).

Discussion

This was the first UK-based study of temperature and mental health service use in children and adolescents. Contrary to hypotheses, we observed lower rates of appointments and emergency department (ED) visits under conditions of extreme heat, and significantly higher ED visits at cooler temperatures. In contrast to the overall patterns, referrals and inpatient admissions were significantly elevated during extreme heat for those with neurodevelopmental conditions. However, we saw lower risk of service use at high temperatures among those with mood and anxiety disorders. High $PM_{2.5}$ combined with extreme heat was associated with a dramatically increased risk of inpatient admissions, whereas high neighbourhood greenspace mitigated the heat-related risk of referrals (significantly associated for those exposed to low greenspace).

The distinction between underlying need and healthcare utilisation may help elucidate these findings; service use reflects not only symptom severity but also access to care and patterns of help-seeking, both of which may be disrupted during periods of extreme heat. It is possible that, in our study, decreased utilisation was driven by missed or cancelled appointments (which could be prompted by the health service or the patient/family) rather than reduced clinical need. This interpretation is supported by evidence from other outpatient services showing increased non-attendance during both very hot and cooler conditions, alongside elevated acute presentations[25,26]. Another possible explanation is that children and adolescents may have less exposure to the heat-related stressors affecting adults (e.g. occupational heat stress) and may be more likely to benefit from warmer weather while being more adversely affected by colder weather, due to the corresponding effects on their routines, habits, and social activities.

Examination of subgroups further illuminated the effects of temperature on child and adolescent mental health service use. Increased risk in children and adolescents with neurodevelopmental conditions suggests that extreme heat may exacerbate vulnerability in specific subgroups, even where overall service use declines. This interpretation is consistent with previous studies suggesting that heat can elevate symptom severity, ED visits and mental health admissions in children and youth with Attention Deficit/ Hyperactivity Disorder[14,27,28]. Although some studies have suggested that children adolescents with anxiety and depressive disorders (but not other mood disorders such as manic episode and bipolar disorder) may be particularly vulnerable to elevated temperatures[12,14]. Our findings align with prior research in adults showing reduced ED visits for mood disorders during hotter periods[29].

Air pollution and greenspace interacted with extreme heat in important ways. Our findings are consistent with prior research suggesting air pollution and heat can synergistically threaten a range of health outcomes[17,30]. Acting concurrently on overlapping stress pathways (such as inflammation, oxidative stress, and thermoregulation), air pollution may amplify the effects of heat[30]. However, it is important to acknowledge that confidence intervals were very wide and unstable at high temperatures for ED visits, and $PM_{2.5}$ so results should be taken as

preliminary/suggestive. Conversely, greenspace mitigated the harms of extreme heat, which has been hypothesised to occur via two key pathways: 1) reducing the temperature experienced by people by providing shade and reducing heat absorption; 2) increasing mental resilience by inducing calmness and attention restoration and providing a comfortable space for health-promoting activities such as socialising and exercising[18,19]. Altogether, these findings suggest that associations between temperature and service use are complex and can vary by age, outcome, environmental context, and diagnosis.

Strengths of this study include the range of outcomes and diagnostic groups being studied, allowing us to identify different patterns of association, and our accounting for a range of time-variant environmental confounders. The time-series design also eliminates confounding risk by time-invariant covariates. Other strengths include the inclusion of air pollution and greenspace as effect modifiers, thorough sensitivity analyses, and a long (12-year) study period. Limitations include relatively low daily counts of some events, especially in subgroup and interaction analyses, which led to instability at the temperature extremes and some very wide confidence intervals. Referral counts were high, making some smaller effects detectable that may not have been observable at lower counts with less statistical power. With our focus on extreme heat as a hypothesised risk factor, we used daily maximum summer temperature as our exposure metric, whereas effects could be different in different seasons or using different metrics. These results also may not be generalisable to non-urban settings or countries with substantial differences in wealth, culture or climate. Use of NDVI as a proxy for residential greenspace exposure could also be a limitation, as it does not reflect actual greenspace use, type, quality or accessibility.

This work has a range of implications for policy and practice. Increased risk and vulnerabilities in some groups (particularly children with neurodevelopmental conditions, in areas with poor air quality and low greenspace exposure) highlights the need for climate mitigation, including green infrastructure, and climate-responsive and resilient mental health services. Examples include: ensuring continuity of care and accessibility during periods of disruption to health and other services; ensuring clinicians, Special Educational Needs staff and families are prepared for increased distress in these times; providing training and information about heat-specific impacts (such as relating to sensory issues, change tolerance, and climate anxiety); arranging well-ventilated and air-conditioned facilities with available refreshments; and incorporating environmental considerations (such as heat islands, air pollution levels, and greenspace) into placement decisions for new health facilities and schools. Increasing greenspace could also help mitigate the negative impacts of heat, which should be approached with an equity lens that prioritises vulnerable neighbourhoods (e.g., those with higher levels of air pollution or mental health service use). The relatively increased risk of inpatient admissions on cold summer days should also be integrated into policy and practice, for example through service planning, patient and public awareness, and evaluation of support including pathways into care.

Whilst some adverse outcomes were lower at high temperatures, this work does not imply that climate change lowers young people's mental health risk. Climate change mitigation is unlikely to shift temperatures to the extent that cold summer days increase, and the overall mental health-related risks of unmitigated climate change far outweigh any potential benefits for cold-related psychiatric morbidity[4-6]. However, the impacts of cold weather on mental health service use warrant further research, where heat has so far received relatively more attention. Future research should also seek to investigate specific diagnoses and driving mechanisms such as appointment cancellations (ideally delineating service availability and attendance), behavioural change and effects on medication.

Conclusion

Our findings have added to the evidence base for associations between temperature and mental health in children and adolescents, highlighting many nuances and complexities. While cooler summer temperatures were associated with increased service use overall, extreme heat elevated risk for specific groups, particularly those with neurodevelopmental conditions, high air pollution exposure, and limited greenspace exposure. These results emphasise the need for climate-responsive mental health services that account for both heat and cold events, ensuring continuity of care, targeted provision for vulnerable populations, and supportive design and infrastructure. Importantly, these findings support climate mitigation and adaptation efforts, as temperature variability and extreme events will continue to impact mental health and shape service demand.

Methods

Study design and population

The study population included all children (3-12 years old) and adolescents (13-17 years old) who had a face-to-face contact between 1st January 2008 and 31st December 2019 and engaged with mental health services and residing within South London and Maudsley (SLaM) National Health Service (NHS) Foundation Trust (Figure 1). We applied a standard time-series (aggregated series) design to data from patients covering four ethnically diverse and densely populated London boroughs (Southwark, Lewisham, Croydon and Lambeth). We accessed the data using the Clinical Record Interactive Search (CRIS) platform which enables research access to full but de-identified data from source electronic health records which, in turn, contain comprehensive information about SLaM patients' mental health service use and their journey through services[20,21]. The CRIS platform and security model received ethical approval (Oxford C Research Ethics Committee, reference 23/SC/0257). Our sample included children and adolescents (aged 3-18 years) with a primary diagnosis of a mental health or behavioural disorder (ICD-10 codes F00-F99) whose first face-to-face contact with SLaM took place between 1/01/2008- 31/12/2019.

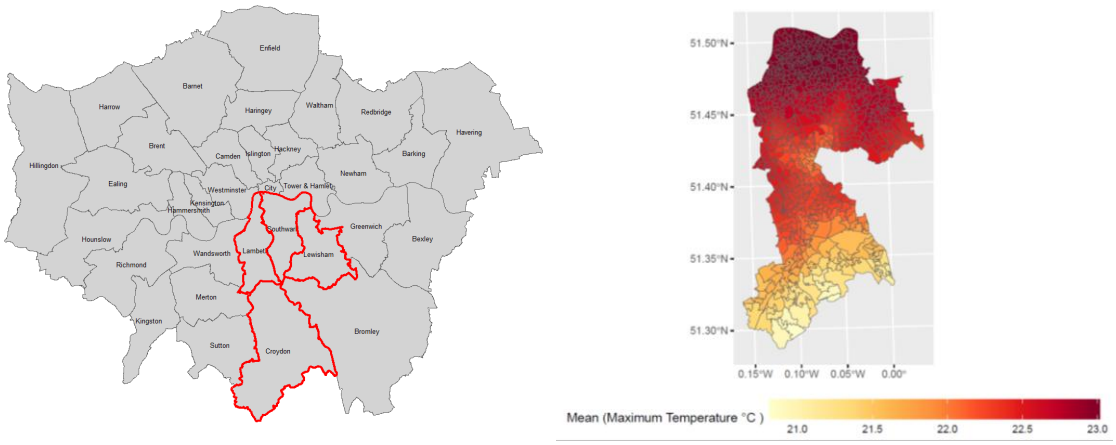


Figure 1: Study area showing the distribution of LSOA-level mean (maximum) summer temperature, covering the period between 2008 to 2019 for South London (Lambert, Lewisham, Southwark, and Croydon).

Measures

Mental health service use

We assessed four count-based outcomes in patients aged 3-17 to evaluate a range of mental health service use: inpatient admissions, emergency department (ED) visits, referrals, and appointments. Inpatient admissions were counted as each distinct spell or stay, from admission to discharge date. ED visits represent emergency care attendance, with each count corresponding to an individual visit by one patient to an Emergency Care Department. Referrals represent the patients' first-ever recorded entry event into secondary mental healthcare with SLaM (e.g., General Practitioner, school, or service-triggered referral). Each appointment represented a distinct face-to-face appointment, excluding home treatment team visits.

In addition to analysing outcomes across all patients, we also specifically defined outcomes for young people with mood and anxiety disorders (encompassing Mood Affective (ICD-10 codes F30-F39) and Neurotic, stress-related and somatoform disorders (F40-48)), and neurodevelopmental disorders (NDDs, encompassing Autism Spectrum disorders (F84.0, F84.1, F84.5, F84.9) and Attention-Deficit/Hyperactivity Disorder (F90.0, F90.1, F90.8, F90.9)). Other diagnostic groups did not present to services at a high enough frequency for analysis.

Daily ambient temperature

Minimum, maximum, and mean daily air temperature data at 1000-metre resolution were derived from the Had-UK-Grid[22]. The primary temperature metric was maximum daily temperature, with extreme heat defined as the 99th percentile of maximum daily temperature (32.3°C). As CRIS is a de-identified data resource, linkage of patients' residential postcode addresses to temperature data took place within a pre-CRIS data processing pipeline.

Covariates

Total daily precipitation (in mm) was also extracted from the Had-UK Grid[22], daily surface pressure (in Pascals, Pa) was derived from the ERA5-land dataset[23], and relative humidity (%) was calculated using temperature and dewpoint temperature from ERA5-land[23]. Daily concentrations of air pollutants (particulate matter < 2.5 μm, $PM_{2.5}$ and nitrogen dioxide, NO_2, both $\mu g/m^3$) were estimated using a satellite-based spatiotemporal machine-learning model, the details of which have been described elsewhere[24]. Greenspace exposure was estimated using annual NDVI (Normalised Difference Vegetation Index) at a 30-m spatial resolution, derived from Landsat 5, 7 (up to 2014) and 8 imagery (2014 onwards).

Statistical analysis

We aggregated daily counts of each outcome by postcode and linked these to the corresponding environmental exposure estimates for patients presenting with that outcome on that day. The association between short-term heat exposure and daily mental health service use across the trust was analysed using a time-series design restricted to the warmest summer months (June-August). To account for overdispersion and autocorrelation, we fitted a quasi-Poisson regression model combined with a Distributed Lag Non-Linear Model (DLNM) to capture the non-linear and delayed effects of maximum daily temperature. The exposure-response relationship was modelled using a B-spline with a knot placed at the 50th percentile of the temperature distribution. A maximum lag of 14 days was specified to capture immediate and delayed effects, with the lag-response relationship modelled using a natural spline with four equally spaced internal knots on the logarithmic scale. Models were adjusted for air pollution, holidays, precipitation, humidity, surface pressure, stratum-specific effects (conditional elimination), and total patients seen by services that day (log offset). To avoid collinearity, $PM_{2.5}$ was retained as an indicator of air pollution and NO_2 was excluded in the final main model. Models were estimated for the total daily outcome counts for all patients, for patients with NDD diagnoses, and for patients with mood and anxiety disorders.

Effect modification by air pollution (NO_2 and $PM_{2.5}$) and residential greenness (NDVI) was also explored, stratified into sample-relative high (at or above the 75th percentile) and low (below the 75th percentile) exposure. Categorical interaction terms, multiplied by the temperature cross-basis variable, were added to the main model and Likelihood ratio testing was used to compare goodness of fit between the two models and determine the significance of the interaction term/effect modification.

For outcomes that were significantly elevated, we estimated the risk of mental health service use attributable to extreme heat by calculating attributable counts and fractions relative to the minimum-risk temperature, with 95% empirical confidence intervals (eCIs) derived using Monte Carlo simulation.

Three sensitivity analyses were conducted:

1. Applying mean daily temperature as the main exposure metric.
2. Varying the number of lag days to a shorter period of 7 days and to a longer period of 21 days.
3. Including additional knots at the 75th and 90th percentile of temperature when estimating the exposure-response relationship.

We present results using cumulative exposure-response curves and relative risks (RR) with 95% confidence intervals at the 99th percentile of temperature (for maximum temperature, 32.3°C) relative to/centred at the median temperature (for maximum temperature, 22.1°C). Analyses were run in R using the packages Splines, dlnm and gnm (R Version 4.4.2) and statistical tests were two-sided with the threshold for statistical significance set at p <0.05.

Role of the funding source

The funders of the study had no role in study design, data collection, data analysis, data interpretation, or writing of the report.

Data sharing statement

The data that support the findings of this study are not publicly available but can be accessed with permissions from the South London and Maudsley NHS Foundation Trust.

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Ethics statement

As an anonymized data source for secondary analyses, the requirement for informed patient consent/assent has not been applied to CRIS, which was first ethically approved on 2008 and subsequently renewed (1st September 2023, Oxford Research Ethics Committee, reference 23/SC/0257). The study was performed in accordance with the ethical standards as laid down in the 1964 Declaration of Helsinki and its later amendments.

References

1. Caspi A, Houts RM, Ambler A, et al. Longitudinal Assessment of Mental Health Disorders and Comorbidities Across 4 Decades Among Participants in the Dunedin Birth Cohort Study. *JAMA Network Open* 2020; **3**(4): e203221–e.
2. McGorry PD, Mei C, Dalal N, et al. The Lancet Psychiatry Commission on youth mental health. *The Lancet Psychiatry* 2024; **11**(9): 731–74.
3. Rice F, Eyre O, Riglin L, Potter R. Adolescent depression and the treatment gap. *The Lancet Psychiatry* 2017; **4**(2): 86–7.
4. Burke SE, Sanson AV, Van Hoorn J. The psychological effects of climate change on children. *Current psychiatry reports* 2018; **20**(5): 35.
5. Lawrance EL, Thompson R, Newberry Le Vay J, Page L, Jennings N. The impact of climate change on mental health and emotional wellbeing: a narrative review of current evidence, and its implications. *International review of psychiatry* 2022; **34**(5): 443–98.
6. Vergunst F, Berry HL. Climate change and children's mental health: a developmental perspective. *Clinical Psychological Science* 2022; **10**(4): 767–85.
7. Thompson R, Lawrance EL, Roberts LF, et al. Ambient temperature and mental health: a systematic review and meta-analysis. *Lancet Planetary Health* 2023; **7**(7).
8. Yi W, Zhang X, Gao J, et al. Examining the association between apparent temperature and admissions for schizophrenia in Hefei, China, 2005–2014: A time-series analysis. *Science of The Total Environment* 2019; **672**: 1–6.
9. Yoo E-h, Eum Y, Roberts JE, Gao Q, Chen K. Association between extreme temperatures and emergency room visits related to mental disorders: A multi-region time-series study in New York, USA. *Science of The Total Environment* 2021; **792**: 148246.
10. Cohen G, Rowland ST, Benavides J, Lindert J, Kioumourtzoglou MA, Parks RM. Daily temperature variability and mental health-related hospital visits in New York State. *Environ Res* 2024; **257**: 119238.
11. Ryan SC, Wertis L, Sugg MM, Runkle JD. A small area analysis of acute exposure to temperatures and mental health in North Carolina. *International Journal of Biometeorology* 2025; **69**(4): 805–19.
12. Niu L, Girma B, Liu B, Schinasi LH, Clougherty JE, Sheffield P. Temperature and mental health-related emergency department and hospital encounters among children, adolescents and young adults. *Epidemiology and Psychiatric Sciences* 2023; **32**.
13. Tang C, Ji Y, Li Q, et al. Effects of different heat exposure patterns (accumulated and transient) and schizophrenia hospitalizations: a time-series analysis on hourly

temperature basis. *Environmental Science and Pollution Research* 2021; **28**(48): 69160–70.
14. He W-Q, Dey C, Li C, et al. Heat Exposure and Hospital Admissions for Mental Health Disorders in a Changing Climate. *Journal of the American Academy of Child & Adolescent Psychiatry* 2026.
15. Duong MT, Bruns EJ, Lee K, et al. Rates of Mental Health Service Utilization by Children and Adolescents in Schools and Other Common Service Settings: A Systematic Review and Meta-Analysis. *Administration and Policy in Mental Health and Mental Health Services Research* 2021; **48**(3): 420–39.
16. Sugg MM, Dixon PG, Runkle JD. Crisis support-seeking behavior and temperature in the United States: is there an association in young adults and adolescents? *Science of the Total Environment* 2019; **669**: 400–11.
17. Rackow B, König H-H, Wall M, Konnopka C. The interaction between air pollution, weather conditions, and health risks: a systematic review. *Science of The Total Environment* 2025; **996**: 180080.
18. Park J, Moon J, Kwon D, Ji JS, Kim H, Kim Y. A protective role of urban greenspace on the association between night-time heat and suicide in Seoul, South Korea. *Environmental Research: Health* 2024; **2**(1).
19. Yang Y, Zhang YX, Sheng SJ. Residential greenness for mitigating impacts of extreme heat events on depression and supporting mental health. *Frontiers in Public Health* 2023; **11**.
20. Perera G, Broadbent M, Callard F, et al. Cohort profile of the South London and Maudsley NHS Foundation Trust Biomedical Research Centre (SLaM BRC) Case Register: current status and recent enhancement of an Electronic Mental Health Record-derived data resource. *BMJ Open* 2016; **6**(3): e008721.
21. Stewart R, Soremekun M, Perera G, et al. The South London and Maudsley NHS Foundation Trust Biomedical Research Centre (SLAM BRC) case register: development and descriptive data. *BMC Psychiatry* 2009; **9**: 51.
22. Hollis D, McCarthy M, Kendon M, Legg T, Simpson I. HadUK-Grid—A new UK dataset of gridded climate observations. *Geoscience Data Journal* 2019; **6**(2): 151–9.
23. Sabater M. ERA5-Land monthly averaged data from 1981 to present. Copernicus Climate Change Service (C3S) Climate Data Store (CDS). 2019.
24. de la Cruz Libardi A, Masselot P, Schneider R, et al. High resolution mapping of nitrogen dioxide and particulate matter in Great Britain (2003–2021) with multi-stage data reconstruction and ensemble machine learning methods. *Atmospheric Pollution Research* 2024; **15**(11): 102284.
25. Fitzpatrick JH, Willard A, Edwards JR, et al. Time Series Analysis: Associations Between Temperature and Primary Care Utilization in Philadelphia, Pennsylvania. *American Journal of Preventive Medicine* 2024; **67**(5): 658–65.
26. Mayne SL, Ramachandran J, Sharma P, et al. Extreme Temperatures and Missed Pediatric Preventive Care Visits. *JAMA Network Open* 2026; **9**(4): e2610114–e.
27. Yu T, Wen Y, Dong P-P, et al. The association between anthropogenic heat and parent-report symptoms of childhood attention deficit hyperactivity disorder in China: A novel perspective reflecting climate change. *International Journal of Hygiene and Environmental Health* 2025; **264**: 114518.
28. Runkle JD, Reed C, Weidner K, Rothschild J, Chandrasekhar T, Sugg MM. Assessing the impact of heatwaves on emergency visits for major depression and suicidal ideation in youth with attention-deficit/hyperactivity disorder. *PLOS Mental Health* 2025; **2**(10): e0000444.

29. Christodoulou N, Laaidi K, Fifre G, Lejoyeux M, Ambar Akkaoui M, Geoffroy PA. Heatwaves and mental disorders: A study on national emergency and weather services data. *The European Journal of Psychiatry* 2024; **38**(3): 100249.
30. Anenberg SC, Haines S, Wang E, Nassikas N, Kinney PL. Synergistic health effects of air pollution, temperature, and pollen exposure: a systematic review of epidemiological evidence. *Environmental Health* 2020; **19**(1): 130.