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Socioeconomic position during pregnancy and pre-school exposome in children from eight European birth cohort studies

Costanza Pizzi [a,*], Giovenale Moirano [a], Chiara Moccia [a], Milena Maule [a], Antonio D'Errico [a], Martine Vrijheid [b,c,d], Timothy J. Cadman [e], Serena Fossati [b,c], Mark Nieuwenhuijsen [b,c,d], Andrea Beneito [f], Lucinda Calas [g], Liesbeth Duijts [h], Ahmed Elhakeem [i], Jennifer R. Harris [j], Barbara Heude [g], Vincent Jaddoe [h], Deborah A. Lawlor [i], Sandrine Lioret [g], Rosemary RC. McEachan [k], Johanna L. Nader [l], Marie Pedersen [e], Angela Pinot de Moira [e,m], Katrine Strandberg-Larsen [e], Mikel Subiza-Pérez [d,k,n,o], Marina Vafeiadi [p], Marieke Welten [h], John Wright [k], Tiffany C. Yang [k], Lorenzo Richiardi [a]

[a] *Cancer Epidemiology Unit, Department of Medical Sciences, University of Turin and CPO Piemonte, Turin, Italy*
[b] *ISGlobal (Barcelona Institute for Global Health), Barcelona, Spain*
[c] *Universitat Pompeu Fabra (UPF), Barcelona, Spain*
[d] *Spanish Consortium for Research on Epidemiology and Public Health (CIBERESP), Madrid, Spain*
[e] *Section of Epidemiology, Department of Public Health, University of Copenhagen, Copenhagen, Denmark*
[f] *Epidemiology and Environmental Health Joint Research Unit, University of Valencia, Valencia, Spain*
[g] *Université Paris Cité and Université Sorbonne Paris Nord, Inserm, INRAE, Center for Research in Epidemiology and StatisticS (CRESS), F-75004, Paris, France*
[h] *Generation R Study Group, Erasmus MC, University Medical Center Rotterdam, Rotterdam, the Netherlands*
[i] *MRC Integrative Epidemiology Unit, Population Health Science, Bristol Medical School, University of Bristol, Bristol, UK*
[j] *Center for Fertility and Health, The Norwegian Institute of Public Health, Oslo, Norway*
[k] *Bradford Institute for Health Research, Bradford Teaching Hospitals NHS Foundation Trust, Bradford, UK*
[l] *Department of Genetics and Bioinformatics, Division of Health Data and Digitalisation, Norwegian Institute of Public Health, Oslo, Norway*
[m] *National Heart and Lung Institute, Imperial College London, London, UK*
[n] *Department of Clinical and Health Psychology and Research Methods, University of the Basque Country UPV/EHU, Bilbao, Spain*
[o] *Biogipuzkoa Health Research Institute, Environmental Epidemiology and Child Development Group, San Sebastian, Spain*
[p] *Department of Social Medicine, School of Medicine, University of Crete, Greece*

A R T I C L E I N F O

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A B S T R A C T

Distribution of environmental hazards and vulnerability to their effects vary across socioeconomic groups. Our objective was to analyse the relationship between child socioeconomic position (SEP) at birth and the external exposome at pre-school age (0–4 years).

This study included more than 60,000 children from eight cohorts in eleven European cities (Oslo, Copenhagen, Bristol, Bradford, Rotterdam, Nancy, Poitiers, Gipuzkoa, Sabadell, Valencia and Turin). SEP was measured through maternal education and a standardised indicator of household income. Three child exposome domains were investigated: behavioral, diet and urban environment. We fitted separate logistic regression model for each exposome variable - dichotomised using the city-specific median - on SEP (medium/low vs high) adjusting for maternal age, country of birth and parity. Analyses were carried out separately in each study-area.

Low-SEP children had, consistently across study-areas, lower Odds Ratios (ORs) of breastfeeding, consumption of eggs, fish, fruit, vegetables and higher ORs of TV screen time, pet ownership, exposure to second-hand smoke, consumption of dairy, potatoes, sweet beverages, savory biscuits and crisps, fats and carbohydrates. For example, maternal education-breastfeeding OR (95% Confidence Interval (CI)) ranged from 0.18 (0.14–0.24) in Bristol to 0.73 (0.58–0.90) in Oslo. SEP was also strongly associated with the urban environment with marked between-city heterogeneity. For example, income-$PM_{2.5}$ OR (95%CI) ranged from 0.69 (0.47–1.02) in Sabadell to 2.44 (2.16–2.72) in Oslo.

* Corresponding author. Cancer Epidemiology Unit, Department of Medical Sciences, University of Turin and CPO Piemonte Via Santena 7, 10126, Turin, Italy.
E-mail address: costanza.pizzi@unito.it (C. Pizzi).

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Already at pre-school age, children with lower SEP have consistently poorer diets and behaviours, which might influence their future health and wellbeing. SEP-urban environment relationships are strongly context-dependent.

1. Introduction

Early life is a key period where inequalities in exposure to different hazards can shape lifecourse health trajectories (Barker, 2007). The exposures experienced by individuals can differ by socioeconomic position (SEP), contributing to inequalities (Davey Smith and Lynch, 2004). The concept of environmental inequalities refers to a differential distribution of environmental hazards and vulnerability to their effects and – consequently - a differential distribution of health outcomes across different socioeconomic groups (Deguen et al., 2022). Examining the relationship between SEP and patterns of early life environmental exposures is essential to inform policies on how to mitigate environmental injustice and health inequalities and where to act most urgently (Ganzleben and Kazmierczak, 2020). From this perspective, the socio-exposome framework has been proposed in the literature to integrate the exposome concept, i.e. a representation of a person's life-time totality of environmental exposures, with sociological and political research (Senier et al., 2017). The exposome consists of a multitude of exposures from both external (e.g. chemicals, air pollutants, lifestyle, diet) and internal (e.g. metabolism, inflammatory factors, microbiota) sources, many of which are inter-related (Wild, 2005). Under the socio-exposome framework, exposures are studied as a complex, socially-driven phenomena.

Despite SEP being recognised as a key exposome determinant, its effects vary across communities and geographical areas due to context-dependent factors (Montazeri et al., 2019; Robinson et al., 2018; Senier et al., 2017). Studying the early life exposome in multiple regions and countries, where lifestyle, national economical level, policies and geography vary, may improve understanding of the mechanisms giving rise to socioeconomic inequalities. Moreover, as SEP is a complex concept which may vary across countries, it is important to assess it accounting for its different underlying dimensions and using standardised measure across countries and studies.

Previous cohort studies have examined the SEP-early life exposures relationship using an exposome approach. In particular, Vrijheid et al. examined the presence of socioeconomic inequalities in pregnancy exposures to multiple environmental contaminants in air, water and food in the participants of the Spanish INMA cohort using different SEP indicators (Vrijheid et al., 2012). Robinson et al. analysed the socioeconomic determinants of the urban exposome (outdoor environment) during pregnancy using data from six countries, considering family education, occupation, income and an area-level indicator as SEP measures, although occupation and income were not available for all the studies and income was measured differently across the cohorts (Robinson et al., 2018). The same data were used by Montazeri et al. to investigate the association between SEP and several chemical contaminants in school-age children and their mothers during pregnancy (Montazeri et al., 2019). Sum et al. also focused on the exposome during pregnancy considering several individual and geographical SEP indicators and focusing, mainly, on internal exposures (e.g. micronutrients, hormones, metabolites) using data of 1450 women from Singapore (Sum et al., 2022). As most of these studies focused on the maternal exposome during pregnancy, there is less knowledge on the relationship between family SEP and the child exposome during the first years of life. Moreover, in the studies including subjects from different cohorts, family education was the only available and standardised SEP indicator in all populations.

In this study, we used the EU Child Cohort Network, which brings together birth cohorts from across Europe and Australia and currently includes harmonised data on more than 250,000 children and their parents on lifestyle, socio-demographic factors, birth outcomes, household exposures and maternal, paternal and child health as well as urban environment variables (Pinot de Moira et al., 2021). This multi-cohort/country data resource was used to i) analyse the association between child SEP at birth, measured using maternal education and an indicator of total disposable household income derived in a standardized way for the cohorts member of the network, and the pre-school age external exposome (behaviors, diet, urban environment) in several birth cohorts representing different European cities, and ii) understand whether these associations may be explained by context-specific factors.

2. Methods

2.1. The conceptual framework

This study was based on the conceptual framework illustrated in Fig. 1. Within this framework pathway III is the one under study in this paper, with focus on household income and maternal education as indicators of child SEP at birth and on the dietary intake, behavioural factors and urban environment as the preschool age exposome domains of interest.

2.2. Study design and populations

Birth cohorts within the EU Child Cohort Network from the LifeCycle (Jaddoe et al., 2020) and ATHLETE (Vrijheid et al., 2021) projects were invited to participate in this study in November 2020. Details on available variables and how these were harmonised in each study are provided in a dedicated catalogue (https://data-catalogue.molgeniscloud.org/catalogue/catalogue/#/variable-explorer) and in the harmonization manuals available under the "Guides and Manuals" section of the LifeCycle project website (https://lifecycle-project.eu). Moreover, the harmonization process is described in detail in another paper (Pinot de Moira et al., 2021). Cohorts in the network were eligible for inclusion if they had information on family income and/or maternal education at time of child birth and on the urban exposome in the pre-school age period (0–4 years). Eight cohorts participated: Avon Longitudinal Study of Parents and Children (ALSPAC) and Born in Bradford (BIB) from the UK, the Danish National Birth Cohort (DNBC), the EDEN study on the prenatal and early postnatal determinants of child health and development (Etude sur les Déterminants pré et post-natals du développement de la santé de l'ENfant) from France, Generation R (GenR) from the Netherlands, the INMA environment and childhood project (INfancia y Medio Ambiente) from Spain, the Norwegian Mother, Father and Child Cohort Study (MoBa), and the NINFEA birth and childhood: effects of the environment study (Nascita e INFanzia: gli Effetti dell'Ambiente) from Italy. Ethical approval for these studies was obtained from local ethic committees. General descriptions of the participating cohorts are provided in the Supplementary material (pp 2–5). As the urban exposome variables were measured for urban subjects only and most of the cohorts recruited their populations in urban context, we restricted the study population to subjects living in urban areas. In particular participants from 11 cities were included: Bristol (ASLPAC, n = 13874), Bradford (BIB, n = 13854), Copenhagen (DNBC, n = 14417), Nancy and Poitiers (EDEN, n = 1034 and 968 respectively), Rotterdam (GenR, n = 9523), Gipuzkoa, Sabadell and Valencia (INMA, n = 638, 774 and 792 respectively), Oslo (MoBa, n = 12529) and Turin (NINFEA, n = 2430). The study flowchart, a map showing location of each study-area and a table providing information on city demographic data and economic well-being are reported in the supplementary material (Supplementary Figs. 1 and 2 and Supplementary Table 1).

2.3. SEP indicators

We measured child SEP using two different indicators, both measured at birth and described in this section: i) maternal educational level and ii) household income.

Maternal educational level. Maternal education was available as a categorical variable with three levels based on the International Standard Classification of Education 97/2011 (ISCED-97/2011): low (ISCED-97/2011: 0–2), medium (ISCED-97/2011: 3–4) and high (ISCED-2011: 5–8, ISCED-97: 5–6). Since in some cohorts the proportion of subjects in the low-level was too low to create a three-level indicator (Supplementary Table 2), the low and medium level were combined (Table 1).

Household income. The Equivalised Household Income Indicator (EHII) is a direct measure of income measuring the total disposable monthly household income, standardised for household size and composition. It was developed, within the LifeCycle project, for all the cohorts included in this paper using external data from the 2011 country-specific European Surveys on Income and Living Condition (EUSILC) and cohorts' specific data (methods have been described previously) (Pizzi et al., 2020). As for maternal education, the continuous variable was dichotomised into low/medium vs high income using, as external cut-off, the upper tertile of the distribution of the equivalised total disposable household income from the 2011 EUSILC country-specific population used to derive the EHII (i.e. all households with at least one child (≤16 years old) and his/her mother, excluding households with eight or more members or atypical/rare structures). The country-specific cut-off allowed for comparability across the different study-areas.

2.4. Pre-school age (0–4 years) exposome

In the LifeCycle project, the set of variables to harmonize were chosen based on their identification as relevant early-life stressors and exposures related to cardio-metabolic, respiratory and mental health outcomes. In this study, we considered three main exposome domains: behavior, diet and urban environment. We selected the harmonised variables belonging to these domains available in at least two cohorts. The list of variables included in each domain is reported in Table 2. In the Supplementary material a more detailed description of the exposome variable is provided and Supplementary Table 4 shows descriptive statistics of the exposome variables in each study-area.

With the exception of passive smoking and pet ownership, all the variables included in the behavior domain were available for the 2–4 years period as single non-repeated variable. These harmonised exposures were generated for each cohort within the framework of the LifeCycle project. In contrast, the urban variables, passive smoking and pet ownership were available at different time occasions in each cohort (time occasions varying between cohorts according to study design). For these time-varying variables for each cohort the measures collected in the 0–4 years period closest to two years of age were considered for these analyses (Table 2).

The variables included in the urban environment domain were generated using methods described in the LifeCycle harmonization manuals (https://lifecycle-project.eu) and elsewhere (Moccia et al., 2023). In brief, Geographic Information System tools were used to geocode the residential address of the cohort participants at different time points starting from pregnancy. Exposures in this domain are grouped in seven sets: noise, food environment, natural spaces, meteo-climatic factors, traffic, air pollution and built environment. For spatial variables measured with different buffers (100, 300, 500 m), only those in a 300-m buffer from the residence were considered (with the exception of road traffic variables) (Table 2).

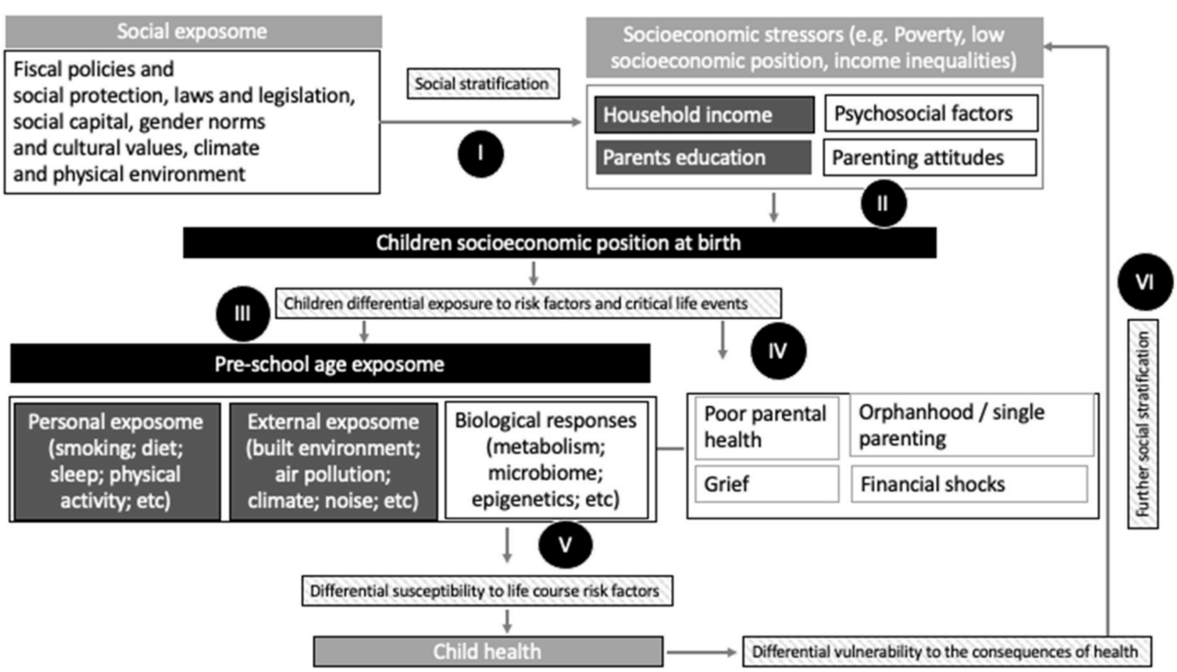

Fig. 1. The conceptual framework. It can be assumed that the primer driver of socioeconomic stressors in childhood are positioned at distal level and refer to those structures and constructs (i.e. the social exposome) that influence the household/parents SEP in a society (***Pathway I***). The household income and parental education are two of the most important indicators of child SEP at birth (***Pathway II)***. SEP at birth is responsible of a differential exposure to important material, psychosocial, environmental, behavioural and biological risk factors, that in this study represents the pre-school exposome (***Pathway III***) or can affect the differential exposure of children to a number of critical life events (***Pathway IV***). All these risk factors are responsible of differential susceptibility to a series of early life and life course risk factors that are ultimately responsible of the health status of a child (***Pathway V***). Finally, it can be assumed that children from a low socioeconomic background have a differential vulnerability to the clinical and financial consequences of poor health in childhood which ultimately can further exacerbate the disadvantage in early life and adulthood (***Pathway VI***).

Table 1
Socio-economic position (SEP) information of study participants by study area.

Cohort	Maternal education				EHII				
	N missing (%)	N valid	Low/Med (%)[a]	High (%)[a]	N missing (%)	N valid	Low/Med (%)[a]	High (%)[a]	Cut-off (€)[b]
MoBa-Oslo	1016 (8.1)	11513	16.9	83.1	1736 (13.8)	10793	76.4	23.6	3421.3
DNBC-Copenhagen	1933 (13.4)	12484	31.5	68.5	2706 (18.8)	11711	36.7	73.3	2625.5
BIB-Bradford	3295 (23.8)	10559	72.4	27.6	3003 (21.7)	10851	98.5	1.5	1674.1
ALSPAC-Bristol	2127 (15.3)	11747	87.1	12.9	4614 (33.2)	9260	90.7	9.3	1674.1
GenR-Rotterdam	1151 (12.1)	8372	56.8	43.2	3176 (33.3)	6347	59.5	40.5	1915.3
EDEN-Poitiers	32 (3.3)	936	53.1	46.9	90 (9.3)	878	69.7	30.3	1841.7
EDEN-Nancy	60 (5.8)	974	40.2	59.8	97 (9.3)	937	58.9	41.1	1841.7
NINFEA-Turin	66 (2.7)	2364	32.4	67.6	262 (10.8)	2162	29.0	71.0	1572.6
INMA-Gipuzkoa	2 (0.3)	636	50.0	50.0	61 (9.5)	577	53.7	46.3	1400.4
INMA-Sabadell	3 (0.4)	713	71.4	28.6	92 (14.0)	564	71.3	28.7	1400.4
INMA-Valencia	4 (0.5)	788	76.5	23.5	97 (12.2)	695	81.0	19.0	1400.4

[a] Proportion calculated out of the subjects without missing values (N valid).
[b] Upper tertile of the 2011 EUSILC country-specific distribution of the equivalized total disposable household income considering households with at least one child (≤16 years old) and his/her mother and excluding households with 8 or more members or atypical/rare structures.

2.5. Statistical analyses

All analyses were conducted remotely through the federated analysis platform DataSHIELD (version 6.10) using the R software (version 4.2.3) and DataSHIELD specific libraries (https://github.com/datashield).

To evaluate the SEP-exposome relationship, we fitted a separate regression model of each exposome variable (the dependent variable) on the binary SEP indicator (the exposure). This approach was previously used in a paper comparing different statistical methods to analyse the SEP-exposome relationship using the data of the NINFEA-Turin participants (Moccia et al., 2023), which are also included in this study. To account for context-dependent factors, analyses were carried out separately in each study-area. Within each model, we used a complete case approach, implying that sample size may be different for each model (Supplementary Tables 5 and 6). Given that (i) many exposome variables had a skewed distribution, (ii) for the same variable the transformation required to achieve normality could differ between study-areas, and (iii) for some variables none of the tested transformations achieved normality, we dichotomised all the exposome variables using the city-specific median as a cut-off, and fitted logistic regression models to estimate the Odds Ratio (ORs) and 95% Confidence Interval (95% CI) of exposure levels above vs. below the median (Hosmer and Lemeshow, 2013). For the cohorts for which the night noise level variable was categorical, this was dichotomised as above or below 50 dB, as this was the level closest to the median in the other study-areas (Supplementary Table 4). The median was chosen a-priori in order not to selectively choose the cut-offs and to increase power.

Models were adjusted for maternal age at delivery (in years), country of birth (binary, mothers born in the country of the cohort as reference) and parity (binary, nulliparous as reference), chosen a priori as potential confounders. For the MoBa and DNBC cohorts, maternal country of birth was not available (Supplementary Table 3); and in GenR nutrient intake data were only available for a subset of children with mothers born in the Netherlands and therefore the country of birth variable was not included in the nutrient intake models for GenR.

Maternal education and the EHII were analysed as independent and alternative SEP indicators, with all models comparing the combined medium- and low-SEP group to the high-SEP participants (the reference group). To qualitatively assess between study-area heterogeneity in the ORs for each exposome variable, we used the two-sided p-value from an exact binomial test with an expected probability of 50% under the null hypothesis of qualitative heterogeneity in the direction of the ORs (equal number of ORs≥1 and ORs<1). Therefore, a small p-value provides evidence against the null hypothesis of between study heterogeneity.

3. Results

Children for whom at least one of the two SEP indicators was available were included in this study, for a total of 61378 children. The SEP indicators distributions varied considerably across cohorts, with the proportion of children with a highly educated mother ranging from 13.0% in ALSPAC-Bristol to 83.0% in MoBa-Oslo and the proportion with a high-EHII ranging from 1.5% in BIB-Bradford to 73.0% in DNBC-Copenhagen (Table 1). Also, the proportion of missing values varied by study-area, being lower for maternal education than the EHII in all cohorts except BIB. The largest proportion of missing values were observed in DNBC, BIB, ALSPAC and GEN-R for the EHII and in BIB for maternal education. The latter was due to the fact that BIB had a higher proportion of mothers with other or unknown overseas qualification that in the harmonization process were coded as missing. For the other study-areas proportion of missing values were all around or below 10% (Table 1). Participants in the cohorts also differed in term of sociodemographic characteristics (Supplementary Table 3) and in the number and levels of available exposome variables (Supplementary Table 4).

Tables 3 and 4 show the study-area specific ORs of exposome variable level above the study-area specific median in association with EHII and maternal education, respectively. In the last column, the p-value of the between study-area qualitative heterogeneity test was reported. The ORs with their 95% CI and the sample size were reported in the supplementary material (Supplementary Tables 5 and 6).

Concerning the behavior and diet domains, consistently across cohorts (p-value for qualitative heterogeneity test <0.2) children with a low/medium income had lower ORs of breastfeeding, consumption of fish, fruit and whole grain, and higher ORs of TV screen time, pet ownership, passive smoking, unhealthy lifestyle pattern, consumption of dairy, potatoes, savory biscuits and crisp, sweet beverages, total carbohydrate and fat with respect to children with a high income (Table 3). Even if the direction of these associations was the same for most cohorts, estimate magnitudes varied considerably: for example, the OR of breastfeeding was 0.22 (95% CI 0.08–0.63) in INMA-Sabadell and 0.94 (95% CI 0.64–1.38) in NINFEA-Turin, and the OR (95%CI) of exposure to passive smoking varied from 1.07 (0.71–1.62) in INMA-Sabadell to 2.92 (2.46–3.42) in GenR-Rotterdam (Supplementary Table 5).

Regarding the urban environment, consistent findings across study-areas were observed only for blue spaces, with low-EHII children less exposed to them, and for connectivity density, percentage of presence of industrial and other (Mineral Extraction and Dump Sites, Construction Sites, Land Without Current Use) areas, which were instead higher among low-EHII children (Table 3). For the other urban variables, associations were more heterogenous across study-areas; for example, income-$PM_{2.5}$ OR (95%CI) ranged from 0.69 (0.47–1.02) in Sabadell to 2.44 (2.16–2.72) in Oslo. Also, in MoBa-Oslo and INMA-Valencia,

Table 2
Overview of the variables included in the children exposome at pre-school age.

Exposome Domain	Exposure Group	Variables	Categorization/Unit of measurement	Time period
Behavior	Lifestyle	Daily outdoor time	Seasonal z-score hours/day	2–4 years
		Sleep time	Hours/day	2–4 years
		Daily TV screen time	Hours/day	2–4 years
	Pet	Score of unhealthy lifestyle pattern[a]	.	2–4 years
		Score of healthy lifestyle pattern[a]	.	2–4 years
		Fast food restaurants visits	Times per week	2–4 years
		Pet ownership	No/Yes	0–4 years (measure closest to 2 years)
	Tobacco	Exposure to passive smoking	No/Yes	0–4 years (measure closest to 2 years)
Diet	Breastfeeding	Ever breastfed	No/Yes	.
	Food groups	Total dairy products	Servings per day	2–4 years
		Low-fat dairy products	Servings per day	2–4 years
		Eggs	Servings per day	2–4 years
		Potatoes	Servings per day	2–4 years
		Fatty fish	Servings per day	2–4 years
		Non-fatty fish	Servings per day	2–4 years
		Total fish	Servings per day	2–4 years
		Total meat	Servings per day	2–4 years
		Pulses	Servings per day	2–4 years
		Red meat	Servings per day	2–4 years
		Processed meat	Servings per day	2–4 years
		Fruit	Servings per day	2–4 years
		Vegetables	Servings per day	2–4 years
		Total grain products	Servings per day	2–4 years
		Whole grains products	Servings per day	2–4 years
		Savory biscuits and crisps	Servings per day	2–4 years
		Sugar products	Servings per day	2–4 years
		Sweet beverages	Servings per day	2–4 years
	Nutrients	Daily kilo calories	kcal/day	2–4 years
		Sodium	mg/day	2–4 years
		Polyunsaturated fats	% of total food	2–4 years
		Saturated fats	% of total food	2–4 years
		Trans fats	% of total food	2–4 years
		Total fat	gr/day	2–4 years
		Percentage fat	% of energy intake	2–4 years
		Total carbohydrate	gr/day	2–4 years
		Percentage carbohydrate	% of energy intake	2–4 years
		Total protein	gr/day	2–4 years
		Percentage protein	% of energy intake	2–4 years
Urban environment	Noise	Night noise level from closest street[b]	Decibels	0–4 years (measure closest to 2 years)
	Food environment	Facilities related to unhealthy food	No. of facilities/area	0–4 years (measure closest to 2 years)
	Natural spaces	Presence of major blue spaces	No/Yes	0–4 years (measure closest to 2 years)
		Presence of major green spaces	No/Yes	0–4 years (measure closest to 2 years)
		NDVI	.	0–4 years (measure closest to 2 years)
	Meteoclimatic	Humidity percentage	%	0–4 years (measure closest to 2 years)
		Temperature	Degree Celsius	0–4 years (measure closest to 2 years)
		Land surface temperature	Degree Celsius	0–4 years (measure closest to 2 years)
		UV irradiance DNA damaging dose	kilojoules per m^2	0–4 years (measure closest to 2 years)
	Traffic	Total traffic load[c]	Vehicles per day and meter	0–4 years (measure closest to 2 years)
		Total traffic load of major roads[c]	Vehicles per day and meter	0–4 years (measure closest to 2 years)
		Traffic density on nearest road	Vehicles per day	0–4 years (measure closest to 2 years)
		Inverse distance to the nearest road	Inverse meter	0–4 years (measure closest to 2 years)
	Air pollution	NO_2	$\mu g/m^3$	0–4 years (measure closest to 2 years)
		NO_X	$\mu g/m^3$	0–4 years (measure closest to 2 years)
		PM_{10}	$\mu g/m^3$	0–4 years (measure closest to 2 years)

(continued on next page)

Table 2 (*continued*)

Exposome Domain	Exposure Group	Variables	Categorization/Unit of measurement	Time period
		$PM_{2.5}$	μg/m^3	0–4 years (measure closest to 2 years)
		PM_{coarse}	μg/m^3	0–4 years (measure closest to 2 years)
		$PM_{absorbance}$	μg/m^3	0–4 years (measure closest to 2 years)
	Built environment	Population density	Inhabitants/km^2	0–4 years (measure closest to 2 years)
		Building density	m^2 built/km^2	0–4 years (measure closest to 2 years)
		Connectivity density	No. of intersections/km^2	0–4 years (measure closest to 2 years)
		Buses lines	Meters	0–4 years (measure closest to 2 years)
		Buses stops	No.	0–4 years (measure closest to 2 years)
		Facility richness	No. of different facility types/max potential no. of facility types	0–4 years (measure closest to 2 years)
		Shannon land-used diversity index	.	0–4 years (measure closest to 2 years)
		Walkability index	.	0–4 years (measure closest to 2 years)
		% of high density residential areas land use	%	0–4 years (measure closest to 2 years)
		% of low density residential areas land use	%	0–4 years (measure closest to 2 years)
		% of very low density residential areas land use	%	0–4 years (measure closest to 2 years)
		% of industrial/commercial land use	%	0–4 years (measure closest to 2 years)
		% of transports land use	%	0–4 years (measure closest to 2 years)
		% of green urban areas land use	%	0–4 years (measure closest to 2 years)
		% of agricultural areas land use	%	0–4 years (measure closest to 2 years)
		% of forests land use	%	0–4 years (measure closest to 2 years)
		% of water land use	%	0–4 years (measure closest to 2 years)
		% of other areas land use[d]	%	0–4 years (measure closest to 2 years)

[a] Scores created within the framework of the LifeCycle project (Descarpentrie et al., 2023).
[b] In the ALSPAC, BIB and DNBC cohorts night noise was available as a categorical variable with cutoffs at 50, 55, 60, 65 and 75 dB.
[c] Measured in a 100-m buffer from the residence.
[d] Others areas: mineral extraction and dump sites, construction sites and land without current use.

children with a low/medium income were more exposed to unhealthy food environment, noise, air pollution, population and building density and showed lower levels of Normalized Difference Vegetation Index (NDVI) than children with a high income; whilst in NINFEA-Turin and INMA-Sabadell, low/medium-EHII children were less exposed to unhealthy food environment, traffic, air pollution and high-density residential area and showed higher levels of Shannon land-use diversity index. In EDEN-Poitiers, and with some exceptions, in ALSPAC, household income was mostly not associated with the urban exposome (Table 3).

When maternal education was used instead of income, we observed similar results (Table 4 and Supplementary Fig. 3). Concerning the behavior and diet domains, in addition to the associations described above, it was consistently observed that children of mothers with a low/medium educational level had lower consumption of eggs and vegetables and higher consumption of sugar, meat, processed meat, higher levels of daily kcal, are more likely to visit fast food restaurants and spent more time playing outdoor (Table 4). Moreover, in a few cohorts, we observed differences between the EHII and maternal education associational estimates for some of the urban environment variables. In particular, the magnitude of the maternal education estimate was smaller than that of income in BIB and MoBa-Oslo (Supplementary Fig. 3) and larger in ALSPAC (Table 4). The smaller magnitude of the maternal education associational estimates observed in BIB and MoBa might be in part explained by the fact that these were the two cohorts for which the distribution in the low/middle vs high categories differed the most between education and income (Table 1).

4. Discussion

In this study, we found that, in all study-areas, children with low SEP were more likely to have unhealthy diet and behaviors. The SEP-urban environment associations were strong but with marked between study-area heterogeneity.

Overall, our findings add on previous studies focusing on the relationship between SEP and single exposures or groups of similar exposures. In particular, the observed link between low-SEP and unhealthy diet, especially the lower consumption of fruit and vegetables and the higher consumption of snacks, fast foods and sweet beverages among children with social vulnerabilities, has been found in other European studies (Iguacel et al., 2016; Papamichael et al., 2022). A recent meta-analysis revealed that maternal education was an important determinant of breastfeeding initiation and continuation in high-income countries (Cohen et al., 2018). In a systematic review, low-SEP,

Table 3
Study-area specific Odds Ratios of the exposome variable level above the study-area specific median in association with the EHII (low-medium vs high = reference).

			Oslo	Copenhagen	Bradford	Bristol	Rotterdam	Poitiers	Nancy	Turin	Gipuzkoa	Sabadell	Valencia	p[a]
BEHAVIOR	Lifestyle	Outdoor time	1.11		0.39	1.23	1.09	1.40	1.49					0.22
		Sleep time	0.89		1.19	1.00		0.94	0.77		1.38	0.74	0.96	0.72
		Tv screen time	1.10		2.08	1.73	2.01	2.41	1.65		0.92	1.99	1.58	0.04
		Unhealthy lifestyle pattern[b]	0.97		1.73	2.14		1.72	1.65		1.38	1.40	2.18	0.07
		Healthy lifestyle pattern[b]	1.11		2.12	0.70		0.57	0.56		0.54	0.51	1.05	0.73
		Fast food restaurant				1.32					1.34	0.94	1.20	0.63
		Pets ownership	0.84	1.09	2.97	1.11	1.80	1.73	1.82	1.62	1.90	1.31	2.97	0.01
		Passive smoking	1.84	1.36	6.62	1.80	2.92	1.34	2.53	1.39	1.62	1.07	1.02	<0.01
DIET		Breastfeeding	0.89	0.48	0.26	0.39	0.34	0.64	0.59	0.94	0.65	0.22	0.55	<0.01
	Food Groups	Dairy			1.49	0.91		1.63	1.11	1.13	1.84	1.97	1.99	0.07
		Low-fat dairy			1.11	0.84					0.86	1.13	0.87	>0.99
		Eggs			1.99	0.74		0.70	0.88	0.73	0.96	1.09	0.70	0.29
		Potatoes			1.51	1.07		1.19	1.15	1.27	1.45	1.06	1.79	<0.01
		Fatty fish			1.28	0.70		0.99	0.74		0.84	0.90	0.99	0.13
		Non-fatty fish			0.62	0.91		0.61	0.75		0.90	0.46	0.72	0.02
		Fish			0.88	0.87		0.75	0.68	0.88	0.76	0.66	0.64	<0.01
		Meat			1.05	1.03		0.91	1.38	0.96	1.27	1.13	1.25	0.29
		Pulses			1.02	0.82		1.30	1.45	0.84	0.75	0.90	1.04	>0.99
		Red meat			1.34	1.04		0.68	1.11		1.22	0.90	1.12	0.45
		Processed meat			0.95	0.84		0.95	1.48		1.26	1.38	1.23	>0.99
		Fruit			1.49	0.67		0.82	0.61	0.73	0.66	0.73	0.98	0.07
		Vegetables			1.15	0.94		0.56	0.53	0.84	0.76	0.59	1.23	0.29
		Grain			1.40	0.77		1.09	1.19	0.89	1.32	0.79	1.16	0.73
		Whole grains			0.65	0.70					0.86	0.57	0.64	0.06
		Savory biscuits & crispy			0.90	1.75		1.57	1.00		1.62	1.97	2.12	0.13
		Sugar			1.92	1.35		0.66	0.94	1.32	1.62	1.73	1.36	0.29
		Sweet beverages			2.34	1.45		1.25	1.36	1.02	1.22	1.45	1.84	<0.01
		Kcal				0.98	1.32				1.75	1.67	2.39	0.38
		Sodium				0.91					1.12	1.62	1.84	0.63
		Polyunsaturated fats				0.98	1.04				0.65	0.94	1.00	>0.99

OR>1.05	OR<0.95	
		p≤0.01
		0.01<p≤0.05
		0.05<p≤0.1
		p>0.1

	Nutrients intake	Saturated fats				1.09	0.87				1.38	1.03	1.20	0.38
		Trans fats									1.84	1.32	1.28	0.25
		Total fat				1.05	1.60				1.75	1.25	1.65	0.06
		Percentage fat				1.27					1.00	0.88	0.88	>0.99
		Total carbohydrate				1.00	1.16				1.73	1.62	2.36	0.06
		Percentage carbohydrate				0.98					1.11	1.08	1.67	0.63
		Total protein				0.78	1.07				1.45	1.36	1.90	0.38
		Percentage protein				0.78					0.84	1.00	0.54	0.63
	Noise	Night noise	1.40	1.25	0.82	1.01	1.14	1.62	1.15	0.85		0.69		0.51
	Food environment	Unhealthy food facilities	1.62	0.84	1.72	0.87	1.04	1.13	1.19	0.71	0.64	0.55	1.46	>0.99
	Natural spaces	Blue spaces	0.84	0.82	1.77	0.99	0.87	0.92	0.63	1.13	0.68	0.57	0.51	0.07
		Green spaces	0.52	1.19	4.85	0.88	0.94	1.06	1.16	1.22	0.54	1.67	0.57	>0.99
		NDVI index	0.37	1.00	0.59	0.92	0.90	0.88	0.84	1.14	1.14	1.27	0.68	0.55
	Meteoclimatic	Humidity			1.40	1.09	0.90			0.78				>0.99
		Land surface temperature		1.02	1.39		1.16			0.80				0.63
		Temperature		0.95	1.23	1.15	0.92			0.88				>0.99
		DNA-damage UV dose		1.00	1.31		0.99			0.92				>0.99
	Traffic	Traffic all roads			0.99		1.00	0.69	1.22		0.91	0.69	1.32	>0.99
		Traffic major roads			0.56	0.79			1.00	0.71		0.61		0.38
		Traffic nearest road	0.81		0.76		1.06	0.89	1.21		0.93	1.02	1.22	>0.99
		Distance nearest road	1.27	1.11	1.27	1.01	1.09	0.85	1.07	0.98	0.90	0.95	0.79	>0.99
URBAN	**Air pollution**	NO_2	3.49	0.84	1.30	0.86	1.05	1.20	1.12	0.73	0.59	0.57	1.38	>0.99
		NO_x	2.34		1.09		0.98			0.87	0.71	0.59	1.33	>0.99
		PM_{10}	1.04		0.97		0.88			0.95		0.60		0.38
		$PM_{2.5}$	2.44	0.93	0.98	1.23	1.05	0.99	0.97	1.04	0.71	0.69	0.89	0.55
		$PM_{absorbance}$	1.04		1.20		0.86			0.90		0.58		>0.99
		PM_{coarse}	1.08		0.85		1.11			0.95		0.76		>0.99
	Built environment	Population density	4.01	0.91	1.25	1.02	0.88	0.86	1.16	1.14	1.02	0.76	1.40	0.55
		Building density	1.93	0.90	1.17	1.00	1.06	1.19	1.04	0.79	0.80	0.71	1.54	0.55
		Connectivity density	1.62	1.04	1.28	1.11	1.43	1.12	1.15	0.66	0.83	1.09	1.20	0.07
		Buses lines		0.84	1.00	1.12	1.13	1.43	1.43	0.84	0.78	0.88	1.09	0.75
		Buses stops	1.54	0.93	1.42		1.21	1.51	1.16	0.88	0.86	0.90	0.99	>0.99
		Facility richness	2.44	0.90	1.34	0.92	0.98	1.15	1.17	0.81	0.81	0.63	1.01	>0.99
		Shannon land use index	1.67	1.02	1.84	1.17	0.93	1.02	1.52	1.32	0.76	1.55	0.88	0.23
		Walkability index	2.61	1.04	1.32	0.95	1.14	0.86	1.36	0.76	0.68	1.03	1.09	0.55
		High-density residential	0.32	0.98	1.42	0.92	1.15	1.09	1.43	0.76	0.84	0.68	1.46	>0.99
		Low-density residential	3.46	0.96	0.95	0.92	0.81	1.26	0.83	1.32	1.39	1.40	0.61	>0.99
		Very low-density residential			0.62	0.59	0.90	1.02	1.12	1.07		1.68	0.49	0.73
		Industrial/commercial	1.73	1.16	1.88	1.19	1.01	1.16	1.42	1.00		0.84	1.45	0.02
		Transports		0.99	1.19	0.93	1.42	1.09	1.30	0.76	0.76	0.84	0.90	0.75
		Urban green	1.48	1.20	1.35	0.98	0.90	0.89	1.25	1.13	1.42	2.05	0.80	0.55
		Agricultural areas	0.76	1.05	0.48	1.03	1.25	0.79	0.93	1.97	1.12	1.40	0.84	>0.99
		Forests		1.77	0.68	0.79	0.88	0.89	0.84	1.36	1.22	0.95	0.67	0.34
		Water	0.86	1.03	0.57	1.03	0.87	0.75	1.63	1.13	0.94	0.57	0.50	0.55
		Other areas[c]	1.05	1.12	1.99	1.63	0.93	1.39	1.35	1.16	2.80	2.14	0.92	0.07

[a] p-value from between study-area qualitative heterogeneity test
[b] Scores created within the framework of the LifeCycle project (Descarpentrie et al., 2023)
[c] Others areas: mineral extraction and dump sites, construction sites and land without current use

Table 4
Study-area specific Odds Ratios of the exposome variable level above the study-area specific median in association with maternal education (low-medium vs high = reference).

			Oslo	Copenhagen	Bradford	Bristol	Rotterdam	Poitiers	Nancy	Turin	Gipuzkoa	Sabadell	Valencia	p[a]
BEHAVIOR	Lifestyle	Outdoor time	1.08		1.35	1.79	1.05	2.03	1.79					0.03
		Sleep time	0.94		1.08	1.06		0.68	0.68		1.27	0.78	0.99	0.73
		Tv screen time	1.25		1.02	2.03	2.51	3.00	2.10		0.97	2.34	1.55	0.04
		Unhealthy lifestyle pattern[b]	1.49		1.22	2.75		2.51	2.27		1.38	1.62	1.62	0.01
		Healthy lifestyle pattern[b]	0.83		1.17	0.85		0.55	0.58		0.70	0.45	1.01	0.29
		Fast food restaurant				1.45					1.75	1.60	1.46	0.13
		Pets ownership	1.68	1.62	1.05	1.52	1.79	1.58	1.67	1.77	1.67	1.99	1.68	<0.01
		Passive smoking	4.76	1.77	1.92	2.66	2.89	1.60	2.51	1.52	1.46	1.01	1.20	<0.01
DIET		Breastfeeding	0.73	0.36	0.27	0.18	0.30	0.46	0.50	0.52	0.79	0.29	0.51	<0.01
	Food Groups	Dairy			1.20	0.98		1.36	1.39	1.16	1.20	1.99	1.63	0.07
		Low-fat dairy			0.92	0.96					1.06	1.12	0.93	>0.99
		Eggs			0.74	0.84		0.73	0.84	0.79	0.79	0.80	0.97	<0.01
		Potatoes			1.21	1.38		1.13	0.91	1.06	1.46	1.26	1.62	0.07
		Fatty fish			0.66	0.55		1.17	0.81		0.99	1.14	0.92	0.45
		Non-fatty fish			0.98	0.97		0.84	0.80		1.09	0.61	0.80	0.13
		Fish			0.80	0.80		0.93	0.94	0.84	0.85	0.83	0.67	<0.01
		Meat			1.28	1.31		1.08	1.25	1.22	1.25	0.98	1.48	0.07
		Pulses			0.81	0.59		1.34	1.38	0.79	0.73	0.76	0.98	0.29
		Red meat			1.21	1.25		0.63	0.96		1.27	0.99	1.13	>0.99
		Processed meat			1.04	1.27		1.19	1.17		1.25	1.15	1.73	0.02
		Fruit			0.76	0.47		0.71	0.58	0.68	0.60	0.68	0.91	<0.01
		Vegetables			0.73	0.97		0.40	0.52	0.62	0.66	0.64	1.27	0.07
		Grain			0.94	0.58		1.13	0.92	0.90	1.19	0.80	0.94	0.29
		Whole grains			0.61	0.49					0.84	0.54	0.42	0.06
		Savory biscuits & crispy			1.45	2.08		1.86	1.16		1.48	2.25	1.88	<0.01
		Sugar			1.03	1.65		0.79	1.06	1.13	1.32	1.70	1.08	0.07
		Sweet beverages			1.43	2.61		1.39	1.70	1.06	1.49	1.23	1.36	<0.01
		Kcal				1.06	1.46				1.36	1.55	1.80	0.06
		Sodium				0.85					1.08	1.58	1.67	0.63
		Polyunsaturated fats				0.87	0.85				0.79	1.25	0.86	0.38

OR>1.05	OR<0.95	
		p≤0.01
		0.01<p≤0.05
		0.05<p≤0.1
		p>0.1

		Saturated fats				1.07	1.09				1.05	1.35	0.81	0.38
		Trans fats									1.51	0.83	1.16	>0.99
	Nutrients intake	Total fat				1.04	1.52				1.43	1.20	1.30	0.06
		Percentage fat				1.17					0.97	1.07	0.72	>0.99
		Total carbohydrate				1.04	1.39				1.55	1.88	1.67	0.06
		Percentage carbohydrate				0.99					1.04	1.09	1.62	0.63
		Total protein				0.84	1.12				1.39	1.48	1.82	0.38
		Percentage protein				0.74					1.00	0.92	0.73	0.63
	Noise	Night noise	1.27	1.02	1.11	1.31	1.07	1.30	1.58	0.89		0.76		0.18
	Food environment	Unhealthy food facilities	0.84	0.68	1.36	0.58	1.08	0.89	1.12	0.66	0.86	0.58	1.21	0.55
		Blue spaces	0.95	0.78	1.65	1.07	0.90	1.43	0.58	0.93	0.79	0.54	0.33	0.23
	Natural spaces	Green spaces	1.30	0.90	1.54	0.63	0.94	0.99	1.00	1.15	0.97	2.03	0.47	>0.99
		NDVI index	1.09	1.30	0.67	1.21	0.83	0.97	0.89	1.11	0.95	1.45	0.79	>0.99
		Humidity			1.04	0.93	0.91			0.84				0.63
		Land surface temperature		0.90	1.34		1.12			0.70				>0.99
	Meteoclimatic	Temperature		1.12	1.01	1.01	0.90			0.63				>0.99
		DNA-damage UV dose		1.09	0.98		0.97			1.23				>0.99
		Traffic all roads			1.08		1.90	0.66	0.93		0.94	0.74	1.23	>0.99
		Traffic major roads			1.12	0.79			0.82	0.87		0.70		0.38
	Traffic	Traffic nearest road	0.85		1.13		1.07	0.79	0.94		1.19	0.84	1.05	>0.99
		Distance nearest road	0.92	0.82	1.02	0.95	1.20	1.25	1.04	0.88	1.13	0.80	0.98	>0.99
		NO_2	1.04	0.88	1.23	0.60	0.98	0.97	1.02	0.93	0.94	0.55	1.06	0.55
		NO_x	1.11		1.16		0.93			0.96	0.89	0.61	1.05	>0.99
		PM_{10}	1.25		1.04		0.79			1.28		0.60		>0.99
	Air pollution	$PM_{2.5}$	0.95	0.78	1.12	1.08	0.99	1.05	1.20	1.67	0.72	0.64	0.95	>0.99
URBAN		$PM_{absorbance}$	1.00		1.15		0.82			1.04		0.56		>0.99
		PM_{coarse}	1.12		1.04		1.12			1.16		0.66		0.38
		Population density	1.14	0.85	1.36	0.85	0.84	0.75	0.84	0.91	1.22	0.63	1.21	0.55
		Building density	0.68	0.78	1.17	0.63	1.09	1.03	0.94	0.79	1.01	0.57	1.26	>0.99
		Connectivity density	0.86	0.74	1.27	0.85	1.43	0.93	0.94	0.60	0.91	0.94	1.09	0.23
		Buses lines		0.93	0.89	1.27	1.13	1.00	1.54	0.90	0.93	0.86	0.69	0.75
		Buses stops	1.06	0.83	1.12		1.20	1.12	0.97	0.90	1.00	0.84	0.80	>0.99
		Facility richness	0.95	0.68	1.35	0.66	1.00	0.99	1.07	0.59	0.91	0.74	0.88	0.23
		Shannon land use index	0.99	1.16	1.13	1.13	0.88	1.15	1.46	1.35	0.85	1.63	1.01	0.23
	Built	Walkability index	0.86	0.73	1.38	0.68	1.12	0.79	1.04	0.64	0.84	1.15	0.94	0.55
	environment	High-density residential	0.76	0.77	1.49	0.59	1.21	1.11	1.08	0.76	1.03	0.58	1.19	>0.99
		Low-density residential	0.73	1.42	0.75	0.80	0.76	1.05	1.01	1.42	1.04	1.34	0.77	>0.99
		Very low-density residential			0.76	0.86	0.59	1.14	1.21	0.84		1.86	0.66	0.73
		Industrial/commercial	0.90	1.00	1.32	1.07	0.99	1.13	1.34	1.19		0.71	1.14	0.34
		Transports		0.97	1.27	0.72	1.45	1.00	1.20	0.84	0.97	0.83	1.16	>0.99
		Urban green	1.12	0.90	1.00	1.12	0.91	0.94	1.30	0.99	1.55	2.05	0.87	>0.99
		Agricultural areas	1.30	1.31	0.73	1.51	1.22	1.04	1.28	2.51	0.96	1.84	0.90	0.23
		Forests		1.02	0.73	0.93	0.81	1.02	0.93	2.18	0.95	1.04	1.35	>0.99
		Water	1.27	1.03	0.60	0.97	0.92	0.94	1.70	0.93	1.06	0.54	0.33	0.55
		Other areas[c]	2.10	1.20	1.19	1.86	1.04	1.27	1.20	1.52	1.03	1.86	0.97	0.01

[a] p-value from between study-area qualitative heterogeneity test
[b] Scores created within the framework of the LifeCycle project (Descarpentrie et al., 2023)
[c] Others areas: mineral extraction and dump sites, construction sites and land without current use

measured using different indicators including parental education and income, was found to be associated with children's second-hand smoke exposure (Orton et al., 2014). A meta-analysis of twelve European birth cohorts, different from those included in this study, observed an inverse relationship between parental education and pet ownership (Eller et al., 2008). In addition, the observed strong link between low-SEP and increased screen time in children is supported by several strands of evidence (Cárdenas-Fuentes et al., 2021; Hoyos Cillero and Jago, 2010). A recent systematic review looking at social inequalities in sleep time classified existing studies by geographical area and found that, in

Europe, a lower SEP was associated with shorter children sleep and other sleep problems; however, the authors strongly emphasised the need for standardised SEP measures (Sosso and Khoury, 2021). Our analyses do not show solid and consistent results with regard to the SEP-sleep time relationship; evidence of shorter children sleep among low-SEP children was observed only in EDEN and only for maternal education. Concerning physical activity, we observed that low-SEP children from the ALSPAC and EDEN cohorts spent more hours playing outside than high-SEP children. Results from the literature are conflicting, with some studies showing direct, inverse or no associations between SEP and children physical activity and sedentary behaviour (Cárdenas-Fuentes et al., 2021; Lu et al., 2023; Wijtzes et al., 2014). Results of a recent scoping review from UK led to the conclusion that SEP influence on physical activity varied according to the SEP indicators used, the behavioral outcome and the age, and that greater consistency in the SEP measures is needed for robust country-specific meta-analyses (Pearson et al., 2022). With our study, using standardised SEP indicators and an exposome and multi-cohort approach, we showed that the relationship between SEP and children behavior and diet at pre-school age is notable and consistent across study-areas that reflect populations with considerable variation in years of birth, lifestyle, national economical level and geographical areas (Supplementary Table 1). Moreover, the magnitude of the associations was particularly large for some of the behavior and diet variables, especially for TV screen time, exposure to passive smoking, breastfeeding, consumption of vegetables and savory biscuits and crisps.

Regarding the SEP-urban environment relationship, there are previous studies that used an exposome approach (Montazeri et al., 2019; Robinson et al., 2018; Sum et al., 2022; Vrijheid et al., 2012), however these were mainly focused on the exposome during pregnancy and/or considered only one exposome domain at the time and/or included only one cohort. In particular Robinson et al. (2018), who investigated the urban environment during pregnancy in nine European cities, found considerable heterogeneity in the SEP effects across cities, with low-SEP being associated with harmful factors in some geographical areas and beneficial ones in others. In our study, that focused on the first years of life, we observed similar patterns. Vrijheid et al. (2012), analysing exposure to environmental pollutants during pregnancy in the INMA cohort, discussed that, especially in southern Europe, in some cities wealthier people are more likely to live in city centers, characterised by higher level of air pollution, traffic load and building density. This might partly explain the geographical heterogeneity observed in our study in the relationships between SEP and air pollutants, traffic measures, and built environment characteristics, with higher exposures observed among low-SEP children in MoBa (Norway) and BIB (UK), and lower concentrations in INMA (Spain) and NINFEA (Italy).

Fitting a separate model for each exposome variable we dealt with a set of potentially highly correlated outcomes (Moccia et al., 2023). In this framework to overcome the problem of the correlation structure it would be sufficient to control for confounding, which we did by adjusting for maternal age, parity and country of birth (VanderWeele, 2017). Although SEP is a distal exposure that is not likely to be affected by most of the factors that could influence the exposome, we have adjusted for a priori selected maternal characteristics that are likely to be important determinants of being a member of the cohort studies or becoming pregnant in the general populations to avoid baseline collider bias (Richiardi et al., 2019). Finally, we did not adjust for multiple testing as we were not in favour of interpreting p-values in a dichotomous way (below or above a significance level) but rather of focusing on the strength of the evidence against the null hypothesis (colour intensity in Tables 3 and 4) and on the consistency of the results across the different cities.

This study has some limitations. We focused only on selected components of the external exposome and did not consider the internal exposome. Also, as the urban environment exposures were measured only for subjects living in the urban areas, we have restricted our study sample to this subgroup; it would be important to understand whether similar social inequalities in the exposure pattern of pre-school age children exist for those living in rural or semi-rural areas. We used a complete-case approach because methods to deal with missing data were under development in DataSHIELD at the time of the study, therefore missing data might have introduced some bias in our estimates, especially those for the income indicator, that has a higher proportion of missing values (Table 1); however, results were overall similar when using the two SEP indicators and for many study-areas proportions were around or below 10%. Another limiting point is that variability in the assessment of urban exposures due to variability in data sources across cities might exist; moreover, these exposures were based only on the geocoded residential address of participants and do not account for the time children might spend in other places. Another limitation is that, although for some of the urban exposures repeated measures were available for most of cohorts, we have not investigated longitudinal effects. Also, we should acknowledge that unmeasured confounders, such as local policies or other potential determinants of being a member of the source population might be present. Finally, we should acknowledge that the statistical approach chosen to study the SEP influence on the exposome does not allow us to summarize the complex structure of the exposome and capture its salient features, as other methods might do. However, we believe this approach was the most suitable for our aims, as it has been shown to convey most of the information and to be replicable and transparent (Moccia et al., 2023). Also, analysing each exposome variable individually allowed us to provide a useful picture to inform policies on how to mitigate environmental injustice and health inequalities.

This study has also important strengths. The range of exposome domains analysed and of geographical areas represented by the cohorts as well as the use of standardised SEP indicators and harmonised exposome variables expand upon previous research on social inequalities in children's exposome. In particular, the use of data from eight birth cohorts in 11 European cities, which vary in lifestyles, national economic background and geographical areas (Supplementary Table 1), allowed us to understand which results were generalizable to varying socioeconomical and sociocultural contexts and which were context-specific. Maternal education and disposable household income were chosen as SEP indicators because they capture different, although correlated, dimensions of SEP, with education being a measure of intellectual resources and income a direct measure of material resources. While maternal education is easy to collect, stable over time and fairly comparable across different populations and countries (although not always), several factors make family income difficult to measure through interviews or self-administered questionnaire and to compare across different populations (e.g. low response to income questions, accounting for all members of the household, taxes and different types of income). Using the EHII allowed us to overcome these problems.

Our findings have potential implications for health policies. We focused on the early life (0–4 years) period as a key time window potentially shaping the lifetime exposome and influencing lifecourse health trajectories (Barker, 2007). Therefore, identifying the subgroups at risk of being exposed to environmental hazards, unhealthy behaviors and suboptimal dietary intake from an early age is crucial to inform policies to mitigate inequalities in children exposome and health. In particular – although we acknowledge that our study cannot establish causal links - our results suggest that policy makers should consider the pre-school age period, with focus on improving diet and behaviors in low SEP children from across Europe, and should use a place-based approach to consider city-specific patterns of environmental hazards and inequalities.

In conclusion, socioeconomic inequalities in the exposome pattern were observed already in the earliest years of life. In particular, consistently across study-areas at pre-school age children from low-SEP had unhealthy behaviors and poorer diet that might influence their future health and wellbeing. Results on the SEP-urban environment relationship were more heterogeneous, likely as a consequence of patterns of context-dependent environmental inequalities.

Declaration of competing interests

Serena Fossati, Liesbeth Duijts, Ahmed Elhakeem, Vincent Jaddoe, Deborah A Lawlor, Katrine Strandberg-Larsen and Marieke Welten report grants from the European Union's Horizon 2020 research and innovation programme during the conduction of the study. Liesbeth Duijts received grants related to COVID-19 (ZonMW, CoKIDS study No 10150062010006, Stichting Vrienden van Sophia) and speaker or opponent fees (Astra Zeneca, British Thoracic Society, Karolinska Institutet, University of Copenhagen, Barcelona Institute for Global Health during the conduction of the study. Vincent Jaddoe and Deborah A Lawlor report grants from the European Research Council during the conduction of the study. Deborah A Lawlor reports grants from the UK Medical Research Council, the Wellcome Trust, the British Heart Foundation and the Diabetes UK during the conduction of the study. Katrine Strandberg-Larsen reports grants from the Danish Research Foundation during the conduction of the study. All other authors declare no competing interests.

Ethics approval

Ethical approval not required in this case as ethical approval for the studies included in this manuscript was already obtained from local ethic committees. Details on each approval are included in the general descriptions of the participating cohorts are provided in the Supplementary material.

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CRediT authorship contribution statement

Costanza Pizzi: Writing – review & editing, Writing – original draft, Software, Methodology, Formal analysis, Data curation, Conceptualization. **Giovenale Moirano:** Writing – review & editing, Methodology, Conceptualization. **Chiara Moccia:** Writing – review & editing, Conceptualization. **Milena Maule:** Writing – review & editing, Conceptualization. **Antonio D'Errico:** Writing – review & editing. **Martine Vrijheid:** Writing – review & editing, Funding acquisition, Data curation, Conceptualization. **Timothy J. Cadman:** Writing – review & editing, Software, Data curation. **Serena Fossati:** Writing – review & editing, Data curation. **Mark Nieuwenhuijsen:** Writing – review & editing, Funding acquisition. **Andrea Beneito:** Writing – review & editing. **Lucinda Calas:** Writing – review & editing. **Liesbeth Duijts:** Writing – review & editing. **Ahmed Elhakeem:** Writing – review & editing, Data curation. **Jennifer R. Harris:** Writing – review & editing, Funding acquisition. **Barbara Heude:** Writing – review & editing, Funding acquisition, Data curation. **Vincent Jaddoe:** Writing – review & editing, Funding acquisition. **Deborah A. Lawlor:** Writing – review & editing, Funding acquisition, Data curation. **Sandrine Lioret:** Writing – review & editing. **Rosemary RC. McEachan:** Writing – review & editing, Funding acquisition. **Johanna L. Nader:** Writing – review & editing, Data curation. **Marie Pedersen:** Writing – review & editing. **Angela Pinot de Moira:** Writing – review & editing, Data curation. **Katrine Strandberg-Larsen:** Writing – review & editing, Funding acquisition. **Mikel Subiza-Pérez:** Writing – review & editing, Data curation. **Marina Vafeiadi:** Writing – review & editing, Funding acquisition, Data curation. **Marieke Welten:** Writing – review & editing, Data curation. **John Wright:** Writing – review & editing, Funding acquisition. **Tiffany C. Yang:** Writing – review & editing, Data curation. **Lorenzo Richiardi:** Writing – review & editing, Supervision, Methodology, Funding acquisition, Conceptualization.

Data availability

Each cohort has its own data sharing policy; please refer to the co-authors representing the individual cohorts for information on the policies for the data used in this study. The code is available.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.socscimed.2024.117275.

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