

Beyond Single-Axis Inequality: An Intersectional MAIHDA Analysis of Major Cardiovascular Disease in Europe

Ana Margarida Pereira Silva

am.pereira423@gmail.com

Centro de Salud Urbano I Mérida

Juan A López-Rodríguez

Department of Preventive Medicine and Public Health, Universidad Rey Juan Carlos

Luis Andrés Gimeno-Feliu

GdT semFYC Inequidades en Salud y Salud Internacional

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Beyond Single-Axis Inequality: An Intersectional MAIHDA Analysis of Major Cardiovascular Disease in Europe

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Authors: Ana Margarida Pereira Silva^{1,2,3}; Juan A López-Rodríguez^{1,4,5,6}; Luis Andrés Gimeno-Feliu^{3,7,8,9}

Affiliations:

¹ Department of Preventive Medicine and Public Health, Universidad Rey Juan Carlos, Madrid, Spain.

² Urbano I Primary Care Centre, Mérida, Spain.

³ GdT semFYC Inequidades en Salud y Salud Internacional, Barcelona, Spain.

⁴ Network for Research on Chronicity, Primary Care and Health Promotion (RICAPPS), Institute of Health Carlos III (ISCIII), Madrid, Spain.

⁵ General Ricardos Primary Care Centre, Madrid, Spain.

⁶ semFYC International Officer, Barcelona, Spain.

⁷ EpiChron Research Group, Aragon Health Sciences Institute (IACS), IIS Aragón, Miguel Servet University Hospital, Zaragoza, Spain.

⁸ University of Zaragoza, Zaragoza, Spain.

⁹ San Pablo Primary Care Health Centre, Aragon Health Service (SALUD), Zaragoza, Spain.

Corresponding author: Ana Margarida Pereira Silva, MD; Centro de Salud Urbano I Mérida, Spain. Email: am.pereira423@gmail.com

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Abstract

Background

Cardiovascular disease (CVD) remains socially patterned across Europe, but single-axis analyses can obscure how social positions combine. We used Multilevel Analysis of Individual Heterogeneity and Discriminatory Accuracy (MAIHDA) to examine intersectional inequalities in self-reported major CVD.

Methods

We analysed cross-sectional European Health Interview Survey wave 3 data from 218 539 adults aged 40 years or older in 30 European countries. Major CVD comprised self-reported myocardial infarction, coronary heart disease or angina, or stroke, including chronic consequences. Twenty-four strata combined gender, household income, country of birth, and area of residence. Multilevel logistic models estimated predicted prevalence and assessed between-stratum heterogeneity and discriminatory accuracy before and after adjustment for age, education, obesity, smoking, and sedentary lifestyle.

Results

Weighted major CVD prevalence was 7.5%. Fully adjusted predicted prevalence ranged from 4.0% to 12.9% across intersectional strata, with the highest prevalence among low-income men

and the lowest among medium/high-income women. In the fully adjusted model, women had lower odds of major CVD than men (odds ratio 0.67, 95% confidence interval 0.62-0.71), whereas low-income participants had higher odds than those with medium/high income (1.40, 1.31-1.49). Residual between-stratum heterogeneity was very small (variance partition coefficient 0.07%; proportional change in variance 98.5%), and the fully adjusted model had an area under the curve of 0.728.

Conclusions

Major CVD was clearly socially patterned, but inequalities reflected mainly the accumulation of measured disadvantages rather than large effects unique to particular intersections. These findings support population-wide cardiovascular prevention combined with proportionately greater support for socially disadvantaged groups.

Keywords: cardiovascular disease; health inequalities; intersectionality; MAIHDA; social determinants of health; Europe

Background

Cardiovascular disease (CVD) remains a leading cause of morbidity and mortality and a major contributor to preventable health loss. Despite advances in therapy and prevention, CVD risk, access to health care, and outcomes are unequally distributed along social axes including gender, socioeconomic status, migration-related position, health-care access, and neighbourhood environment. These disparities are not random; they reflect structural arrangements with important clinical, economic, and social consequences. Across Europe, poor cardiovascular health remains shaped not only by established clinical risk factors, such as hypertension,

dyslipidaemia, and diabetes, but also by behavioural patterns, environmental exposures, and sociodemographic conditions [1].

Social determinants of health, including income, education, employment, health-care access, and neighbourhood deprivation, are key pathways through which structural inequities become embodied. They influence exposure to cardiometabolic risk factors, stressors, and health-promoting resources, as well as the utilisation, quality, and continuity of health care [2].

Recent European evidence has shown that declines in cardiovascular mortality have not benefited all socioeconomic groups equally. Relative declines have been faster among higher socioeconomic groups, contributing to persistent or widening inequalities; these inequalities also show a geographical pattern, being smallest in Southern Europe, intermediate in Northern and Western Europe, and largest in Central-Eastern European and Baltic countries [3].

Conventional disparity studies often examine one dimension at a time, for example income, gender, or migration status, implicitly assuming that social positions operate independently and additively. Single-axis framing can underestimate risk, conceal who is most affected, and misinform intervention design. Intersectional perspectives, grounded in the work of Crenshaw and Collins [4,5], emphasise that social categories do not exist independently but are structured by systems of power, shaping different exposures, opportunities, and outcomes. They also allow investigation of whether some combinations of social position are associated with risks beyond the sum of their parts [6,7].

In Sweden, an intersectional categorisation of 3.6 million adults revealed substantial differences in average risk of ischaemic heart disease across social categories such as socioeconomic status and ethnicity [8]. However, evidence from multinational European settings remains limited. This study aimed to estimate inequalities in major CVD among European adults using an

intersectional framework. Specifically, we examined differences in major CVD prevalence across population groups defined by combinations of gender, household income, country of birth, and area of residence, using a Multilevel Analysis of Individual Heterogeneity and Discriminatory Accuracy (MAIHDA) framework to identify higher-risk groups and quantify residual between-stratum heterogeneity [9,10].

Methods

Study design and population

This cross-sectional study used data from the European Health Interview Survey (EHIS) wave 3, conducted in 2019 by the European Commission with the support of Eurostat. EHIS wave 3 was based on nationally representative probability samples from 30 European countries and collected information through face-to-face interviews, telephone interviews, or self-administered questionnaires completed by post or online. Detailed information on survey design, variable construction, response categories, and Eurostat procedures for handling missing data is available in the EHIS survey manual [11].

The study population was restricted to adults aged 40 years or older, as cardiovascular risk is substantially lower in younger adults and European risk assessment guidelines are primarily focused on middle-aged and older populations, as reflected in SCORE2 and SCORE2-OP [12,13]. After the age restriction, 248 420 participants remained. Complete information on the outcome, intersectional strata, and age group was available for 221 597 participants. The final complete-case analytic sample for the fully adjusted MAIHDA model comprised 218 539 individuals after additionally excluding missing values in education, obesity, smoking, and sedentary lifestyle. The analysis included participants from Belgium, Bulgaria, Cyprus, Czech

2 Republic, Germany, Denmark, Estonia, Greece, Spain, Finland, France, Croatia, Hungary,
3 Ireland, Iceland, Italy, Lithuania, Luxembourg, Latvia, Malta, the Netherlands, Norway, Poland,
4 Portugal, Romania, Serbia, Sweden, Slovenia, Slovakia, and the United Kingdom.

5 **Outcome**

6 The primary outcome was major CVD, operationalised as a binary variable. Participants were
7 classified as having major CVD if they reported at least one of the following conditions:
8 myocardial infarction or its chronic consequences, coronary heart disease or angina pectoris, or
9 stroke, including cerebral haemorrhage, cerebral thrombosis, or their chronic consequences. The
10 outcome was derived from EHIS wave 3 items asking whether respondents had ever suffered
11 from the condition or had suffered from it during the previous 12 months. This measure therefore
12 captures self-reported prevalent major CVD rather than incident disease.

13 **Intersectional strata**

14 Four social dimensions were used to define the intersectional strata: gender (men/women),
15 household income (low vs medium/high), country of birth (native-born, born in another EU
16 country, or born outside the EU), and area of residence (urban/suburban vs rural). The EHIS
17 variable recorded respondents as men or women; because this analysis treats the variable as a
18 social stratification dimension rather than a biological attribute, we use the term gender while
19 acknowledging that gender diversity was not captured. Cross-classification of these variables
20 yielded 24 intersectional strata.

21 **Covariates**

22 Covariates were selected a priori based on their established association with cardiovascular
23 morbidity and their potential to confound the relationship between intersectional social position
24 and major CVD. Age was categorised as 40-64 years and 65 years or older. Educational

attainment was recoded into incomplete primary education, primary/lower secondary education, and upper secondary/tertiary education. Obesity was defined using body mass index, calculated from self-reported height and weight, and coded as present when body mass index was at least 30 kg/m². Smoking was defined as current smoking status. Sedentary lifestyle was defined as the absence of regular weekly physical activity according to EHIS physical activity items.

Statistical analysis

We first described the analytic sample using weighted proportions and means. We then fitted two-level logistic MAIHDA models, with individuals at level 1 nested within intersectional strata at level 2. Model 0 was an empty model with a random intercept for intersectional stratum. Model 1 added the additive fixed effects of the four stratum-defining variables. Model 2 additionally adjusted for age group and educational attainment. Model 3 was the fully adjusted model and additionally included obesity, current smoking, and sedentary lifestyle.

The proportion of latent individual-level variance attributable to intersectional strata was quantified using the variance partition coefficient (VPC), calculated as stratum-level variance divided by stratum-level variance plus 3.29, the conventional level-1 variance for logistic regression. The proportional change in variance (PCV) was calculated relative to Model 0. Discriminatory accuracy was assessed using the area under the receiver operating characteristic curve (AUC) for fixed-only and total model predictions. Stratum-specific predicted probabilities were estimated from the fully adjusted model. The residual intersectional contribution was calculated as the difference between total predicted probability and fixed-only predicted probability on the percentage-point scale.

Conventional single-level logistic regression was fitted as a sensitivity analysis to facilitate comparison with standard epidemiological approaches. As a further sensitivity analysis, age was

alternatively categorised into three groups (40-64, 65-79, and ≥ 80 years), and the main 24-stratum MAIHDA model was refitted using this three-category age variable as an adjustment covariate. Data management, statistical analyses, model estimation, and figure generation were conducted in Stata 18.

Results

The final complete-case sample included 218 539 adults aged 40 years or older, corresponding to a weighted population size of approximately 265.4 million. The age-restricted EHIS sample comprised 248 420 individuals, of whom 221 597 had complete data for the outcome, the four stratum-defining variables, and age group. Weighted characteristics of the final analytic sample are shown in Table 1. In the weighted analytic sample, 52.8% were women, 36.2% were aged 65 years or older, 37.3% were in the low-income category, and 26.0% lived in rural areas. Most participants were native-born (90.2%). The weighted prevalence of major CVD was 7.5%; component prevalences were 2.4% for myocardial infarction or chronic consequences, 4.5% for coronary heart disease or angina pectoris, and 2.2% for stroke or chronic consequences.

Table 1. Weighted analytic sample characteristics.

Characteristic	Category	Weighted %
Gender	Men	47.2
	Women	52.8
Age group	40-64 years	63.8
	65+ years	36.2
Household income	Medium/high income	62.7
	Low income	37.3
Country of birth	Native-born	90.2
	EU-born	3.3
	Non-EU-born	6.5
Residence area	Urban/suburban	74.0
	Rural	26.0

Characteristic	Category	Weighted %
Education	Lowest education	34.0
	Primary/lower secondary	39.2
	Upper secondary/tertiary	26.7
Risk factors	Obesity	17.2
	Current smoking	20.6
	Sedentary lifestyle	56.5
CVD components	Myocardial infarction or chronic consequences	2.4
	Coronary heart disease or angina pectoris	4.5
	Stroke or chronic consequences	2.2
Outcome	Major CVD	7.5

Abbreviation: CVD, cardiovascular disease. The fully adjusted MAIHDA model included 218 539 participants.

The empty MAIHDA model showed modest clustering of major CVD by intersectional stratum.

The stratum-level variance was 0.1534 and the VPC was 4.45%, indicating that approximately 4.5% of the latent individual propensity for major CVD was attributable to differences between the 24 strata before adjustment. The AUC was 0.598, indicating limited discriminatory accuracy based on stratum membership alone. After adding the four stratum-defining variables as additive fixed effects, stratum-level variance decreased to 0.0038, the VPC fell to 0.12%, and the PCV was 97.5%. Further adjustment for age and education reduced the VPC to 0.08%, and in the fully adjusted model the VPC was 0.07% with a PCV of 98.5%. The AUC increased to 0.728 in the fully adjusted model, while fixed-only and total AUCs were almost identical, reflecting the very small residual contribution of random stratum effects (Table 2). In practical terms, the intersectional strata were useful for mapping average social differences in CVD prevalence, but added little information for classifying individual CVD risk once additive social and clinical factors were considered.

Table 2. MAIHDA model summary.

Model	Description	Stratum variance	VPC/ICC (%)	PCV (%)	AUC fixed-only	AUC total
M0	Empty MAIHDA model	0.1534	4.45	--	--	0.598

Model	Description	Stratum variance	VPC/ICC (%)	PCV (%)	AUC fixed-only	AUC total
M1	Stratum dimensions only	0.0038	0.12	97.5	0.597	0.598
M2	Stratum dimensions + age + education	0.0026	0.08	98.3	0.716	0.716
M3	Fully adjusted	0.0023	0.07	98.5	0.728	0.728

Abbreviations: AUC, area under the receiver operating characteristic curve; PCV, proportional change in stratum-level variance relative to Model 0; VPC/ICC, variance partition coefficient/intraclass correlation coefficient on the logistic latent scale.

In the fully adjusted MAIHDA model, women had lower odds of major CVD than men (odds ratio [OR] 0.67, 95% confidence interval [CI] 0.62-0.71), while low income was associated with higher odds compared with medium/high income (OR 1.40, 95% CI 1.31-1.49). After adjustment, country of birth and rural residence were not clearly associated with major CVD. Age 65 years or older was the strongest covariate association (OR 4.11, 95% CI 3.96-4.26). Obesity and sedentary lifestyle were also associated with higher odds. Current smoking showed lower adjusted odds, a pattern that should be interpreted cautiously in a cross-sectional prevalence analysis because current smoking status does not capture former smoking or survival-related selection (Table 3).

Table 3. Fully adjusted fixed effects.

Characteristic	OR	95% CI	p-value
Women (vs men)	0.67	0.62, 0.71	<0.001
Low income (vs medium/high income)	1.40	1.31, 1.49	<0.001
EU-born (vs native-born)	0.99	0.89, 1.10	0.818
Non-EU-born (vs native-born)	0.95	0.86, 1.04	0.270
Rural (vs urban/suburban)	1.05	0.98, 1.13	0.137
65+ years (vs 40-64 years)	4.11	3.96, 4.26	<0.001
Lowest education (vs upper secondary/tertiary)	1.27	1.21, 1.33	<0.001
Primary/lower secondary (vs upper secondary/tertiary)	1.30	1.24, 1.36	<0.001
Obesity (vs no obesity)	1.51	1.45, 1.56	<0.001
Current smoking (vs non-smoking)	0.88	0.84, 0.92	<0.001
Sedentary lifestyle (vs not sedentary)	1.48	1.43, 1.54	<0.001

Abbreviations: CI, confidence interval; OR, odds ratio. Reference categories are shown in parentheses.

Fully adjusted predicted CVD prevalence varied from 4.0% to 12.9% across the 24 intersectional strata. The lowest predicted prevalences were observed mainly among medium/high-income

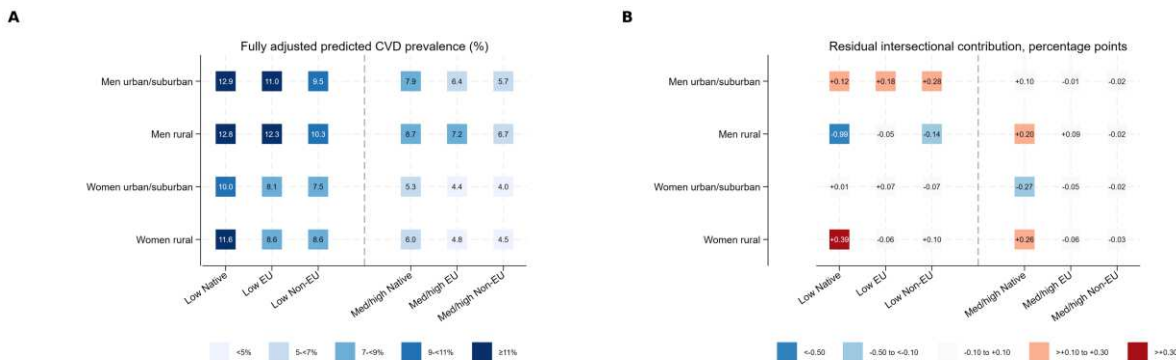
women who were EU-born or non-EU-born, whereas the highest predicted prevalences were observed mainly among low-income men, especially native-born men living in urban/suburban or rural areas and EU-born men living in rural areas (Table 4). Figure 1 summarises both total predicted prevalence and the MAIHDA residual contribution. Panel A highlights the central role of gender and income, with country of birth and residence further shaping differences between groups. Panel B shows that residual contributions beyond additive fixed effects were small, ranging from -0.99 to +0.39 percentage points, consistent with the very low residual VPC in the fully adjusted model.

Table 4. Extreme predicted-prevalence strata.

Rank	Gender	Income	Birthplace	Residence	n	Observed %	Predicted %
1	Women	Med/high	Non-EU-born	Urban/sub.	2472	3.9	4.0
2	Women	Med/high	EU-born	Urban/sub.	1804	4.0	4.4
3	Women	Med/high	Non-EU-born	Rural	544	3.9	4.5
4	Women	Med/high	EU-born	Rural	540	3.7	4.8
5	Women	Med/high	Native-born	Urban/sub.	45915	5.2	5.3
6	Men	Med/high	Non-EU-born	Urban/sub.	2156	5.6	5.7
19	Men	Low income	Non-EU-born	Rural	445	8.8	10.3
20	Men	Low income	EU-born	Urban/sub.	776	12.1	11.0
21	Women	Low income	Native-born	Rural	16686	11.7	11.6
22	Men	Low income	EU-born	Rural	287	11.5	12.3
23	Men	Low income	Native-born	Rural	12022	12.5	12.8
24	Men	Low income	Native-born	Urban/sub.	18296	12.9	12.9

Abbreviations: Med/high, medium/high income; urban/sub., urban/suburban. Strata are the lowest and highest six ranked by fully adjusted predicted CVD prevalence.

Figure 1. Predicted CVD prevalence and MAIHDA residual contribution.



Panel A presents total model-based predicted prevalence (%) from the fully adjusted MAIHDA model. Panel B presents the MAIHDA residual contribution, calculated as total predicted prevalence minus fixed-only predicted prevalence in percentage points. Strata are defined by gender, household income, country of birth, and area of residence. Models are adjusted for age, education, obesity, current smoking, and sedentary lifestyle. Positive residual values indicate higher predicted prevalence than expected under additive fixed effects, whereas negative values indicate lower predicted prevalence.

Sensitivity analysis using age categorised as 40-64, 65-79, and ≥ 80 years as an adjustment covariate produced results consistent with the main model. The PCV remained very high (98.52%) and fixed-only and total AUCs were identical (0.740), indicating that the main conclusion was not driven by the two-category age specification (see Additional file 1: Table S1).

Discussion

This study applied an intersectional MAIHDA approach to examine inequalities in self-reported major CVD among adults aged 40 years or older in Europe. Three findings are central. First, major CVD prevalence differed across the 24 intersectional strata, with fully adjusted predicted prevalence ranging from approximately 4% to 13%. Second, the clearest social gradients were observed for gender and household income, while age, obesity, and sedentary lifestyle were important individual-level covariates. Third, the MAIHDA variance results showed that most between-stratum heterogeneity was explained by additive fixed effects and covariates, leaving very limited residual between-stratum variation in the fully adjusted model.

The empty MAIHDA model suggested that intersectional strata captured some clustering of CVD risk. However, the VPC fell sharply after adding the four stratum-defining variables as additive fixed effects and remained very low in the fully adjusted model. This large PCV indicates that the observed differences between strata were driven mainly by the additive contributions of gender, income, country of birth, residence, and covariates, rather than by substantial excess residual intersectional effects. The higher predicted prevalence observed in

some strata therefore appears to reflect mainly the cumulative burden of measured disadvantages, particularly gender and income, rather than strong amplification or attenuation of risk specific to particular intersections [6,14].

The AUC results reinforce this interpretation. Stratum membership alone had limited discriminatory accuracy, while adding age, education, and behavioural/metabolic covariates increased the AUC. Thus, intersectional strata are useful for mapping average inequalities and identifying where social disadvantage accumulates, but they are not sufficient as stand-alone tools for individual-level risk classification. This is consistent with the MAIHDA emphasis on considering both average differences between groups and individual heterogeneity within groups [9,10].

The income gradient was consistent with the social determinants of health framework [15-17]. Low-income participants had substantially higher odds of major CVD after adjustment. Income may shape CVD through multiple pathways, including material deprivation, chronic stress, neighbourhood conditions, access to preventive resources, health behaviours, and continuity of health care. The gender pattern also persisted after adjustment, with women having lower odds of major CVD than men. However, the intersectional results show that gender should not be interpreted in isolation: predicted prevalence was lowest among women with medium/high income and highest among men with low income, especially native-born men.

Findings for country of birth require cautious interpretation. In the fully adjusted model, EU-born and non-EU-born participants did not differ clearly from native-born participants. Although lower CVD odds among foreign-born participants may be compatible with a healthy migrant effect described in European studies [18,19], these differences were not evident after full adjustment. Because the outcome is self-reported prevalent disease, measured differences by

country of birth may reflect selective migration, age composition, health-care access, diagnostic opportunity, and reporting differences rather than true underlying disease risk alone [20-22].

The residual probability-scale contributions were modest, with absolute differences generally below half a percentage point except for one negative residual close to one percentage point. From a policy perspective, this argues against interpreting a small number of intersectional strata as discrete groups with unique residual risks that would justify exclusive targeting [8]. Instead, the findings support a strategy closer to proportionate universalism: broad cardiovascular prevention and care should be available across the population, with proportionately greater intensity in socially disadvantaged groups, particularly low-income adults and high-risk older adults.

This study has several strengths. It used a large multinational European health survey, defined a clear and interpretable intersectional matrix, and applied a MAIHDA framework that separates average differences between strata from discriminatory accuracy and residual intersectional effects. The approach helps avoid overinterpreting group-level averages as precise individual-level risk classifications. The analysis also compared fixed-only and total model predictions, showing that residual random effects contributed little after adjustment.

Several limitations should be considered. First, the cross-sectional design precludes causal inference and cannot distinguish whether risk factors preceded CVD. Second, CVD was self-reported and may be influenced by health-care access, diagnosis, and recall bias. Third, current smoking was inversely associated with CVD in the adjusted prevalence model, probably reflecting limitations of current smoking status, lack of former-smoking information, survival bias, or disease-related smoking cessation rather than a protective effect. Fourth, the analysis used complete cases and therefore excludes individuals with missing covariate data. Finally, the

intersectional strata were defined using four available social dimensions. Other relevant axes, such as detailed occupational class, working conditions, ethnicity, disability, health-care access, and country-level context, could not be incorporated because they were unavailable, inconsistently measured across countries, or would have produced sparse strata.

Conclusions

Major CVD was clearly socially patterned across intersectional strata in Europe. Predicted prevalence was highest among low-income men and lowest among medium/high-income women, indicating that gender and income remain central axes of cardiovascular inequality. However, most between-stratum differences were explained by additive social and clinical factors, leaving very limited residual heterogeneity. These findings suggest that cardiovascular disadvantage in this population is mainly cumulative, driven by the accumulation of measured social and clinical disadvantages rather than by strong excess effects unique to particular intersections.

Additional files

Additional file 1. DOCX. Sensitivity analysis using a three-category age specification. This file contains Table S1, which compares the main 24-stratum model with the sensitivity model using age categorised as 40-64, 65-79, and ≥ 80 years as an adjustment covariate.

Declarations

Ethics approval and consent to participate

This study used anonymised European Health Interview Survey (EHIS) microdata accessed under Eurostat authorisation. The authors did not have access to directly identifiable information.

The study was approved by the Research Ethics Committee of 12 de Octubre University Hospital, Madrid, Spain (approval number 23/045). All methods were carried out in accordance with relevant guidelines and regulations, including the Declaration of Helsinki. Consent to participate in the original EHIS survey was managed by Eurostat and the participating national statistical authorities as part of the original data collection procedures. For the present secondary analysis of anonymised microdata, the Research Ethics Committee of 12 de Octubre University Hospital waived the requirement for additional informed consent to participate.

Consent for publication

Not applicable.

Availability of data and materials

The individual participant data used in this study were obtained from Eurostat under research microdata access authorisation and cannot be shared by the authors because of Eurostat data protection and access conditions. Researchers may apply to Eurostat for access to EHIS microdata through the official research microdata access procedure. Statistical code and aggregate derived tables may be made available from the corresponding author upon reasonable request, subject to Eurostat disclosure control rules and applicable data-use restrictions.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

AMPS accessed the underlying data and carried out the data analysis. AMPS drafted the first version of the manuscript. All authors contributed to study design, methodological supervision, interpretation of findings, and critical revision of the manuscript. All authors reviewed and approved the final manuscript and accept responsibility for the decision to submit for publication.

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Declaration of generative AI and AI-assisted technologies

During preparation of this manuscript, the authors used ChatGPT (OpenAI; GPT-5.5 Thinking) for language refinement, editorial restructuring, and troubleshooting of Stata syntax. The tool was not used to make autonomous analytical or interpretive decisions. All outputs were critically reviewed, edited, and verified by the authors, who take full responsibility for the manuscript.

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