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Research paper

Spatial and temporal trends and risk factors for intentional carbon monoxide poisoning hospitalizations in England between 2002 and 2016

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A B S T R A C T

Introduction: Suicide and mental health disorders are a recognized increasing public concern. Most suicide prevention rely on evidence from mortality data, although suicide attempts are a better predictor for completed suicides. Understanding spatio-temporal patterns and demographic profiles of people at risk can improve suicide prevention schemes, including for carbon monoxide (CO) poisoning, a common method for gas-related suicides.
Objective: Describe spatio-temporal patterns of intentional CO poisoning hospitalization rates in England between 2002 and 2016, and identify population sub-groups at risk.
Methods: We used NHS Digital's Hospital Episode Statistics (HES) routinely collected data on hospital admissions for intentional CO poisoning. We estimated age-standardised rates (ASR) by year, gender and residential small-area characteristics, including rural/urban, deprivation and ethnic composition. Temporal trends were assessed through linear regression and joinpoint regression analysis. Regional differences were explored.
Results: On average, we identified 178 hospital admissions for intentional CO poisoning per year. The ASR decreased substantially over the study period, particularly among males (average annual percent change of −7.8 % (95 % CI: −11.0; −4.6)), in comparison to 3.9 % (95%CI, −6.4; −1.4) among females. Most admissions (81 %) occurred in males. White men aged 35–44 years were particularly at risk. The ASR in London (0.08/100,000) was almost six times lower than in the South-West (0.47/100,000).
Conclusions: This study provides novel insights into attempted suicides by intentional CO poisoning. Further prevention interventions, targeting sub-groups at risk (i.e. white men in their 30s/40s), need to be developed and implemented to reduce the burden of suicides and of CO poisoning.

1. Introduction

Globally, >700,000 people complete suicide every year, leading to more deaths than malaria, HIV/AIDS or breast cancer (World Health Organization, 2021). In England alone, almost 5000 individuals lost their lives to suicide in 2020, giving an age-standardised rate (ASR) of 10.0 deaths per 100,000 people (ONS, 2021a). After a substantial drop (31 % decrease) in suicide rates over the 1980s and 1990s from 14.5 deaths per 100,000 observed in 1981, suicide rates have remained rather stable up to 2020. Although data on suicides for 2021 and 2022 have not been released at the time of this study, the COVID19 pandemic has had profound psychological and social effects on most of the population, which have been associated with a substantial impact on mental health and a possible increase in suicides (Fushimi, 2022; Appleby et al., 2021). Routine assessment of data are required to monitor such changes and to achieve the United Nations (UN) Sustainable Development Goals targets of reducing suicide mortality rate (indicator 3.4.2) (World Health Organization, 2021).

Methods of suicide vary from country to country, and over time. In some countries, data are routinely collected for surveillance, including of suicides (Boffin et al., 2013; Boffin et al., 2019; Pearson et al., 2009; Bajaj et al., 2008), through a Sentinel General Practices network, but these usually tend to focus on communicable diseases (Garcia-Abreu et al., 2002). Carbon monoxide (CO) is an odourless, tasteless,

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colourless, and toxic gas which can cause severe hypoxia, cell damage and eventually death at high concentrations. As a result, CO poisoning has long been a method commonly used to attempt suicide. Of all gas-related suicides that occurred between 2001 and 2011 in the UK, 89 % were attributed to CO poisoning (Gunnell et al., 2015). Moreover, of all UK deaths caused by CO poisoning, >80 % were identified as intentional. Multiple modes of exposure can be used for intentional CO poisoning including domestic gas (Kreitman and Platt, 1984), car exhaust (Amos et al., 2001), burning charcoal (e.g., barbeques) (Chen et al., 2012), or gas heaters (Breindl and Pollak, 1989). Methods of choice also vary with changes in regulations, availability of CO producing appliances, and cultural factors. For example, significant decreases in the incidence of suicidal attempts by CO poisoning were reported following the replacement of domestic gas with natural gas in the 60s in the UK (Kreitman and Platt, 1984; Kreitman, 1976) and in the 1990s in the Czech Republic (Janík et al., 2017). Similarly, a decrease was also observed following the widespread introduction of catalytic converters on vehicles around the 1990s (McClure, 2000). Recently, a shift towards the use of charcoal burning as a source of CO for suicide has been observed in several Southeast Asian Countries (Chen et al., 2012; Sircar et al., 2015; Chang et al., 2014). Although the mode of exposure is rarely available in routinely collected data, analysing temporal trends can help detect important changes which could reflect a change of behaviours and main modes of exposure used for suicides by CO poisoning.

Suicides are preventable. Insights into patterns of suicide trends and preventive interventions are currently largely derived from mortality data on completed suicides (Bertolote, 2004; Naghavi, 2019). Yet, effective prevention of suicides by CO poisoning requires a comprehensive understanding of all CO poisoning events, not just those leading to deaths. A prior suicide attempt is the single most significant risk factor for suicide in individuals (Hawton et al., 2020) and so, data on attempts can provide valuable information to better address and reduce completed suicides. Attempted suicide and self-harm data by specific method are scarce compared to mortality data, yet they are essential to develop appropriate prevention strategies. Although they only capture exposure events leading to serious health complications requiring hospitalization, data on hospital admissions can provide insight on intentional CO poisoning behaviours, including both suicide attempts and completed suicides.

Finally, suicide rates vary considerably across population groups and within countries. Better understanding these variations can provide valuable information to learn from public health prevention successes and possible mistakes, and to develop appropriate measures to reduce fatalities due to such events. In England and Wales, suicide rates are notably higher among males (15.4 deaths per 100,000 compared to 4.9 in females) and adults in their mid-forties (24.1 and 7.1 deaths per 100,000 in males and females, respectively) (ONS, 2021a). Monitoring risk factors and changes in intentional CO poisonings can help developing better public health prevention measures to reduce fatalities due to such events. Furthermore, data on suicide in England suggests that people among the most deprived 10 % of society are more than twice as likely to die from suicide than the least deprived 10 % of society (ONS, 2017). Nevertheless, these general data can mask important variations associated with specific suicide methods, including CO poisoning resulting in either completed suicides or uncompleted suicide attempts. Hence, studying spatio-temporal patterns of hospital admissions for intentional CO poisoning can help identifying demographic, geographic and socio-economic characteristics of those attempting suicide (Sy et al., 2019; Helbich et al., 2017) and to target information and prevention campaigns to population sub-groups particularly at risk.

The aim of this study was therefore to comprehensively describe hospital admissions for suicide attempts by CO poisoning over a 15-year period (2002–2016) and to identify population sub-groups particularly at risk. This work complements a previous study on accidental CO poisoning in England (Roca-Barceló et al., 2020).

2. Materials and methods

2.1. Data sources

2.1.1. Hospital admission data

We extracted information on all non-elective hospital admissions for CO poisoning in England from the Hospital Episode Statistics (HES) inpatient data, provided by NHS Digital, for the period 2002–2016 (NHS Digital, 2018). The data are held by the UK Small Area Health Statistics Unit (SAHSU) at Imperial College London, UK. HES inpatient data contains detailed information on any admission at a National Health Service (NHS) hospital – i.e., public hospital – in England, including private patients treated in NHS facilities. Hospital stays are broken down in periods of care under different consultants, referred to as 'episodes'. The order of episodes reflects the relevance of clinical events in relation to the reason of hospitalization. Each episode contains a primary diagnosis and up to 19 secondary diagnostic fields, coded based on the International Classification of Disease 10th edition (ICD-10) (WHO, 2010).

We considered both primary and secondary diagnostic fields of a first episode. Multiple admissions by the same patient were retained as exposure to the same emission source is plausible. Admissions were divided by type of CO poisoning in intentional (ICD10: T58 + X67), accidental (ICD10:T58 + X47), and unknown (ICD10:T58 + Y17); refer to the Supplementary Table S1 for detailed information. Our focus here is on intentional admissions. We excluded fire-related admissions (ICD-10: X00-X09; T20-T32 or Y26). We also excluded patients whose residential postcode at time of diagnosis was outside of England. Multiple admissions ($n \geq 2$) for a patient were included as they capture repeated poisoning attempts.

Data on the survival of patients after hospital admission, requiring linkage with death registrations, were not available as part of this study. Hence, the cases reported represent any intentional CO poisoning leading to a hospital admission regardless of whether they resulted in death.

2.1.2. Individual- and area-level characteristics

Individual-level characteristics included age at admission, gender and residential postcode as provided in the hospital records. Area-level characteristics included ethnic composition, rural-urban classification (or urbanicity), and socioeconomic deprivation. We used the small area 2011 Middle Layer Super Output Areas (MSOAs, n = 6791 in England) as area units to describe the characteristics of the areas of the patients. Information on the area-level characteristics was obtained from the Census of England. We used the 2011 census as it represents the mid-point census for the study period. Hospital records were matched to the corresponding MSOA based on the residential postcode recorded at the time of hospitalization. Area-level ethnic composition was defined as the proportions of White, Non-White, Asian and Black ethnicities below or equal to: i) the national average; ii) two-fold the national average; and iii) six-fold the national average (Supplementary Methods S1) (Roca-Barceló et al., 2020). MSOAs were classified as urban or rural based on the Office of National Statistics (ONS) 2011 Rural/Urban Classification (Office of National Statistics, 2011). For deprivation, we used the Carstairs Index, a composite measure of unemployment, household overcrowding, car ownership and social class (Carstairs and Morris, 1989). Carstairs scores (a score of 1 corresponding to the least deprived area) were standardised at MSOA-level and categorised into quintiles for the analysis. Finally, spatial variability in hospital admissions was assessed for the nine regions of England: East Midlands, East of England, Greater London, North-East England, North-West England, South-East England, South-West England, West Midlands and Yorkshire and the Humber (see Supplementary Fig. S1).

Information on the date of admission was used to assess temporal and seasonal patterns. Mid-year population estimates by sex, age group and year for regions and MSOAs were obtained from the Office of National Statistics (ONS, 2020).

2.2. Statistical analysis

We estimated ASRs for England overall, by gender, region as well as category of area-level characteristic for the entire study period. We used 5-year age group bands (0–4, 5–9, …, 80–84, 85+) and the 2013 European Standard Population (Eurostat, 2013) for the standardization. The ASR 95 % confidence intervals (95 % CI) were estimated according to the method proposed by Tiwari and colleagues (Tiwari et al., 2006). In addition, we estimated annual rates to evaluate temporal trends and age-specific rates to explore age group differences (we used the same 5-year age bands as used in the standardization). All rates are given per 100,000 inhabitants.

Trends in annual ASRs were investigated using piecewise linear regression or joinpoint regression using the Joinpoint Regression Program 4.9.1 (Surveillance Research Program National Cancer Institute, 2018). A joinpoint analysis identifies change points in trends and estimates the regression function for the resulting segments. We modelled the ASRs as log-linear piece-wise functions of time where the slope of each of the segment is the annual percentage change (APC). Significance was set at $p < 0.05$ and tested using the Monte Carlo Permutation method. We tested up to three joinpoints and assessed the model fit and the numbers of joinpoints with the Bayesian Information Criterion (BIC). Average annual percent changes (AAPC) were calculated for the overall study period and each joinpoint segment. To put our data in context, we plotted it together with official annual age-standardised all-cause suicide rates (registered deaths) for England published by the ONS (ONS, 2021a). We tested the monthly admission data using a regression for seasonality.

Finally, we investigated temporal trends in ASR across groups by individual and area-level characteristics. The small numbers caused high levels of uncertainty and so, should be interpreted with caution. They can be accessed in the Supplementary material.

2.3. Ethics

This study was conducted under SAHSU's ethics approvals from the London-Southeast Research Ethics Committee (17/LO/0846) and the Health Research Authority — Confidentiality Advisory Group- HRA CAG (14/CAG/1039).

3. Results

Between 2002 and 2016, we identified a total of 2677 hospital admissions for intentional CO poisoning in England, which corresponds on average to 178 hospital admissions per year. This represented a 40.5 % of total hospital admissions linked to CO poisoning in England (Table 1). About 8.1 % of admissions (n = 538) were not classified as accidental nor intentional. Over 2.6 % of patients were admitted two or more times to hospital for CO poisoning (data not shown). Although all CO-related admissions were higher in males, the gender difference was particularly striking for intentional admissions with 80.8 % occurring in males, compared to 52.4 % for accidental admissions (Table 1).

Table 1
Number of intentional CO-related hospital admissions in England between 2002 and 2016 by gender and type of CO poisoning. Fire-related cases were excluded.

Type of CO poisoning	Male		Female		p-Value[†]	Total	
	n	$\%_R$	n	$\%_R$		n	$\%_C$
Accidental	1781	52.4	1621	47.6	0.002	3402	51.4
Intentional	2164	80.8	513	19.2	<0.001	2677	40.5
Unknown	319	59.3	219	40.7	<0.001	538	8.1
Total	4264	64.4	2532	35.6	<0.001	6617	

$\%_R$: percentage within the row. $\%_C$: percentage within the column.
[†] p-Values of the test of proportions to check deviance from the expected proportions in the English population by type of CO poisoning group.

3.1.1. Seasonal and temporal trends

The number of hospital admissions for intentional CO poisoning were the lowest in March, and the highest in May, for both males and females (Supplementary Fig. S2). Nonetheless, we observed no statistically significant seasonal trends in the monthly admission data ($p = 0.640$).

Over our 15-year study period, the ASR significantly decreased in both men and women (Fig. 1). The AAPCs over the whole study period were −7.0 % (95%CI: −8.6; −5.4) and −4.1 % (95%CI: −6.2 %; −1.9 %), respectively (both statistically significant, $p < 0.05$). The joinpoint analysis identified a sharp change point in trend in males in 2013, with the APC decreasing from −5.3 % (95%CI: −7.5 %; −3.1 %) during 2002–2013 to −16.6 % (95%CI: −29.0 %; −1.9 %) over 2013–2016. In females, we identified a shift from a positive APC (2.4 %, 95%CI: −1.9 %; 7.0 %) between 2002 and 2009 to a negative APC (−9.9 %. 95%CI: −13.4 %; −6.1 %) in the remaining part of the study period (2009–2016). This contrasts with the patterns of ASRs of all-cause suicides which remained around 15 per 100,000 in males and only slightly decreased in females between 2002 and 2016 (Fig. 1).

We found statistically significant differences in the ASR of intentional CO poisoning by gender, with intentional poisoning being more than twice higher in males than in females overall (Table 2). The ASR for males was 0.570 (95%CI: 0.546–0.595) compared to 0.130 (95%CI: 0.119–0.141) for females.

When looking at age-specific rates, we observed a bimodal distribution affecting men in particular (Fig. 2). The ASRs of admissions peaked in individuals aged 40 to 44 years (1.23 per 100,000 [95%CI: 1.11–1.37] in males; 0.28 per 100,000 in females [95%CI: 0.22–0.34]) and in those above 80 years (0.52 per 100,000 in males [95%CI: 0.34–0.75]; 0.09 per 100,000 in females [95%CI: 0.04–0.16]) (Table 2). Gender differences were significant across all age group ($p < 0.005$) apart from in the 10–14 years old group.

3.1.2. ASRs by area-level characteristics

The highest ASRs of intentional CO poisoning were reported in MSOAs with the lowest proportion (<15 %) of non-White population (0.66/100,000 [95%CI: 0.63–0.69] and 0.15/100,000 [95%CI: 0.14–0.17] for males and females, respectively), while the lowest ASRs were found in MSOAs with the highest proportion (>21 %) of Black population (0.13/100,000 [95%CI: 0.07–0.24] and 0.02/100,000 [95% CI: 0.01–0.06], respectively) (Table 2).

ASRs were higher in rural areas for both males (0.74/100,000 [95% CI: 0.68; 0.82]) and females (0.16/100,000, [95%CI: 0.13; 0.19]) than in urban areas (0.51/100,000 [95%CI: 0.49; 0.54] and 0.12/100,000 [95%CI: 0.11; 0.13], respectively) (Table 2) but differences seemed to reduce over the study period (Fig. S3).

ASRs by deprivation quintile and gender are presented in Table 2 and plotted in Fig. 4. Among males, although the rates decreased with increasing deprivation from the second quintile, the second lowest ASR was found in the least deprived group. A decreasing trend with increasing deprivation was also observed for females, although differences between the three least deprived quintiles were small. Differences were not statistically significant across quintiles ($p = 0.3838$ for males, $p = 0.6136$ for females). Over the study period, ASRs declined faster in the most deprived quantiles ($\beta = -0.021$) compared to the least deprived ones ($\beta = -0.015$) (Fig. S4).

3.1.3. Regional variability

Finally, the ASRs of intentional CO poisoning hospitalization across England showed substantial regional variability (Table 2 & Fig. 5). The highest ASRs were recorded in the South West of England (0.80/100,000 [95%CI: 0.71; 0.90] in males and 0.18/100,000 [95%CI: 0.14; 0.23] in females) followed by the East Midlands of England (0.72/100,000 [95%

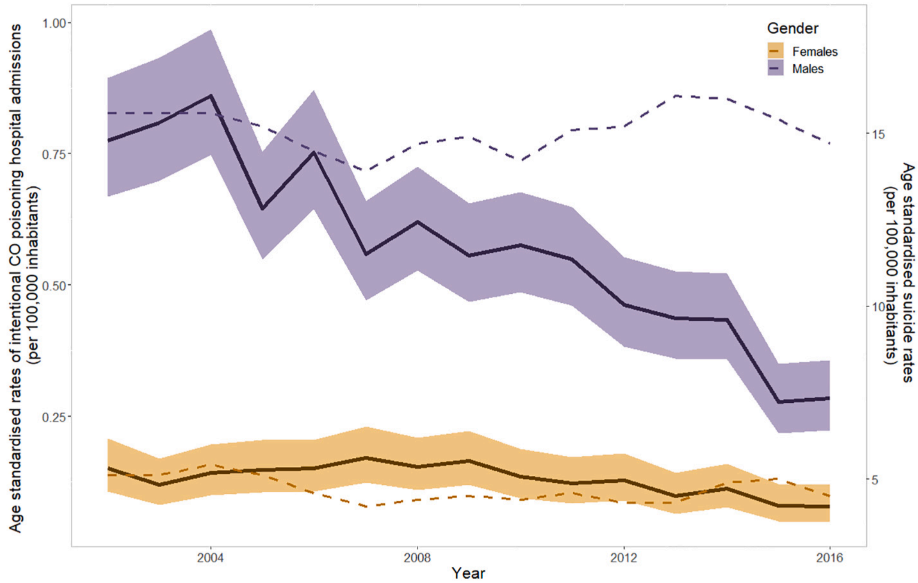

Fig. 1. Age-standardised rates of intentional CO poisoning for males and females over time (2002–2016). Shades indicated 95 % confidence intervals. Dashed lines present the age-standardised suicide rate, regardless of method, by gender in England (ONS, 2021b). Population standardised based on the 2013 European Standard Population.

CI: 0.63; 0.82] in males and in Yorkshire and the Humber (0.16/100,000 [95%CI: 0.13; 0.21]) in females). ASRs in the Greater London region (0.14/100,000 [95%CI: 0.11; 0.18] for males and 0.03/100,000 [95% CI: 0.02; 0.05] for females) were more than five times lower than those seen in the South West.

4. Discussion

The WHO and the UN have set clear targets to reduce the death toll of suicides. CO poisoning is a preventable public health burden, which needs to be considered to achieve these targets. A better understanding of suicide attempts, not just completed suicides, is therefore essential to reduce the burden of CO poisoning and to prevent deaths associated with CO. In this national study, we provide novel insights on spatial and temporal heterogeneities and on individual- and population-level risk factors for intentional CO poisoning events based on routinely collected hospital admission data over a study period of 15 years. Although we found similarities with patterns of all-cause suicide rates, we also identify substantial heterogeneities among population sub-groups and regions which can guide future prevention policies.

Our findings of important gender differences in rates of hospital admissions for intentional CO poisoning do not fully align with the gender paradox in suicide (Canetto and Sakinofsky, 1998). According to this paradox, in most Western countries, the rate of suicide attempts would be higher among females while suicide deaths would be more common among males than females (Bommersbach et al., 2022; Freeman et al., 2017). Here, considering hospital admissions for intentional CO poisoning, we found consistently higher rates of suicide attempts in males than in females. These differences could potentially be associated with different choices in the method of suicide by gender. Alternatively, we argue that it could be due to selection bias, as only most severe cases would lead to hospital admissions.

Spring has been identified in numerous studies as the season with the highest suicide rates (Holopainen et al., 2013; White et al., 2015; Christodoulou et al., 2012). Studies in the UK have also reported an additional peak for females in autumn (Meares et al., 1981). It has been suggested that radical changes in temperature could act as a trigger for alterations in the composition and activity of the adipose tissue which would worsen depression episodes (Holopainen et al., 2013). Our results showed limited seasonality in hospital admissions for intentional CO poisoning. Information on the occupation of individuals admitted and the methods of poisoning, not available in HES, might contribute to explain these differences.

Encouragingly, the ASRs declined substantially between 2002 and 2016, particularly among males. Nevertheless, rates of admissions for intentional CO poisoning were consistently much higher among males than females, a pattern not observed in accidental admissions (Roca-Barceló et al., 2020) but consistent with the three-times higher all-cause suicide rates among males seen in England since the mid-1990s (ONS, 2021b; Biddle et al., 2008). The decline observed in both genders cannot be explained by trends in all-cause self-harm hospital admission rates as this showed a rather steady increase in England between 2003 and 2015 (Clements et al., 2016). Our results may therefore illustrate an overall shift in the chosen methods for suicide attempts in England. The proportion of completed suicides by hanging, strangulation and suffocation has been steadily increasing since the early 2000s (from 44.5 % in 2001 to 61.7 % in 2019 in males; from 26.6 % in 2001 to 46.7 % in 2019 in females), while the share of poisoning has decreased (from 29.2 % in 2001 to 16 % in 2019 in males; from 49.0 % in 2001 to 32.8 % in 2019 in females) (ONS, 2021b). Gunnell and colleagues reported respective decreases of 75 % and 69 % in suicide rates by car exhaust and other CO sources, between 2001 and 2011 (Gunnell et al., 2015). By contrast, the prevalence of suicides using helium and gases other than CO have increased (Gunnell et al., 2015). Similar patterns have been suggested in studies assessing suicide rates in the US and in Southeast Asia (Kreitman, 1976; Janík et al., 2017; McClure, 2000). Here, we did not find higher ASRs in Asians or in MSOAs with a higher proportion of Asian population, although the number of admissions in individuals of Asian ethnicity was likely to be low, causing uncertainty to be high.

The highest rates of hospital admissions were seen in middle-aged adults, which aligns with general age-specific trends in suicide and suicide-intent practises widely described worldwide (WHO, 2014). Our finding that middle-aged adults, and men in particular, are at higher risk also supports earlier findings of the Multicentre Study of Self-arm in England (Clements et al., 2019). High self-harm and suicidal rates among middle-aged adults have been hypothesized to reflect more psychological and economic strains, poor perceived health status, substance abuse and deteriorating mental wellbeing in this age group (Biddle et al., 2008; Jo et al., 2017). In addition, we also observed high rates among adults above 80 years old. This follows a similar pattern to

Table 2
Sex-specific age-standardised rates (ASR), with 95 % confidence intervals (CI) based on age group, area-level ethnic composition, urban-rural classification, deprivation, and regions. Rates per 100,000 inhabitants and standardised using the 2013 European Standard Population.

			Total			Females			Males		
			ASR	95%CI		ASR	95%CI		ASR	95%CI	
Age group	0–4		0.004	*0.001*	*0.015*	0.000	*0.000*	*0.016*	0.008	*0.001*	*0.030*
	5–9		0.004	*0.001*	*0.016*	0.000	*0.000*	*0.016*	0.008	*0.001*	*0.031*
	10–14		0.019	*0.009*	*0.037*	0.018	*0.005*	*0.045*	0.021	*0.007*	*0.049*
	15–19		0.112	*0.085*	*0.146*	0.042	*0.020*	*0.077*	0.180	*0.131*	*0.241*
	20–24		0.258	*0.216*	*0.306*	0.121	*0.082*	*0.172*	0.393	*0.321*	*0.477*
	25–29		0.408	*0.356*	*0.467*	0.125	*0.086*	*0.176*	0.692	*0.595*	*0.800*
	30–34		0.609	*0.545*	*0.678*	0.201	*0.151*	*0.262*	1.019	*0.902*	*1.147*
	35–39		0.691	*0.624*	*0.764*	0.244	*0.190*	*0.310*	1.142	*1.019*	*1.275*
	40–44		0.749	*0.680*	*0.824*	0.275	*0.218*	*0.343*	1.231	*1.105*	*1.367*
	45–49		0.632	*0.567*	*0.702*	0.257	*0.201*	*0.324*	1.014	*0.898*	*1.141*
	50–54		0.552	*0.489*	*0.621*	0.221	*0.167*	*0.286*	0.890	*0.776*	*1.015*
	55–59		0.418	*0.361*	*0.480*	0.155	*0.109*	*0.214*	0.686	*0.584*	*0.801*
	60–64		0.253	*0.207*	*0.305*	0.083	*0.049*	*0.131*	0.429	*0.345*	*0.527*
	65–69		0.180	*0.140*	*0.229*	0.062	*0.032*	*0.108*	0.307	*0.232*	*0.398*
	70–74		0.140	*0.101*	*0.188*	0.061	*0.029*	*0.113*	0.228	*0.157*	*0.320*
	75–79		0.107	*0.071*	*0.156*	0.050	*0.020*	*0.103*	0.178	*0.109*	*0.275*
	80–84		0.218	*0.156*	*0.295*	0.125	*0.068*	*0.209*	0.354	*0.233*	*0.515*
	85+		0.225	*0.159*	*0.309*	0.087	*0.042*	*0.160*	0.518	*0.344*	*0.749*
Ethnicity	Non-White	<15 %	0.400	*0.383*	*0.417*	0.150	*0.136*	*0.165*	0.662	*0.631*	*0.694*
		15–30 %	0.255	*0.224*	*0.289*	0.093	*0.068*	*0.124*	0.424	*0.366*	*0.488*
		30–50 %	0.125	*0.100*	*0.155*	0.042	*0.024*	*0.071*	0.209	*0.162*	*0.266*
		>50 %	0.115	*0.086*	*0.150*	0.059	*0.033*	*0.096*	0.178	*0.124*	*0.247*
	Asian	<7.8 %	0.389	*0.373*	*0.405*	0.147	*0.133*	*0.161*	0.643	*0.614*	*0.674*
		7.8–15 %	0.202	*0.175*	*0.232*	0.075	*0.053*	*0.103*	0.337	*0.286*	*0.395*
		15–47 %	0.161	*0.132*	*0.193*	0.057	*0.035*	*0.088*	0.269	*0.216*	*0.332*
		>47 %	0.144	*0.096*	*0.208*	0.073	*0.032*	*0.144*	0.215	*0.130*	*0.335*
	Black	<3.5 %	0.388	*0.372*	*0.404*	0.145	*0.132*	*0.159*	0.642	*0.613*	*0.672*
		3.5–7 %	0.224	*0.190*	*0.261*	0.079	*0.053*	*0.114*	0.373	*0.310*	*0.444*
		7–21 %	0.137	*0.113*	*0.166*	0.064	*0.042*	*0.094*	0.211	*0.167*	*0.263*
		>21 %	0.072	*0.041*	*0.117*	0.021	*0.006*	*0.064*	0.133	*0.067*	*0.235*
Urban/rural	Rural		0.444	*0.408*	*0.482*	0.159	*0.130*	*0.193*	0.744	*0.677*	*0.815*
	Urban		0.312	*0.298*	*0.326*	0.120	*0.109*	*0.133*	0.510	*0.485*	*0.536*
Deprivation	Q1 — least deprived		0.322	*0.295*	*0.352*	0.141	*0.117*	*0.170*	0.513	*0.463*	*0.567*
	Q2		0.374	*0.344*	*0.405*	0.136	*0.111*	*0.163*	0.627	*0.572*	*0.686*
	Q3		0.357	*0.328*	*0.388*	0.138	*0.113*	*0.167*	0.585	*0.532*	*0.643*
	Q4		0.339	*0.310*	*0.370*	0.110	*0.087*	*0.137*	0.572	*0.518*	*0.630*
	Q5 — most deprived		0.273	*0.248*	*0.300*	0.106	*0.085*	*0.131*	0.442	*0.396*	*0.492*
Region	East of England		0.313	*0.277*	*0.352*	0.126	*0.096*	*0.164*	0.517	*0.450*	*0.591*
	East Midlands		0.419	*0.372*	*0.471*	0.148	*0.111*	*0.194*	0.717	*0.628*	*0.816*
	Greater London		0.084	*0.067*	*0.103*	0.031	*0.019*	*0.049*	0.145	*0.113*	*0.183*
	North East		0.395	*0.335*	*0.462*	0.134	*0.088*	*0.194*	0.700	*0.584*	*0.832*
	North West		0.332	*0.298*	*0.368*	0.132	*0.103*	*0.166*	0.555	*0.491*	*0.624*
	South East		0.365	*0.333*	*0.399*	0.125	*0.099*	*0.155*	0.637	*0.575*	*0.703*
	South West		0.473	*0.426*	*0.524*	0.180	*0.141*	*0.226*	0.802	*0.714*	*0.898*
	West Midlands		0.327	*0.289*	*0.368*	0.109	*0.080*	*0.146*	0.577	*0.503*	*0.658*
	Yorkshire and the Humber		0.401	*0.358*	*0.447*	0.161	*0.125*	*0.205*	0.671	*0.591*	*0.760*
Overall			**0.346**	***0.333***	***0.359***	**0.130**	***0.119***	***0.141***	**0.570**	***0.546***	***0.595***

that observed in our previous study assessing trends in accidental CO poisoning hospital admissions (Roca-Barceló et al., 2020) and deaths (Close et al., 2022), as well as in all-cause suicides. For the elderly, a stronger level of dependency, deterioration of mental and physical health and social loneliness are some factors which have been previously suggested to explain raises in suicide rates in this age group (WHO, 2014). Further data on methods used for suicide attempts in different age groups might help explaining these patterns.

Earlier work on CO poisonings in England identified a weak negative relationship with increasing deprivation level ($p = 0.07$, $r^2 = 0.36$) (Croxford et al., 2015; Wilson et al., 1998). Here, we did not find a linear association between rates of admissions for intentional CO poisoning and deprivation. Limited access to vehicles by highly deprived individuals has previously been suggested as a possible explanation of the lower rates of intentional CO poisoning across the most deprived. This method has nevertheless been much less common since the introduction of catalytic converters on vehicles in the 1990s. Furthermore, changes in the relationship between car ownership and deprivation over the study period (e.g. restricted car parking, good public transport and low emission zones in large cities) (Johnson et al., 2010) and the above-mentioned shift in chosen method of suicidal may have diluted differences previously seen.

Our study identified rural areas as having higher ASRs for CO intentional poisoning hospitalizations, with the gap being larger for males than females. In addition, ASRs were much lower in Greater London than in other regions of England. According to a recent systematic review, there is strong evidence of a higher prevalence of suicide in areas defined as rural (Casant and Helbich, 2022). Although detailed data to explain these differences are currently lacking, this is likely to reflect differences in access to methods, with hanging, strangulation, and suffocation being potentially more common in urban areas, and poisoning, including with toxic pesticides or CO, more frequent in rural areas, potentially involving the farming community. It is likely that even larger differences would be identified in a spatial analysis conducted at a finer geographical scale (e.g., local authorities). The spatial patterns observed were quite different to those of age-standardised suicide rates for England over the same period (ONS, 2021b), which would warrant further investigation. Accounting for spatial heterogeneities may help to develop targeted suicide prevention campaigns. Such data could therefore directly help shaping prevention strategies managed by directors of

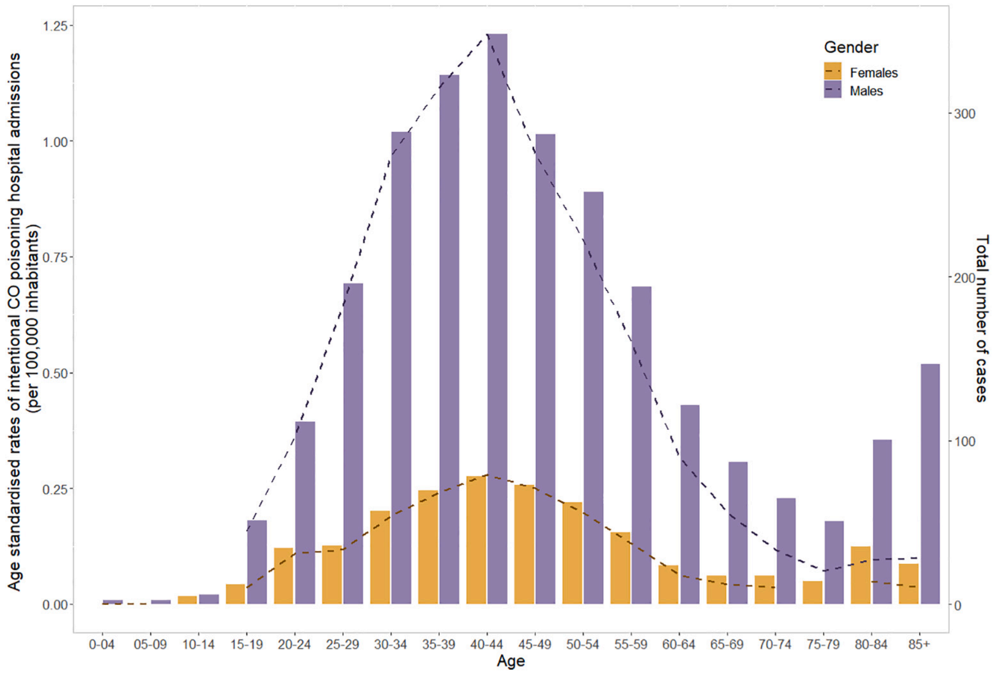

Fig. 2. Number and rates of intentional CO poisoning hospitalizations by 5-year age group and gender. Bars show the age-standardised rates (left y-axis). Dashed lines reflect number of cases (right y-axis). Counts <10 have been suppressed, hence the interrupted lines. Population standardised based on the 2013 European Standard Population.

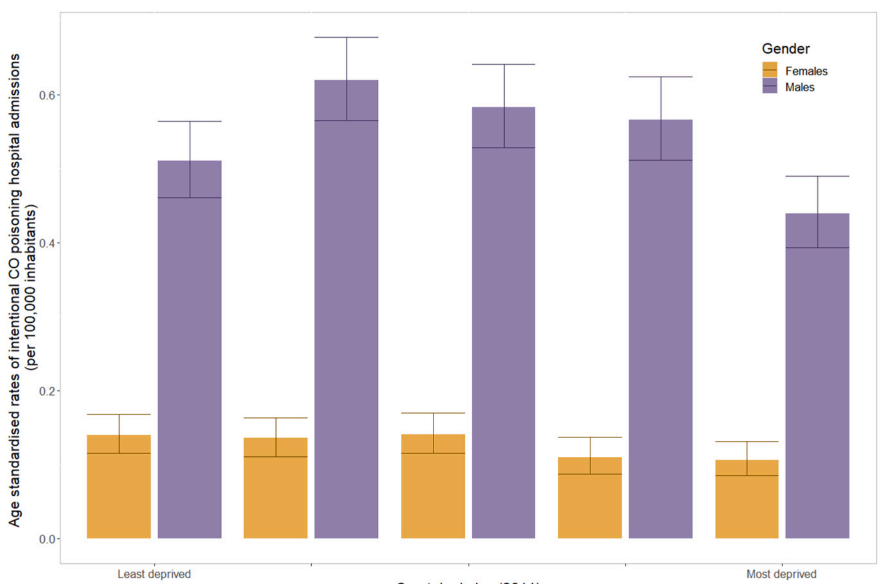

Fig. 4. Sex-specific age-standardised rates by Carstairs 2011 deprivation quintile (2002–2016). Rates per 100,000 inhabitants and age-standardised using the 2013 European Standard Population. Error bars show the 95 % confidence intervals.

public health within local authorities across the country, in collaboration with mental health support services, psychologists and behavioural scientists.

Although we provide a detailed analysis of temporal trends and risks factors associated with intentional CO poisoning in England over a 15-year period, we do not include the most recent years, including those during the COVID19 pandemic which may have affected trends in poisonings. Furthermore, the method of exposure, which would provide valuable information, is not recorded in HES. Given the limited information on individual-level ethnicity and socio-economic status in HES, we used area-level proxies in our analyses, which could have led to some biases and misclassifications. Finally, we did not have access to linked HES-mortality data as part of this study, which would have allowed to differentiate completed and uncompleted suicides.

5. Conclusion

To our knowledge, this is the first study to describe temporal trends and spatial patterns of suicide attempts by CO poisonings in England, and to identify individual and area-level characteristics useful to define population groups at risk. As outlined above, routine analysis of spatial, temporal and risk factors can provide valuable insights to guide suicide

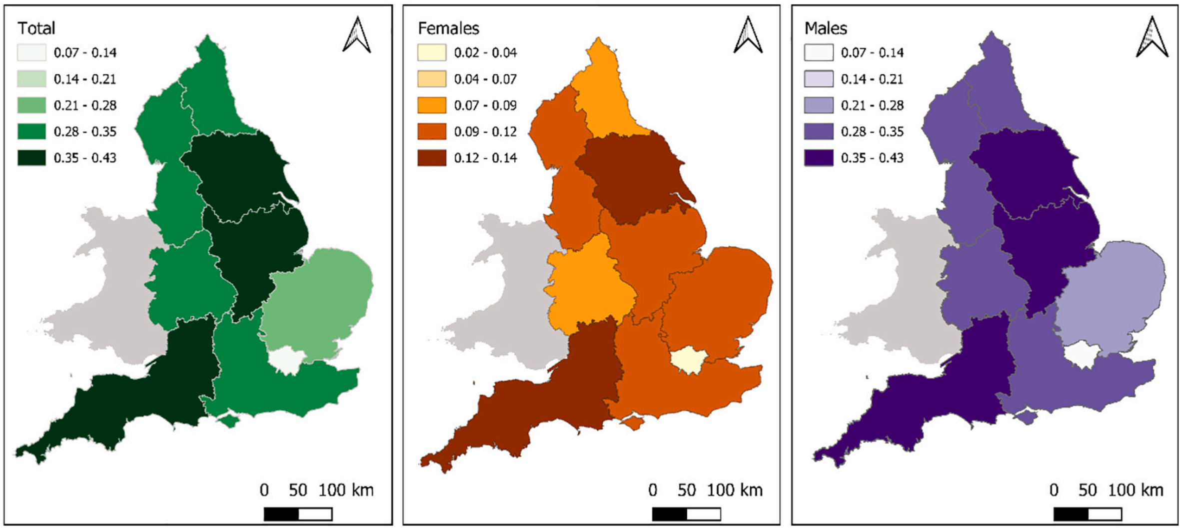

Fig. 5. Age-standardised rates of intentional CO poisoning hospital admissions by region across all the population (left), and among females (centre) and males (right) in England between 2002 and 2016. Standardised using the 2013 European Standard Population.

prevention schemes and to better understand the underlying behaviours and social circumstances leading to suicide. Based on this work, we recommend i) the implementation of better mental health interventions and suicide prevention schemes aimed specifically at men, those aged 35–44 and areas with a high proportion of white population; ii) the systematic collection of data on methods of suicide attempts to allow a better understanding of temporal and spatial heterogeneities; and iii) the routine monitoring of data on suicide attempts at more granular level (e.g. local authority) to guide more effective targeted policies.

Knowing the number of attempts per year of those that do not complete suicide provides an opportunity for intervention. Our descriptive study complements available data on general suicide rates and patterns regularly published by the ONS and should help in defining public health interventions to further reduce suicide attempts by CO poisoning. Suicides are largely preventable, and the WHO has called for action to address this large and neglected public health problem (WHO, 2014).

Disclosure statement

The views expressed are those of the author(s) and not necessarily those of the NIHR, UKHSA, or the Department of Health and Social Care.

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CRediT authorship contribution statement

Aina Roca-Barceló: Conceptualization, Methodology, Software, Formal analysis, Investigation, Data curation, Writing – original draft, Visualization, Project administration. **Helen Crabbe:** Conceptualization, Writing – review & editing. **Rebecca Close:** Conceptualization, Writing – review & editing. **Helena Fahie:** Conceptualization, Writing – review & editing. **Giovanni S. Leonardi:** Conceptualization, Writing – review & editing, Funding acquisition. **Frédéric B. Piel:** Conceptualization, Methodology, Software, Formal analysis, Investigation, Data curation, Writing – original draft, Writing – review & editing, Visualization, Supervision, Project administration, Funding acquisition.

Conflict of interest

No potential conflict of interest was reported by the author(s).

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jad.2023.02.036.

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