

# Mortality associated with exposure to carbon monoxide in WHO European Member States

**Abstract** In closed environments, the concentration of carbon monoxide (CO) can easily rise to health-threatening levels. CO-related incidents are often caused by poor condition or inappropriate use of indoor combustion devices as well as structure fires but are also due to suicides. To evaluate the incidence of CO poisoning in Europe, national data on CO-related mortality and morbidity were compiled from Member States of the WHO European Region using a standardized data collection form. National data on CO poisoning were provided by 28 Member States. Within the maximum reporting period (1980–2008), a total of 140 490 CO-related deaths were reported (annual death rate of 2.2/100 000). The number of hospital admissions available from six countries was 31 473. Unintentional CO deaths accounted for 54.7% of the CO-related deaths (35.9%: unintentional inhalation; 18.8%: related to structure fires). The intentional deaths related to CO exposure account for 38.6% of all CO-related deaths (38.1%: suicides; 0.5%: homicides). CO exposure is preventable but causes a substantial amount of deaths in many European countries. More efficient measures and policies to prevent CO poisoning and better reporting of CO mortality are necessary.

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## Practical Implications

Carbon monoxide is known to be a highly dangerous indoor pollutant leading to severe health outcomes. However, CO-related mortality data are not available through standard reporting schemes, and therefore, the magnitude of CO-related mortality has always been subject to estimation. The compilation of CO mortality data presented in this study provides, for the first time, an indication of the magnitude of CO-related health risk and documents that CO poisoning is associated with substantial mortality across Europe. The study identifies the problems that exist with the current reporting schemes and suggests actions for better monitoring. Furthermore, it provides recommendations related to the prevention and diagnosis of CO-related mortality.

## Introduction

Carbon monoxide (CO) is a colorless and odorless gas produced by an incomplete combustion of any carbon-containing fuel, such as propane, natural gas, gasoline, oil, coal, and wood. CO poisoning occurs after inhalation of CO which reduces the blood's ability to carry oxygen, leaving the body's organs and cells starved of oxygen (Prockop and Chichkova, 2007). Symptoms of CO poisoning vary depending on the acute exposure level and include, with rising proportion of carboxyhemoglobin in human blood (COHb), the following: shortness of breath, headache, irritability, fatigue, dizziness, dimness of vision, confusion, collapse, fainting on exertion, unconsciousness, intermittent convulsion, respiratory failure, brain damage, and significant long-term sequelae (such as

problems with memory, attention, or concentration) and death (Weaver et al., 2007; WHO, 1999; WHO Regional Office for Europe, 2010).

Due to its toxicity, CO is also often associated with intentional poisoning, for example, described for suicides due to car exhaust (Nordentoft, 2007), burning charcoal (Pan et al., 2010), or gas heaters (Breindl and Pollak, 1989).

Indoor environments are the most common setting for CO intoxication as a result of residential indoor exposure related to combustion or structure fires. Data from several developed countries demonstrate that about 60% of CO poisoning occurs in the home (Clifton et al., 2001), and recent data from Quebec, Canada, indicate that 66% of all reported cases from 2005–2010 occur in the home setting (Ministère de la Santé et des Services sociaux, Québec, 2012). The

European Union (EU) Injury database (IDB) (2006) indicates that even 87% of all CO-related injuries occur in private residential areas (EuroSafe, 2008). As CO is difficult to notice without special instruments, it is not always evident when indoor exposures are rising, and the associated health symptoms are not specific. Often people with a mild to moderate intoxication will feel sick while at home but rarely will associate it with CO.

Unintentional inhalation and subsequent CO intoxication seem to be more common:

- during winter, when almost 50% of the cases occur (Centers for Disease Control and Prevention, 2007, 2008);
- in the fall and spring, when gas devices are used episodically or after a period of non-use (Déoux and Déoux, 2004);
- during the days of fog, with no wind, causing a reduction or even a reversal in the circulation of gas vents (Déoux and Déoux, 2004).

Common sources of CO in the home include faulty heating systems, gas appliances, and open fires (EuroSafe, 2008). Data from Quebec, Canada, suggest that a good third of all CO intoxications are due to such problems with appliances (related to faulty installations, improper use of equipment, inadequate maintenance, etc.) (Ministère de la Santé et des Services sociaux, Québec, 2012). These can include furnaces, gas ranges/stoves, gas clothes dryers, water heaters, gas or wood fireplaces, wood-burning stoves, and auto exhaust from an attached garage. Data from Bursa, Turkey, for example, showed that 86% of CO poisoning cases (1996–2006) were caused by coal heater emissions (Akköse et al., 2010). Inadequate ventilation or unvented rooms are causal to 35% of all reported CO intoxications in Quebec, Canada (Ministère de la Santé et des Services sociaux, Québec, 2012), reflecting the relevance of adequate ventilation in indoor spaces. Blocked flues and chimneys mean the gas can not escape and is inhaled by the unsuspecting individual. Back drafting and changes in air pressure increase the risk of high indoor levels of CO (Centers for Disease Control and Prevention, 2008). Thus, CO poisoning can result from many indoor situations and may also occur in occupational places, as well as in churches (Ministère de la Santé et des Sports, 2006), restaurants, and ice-skating arenas (Pelham et al., 2002). Today, CO is the most commonly encountered and pervasive poison in our indoor environment, and, due to brain damage and sequelae, causes enormous suffering and morbidity in those who survive (Sato et al., 2002). CO poisoning has been indicated to be the first cause of death of accidental poisoning in Europe (Burette et al., 2006) and thus has high public health relevance.

The Apollo Project (European Center for Injury Prevention, 2007) collected CO-related hospital discharge data for various EU members, and the EU

Injury Database (IDB) reports that fatalities due to accidental poisoning by gas and vapors are mainly caused by CO (EuroSafe, 2008). However, there is currently no overview of CO poisonings in European Member States with a detailed identification of setting or cause of death. Mortality and morbidity data routinely collected by WHO or other European agencies such as Eurostat do not include information sufficiently specific to establish patterns of this common health problem in Europe and to analyze trends within and between countries. Therefore, WHO conducted a survey focused on CO-specific data aiming at the collection of information from all 53 Member States of the WHO European Region for the period of 1980–2008. This report presents results of this survey.

## **Methods**

National focal points of the WHO environment and health process as well as of the injury prevention program in all 53 Member States of the European Region of WHO were approached to fill in data collection forms on CO-related mortality, morbidity, and hospitalization, on the external cause of CO-related death, and on age and gender of the victims. Existing mortality and morbidity registers were to be used as the data source. Countries were asked to report – if possible – using the International Classification of Diseases (ICD) (WHO, 2010), providing the total number of CO-related deaths using the ICD10 code T58 or ICD9 code 986 (both relating to ‘Toxic effect of carbon monoxide’ used as a supplementary code to associate primary death causes with CO), and details on the death cause itself. The following categories of CO-related deaths were requested for the data reporting through the focal points.

- Unintentional: accidental poisoning by and exposure to gases and vapors (here: CO); reflecting ICD10 code X40-49.
- Unintentional: exposure to smoke, fire, and flames (CO released by fire incidents in a building, etc.); reflecting ICD10 code X00-09.
- Intentional: intentional self-harm or self-poisoning (suicide); reflecting ICD10 code X60-84.
- Intentional: assault (homicide); reflecting ICD10 code X85-Y09.
- Undetermined intent: poisoning by and exposure to gases and vapors (here: CO) with undetermined intent; reflecting ICD10 code Y10-34.

Death rates per 100 000 population were calculated based on population data for the respective years taken from the 2009 version of the WHO Health for All database with a correction requested by Turkey.

In this context, it is to be noted that the transition from ICD9 to ICD10 has caused some changes in the

coding system, and thus, some countries show discrepancies between the CO mortality reported according to ICD9 and ICD10 (see, for example, Ball et al., 2005). Also, some countries used other reporting mechanisms than ICD. In Finland, CO mortality data are derived from postmortem examinations that are carried out for deaths caused by accidents. Maltese data are limited to the largest hospital; thus, underreporting is possible but, in poisoning cases, expected to be marginal. In Belarus, the Republic of Moldova, and the Russian Federation, a variety of instruments and reporting tools used by Sanepid services during the time of the Soviet Union are still in use. Although it is likely that the diversity of reporting mechanisms significantly affects the data and international comparison, it is almost impossible to assess the magnitude of these effects as the reported data cannot be validated by other sources.

Despite the diversity of approaches, data on CO-related deaths are more consistent between European countries than data on CO-related morbidity, exposure incidents, and hospitalization. Therefore, this publication focuses on CO-related mortality and only shortly describes the reported patterns of hospital admissions.

## Results

Over the study period (1980–2008), 140 490 CO-related deaths were reported by 28 countries for a total of 405 reporting years. The annual death rate per 100 000 population was 2.24 on average for all countries contributing data and ranged from 0.02 (Azerbaijan) to 12.81 (Russian Federation). The overall number of reported CO-related deaths for the 28 countries is shown in Table 1 below.

Comparison of the time trends of CO-related mortality in the reporting countries is difficult due to different time ranges of reporting, for example, 29 years in the case of Austria (1980–2008) and only 1 year in the case of Turkey and Estonia (2008). Although there is a high variability in CO-related mortality within and between the reporting countries, general tendencies in the data indicate that the mortality rates are stagnating or slowly decreasing for most countries. However, for five countries, the reported number of CO-related death cases has increased during their last years of reporting. For annual data by country, see Table S1.

Six countries provided information on hospital admissions due to CO poisoning. In total, CO exposure was involved in a total of 31 473 hospital admissions for the study period 1980–2008 for a total of 92 reporting years. There were, on average, 342 admissions/year, ranging from 2 (Malta) to 1307 (France). Per 100 000 population, there were 2.33 admissions on average (ranging from 0.62 in Malta to 7.72 in Denmark), which is only 3.6 times higher than the CO-related mortality rate of 0.64/100 000 for the same six

countries. For Sweden, an exceptional situation was identified as it is the only reporting country with a lower rate of CO-related hospital admissions than CO-related deaths per 100 000 population (1.63 and 2.24, respectively). Detailed outcomes on hospitalization are presented in Table 2.

Twenty countries provided data on the sex and 19 countries on the age of the victims of fatal CO exposure (Table 3). Males are more common victims of CO-related death than females in most reporting countries. Although the largest share of mortality is found for the age group of 25–64 years (63.2%), the data indicate that the population aged 65 years and older is most affected as their share of reported CO-related deaths (22.3%) is much higher than the elderly share in the respective total population (14.1%, baseline year 2005, WHO Health for All database). In the Republic of Moldova, the elderly account for three times more CO-related mortality than their population share, while in Austria and Croatia, it is two times more. On the other hand, lower mortality rates are found for the elderly in Azerbaijan, Belgium, Malta, and Slovenia.

In most countries, the reported data are not detailed enough to provide a breakdown by setting, death circumstances, or intention. This is especially relevant as the ICD codes T58 (ICD10) and 986 (ICD9) operate as supplementary codes, that is, they should be marked when the diagnosed cause of death is associated with CO exposure. This indicates that CO exposure may not necessarily be the primary cause of death. One example would be the case of a person who has been moderately exposed to CO and then – in a dizzy state – falls down the stairs, breaking his/her neck. Another example would be a person exposed to CO during a fire in a building, falling unconscious, and then dying in the flames.

However, 11 of the 28 countries (39.3%) reported CO-related mortality by categories that could be used for a more detailed interpretation of the data. For these 11 countries (Andorra, Austria, Bosnia and Herzegovina, Czech Republic, Germany, Hungary, Malta, Republic of Moldova, Slovenia, Sweden, and Switzerland), the cases (22 937 in total) have been categorized into six categories as presented in Table 4.

Unintentional deaths constitute 54.7% of all CO-related deaths. The largest share of these unintentional deaths (35.9% of all CO-related deaths) is associated with accidental CO exposure. This indicates that faulty heating systems and gas appliances, unvented coal or wood combustion, or incorrect use of such devices may be a main risk for unintentionally dying from CO. Based on the reported data, the percentage of deaths associated with such accidental poisoning by exposure to CO can reach as high as 82.9% (Republic of Moldova).

Direct exposure to smoke, fire, and flames – usually uncontrolled fires within a building – accounts for

**Table 1** CO-related deaths as reported by European Member States

| Country                | Reporting period     | Reporting years | Deaths in reporting period | Average number of deaths per year | Annual death rate (per 100 000 population) | Range of annual death rates in reporting period |
|------------------------|----------------------|-----------------|----------------------------|-----------------------------------|--|---|
| Andorra                | 1994–2007            | 14              | 4                          | 0.3                               | 0.41                                       | 0–1.56  |
| Austria                | 1980–2008            | 29              | 922                        | 31.8                              | 0.4  | 0.15–0.74                                       |
| Azerbaijan             | 1982–2008            | 27              | 48                         | 1.8                               | 0.02                                       | 0–0.08  |
| Belarus                | 1999–2008            | 10              | 11 809                     | 1180.9                            | 11.99                                      | 8.61–14.64                                      |
| Belgium                | 1995–2008            | 14              | 553                        | 39.5                              | 0.38                                       | 0.12–0.60                                       |
| Bosnia and Herzegovina | 2003–2008            | 6               | 49                         | 8.2                               | 0.21                                       | 0.13–0.44                                       |
| Croatia                | 1998–2007            | 10              | 314                        | 31.4                              | 0.7  | 0.35–0.97                                       |
| Cyprus                 | 2005–2007            | 3               | 6                          | 2.0                               | 0.25                                       | 0.13–0.35                                       |
| Czech Republic         | 1986–2008            | 23              | 6203                       | 269.7                             | 2.62                                       | 0.87–6.00                                       |
| Denmark                | 1980–2006            | 27              | 4458                       | 165.1                             | 3.16                                       | 0.76–5.73                                       |
| Estonia                | 2008                 | 1               | 82                         | 82.0                              | 6.16                                       | -   |
| Finland                | 2000–2007            | 8               | 917                        | 114.6                             | 2.19                                       | 1.66–2.55                                       |
| France                 | 1985–1998, 2001–2002 | 16              | 977                        | 61.1                              | 0.11                                       | 0.05–0.21                                       |
| Georgia                | 1999–2002            | 4               | 8                          | 2.0                               | 0.04                                       | 0.02–0.069                                      |
| Germany                | 1980–2007            | 28              | 43 153                     | 1541.2                            | 1.91                                       | 0.34–4.38                                       |
| Hungary                | 1996–2004            | 9               | 1166                       | 129.6                             | 1.27                                       | 0.91–1.61                                       |
| Latvia                 | 1996–2008            | 13              | 758                        | 58.3                              | 2.48                                       | 1.22–3.86                                       |
| Lithuania              | 2000–2008            | 9               | 114                        | 12.7                              | 0.37                                       | 0.33–0.41                                       |
| Luxembourg             | 1998–2007            | 10              | 44                         | 4.4                               | 0.98                                       | 0.21–1.81                                       |
| Malta <sup>a</sup>     | 1991–2008            | 18              | 20                         | 1.1                               | 0.29                                       | 0–1.05  |
| Republic of Moldova    | 1991–2008            | 18              | 4306                       | 239.2                             | 5.83                                       | 3.43–9.93                                       |
| Russian Federation     | 2005–2007            | 3               | 54 778                     | 18 259.3                          | 12.81                                      | 11.32–14.07                                     |
| Slovakia               | 1992–2008            | 17              | 719                        | 42.3                              | 0.79                                       | 0.59–1.07                                       |
| Slovenia               | 1980–2007            | 28              | 1351                       | 48.3                              | 2.44                                       | 1.09–3.48                                       |
| Spain                  | 1981–1998            | 18              | 1932                       | 107.3                             | 0.28                                       | 0.20–0.38                                       |
| Sweden                 | 1980–2007            | 28              | 5449                       | 194.6                             | 2.24                                       | 0.89–3.81                                       |
| Switzerland            | 1995–2007            | 13              | 266                        | 20.5                              | 0.28                                       | 0.15–0.44                                       |
| Turkey                 | 2008                 | 1               | 84                         | 84.0                              | 0.11                                       | -   |
| Total                  |                      | 405             | 140 490                    | 346.9                             | 2.24                                       | 0.60–7.05                                       |

According to the Department of Forensic Medicine and Pathology Hospital of Montenegro, there were 30 lethal cases of CO poisoning in 1993–2006. However, data cannot be provided by year and underreporting may have occurred.

<sup>a</sup>Malta data are restricted as CO reporting is limited to one large hospital. Underreporting is possible but in case of poisoning cases expected to be marginal.

**Table 2** CO-caused hospital admissions as reported by European Member States

| Country            | Reporting period | Reporting years | Total hospital admissions in reporting period | Average number of hospital admissions per year | Average hospital admissions rate (per 100 000 population) | Variation in annual hospital admission rates in reporting period: lowest admission rate – highest admission rate |
|--------------------|------------------|-----------------|---|--|---|--|
| Croatia            | 1998–2007        | 10              | 521   | 52   | 1.17  | 0.88–1.69  |
| Denmark            | 1994–2008        | 15              | 5350  | 357  | 7.72  | 2.22–8.94  |
| France             | 1985–1998        | 14              | 18 303  | 1307   | 2.12  | 1.10–3.63  |
| Malta <sup>a</sup> | 1995–2008        | 14              | 34  | 2  | 0.62  | 0–1.89   |
| Spain              | 1997–2007        | 11              | 3301  | 300  | 0.72  | 0.62–0.92  |
| Sweden             | 1980–2007        | 28              | 3964  | 142  | 1.63  | 0.99–2.66  |
| Total              |                  | 92              | 31 473  | 342  | 2.33  | 0–8.94   |

<sup>a</sup>Malta data are restricted as CO reporting is limited to one large hospital. Underreporting is possible but in case of poisoning cases expected to be marginal.

18.8% of the reported death cases due to CO intoxication. Holstege and Kirk (2006) estimated that 50–80% of fire-related deaths are actually the result of smoke inhalation rather than burns. Based on our database, the percentage of all deaths associated with accidental

CO poisoning by exposure to smoke fire and flames was between 0% (Malta) and 50% (Andorra).

Carbon monoxide is associated with a vast number of suicide cases, representing in average 38.1% of all reported CO-related deaths. In relative terms, suicide is

**Table 3** CO-related mortality by age and gender as reported by European Member States

|                        | Gender (%) |        | Age groups <sup>a</sup> (%) |      |              |      |         |
|------------------------|------------|--------|-----------------------------|------|--------------|------|---------|
|                        | Male       | Female | Unknown                     | 0–24 | 25–64        | 65+  | Unknown |
| Andorra                | 100.0      | 0.0    | 0.0                         | 0.0  | 75.0         | 25.0 | 0.0     |
| Austria <sup>a</sup>   | 59.7       | 40.3   | 0.0                         | 3.0  | 64.8         | 32.1 | 0.0     |
| Belgium <sup>a</sup>   | 43.4       | 34.5   | 22.1                        | 14.8 | 52.6         | 15.6 | 17.0    |
| Croatia <sup>a</sup>   | 66.9       | 33.1   | 0.0                         | 8.9  | 53.8         | 36.3 | 1.0     |
| Cyprus                 | 66.7       | 33.3   | 0.0                         | 16.7 | 66.7         | 16.7 | 0.0     |
| Czech Republic         | 78.3       | 21.7   | 0.0                         | 12.1 | 67.7         | 20.2 | 0.0     |
| Denmark                | 78.4       | 21.6   | 0.0                         | 9.0  | 70.6         | 20.4 | 0.0     |
| Finland                | 85.4       | 14.6   | 0.0                         |      | Not reported |      |         |
| Georgia                | 50.0       | 50.0   | 0.0                         | 0.0  | 62.5         | 25.0 | 12.5    |
| Germany                | 72.4       | 27.6   | 0.0                         | 12.3 | 64.1         | 23.6 | 0.0     |
| Latvia                 | 74.8       | 25.2   | 0.0                         | 7.6  | 71.9         | 20.5 | 0.0     |
| Lithuania <sup>a</sup> | 50.9       | 49.1   | 0.0                         | 62.3 | 15.8         | 21.9 | 0.0     |
| Luxembourg             | 65.9       | 34.1   | 0.0                         | 11.1 | 68.9         | 20.0 | 0.0     |
| Malta <sup>a</sup>     | 90.0       | 10.0   | 0.0                         | 0.0  | 90.0         | 10.0 | 0.0     |
| Republic of Moldova    | 68.2       | 31.8   | 0.0                         | 12.6 | 56.2         | 31.1 | 0.0     |
| Slovakia               | 75.8       | 24.2   | 0.0                         | 13.2 | 65.0         | 21.8 | 0.0     |
| Slovenia               | 82.9       | 17.1   | 0.0                         | 13.8 | 72.8         | 13.5 | 0.0     |
| Spain                  | 68.2       | 31.8   | 0.0                         | 22.1 | 52.2         | 25.7 | 0.0     |
| Sweden                 | 81.8       | 18.2   | 0.0                         | 10.6 | 70.7         | 18.7 | 0.0     |
| Switzerland            | 69.2       | 30.8   | 0.0                         | 15.0 | 60.2         | 24.8 | 0.0     |
| Total                  | 71.4       | 27.5   | 1.1                         | 12.9 | 63.2         | 22.3 | 1.6     |

Different number of reporting years than in annex table as gender and age data are not always available.

Azerbaijan was excluded as 72.9% of cases were missing for gender and 89.6% for age.

<sup>a</sup>Deviating age group categories reported by: 0–24 years: Austria, Belgium, Croatia: 0–19 years; Lithuania: 0–25 years; Malta: 0–14 years; 25–64 years: Belgium: 20–69 years; Croatia: 20–64 years; Lithuania: 26–62 years; Malta: 15–64 years; 65+ years: Belgium: 70+; Lithuania: 63+.

therefore to be considered the main reason for CO-related deaths. Suicide cases by CO accounted for between 0% (Hungary) and 67% (Slovenia) of all CO-related deaths. Although the overall trend in CO-related suicide cases shows a decline in the reporting countries, this decline is not steeper than the overall decline identified for total CO-related mortality in these countries.

Comparison of European data with data from other countries is difficult as CO mortality data are not easily available in most countries. A web search and an e-mail request sent to the WHO global network on housing and health revealed data for a few countries only, but confirmed that the European data are in a range similar to the findings in other countries (Table 5).

Recent CO mortality data for the Province of Québec in Canada indicated 110 deaths in the time period 2005–2010, an average of 18/year. Over the whole time period, there were 1.46 deaths and 7.75 hospitalizations/100 000 population. About 78% of the CO-related deaths have been reported to be suicides.

In the United States of America, there were 4216 confirmed CO-poisoning-related hospitalizations in 2005 (1.42/100 000). During 1999–2004, CO poisoning was listed as a contributing cause of death on

**Table 4** CO-related mortality by cause of death, as reported by European Member States<sup>a</sup>

|   | Andorra (1994–2007) | Austria (2002–2008) | Bosnia and Herzegovina (2005–2008) | Czech Republic (1986–2008) | Germany (1998–2007) | Hungary (1996–2004) | Malta (1991–2008) | Republic of Moldova (1991–2008) | Slovenia (1985–2008) | Sweden (1980–2008) | Switzerland (1995–2007) | Total (%) |
|---|---------------------|---------------------|------------------------------------|----------------------------|---------------------|---------------------|-------------------|---------------------------------|----------------------|--------------------|-------------------------|-----------|
| External causes of death related to CO  |                     |                     |                                    |                            |                     |                     |                   |                                 |                      |                    |                         |           |
| Accidental poisoning by and exposure to gases and vapors (here: CO) (%)               | 0.0                 | 21.1                | 56.4                               | 56.3                       | 6.6                 | 41.6                | 31.6              | 82.9                            | 15.5                 | 2.6                | 20.2                    | 35.9      |
| Exposure to smoke, fire and flames (%)  | 50.0                | 34.3                | 10.3                               | 2.1                        | 29.1                | 53.9                | 0.0               | 14.6                            | 8.5                  | 26.2               | 37.6                    | 18.8      |
| Intentional self-harm or self-poisoning (%)   | 50.0                | 37.4                | 5.1                                | 33.2                       | 55.2                | 0.0                 | 63.2              | 0.2                             | 67.0                 | 62.4               | 37.2                    | 38.1      |
| Assault (%)   | 0.0                 | 1.1                 | 0.0                                | 0.5                        | 0.5                 | 0.4                 | 0.0               | 0.2                             | 0.3                  | 0.7                | 1.2                     | 0.5       |
| Poisoning by and exposure to gases and vapors (here: CO) with undetermined intent (%) | 0.0                 | 6.1                 | 7.7                                | 7.8                        | 8.6                 | 4.0                 | 5.3               | 2.1                             | 8.8                  | 6.7                | 3.7                     | 6.4       |
| Other (%)   | 0.0                 | 0.0                 | 20.5                               | 0.0                        | 0.0                 | 0.0                 | 0.0               | 0.0                             | 0.0                  | 1.3                | 0.0                     | 0.4       |
| Total of death cases (%)  | 100                 | 100                 | 100                                | 100                        | 100                 | 100                 | 100               | 100                             | 100                  | 100                | 100                     | 100       |
| Total of death cases (n)  | 4                   | 361                 | 39                                 | 6136                       | 3962                | 1166                | 19                | 4281                            | 1194                 | 5533               | 242                     | 22 937    |

<sup>a</sup>Depending on application of ICD codes and availability of data by death cause, the number of reporting years may differ from Table 1 and therefore different numbers of death cases may be covered.

**Table 5** Summary table with CO poisoning data for five non-European countries/regions

|  | Argentina (2009–2010) | Australia (2008) | Japan (1997–2009)                | United States of America (1999–2004) | Quebec, Canada (2005–2010) | Europe, total figures <sup>b</sup>                                    |
|--|-----------------------|------------------|----------------------------------|--------------------------------------|----------------------------|---|
| Deaths due to CO   | No information        | 249              | 42 339                           | 16 447                               | 110                        | 140 490   |
| Deaths due to CO per year  | No information        | 249              | 3256.8                           | 2741.2                               | 18                         | 346.9   |
| CO death rate per 100 000 population   | No information        | 1.2              | 2.56                             | 0.96                                 | 1.46                       | 2.24  |
| Deaths due to unintentional, non-fire-related CO exposure                        | No information        | No information   | No information                   | 2631                                 | 21                         | 8234 (11 countries only)  |
| Deaths due to unintentional, non-fire-related CO exposure per year               | No information        | No information   | No information                   | 438.5                                | 3.5                        | 48.4 (11 countries only)  |
| Deaths due to unintentional, non-fire-related CO exposure per 100 000 population | No information        | No information   | No information                   | 0.15                                 | 0.28                       | 0.48 (11 countries only)  |
| Hospitalizations per year per 100 000 population                                 | 4.6 reported          | 2.2 <sup>a</sup> | No information                   | 1.5                                  | 7.75                       | 2.33  |
| Mortality trend  | No information        | No information   | Strong increase: factor 2.5      | Slight increase                      | Increasing                 | Overall reduction with few national exceptions                        |
| Suicide as main issue  | No information        | Yes: 87%         | Yes but impact cannot be defined | Yes but impact cannot be defined     | Yes: 78%                   | Single leading cause of CO mortality with 38.1% of CO-related deaths. |

<sup>a</sup>Australian hospitalization data for 1999–2008.

<sup>b</sup>European summary data: based on Tables 1–4.

Source: Argentina: Reporte Epidemiológico de Córdoba (2011), Australia: Australian Institute of Health and Welfare (2008), Australian Bureau of Statistics (2010), Japan: Ministry of Health, Labour and Welfare (2010), United States: Centers for Disease Control and Prevention (2007, 2008), Quebec, Canada: Ministère de la Santé et des Services sociaux, Gouvernement du Québec (2012).

16 447 death certificates in the USA (2741 deaths/year), resulting in a mortality rate of 0.96/100 000. Sixteen percent of these cases were classified as unintentional and non-fire-related deaths (439 deaths/year; 0.15/100 000). Again, males and older persons were most affected.

In Japan, 42 339 persons died from the toxic effects of CO between 1997 and 2009, that is, 3256 deaths/year with a crude death rate of 2.56/10 000. The highest annual rate was reported for 2009 (3.45/100 000) due to a rising number of CO-related suicide cases. Eighty-three percent of the deaths occurred in males.

In Australia, data were identified for 2008 when 249 persons died from toxic effects of CO (1.2/100 000). The majority of CO-related hospitalizations were males.

In Argentina, the Ministry of Health reported a total of 5549 CO-related poisoning cases from 2008 to 2010 (4.6/100 000), but no data on fatalities are provided. The frequency of poisoning was highest during winter time.

## Discussion

The presented data indicate the health significance of CO-related mortality but also elucidate the challenge of its adequate reporting and monitoring. In the discussion, we therefore (a) emphasize the largely ignored public health relevance of CO intoxications; (b) put selected results in context by providing further interpretations and explanations; and (c) discuss the uncertainty attached to the mortality data and the challenges of proper reporting of CO mortality.

(a) The data show that CO intoxication is a serious public health challenge. With an annual death rate of 2.2 per 100 000 population over the whole reporting period, CO-related mortality can be compared with the recent WHO European Region mortality rates (WHO Regional Office for Europe, 2012) related to HIV/AIDS (SDR 2.0/100 000 in 2010), skin cancer (2.1), and alcohol abuse (2.6) – public health issues for which large-scale health promotion and awareness campaigns have been funded in the recent years. In some countries, CO-related mortality is even comparable with the standardized death rate due to diabetes mellitus (11.4/100 000, year 2010) or transport-related injuries (9.7/100 000, year 2010) in the WHO European Region. Yet, CO intoxication is largely ignored as a public health issue and, due to a lack of monitoring and reporting, statistics are neither easily available nor reliable. Consequently, well-funded campaigns on the prevention of CO intoxication are comparatively rare.

The data reflect the need for action as CO-related mortality does not decrease in many countries, although it is highly preventable. Such lack of success in reducing CO-related mortality is, however, not associated with the absolute mortality rate level or the developmental level of a given country, as increasing and/or stagnating mortality rates are found for western EU countries as well as for new EU member states and countries from Eastern Europe and the Caucasus. Acknowledging and acting on CO mortality is thus necessary throughout the WHO European Region.

(b) Data reported by 11 countries identify suicide as the leading single cause of CO-related mortality

(38.1%). Although there is a large variety of the national relevance of suicides within the CO-related mortality (from 0% of all cases in Hungary to 67% of all cases in Slovenia), the data are striking and illustrate the potential of CO intoxication for self-harm. The dominance of suicide cases is strongest in Germany, Malta, Slovenia, and Sweden, which report more than half of all CO-related death cases as suicides, while Austria and Switzerland are just below 40% and thus in the average range. However, the results indicate that – compared with total CO-related mortality – the proportion of intentional CO poisoning has been rather high and stable over time for all reporting countries and therefore show that CO-related suicide has not been successfully addressed.

A specific situation is found for Sweden that has one of the highest CO-related suicide levels (62.4%). Given this unique feature, it may not be a coincidence that Sweden is the only country where the annual death rate of 2.2/100 000 population is higher than the hospital admission rate of 1.63/100 000, possibly indicating again that suicide attempts using CO may leave the health system with little chance to intervene in due time.

However, the collected data also indicate that more than half (54.7%) of all CO-related deaths are caused by either accidental CO poisoning or the emissions released by structural fire, both of which are almost exclusively related to the home setting. In this context, the data collected suggest that housing conditions may be related to the national levels of unintentional CO poisoning deaths by CO. Bosnia and Herzegovina, Czech Republic, Hungary, and the Republic of Moldova reported 56.4%, 56.3%, 41.6%, and 82.9%, respectively, of all CO-related deaths to be related to unintentional exposure to CO, which is mostly taking place in the home and may be affected by type of energy supply, housing conditions, and ventilation rates. In comparison, Austria, Germany, Slovenia, Sweden, and Switzerland reported 21.1%, 6.6%, 15.5%, 2.6%, and 20.2%, respectively, of all CO-related deaths to be related to such unintentional exposure to CO. This also raises the question whether, next to housing conditions and energy sources, adequate experience and public policies on the prevention of CO exposure may contribute to lower mortality rates. The fact that Sweden, despite cold winters and frequent use of wood for heating, has the lowest unintentional CO poisoning rate may indeed indicate the existence of good preventive practices such as adequate housing (safe heating and cooking appliances, sufficient ventilation) and also adequate residential behaviors. As well, it is essential to better educate the general public on the sources of CO that can lead to a high rate of this pollutant in the indoor environment of homes and the situations under which such exposure may occur (depending on energy supply, type of appliances, maintenance standards, fire safety, etc).

From the five countries with the lowest unintentional poisoning rates (Austria, Germany, Slovenia, Sweden, and Switzerland), four show much higher mortality rates related to CO exposure due to fire than the average for all reporting countries, with the exception of Slovenia. This may indicate that these countries can still improve their fire safety conditions to match the safety levels in place for combustion-fired household appliances.

The significant gender inequality in CO-related mortality cannot be explained based on the available data and would call for further exploration, looking at, for example, lifestyle, risk behavior, and the gender distribution of suicides. Also, the relative increase in mortality in elderly aged 65 years and above cannot be explained on medical grounds and may possibly be related to the fact that older persons tend to reside in older buildings which may be more often equipped with older and less functional or less well-maintained gas-fired devices. Fire safety issues in older buildings as well as the ability to safely operate the gas-burning equipment may also add to an increased risk for the elderly.

(c) The principal sources of uncertainty affecting the assessment of CO-related mortality in the WHO European Region relate to the inadequate quantity and quality of the data themselves. First, there is no or limited mandatory and systematic reporting of CO mortality for many countries. Second, for countries with available information, only few of them seem able to report the data in categories that are needed to draw more specific conclusions. Third, there are strong doubts regarding the accuracy of the data as the partially extreme intra- and inter-country differences in mortality are unlikely to reflect reality.

A major issue related to data reliability is the quality, consistency, and comparability of the reporting mechanisms applied by different countries to collect mortality statistics. Although this review has not been designed to identify in detail the national mechanisms of reporting, it can be concluded that the use of the ICD system often lacks consistency (Ball et al., 2005). The move from ICD9 to ICD10 in 2002 has led to an increase in reported CO cases in Austria, while in Spain, the ICD10 implementation no longer enables the identification of mortality exclusively related to CO from the mortality statistics. Depending on the country, there may also be a separate reporting of mortality by different causes of death (e.g., in Belarus, data on CO intoxication are collected by the trauma unit and may not necessarily be compatible with other mortality databases, while in Malta, CO-related mortality must be obtained from hospital records), which makes it difficult to access the data and assess their completeness. In Finland, the identification of CO as a potential cause of death is confirmed by postmortem

examinations, but it is difficult to assess whether all – and if not all, what ratio of – CO-related death cases are examined. This may specifically apply to CO-related deaths occurring from structural fires. Finally, a variety of countries may be using national reporting tools and mechanisms for CO poisoning cases that may not be fully compatible with the ICD categories, and therefore, it is difficult to compare such data without an in-depth evaluation of the national reporting systems. Adding to the data constraints described above, many symptoms of CO poisoning are similar to other types of poisonings (e.g., food poisoning) as well as infections such as the flu, making correct diagnosis of CO intoxication difficult (Gasman et al., 1990) and potentially leading to a general underreporting of cases.

It can be concluded that despite the availability of the ICD codes, the quality of reporting of CO-related deaths varies strongly between the countries. As a consequence, there is a high degree of uncertainty as to how much of the differences between countries are due to real differences in CO-related mortality and how much are due to different reporting practices. It seems, for example, highly unlikely that the mortality differences found for the Baltic countries (0.37/100 000 in Lithuania compared with 2.48 in Latvia and 6.16 in Estonia) are unrelated to different reporting procedures. As well, there is no reasonable justification for the significant mortality increase in Austria associated with the implementation of the ICD10. Similarly, it is questionable whether the reported CO-related mortality rates in Azerbaijan (0.02/100 000) and Georgia (0.04/100 000) represent the truth, as they are rather marginal compared with the mortality rates observed in many EU countries and extremely small when compared with the CO-related mortality rates in Belarus (11.99/100 000) and the Russian Federation (12.81/100 000). These strong intercountry differences in CO mortality indicate that the collected data probably do not fully reflect the actual situation. On the other hand, it seems extremely likely that CO mortality is being underreported. Therefore, the CO-related mortality as reported by this study can be considered – despite all methodological weaknesses of reporting – a rather conservative estimate, with the real mortality rates possibly being much higher yet impossible to estimate.

### **Potential countermeasures and actions**

While CO intoxication is highly lethal, the occurrence of CO exposure can be controlled if product and technical standards, safety guidelines, and health-related guidance are adequately enforced. Public health professionals therefore need to get involved in and promote activities of non-health sectors to reduce life-threatening CO exposure situations.

### **Building- and product-related measures**

Preventive measures can be implemented to reduce CO sources and emissions. As with any indoor air pollutant, source control should be considered before ventilation. This could be achieved by investing in high-quality appliances and applying clean combustion techniques (Greiner, 1996). While source control cannot provide 100% protection (except by stopping all use of combustion appliances), the risks can be reduced by adequate selection, installation, and maintenance of appliances (Department for Communities and Local Government, 2008). Other measures that can be applied include (Centers for Disease Control and Prevention, 2007; Déoux and Déoux, 2004; INPES, 2009) the following:

- prohibition of usage of petrol- or diesel-powered engines as well as charcoal grills inside buildings;
- effective maintenance and inspection programs for combustion appliances;
- not using a gas oven to heat indoor spaces;
- effective and well-maintained ventilation systems;
- designing flue gas or off gas venting directions to prevent combustion products from re-entering into buildings;
- rooms without proper venting and rooms heated by gas or solid fuels should not be used as bedrooms;
- strict enforcement and when necessary improvement of fire safety regulations;
- mandatory installation of smoke detectors in every room of occupied buildings; and
- specific installation of CO detectors in locations at risk for CO exposure (e.g., rooms with gas water heaters etc.).

Evidence shows that CO detectors equipped with an audible alarm can alert potential victims of CO poisoning before toxic sequelae develop: 63.4% of CO exposure victims without such alarm functions installed developed sequelae, compared with 13.3% of victims warned by audible alarms (Krenzelok et al., 1996).

### **Health literacy and public information**

The population, and especially households using gas or solid and liquid fuels, need to be informed on the risk of CO exposure and the typical symptoms indicating CO intoxication. Several parameters can be used to distinguish between CO poisoning and the flu (U.S. Environmental Protection Agency, 2009). Typical CO exposure indicators are as follows:

- a person feels better when being away from home,
- several people in the home get sick at the same time,
- family members who spend most time in the home are most affected,

- symptoms occur or get worse shortly after turning on a burning appliance or running a vehicle in attached garage,
- indoor pets also appear ill (pets get symptoms first).

#### Exposure-based health guidelines for acute and chronic exposure

Health-based guidelines on acceptable maximum CO concentrations in indoor air are necessary to inform building-related as well as product-related standards and help national governments to set threshold levels to be achieved by buildings. Although acute and intense CO exposure is the most dangerous exposure scenario, chronic CO exposure is relevant as well as it may often remain unrecognized. Thus, separate guidelines for CO exposure have been developed by the WHO Indoor Air Quality Guidelines (Table 6) to address acute CO exposure (15 min), short-term exposure (1 h and 8 h), and long-term or potentially chronic exposure (over 24 h)(WHO Regional Office for Europe, 2010).

#### Health system measures and reporting of CO intoxication

Uncertainty could be reduced by mandating CO poisoning as reportable disease to public health authorities and improving data collection and data quality by better training on CO intoxication symptoms and clear reporting procedures. Timely identification and reporting of exposure situations may be relevant for triggering public health action in acute exposure situations, especially if other residents of the same or neighboring building are potentially in danger. Furthermore, the use of the ICD system and application of the T58 code for national monitoring of CO intoxications should be improved as well as the subsequent data analysis within standardized health statistics and reports.

#### Social cohesion and societal measures

In this survey, suicide represents the main single cause of death from CO. Suicide via CO is common and typically involves the use of motor vehicle exhaust or home appliances as a source of CO. Although – different than, for example, in China, Hong Kong Special Administrative Region (Chung and Leung, 2001), or

Japan (Table 5) – the relative proportion of CO-related suicides has not increased over the study period, it is identified as the leading cause for CO mortality for many European countries. No building measures and control devices will be fully effective to avoid and reduce CO-related suicide. It remains the common responsibility of society, families, and friends to reduce suicides in general and provide a life context conducive to mental health.

#### Conclusions

The analysis of CO mortality data as reported by a variety of Member States of the WHO European Region yields some conclusions that have significance for policy.

First, CO poisoning causes hundreds of deaths per year in Europe. As it is highly preventable and has a high case-fatality rate, it is an important field for public health action. CO poisoning is a serious threat that the public needs to be informed about. However, public health action in this field needs not only to disseminate knowledge on CO exposure and its prevention, but also to spark non-health sectors (housing and construction; industry; do-it-yourself markets; craftsmen, etc.) into action.

Second, gas equipment, heating devices, and other indoor environment features related to combustion need to be produced and installed at a highest level of product safety. Industry needs to be pushed to provide ‘fail-safe’ products that cannot lead to any harmful indoor exposure. Procedures to maintain and control such equipment need to be put in place and adequately enforced. Furthermore, fire safety standards and use of detectors need to be increased.

Third, improved collection and analysis of CO exposure and mortality information at the national and international level are needed. Despite the preventability of the intoxication cases, monitoring of CO-related morbidity and mortality still is inadequate in many countries. To better estimate the total disease burden caused by CO, health agencies should be mandated to report CO poisoning cases based on a consistent system. In this context, the application of the ICD coding system in the different countries needs to become more consistent as well.

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**Table 6** WHO indoor CO exposure guideline values

| Averaging time | Mean CO concentration (mg/m <sup>3</sup> ) not to be exceeded |
|----------------|---|
| 15 min         | 100   |
| 1 h            | 35  |
| 8 h            | 10  |
| 24 h           | 7   |

Source: WHO Regional Office for Europe (2010).

## Supporting Information

Additional Supporting Information may be found in the online version of this article:

**Table S1.** CO mortality and rates by country and year.

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