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An Analysis of Domestic Fire Smoke/Toxic Fumes Inhalation Injuries

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Abstract. Previous studies indicated that inhalation of smoke and toxic fumes is the most common form of domestic fire injury. In this article we examine the socio-demographic, contributory, and firefighting behaviour factors associated with accidental dwelling fire smoke / toxic fumes inhalation injuries. In particular, we examine age band, gender, occupancy level, deprivation, alcohol / drug consumption, and attempting to fight a domestic fire in the Merseyside area of North-West England covered by Merseyside Fire and Rescue Service over the period 2011 to 2022. Smoke / toxic fumes inhalation injuries occurred more in single occupancy as opposed to multiple occupancy dwellings by a ratio of 2 to 1 over the period studied. The majority of the accidental dwelling fire smoke / toxic fumes inhalation injuries occurred in areas with the highest level of deprivation within the area studied. Alcohol / drug consumption was a contributory factor in roughly 14% of the smoke / toxic fumes inhalation injuries. Smoke / toxic fumes inhalation injuries sustained attempting to fight the fire constituted roughly 12% of the total number of smoke / toxic fumes inhalation injuries over the period studied.

Keywords: Smoke, Inhalation, Fire, Injury, Analysis

1. Introduction

Previous research had indicated that inhalation of smoke / toxic fumes is the most common form of accidental dwelling fire injury [1, 13]. Any exposure to even dilute smoke during a dwelling fire incident can constitute a serious health effect [14]. Breathing in hot smoke can cause physical harm to an individual which may only be noticed after a number of hours following a domestic fire incident [23]. Smoke from a domestic fire is typically a mixture of fine solid particles, droplets of water and other liquids, and gases given off by the materials involved in the fire. The most common toxic product in any fire is carbon monoxide (generated from incomplete combustion), which is produced by all organic materials when they burn, in addition, hydrogen cyanide may be generated from burning plastics,

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and phosgene gas may be generated from burning vinyl-based household materials [24]. In addition to producing smoke, a domestic fire can also reduce oxygen levels, either by consuming the oxygen or by displacing it with other gases. Heat from the fire is also a respiratory hazard, as superheated gases can burn the respiratory tract [30].

In England, fire and rescue authorities undertake prevention activities which aim to provide information and advice and encourage fire safety behaviours, and educate householders how to prevent a domestic fire and decrease the risk of injury and death. In England in 2020 / 2021, 94% of households owned a working smoke alarm [9]. Smoke alarms provide an early warning and chance for householders to escape the dwelling before being overcome by smoke and toxic fumes. During a dwelling fire more people die from smoke and toxic fumes inhalation than from burns [22]. Injuries from smoke and toxic fumes inhalation present a complex clinical problem for health services, especially in terms of treating toxin exposure from toxic fumes [3].

The fitting and checking of smoke alarms is an important aspect of fire and fire injury prevention by UK fire and rescue services, since smoke alarms can quickly alert householders to the presence of smoke and hopefully thus assist in avoiding smoke / toxic fumes inhalation and other fire injuries. UK fire and rescue services emphasize the importance of smoke alarm installation, testing, and maintenance. In the United States, the National Fire Protection Association advises testing smoke alarms at least once a month and the following of the manufacturer's maintenance directions [31].

Smoke from a fire can quickly fill a building and hamper evacuation [32]. Internal doors should be kept closed at night in order to prevent smoke from spreading within a dwelling, especially when householders are asleep and likely to respond less quickly to smoke alarms [26].

In order to attempt to reduce the number of accidental dwelling fires, and associated injuries and fatalities it is important to be able to both understand and quantify the behaviour and consequences of accidental dwelling fires in practice [19]. In this article we examine the factors associated with accidental dwelling fire smoke / toxic fumes inhalation injuries including age band, gender, deprivation, whether living alone or with others, alcohol /drug consumption, and attempting to fight a domestic fire in a study in the Merseyside area of North-West England covered by Merseyside Fire and Rescue service during 2011 to 2022. Merseyside contains a mix of high-density urban areas, suburbs, and semi-rural areas, and covers a geographical area of 645 km^2, and had a population of 1,434,300 in 2020 [34].

2. Literature Review

2.1. Accidental Dwelling Fire Injuries

Most accidental dwelling fires do not result in injury or fatality [17, 45]. Of the accidental dwelling fires that do result in injury, the majority are in single occupancy dwellings. In England in 2015 / 2016 of the 5771 dwelling fire injuries, 3704

(64%) were in single occupancy dwellings [10]. In England in the 2021 Census, 78% of dwellings were single occupancy dwellings, down from 79% in the 2011 Census (UK [46]. Accidental dwelling fire injuries may include: smoke / toxic fumes inhalation, burns, and shock or collapse [45]. Previous research had indicated that smoke alarms play a key role in reducing the number of injuries and deaths associated with household fires each year [41]. In the UK, an individual is 8 times more likely to die from a domestic fire if there is not a working smoke alarm in the home [7]. In the UK, the Home Fire Safety Check Initiative [28] aims to increase the number of working smoke alarms in UK dwellings. A home fire safety check includes the fitting and checking of smoke alarms within dwellings. The average fire officer time spent at a home fire safety check is typically one hour and fifteen minutes [8]. For multi-level UK dwellings there should be a smoke alarm on each level [29]. UK fire and rescue services promote the fitting and regular checking of smoke alarms [29] through websites and social media [2, 35]. Landlords in the UK are legally required to install smoke alarms on every floor of the properties they let as living accommodation, and are responsible for ensuring that such smoke alarms are appropriately maintained [7]. Smoke alarms should ideally be tested weekly by pressing the test button until the alarm sounds, and maintained monthly by vacuuming around the alarm and wiping over with a damp cloth to remove any dust [27]. In the UK there is still an ongoing issue concerning the failure rates or absence of domestic smoke alarms [20]. In England in 2015/2016 14% of smoke alarms did not operate in domestic fires due to a missing or defective battery [11].

2.2. Smoke / Toxic Fumes Inhalation Fire Injuries

Numerous studies had indicated that smoke / toxic fumes inhalation is the main cause of fire injury and fatality in domestic fire incidences [1, 13, 15, 18]. During a dwelling fire, the inhalation of toxic gases produced from burning materials is a major cause of injury and death. Common toxic gases in domestic fire smoke include carbon monoxide, carbon dioxide, hydrogen cyanide [40], hydrogen chloride, hydrogen bromide, and nitrogen oxide [16, 37, 38]. The danger from smoke inhalation relates to the toxic potency of the smoke and the exposure an individual experiences to the changing smoke concentration over the time they are near the fire [12]. Those injured by smoke or toxic fumes inhalation during a dwelling fire may experience post-exposure lung complications relating to inflammatory response to irritants and may lead to delayed death [5]. Smoke / toxic fumes inhalation injury is also one of the most serious associated injuries complicating the care of thermally injured patients [4, 42]. Older individuals can be more susceptible to smoke and toxic fumes inhalation injuries since age-related decline and illness increase the susceptibility to smoke and toxic fire gases. In addition, older people may move more slowly when attempting to escape from a dwelling fire resulting in longer exposure times. In particular, for the elderly, there can be increased risk of incapacitation and death for lower exposure levels to smoke and toxic fumes [39].

Overall, although previous research into accidental dwelling fire injuries had identified inhalation of smoke / toxic fumes as the most common form of fire injury, few studies have examined the nature of the factors associated with smoke / toxic fumes inhalation fire injury. The originality of the research reported in this paper is the detailed analysis of smoke / toxic fumes inhalation accidental dwelling fires injuries over the period 2011 to 2022 recorded by Merseyside Fire and Rescue Service. In particular, the research reported in this paper examined a variety of smoke / toxic fumes inhalation fire injury factors.

3. Research Method

Accidental dwelling fire (ADF) data for the area studied and deprivation data from the UK Office for National Statistics was used to examine the factors associated with accidental dwelling fire smoke / toxic fumes inhalation injuries in terms of age band, gender, occupancy level, alcohol / drug related, tiredness related, and fire-fighting related fire injuries over the period 2011 to 2022 in the area studied. The data used regarding accidental dwelling fire smoke and toxic fumes inhalation injuries was from the UK Fire Incident Recording System [6]. Smoke and toxic fumes inhalation injuries were determined by firefighters at the scene of the fire, and were defined as "Overcome by gas, smoke or toxic fumes, asphyxiation" within the nature of injury variable in the UK Fire Incident Recording System. The injuries all concerned non-fatal smoke and toxic fumes inhalation fire injuries only and did not include injuries classified as "Combination of burns and overcome by gas/smoke". Firefighter injuries were not included in the analysis. The age of person injured stored in the incident recording system was in the age bands used in the analysis. None of the available data required treatment before commencing the analysis. No adjustments were necessary to compensate for fires in which the relevant variable was unknown or undetermined, as this did not apply to the variables used in the analysis.

The research method involved using frequency and ratio analysis to examine patterns and trends in accidental dwelling fire smoke and toxic fumes inhalation injury data in terms of age bands, gender, deprivation, occupancy level, contributory factors such as alcohol / drug consumption and falling asleep, and fire behaviour in terms of attempting to tackle a domestic fire. Previous research [45] had used a similar analytical framework for analysing fire injuries in general. The deprivation measure used for the research was the Indices of Multiple Deprivation decile [21] produced by the UK Office for National Statistics. The IMD decile covers all areas in England and ranges from 1 which concerns the ten percent most deprived areas in England to 10 which concerns the ten percent least deprived areas in England. The Index of Multiple Deprivation (IMD) is the official measure of relative deprivation in England that defines deprivation to encompass a wide range of an individual's living conditions. Individuals may be regarded as deprived if they lack any kind of resources, not just income. The Index of Multiple Deprivation is based upon seven domain areas including income, employment, education, health, crime, barriers to housing and services, and living environment [21]. The software used for the statistical data analysis was Microsoft Excel.

The research questions addressed by the research concerned how the following related to accidental dwelling fire smoke / toxic fumes inhalation injury:

- Socio-demographic factors such as age, gender, dwelling occupancy level, and deprivation
- Contributory factors such and alcohol / drug consumption and tiredness
- Firefighting behaviour factors such as attempting to fight a domestic fire

These are important research questions since smoke / toxic fumes inhalation injuries are the most common form of accidental dwelling fire injury, and can potentially cause long term health problems, and significant costs for the UK National Health Service. The originality of the research presented is the detailed analysis of accidental dwelling fire smoke / toxic fumes inhalation injuries over the period 2011 to 2022 recorded by Merseyside Fire and Rescue Service in terms of age band, gender, occupancy level, deprivation, and contributory factors such as alcohol / drug consumption, falling asleep, and attempting to tackle the fire in order to inform fire injury prevention strategies. UK fire and rescue services promote the importance of evacuating the premises, and staying out, rather than householders attempting to tackle a domestic fire themselves [25, 43].

4. Smoke / Toxic Fumes Inhalation Fire Injury Analysis

4.1. Socio-Demographic Factors and Accidental Dwelling Fire Smoke / Toxic Fumes Inhalation Injury

During 2011 to 2022 the number of dwelling fire injuries per year in England were as shown in Fig. 1 [36]. In the area studied, the number of accidental dwelling fire

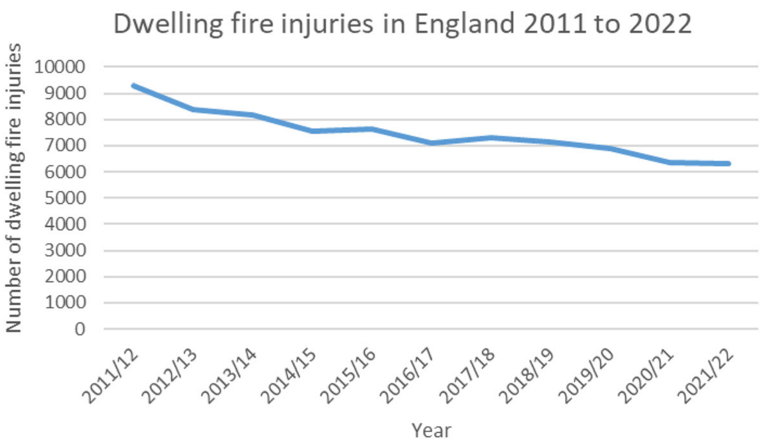

Figure 1. Dwelling fire injuries in England 2011 to 2022.

injuries per year were as shown in Fig. 2, and the number of accidental dwelling fire smoke / toxic fumes inhalation injuries per year were as shown in Fig. 3.

In total there were 473 accidental dwelling fire smoke / toxic fumes inhalation injuries in the area studied during the period 2011 to 2022, which constituted 45% of the 1041 accidental dwelling fire injuries during that period. The number of accidental dwelling fire smoke / toxic fumes inhalation injuries per year varied between 32 and 57 over the period studied. The mean number of smoke / toxic fumes inhalation injuries per year was 43, with a standard deviation of 7.1.

The number of smoke / toxic fumes inhalation injuries per 10,000 population of Merseyside over the period studied was as shown in Fig. 4.

Figure 4 indicated that those aged over 75 and those aged 50–54 were most at risk of smoke / toxic fumes inhalation injuries.

The overall ratio of male to female smoke / toxic fumes inhalation injuries over the period studied was 1.2 to 1. However, the ratio of male to female smoke / toxic fumes inhalation injuries was not uniform across the different age bands as shown in Fig. 5.

The largest numbers of smoke / toxic fumes inhalation injuries occurred in the 20 to 54 age bands. Just under half (47.8%) of the smoke / toxic fumes inhalation injuries occurred in the 20 to 54 age band. There were generally more male smoke / toxic fumes inhalation injuries between the ages of 30 and 85, however below age 30 and above age 85 there were generally more female smoke / toxic fumes inhalation injuries.

Figure 6 shows that in Merseyside in 2020 there were typically more females than males in the higher age bands, especially in the 85 + age band [34]

Figure 7 shows the number of accidental dwelling fire smoke toxic fumes inhalation injuries by type of occupancy during the period studied.

Figure 7 indicated that smoke / toxic fumes inhalation injuries were more common in single occupancy as opposed to multiple occupancy dwellings by a ratio of

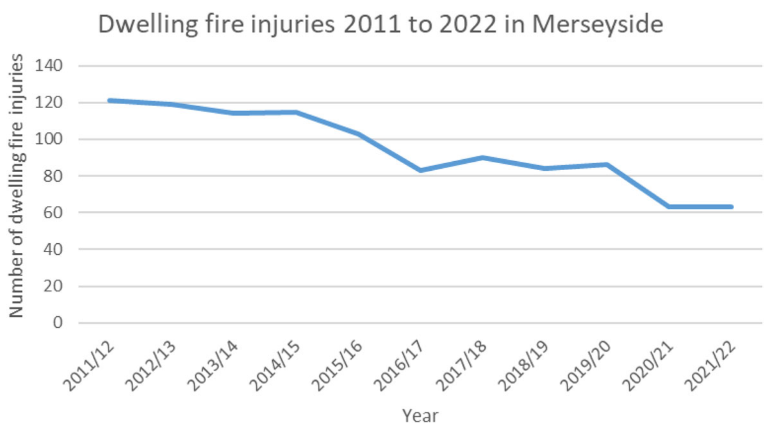

Figure 2. Number of dwelling fire injuries per year in the area studied.

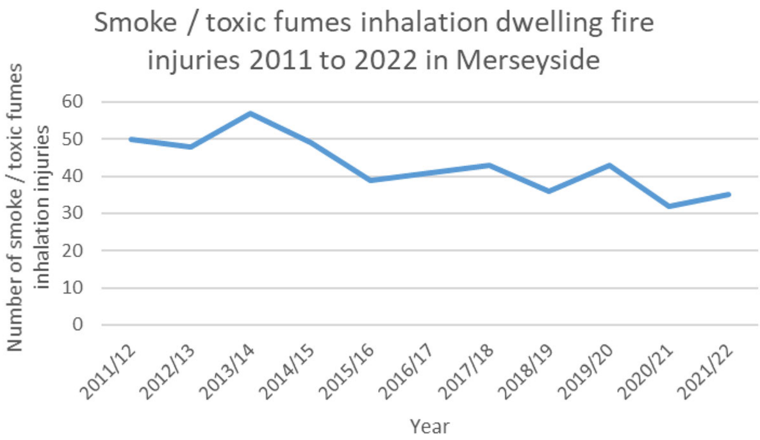

Figure 3. Number of smoke / toxic fumes inhalation fire injuries per year in the area studied.

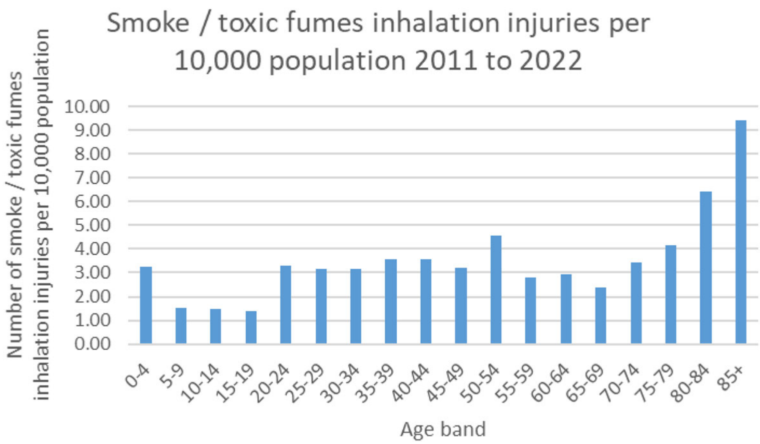

Figure 4. Number of smoke / toxic fumes inhalation injuries per 10,000 population of Merseyside between 2011 and 2022.

1.7 to 1. In the UK, those who live alone are more likely to die or be seriously injured in an accidental dwelling fire [10, 33, 44].

Figure 8 shows the relationship between deprivation (as measured by IMD decile) and accidental dwelling fire smoke / toxic fumes inhalation injury in the area studied between 2011 and 2022.

Figure 8 indicated that the highest rates of accidental dwelling fire smoke / toxic fumes inhalation injuries occurred in areas with the highest levels of deprivation (IMD deciles 1 and 2). IMD decile 1 represents areas in the ten percent most deprived areas in England. IMD decile 10 represents areas in the ten percent least deprived areas in England.

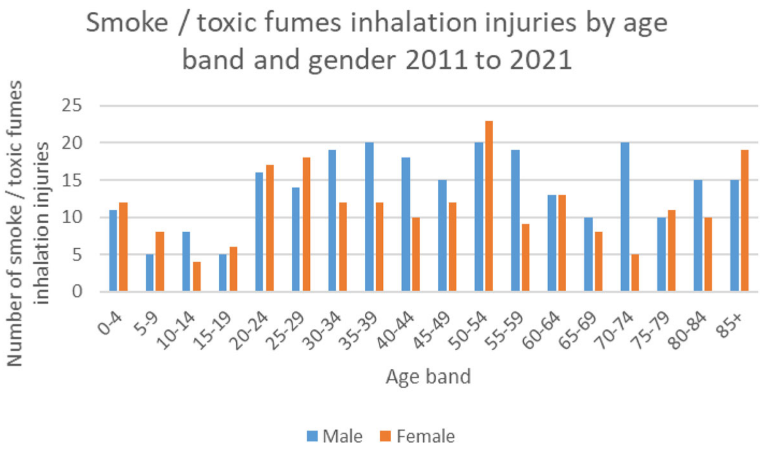

Figure 5. Number of accidental dwelling fire smoke / toxic fumes inhalation injuries by age band and gender.

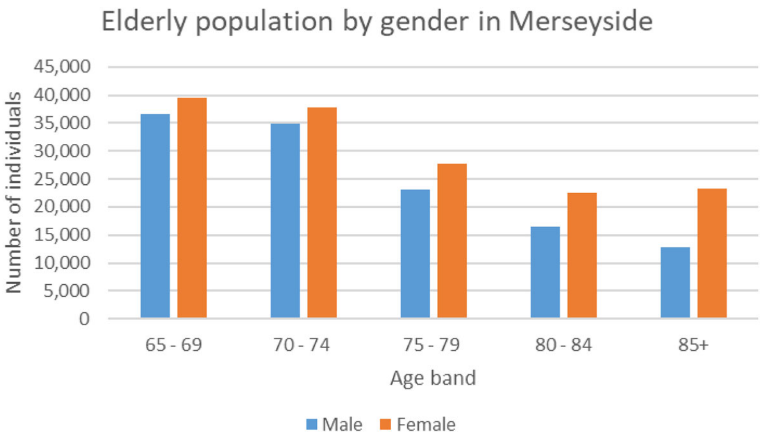

Figure 6. Elderly population by gender in Merseyside in 2020.

4.2. Contributory Factors and Accidental Dwelling Fire Smoke / Toxic Fumes Inhalation Injury

Alcohol / drug related accidental dwelling fire smoke / toxic fumes inhalation injuries accounted for 14.4% of such injuries during the period studied. An accidental dwelling fire injury was recorded as being alcohol related, if the individual concerned was suspected of being under the influence of alcohol by the firefighters that attended the fire. Tiredness accounted for 8.7% of the smoke / toxic fumes inhalation injuries over the period studied. Either tiredness or impaired by alcohol or drugs may be recorded for a fire injury, but not both.

Figure 9 showed that whilst there were roughly equal rates of tiredness related smoke / toxic fumes inhalation injuries by gender, the rate of alcohol / drug

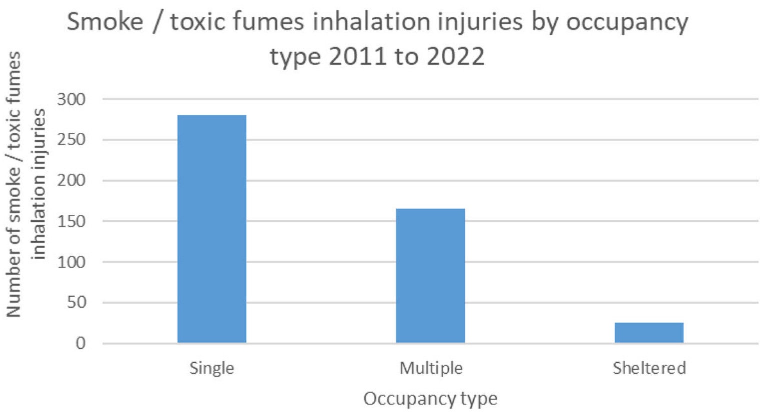

Figure 7. Number of accidental dwelling fire smoke / toxic fumes inhalation injuries by type of occupancy.

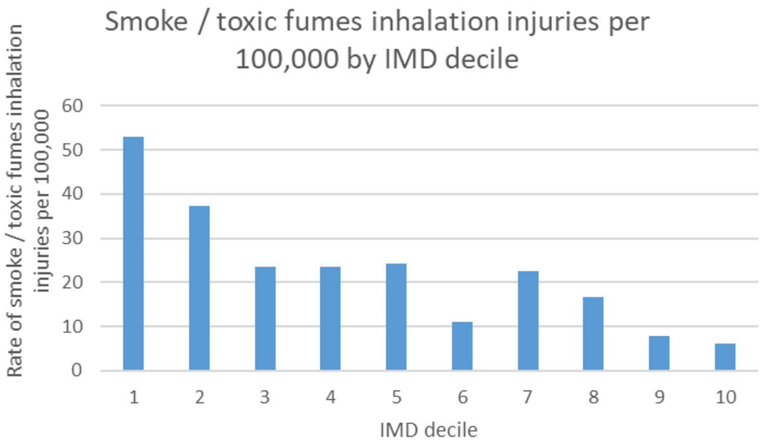

Figure 8. Rates of accidental dwelling fire smoke / toxic fumes inhalation injuries per 100,000 by IMD decile.

smoke / toxic fumes inhalation injuries over the period studied was almost double for males compared to females. The ratio of male to female alcohol / drug smoke / toxic fumes inhalation injury numbers was 1.8 to 1.

Figure 10 shows the number accidental dwelling fire smoke / toxic fumes inhalation injuries by time of day during the period studied. 30% of the smoke / toxic fumes inhalation injuries occurred during mid-day (12:00 to 14:00) and evening (17:00 to 19:00) meal times, and 38% of the smoke / toxic fumes inhalation injuries occurred during the night (22:00 to 06:00). This highlights the importance of householders taking appropriate fire safety precautions whilst cooking and in particular before going to sleep.

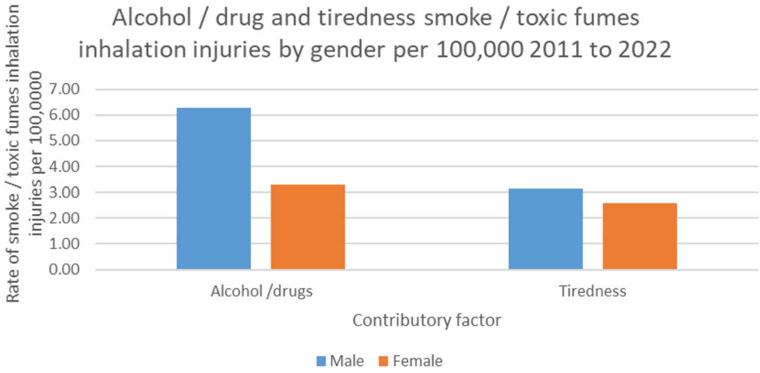

Figure 9. Rates of alcohol / drug and tiredness related accidental dwelling fire smoke / toxic fumes inhalation injuries by gender per 100,000 2011 to 2022.

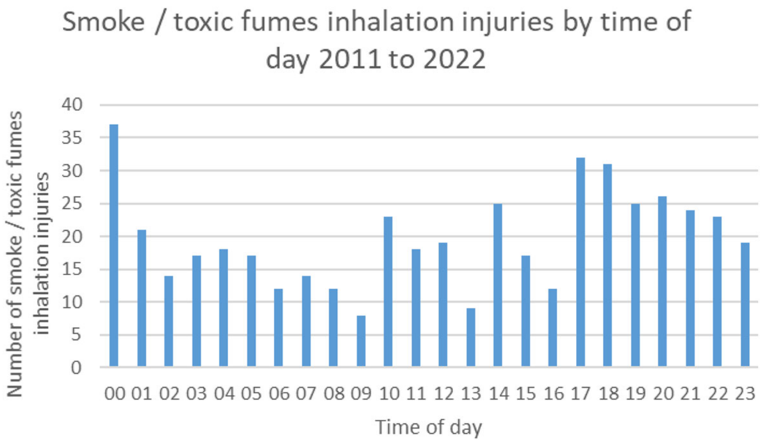

Figure 10. Number of accidental dwelling fire smoke / toxic fumes inhalation injuries by time of day 2011 to 2022.

4.3. Firefighting behaviour factors and accidental dwelling fire smoke / toxic fumes inhalation injury

The ratio of male to female smoke / toxic fumes inhalation injuries sustained attempting to fight the fire was 2.3 to 1. Smoke / toxic fumes inhalation injuries sustained attempting to fight the fire constituted 11.8% of the total number of smoke / toxic fumes inhalation injuries over the period studied. The higher rate of male smoke / toxic fumes inhalation injuries overall might be partially explained by a greater likelihood for males to engage in fire control (Fig. 11).

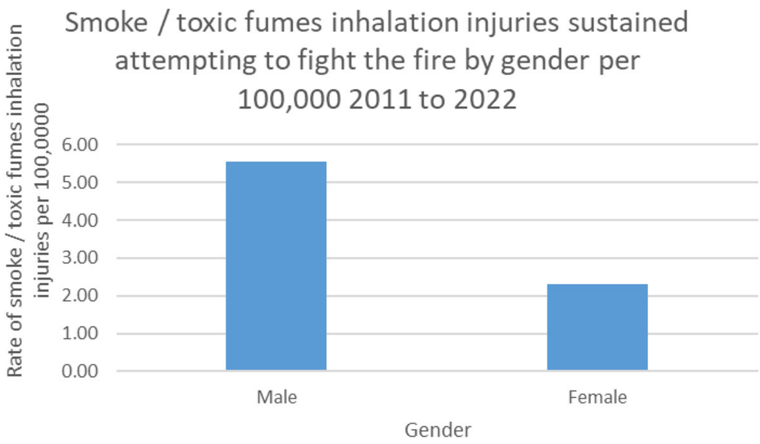

Figure 11. Rates of accidental dwelling fire smoke / toxic fumes inhalation injuries involving attempting to fight a domestic fire by gender per 100,000 2011 to 2022.

5. Limitations

The research undertaken was potentially limited in terms of generalizability to other UK and overseas fire and rescue services, since the area concerned was one of the most deprived areas in England. In addition, data recorded by fire and rescue services regarding fire injuries may potentially not be as detailed as data from health sources.

6. Conclusion

Smoke / toxic fumes inhalation accidental dwelling fire injuries were more likely in single occupancy as opposed to multiple occupancy dwellings by a ratio of 1.7 to 1 over the period studied. This might appear to indicate that those living in single occupancy dwellings may be less aware that a domestic fire has started, giving less time to avoid the effects of smoke / toxic fumes inhalation. Accidental dwelling fire smoke / toxic fumes inhalation injuries occurred mainly in areas with the highest level of deprivation within the area studied. Alcohol / drug consumption was a contributory factor in roughly 14% of the smoke / toxic fumes inhalation injuries. Alcohol / drug consumption may reduce awareness that a domestic fire has started, giving less time to avoid the effects of smoke / toxic fumes inhalation. Smoke / toxic fumes inhalation injuries sustained attempting to fight the fire constituted roughly 12% of the total number of smoke / toxic fumes inhalation injuries over the period studied. There were more male smoke / toxic fumes inhalation injuries between the ages of 20 and 85, however below age 20 and above age 85 there were more female smoke / toxic fumes inhalation injuries. There were fewer smoke / toxic fumes inhalation injuries in the 0–4 age band, and in the 5–9 age band, and these were not related to alcohol / drug consumption or attempts to fight the fire. It would appear that adults may be engaging (or failing to engage) in fire safety related behaviours that result in their children being harmed. This is an area for future studies to further analyse behaviour in relation to smoke / toxic fumes inhalation injuries sustained by young children. Since 38% of the smoke / toxic fumes inhalation injuries occurred during the night, it is important that householders take appropriate fire safety precautions before going to sleep.

The originality of the research reported in this paper concerns an analysis of smoke / toxic fumes inhalation accidental dwelling fires injuries over the period 2011 to 2022 recorded by a UK fire and rescue service. In particular, the effects of a variety of smoke / toxic fumes inhalation fire injury factors were examined in terms of their effect upon the numbers and circumstances of such injuries. This research provides an initial study of smoke / toxic fumes inhalation accidental dwelling fires injuries, and further studies could be conducted in future to see if the reported patterns of such injuries are generalisable and if the most significant factors can be identified.

The recommendations from the research would be for fire and rescue services to further inform the public regarding the importance of having an appropriate number of working smoke detectors in dwellings and the need to check and maintain them regularly. In addition, further information for the public regarding the fire hazards relating to alcohol / drug consumption and calling fire and rescue services, rather than attempting to tackle a domestic fire would appear to be appropriate. In terms of fire injury prevention strategies, increased targeting of those living in single occupancy dwellings, and those living in more deprived areas would be appropriate, since such individuals appear more at risk of smoke / toxic fumes inhalation injuries. Individuals identified as having alcohol / drug consumption issues could also be targeted for fire injury prevention, where such data would be available from health agencies. It is hoped that the research presented in this article will be of use to other fire and rescue services both in the UK and elsewhere.

Funding

There was no funding allocated for this research.

Data Availability

The data used is available upon request.

Declarations

Conflict of interest There was no conflict of interest regarding the research.

Ethical Approval Ethical approval was not required for the research reported in this article since no personal data was involved.

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