

Supplemental appendix 1. Methods for estimating population attributable fractions

In this paper, we used Levin's PAF formula [1, 2]

$$PAF = \frac{p(RR - 1)}{p(RR - 1) + 1}$$

whereby p is the proportion of the population with the exposure of interest, and RR is a measure of relative risk comparing exposed to unexposed groups. Since Levin's formula requires data on the proportion of the population with the exposure of interest (which we have obtained) and Miettinen's formula requires data on the proportion of cases that are exposed (which is extremely difficult to obtain from existing publications in the field of inclusion health), Levin's formula is the most appropriate method for PAF calculation for the specific topic under investigation.

As we used mortality to demonstrate the utility of this approach, standardised mortality ratios (SMRs) were used as RR inputs. In the specific context of inclusion health, the minimally adjusted SMRs used are likely to be reasonable. This is because we are interested in the effect of social exclusion, i.e. a broad multifactorial set of powerful and upstream exposures. We assume that if social exclusion is prevented, then the mortality rates in these groups could be similar to those in the general population. As such, it is not appropriate to control for factors on the causal pathway, i.e. all the factors that lead to social exclusion (e.g. poverty), or the negative consequences of social exclusion (e.g. addictions). Adjusted estimates may be appropriate in cases where researchers are interested in the effect of a specific exposure/behaviour, such as sleeping rough.

We then used the relative metric of PAF to calculate the absolute number of deaths attributable in England [3]

$$\text{Absolute attributable number} = PAF \times N_o$$

whereby N_o is the total number of premature deaths.

Supplemental appendix 2 shows the various data inputs, the parameters of the populations relevant to each RR and p , and sources from which they were derived. RR s and their 95% confidence intervals were extracted from studies that have accounted for bias (e.g. confounding). Very few high quality inclusion health studies in England have been designed in a way that can be used for PAF calculations. We used a summary SMR from a meta-analysis of mortality in high-income country studies to calculate an all-cause PAF for inclusion health groups (including people experiencing homelessness, prisoners and people who use illicit drugs but not including Gypsy, Roma and Traveller populations or vulnerable migrants) [4], followed by an illustrative example of cause-specific PAFs using drug user data, calculated using SMRs for select conditions and International Classification of Diseases 10th Revision (ICD-10) chapters from a recent longitudinal study of mortality in people who use illicit opioids in England [5].

Office for National Statistics (ONS) routine statistical reports [6, 7] and the integrated statistical profile of severe and multiple disadvantage from the Hard Edges report which used administrative and survey data [8] were used to calculate p 's that closely matched the age range and inclusion health group descriptions of the corresponding RR s.

We estimated uncertainty using a Monte Carlo method in which we generated 10,000 simulations of each PAF by sampling from distributions of each parameter. The distribution of risk ratios was based on published standard errors. In the case of estimating the all-cause mortality PAF for multiple overlapping inclusion health groups, we did not have published uncertainty ranges for population sizes, so we used a modified PERT distribution. We based the plausible minimum and maximum values on the Hard Edges England report, where we assumed a minimum overlap of 80% and a maximum overlap of 20% between severe and multiple disadvantage categories (SMD groups). We assumed the ratio between SMD2 and SMD3 is fixed and that the size of each is equal. These SMD groups are described in Hard Edges as combinations of three domains of disadvantage, where SMD2 refers to individuals “*experiencing two out of three disadvantage domains (i.e. ‘homelessness + offending’; ‘substance misuse + offending’; ‘substance misuse + homelessness’)*”, and SMD3 refers to individuals “*experiencing all three relevant disadvantage domains. (i.e. ‘homelessness + offending + substance misuse’)*” [8].

The size and degree of overlap between inclusion health groups is an area of uncertainty that could be explored in sensitivity analyses. Additionally, given that we cannot assume no bias in these PAF estimates, we acknowledge that the tighter the confidence interval, the less likely it is to contain the ‘real’ value.

The code and datasets used to estimate PAFs are available at:

https://github.com/ClaireXZhang/inclusion_health_PAFs.

To calculate the absolute number of attributable deaths, all available ONS data on all-cause and cause-specific deaths for people aged 15-64 years in England were extracted from ONS datasets and Nomis (a database of ONS labour market and population statistics) and totalled across 2013-2021 [9, 10]. All data used in this study are publically available.

Data sources used to extract p 's, RR s, and absolute number of deaths vary in the way they define inclusion health groups, thus limiting comparability. The ever-changing boundaries and overlaps between inclusion health groups also introduces uncertainty into the precision of estimating p . Though labels in Figure 1 have been simplified for ease of visualisation, interpretation varies across each cause of death due to the differences in the population parameters used in the calculations. For example, the analysis of opioid use data involved only data for 15-64 year-olds, which is appropriate since the majority of individuals within inclusion health groups are in this age range [8]. On the other hand, the all-cause mortality estimate for inclusion health groups involved individuals aged 18 years and older.

Supplemental appendix 2. Data inputs and outputs for PAFs and total number of attributable deaths

<i>RR</i>					<i>p</i>				<i>No</i>	<i>Outputs</i>	
Year	Age	IH group(s)	Cause of death	SMR (95% CI)	IH group(s) in England	<i>p</i> (95% CI where available)	Age	Year	Total deaths in England*	PAF (95% CI)	Attributable number of deaths (95% CI)
1970-2012	Various, most 15+	Homeless, prisoners and individuals with substance use disorders in high-income countries	All-cause	8.56(7.78-9.35)	At least 1 of: homeless, offending and substance misuse	0.0177	18+ (numerator) 18-64 (denominator)	2010-11 (numerator) 2011 (denominator)	670726	11.99(10.03-14.29)	80435(67264-95866)
			All-cause	7.72(7.47-7.97)					670726	4.74(4.5-4.98)	31761(30202-33389)
			Drug-related	52.07(46.43-59.48)					7094	27.41(24.83-30.14)	1944(1761-2138)
			Non-drug-related	5.43(5.24-5.61)					663632	3.17(3-3.36)	21055(19888-22279)
			I: INFECTIONS	19.36(15.69-24.93)					7733	11.94(9.62-14.7)	923(744-1137)
			HIV	16.65(9.47-34.87)					1109	10.33(5.71-17.63)	115(63-196)
			Viral hepatitis	103.5(61.74-242.64)					1181	43.03(30.35-56.61)	508(358-669)
			II: CANCERS	3.16(2.96-3.38)					244576	1.57(1.41-1.75)	3844(3438-4285)
			Breast	2.36(1.84-3.02)					26988	0.99(0.6-1.51)	268(162-407)
2001-2013	18-64	History of illicit opioid use in England	Digestive	3.21(2.86-3.64)	High risk opioid users	0.0074 (0.0073-0.0076)	15-64	2016-2017	71359	1.61(1.33-1.92)	1147(950-1370)
			Female genital	2.73(2.03-3.74)					15458	1.26(0.73-1.98)	195(113-306)
			Lymphoid & haematopoietic	2.29(1.72-2.99)					15657	0.94(0.51-1.52)	147(80-239)
			Respiratory	4.89(4.32-5.58)					48446	2.79(2.35-3.3)	1354(1140-1598)
			VI: NERVOUS SYSTEM	2.7(2.19-3.32)					23072	1.24(0.85-1.72)	286(196-398)
			IX: CIRCULATORY	3.61(3.33-3.92)					137261	1.89(1.67-2.14)	2598(2286-2941)
			Ischaemic heart	2.95(2.63-3.28)					73680	1.42(1.17-1.71)	1047(861-1258)
			Cerebrovascular	4.09(3.46-4.86)					22524	2.23(1.75-2.81)	503(394-632)
			X: RESPIRATORY	10.6(9.48-12.03)					45453	6.63(5.81-7.54)	3012(2639-3428)

COPD	14.81(12.62-17.6)	21009	9.26(7.78-10.97)	1945(1634-2305)
Influenza & pneumonia	9.64(8-11.79)	13959	6(4.83-7.4)	837(674-1033)
XI: DIGESTIVE	9.02(8.28-9.95)	60601	5.6(5.03-6.22)	3392(3048-3769)
Liver disease	9.13(8.24-10.18)	43217	5.67(5-6.41)	2450(2161-2771)
XX: EXTERNAL CAUSES	6.58(6-7.19)	59779	3.96(3.51-4.46)	2368(2097-2668)
Accidents	6.9(6.01-7.93)	24575	4.18(3.51-4.95)	1027(862-1216)
Suicide	5.85(5.16-6.63)	30698	3.46(2.93-4.06)	1062(900-1247)

*aged 15-64 in 2013-2021

IH = inclusion health; RR = relative risk; p = population size; N_o = total number of premature deaths

Supplementary appendix references

1. Lin C-K, Chen S-T. Estimation and application of population attributable fraction in ecological studies. *Environmental Health*. 2019;18(1):52.
2. Levin ML. The occurrence of lung cancer in man. *Acta Unio Int Contra Cancrum*. 1953;9(3):531-41.
3. World Health Organization. Environmental health: Estimations of attributable burden of disease due to a risk factor. 2018.
4. Aldridge RW, Story A, Hwang SW, Nordentoft M, Luchenski SA, Hartwell G, et al. Morbidity and mortality in homeless individuals, prisoners, sex workers, and individuals with substance use disorders in high-income countries: a systematic review and meta-analysis. *Lancet*. 2018;391(10117):241-50.
5. Lewer D, Brothers TD, Van Hest N, Hickman M, Holland A, Padmanathan P, et al. Causes of death among people who used illicit opioids in England, 2001-2013;18: a matched cohort study. *The Lancet Public Health*. 2022;7(2):e126-e35.
6. Public Health England, Home Office, Welsh Government, The Scottish Government, Public Health Wales, Department of Health (Northern Ireland). United Kingdom drug situation 2019: Focal Point annual report 2021. Available from: <https://www.gov.uk/government/publications/united-kingdom-drug-situation-focal-point-annual-report/united-kingdom-drug-situation-focal-point-annual-report-2019>.
7. Office for National Statistics. Estimates of the population for the UK, England and Wales, Scotland and Northern Ireland. 2021.
8. LankellyChase Foundation. Hard Edges: Mapping severe and multiple disadvantage (England). 2015.
9. Nomis. Mortality statistics - underlying cause, sex and age 2020. Available from: <https://www.nomisweb.co.uk/query/construct/summary.asp?mode=construct&version=0&dataset=161>.
10. Office for National Statistics. Deaths registered in England and Wales 2021. Available from: <https://www.ons.gov.uk/peoplepopulationandcommunity/birthsdeathsandmarriages/deaths/datasets/deathsregisteredinenglandandwalesseriesdrreferencetables>.