Benefits of population-level interventions for dementia risk factors: an economic modelling study for England

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Summary

Background Individual-level interventions for dementia risk factors could reduce costs associated with dementia and some are cost-effective. We aimed to estimate the cost-effectiveness of population-level interventions for tackling dementia risk factors.

Methods In this economic modelling study, we included recommended population-based interventions from a previously published review article for which there was consistent and robust evidence of effectiveness in tackling a dementia risk factor (tobacco smoking, excess alcohol use, hypertension, obesity, air pollution, and head injury). We only included interventions if they had not been introduced in England or were in place but could be extended. The interventions studied were increases in tobacco pricing, minimum pricing for alcohol, raising alcohol price, salt reduction policies, sugar reduction policies, low emission zones, and compulsory helmet use for cycling by children (aged 5–18 years). We used published intervention effect sizes and relative risks for each risk factor and a Markov model to estimate progression to dementia in populations with and without the intervention, looking at lifetime risk, in the population of England.

Findings We estimated that reductions in excess alcohol use through minimum unit pricing would lead to cost-savings of £280 million and 4767 quality-adjusted life-years (QALYs) gained over an indefinite succession of age cohorts. Reformulation of food products to reduce salt would lead to cost-savings of £2·4 billion and 39 433 QALYs gained and reformulation to reduce sugar would lead to cost-savings of £1·046 billion and 17 985 QALYs gained. Reducing dementia risk from air pollution by introducing low emission zones in English cities with a population of 100 000 or more (that do not already impose restrictions) would lead to £260 million cost-savings and 5119 QALYs gained. Raising cigarette prices by 10% to reduce dementia risk from smoking would lead to 2277 QALYs gained and cost-savings of £157 million. Making bicycle helmets compulsory for children (aged 5–18 years) to reduce dementia risk from head injury would lead to cost-savings of £91 million and 1554 QALYs gained.

Interpretation Population-level interventions could help tackle life course dementia risk and save costs.

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Introduction

Dementia is a clinical syndrome characterised by cognitive decline with resulting impairment of function.[1] Dementia affects the person living with it, their friends, and their families and has substantial health-care and social care costs, estimated at over US$1 trillion worldwide annually.[2] As the worldwide population ages, the number of people living with dementia is expected to rise.[3] Therefore, initiated and sustained prevention efforts are important for individuals and the economy. Some high-income countries have reported age-specific declines in dementia prevalence and incidence over time, which has been suggested to be attributable to improvements in life course population health during the second half of the 20th century.[4] The *Lancet* Commission on dementia prevention, intervention, and care 2020 estimated that up to 40% of dementia cases might be preventable by targeting 12 risk factors—low level of education, hearing loss, air pollution, diabetes, hypertension, smoking, excess alcohol, physical inactivity, social isolation, depression, obesity, and traumatic brain injury.[5]

We have previously reported on cost-effectiveness of individual-level interventions targeting dementia risk factors, finding that interventions to stop smoking and provide hearing aids would recoup their initial cost in terms of reduced dementia treatment costs, and treatment of hypertension would be cost-effective on standard cutoffs of £20 000 per quality-adjusted life-year (QALY).[6] Modelling of multi-domain interventions has also suggested their potential cost-effectiveness,[7,8] although there have been some criticisms of these with regard to assumptions made about the scalability and sustainability of benefit.[9]

These individual-level interventions require individuals to have agency and resources to access, engage with, and adhere to interventions. These factors potentially limit the effect of these interventions to individuals who are more educated, highly motivated, or with more resources,

Research in context

Evidence before this study

We have previously reported on cost-effectiveness of individual-level interventions targeting dementia risk factors, modelling effect on dementia incidence and its expected costs. Considering only the effect on dementia incidence, we estimated that interventions to stop smoking and provision of hearing aids would recoup their initial cost in terms of reduced costs for dementia treatment and treatment of hypertension would be cost-effective. However, individual-level interventions require individuals to have agency and resources to access, engage with, and adhere to interventions, which could limit their effect. Our previous systematic review found highly cost-effective and cost-saving population-based interventions for dementia risk factors, particularly those targeting smoking, educational attainment, and physical inactivity but we did not consider the costs and benefits associated with the potential follow-on effect on dementia prevention.

Added value of this study

To the best of our knowledge, this economic modelling study was the first to estimate the effect of population-level interventions for dementia risk factors, using England as an example. We found evidence that all population-level interventions to tackle excess alcohol use, brain injury, air pollution, smoking, obesity, and hypertension would have large gains in cost-savings and quality-adjusted life-years (QALYs).

Implications of all the available evidence

The population-level interventions accessed had cost-savings and QALY benefits. Given the possible increases in dementia incidence over the next few decades from increased rates of hypertension, diabetes, and obesity, we need policy-based approaches to tackle these risk factors without placing the responsibility on individual behaviour change. The implementation of policy-based approaches could have benefits that exceed any associated costs from implementing such policies. The potential benefits could be greater in low-income and middle-income countries and any country where population-level interventions, such as smoking bans and compulsory education, are not already in place.

exacerbating existing inequalities because these groups already have lower rates of dementia.[10] Therefore, population-level interventions, which target the environments of whole populations rather than requiring individual agency, might be more effective and equitable.[11]

In a previous study, we have shown that population-level approaches are under-considered in the dementia prevention literature compared with individual-level approaches.[12] We have also found cost-effective and cost-saving population-based interventions for dementia risk factors, particularly for those targeting smoking, educational attainment, and physical inactivity.[13] However, we did not model the costs and benefits associated with the potential follow-on effect on dementia prevention. Economic modelling for non-communicable diseases has not generally included the additional impact of preventing or reducing dementia risk, which means the potential benefits of dementia prevention have not been considered[14] despite dementia being a substantial driver of costs in an ageing population. In this study, we assessed population-level approaches to dementia risk reduction in terms of their impact on the costs of the disease and the benefits in terms of health-related quality of life.

See Online for appendix

For more on the **CCEMG–EPPI-Centre Cost Converter** see https://eppi.ioe.ac.uk/costconversion/#:~:text=CCEMG%20%2D%20EPPI%2DCentre%20Cost%20Converter,1.4&text=This%20'CCEMG%E2%80%93EPPI%20Centre%20Cost,target%20currency%20and%20price%20year

Methods

Interventions

In this economic modelling study, we considered any recommended interventions from a previously published review article[15] for which there was consistent and robust evidence of effectiveness in tackling a dementia risk factor using population-based interventions, as evaluated by the review article. We only modelled interventions that were not already in place in England or interventions that were in place but could be extended (eg, increases to existing alcohol taxation). We used published effect sizes for each intervention to estimate the proportion of people with each risk factor who would benefit from the intervention. In some cases, where published effect sizes were not specific enough for the intervention studied or were relatively dated, we searched PubMed using search terms for the relevant risk factor and possible interventions and used studies if they provided an effect estimate for reduction in the specified risk factor associated with an intervention. In each case, the comparator was the current situation in England.

We used previously published population attributable fractions (PAF) from the *Lancet* Commission on dementia prevention, intervention, and care 2020[5] to derive relative risks (RRs) for each risk factor (tobacco smoking, excess alcohol use, hypertension, obesity, air pollution, and head injury). PAF are a statistical construct used to estimate what proportion of disease cases would be prevented if a risk factor was eliminated. Derivation of RRs to account for the communality of risk factors is outlined in the appendix (pp 4–5) and has been published.[7] All costs are reported in 2021£ prices. If costs needed to be converted to UK currency, we used an online calculator (CCEMG–EPPI-Centre Cost Converter (1.4) to adjust for population and the purchasing power parity exchange rate. All data were from previously published work and no ethical approval was needed to complete this work.

Data and statistical analysis

Since costing requires using a specific place as the example, as previously published,[6] we used England as our setting, applying risk effects to the adult English population or population subgroups where appropriate, as we had good pre-existing data on risk factor prevalence in this setting. Risk factor prevalences were used for the time of life to which the risk applies—eg, as hypertension is considered to be a risk factor for dementia in mid-life (age 45–64 years), prevalence is given for all people with hypertension in mid-life in England.

Where possible, we quantified risk on a continuous scale (eg, for air pollution, risk was per unit increase in pollution) and, where this was not possible, we treated risk factors as binary (ie, a person either has the risk factor or does not). We assumed intervention effects would apply equally to everyone and would continue to maintain their effectiveness throughout the life course.

We measured the benefit of interventions in terms of QALYs, which are widely used in assessment of health and social care interventions. One QALY equates to a year of life in perfect health, thus years of life can be weighted to take into account quality as well as quantity of life.[16] Details of annual costs of dementia per sector (health care, social care, and unpaid carer costs), by age group (mid-life [45–64 years] and later life [≥65 years]), and dementia stage and by quality of life and mortality, were from published sources.[17,18] Our general approach to analysis is described in the appendix (pp 2–4). We calculated cost-savings from reduced dementia prevalence from November, 2014 cost-of-illness figures,[19] which were updated to April, 2021, using the Hospital and Community Health Services pay and prices index.[20] Cost-savings or excess costs were considered over the whole remaining lifetime of those with and without the risk factor. We established when in the life course each intervention would be delivered and discounted future dementia-associated savings back to present value using an annual discount rate of 3·5%, as recommended by the UK Treasury.[21] All benefits were summed to represent the lifetime effect for an infinite succession of such age cohorts using a period life table.[22] Costs were calculated over the lifetime of an infinite succession of age cohorts who would benefit from the policy discounted by 3·5% per year to give the final result with all current and future cohorts discounted. All estimates were calculated at net present value.

We used a Markov model previously developed for assessing the cost-effectiveness for disease-modifying therapies in Alzheimer's disease (figure; appendix p 3).[19] The key input in this model was age-specific incidence of dementia in England from the Cognitive Function and Ageing Studies.[23] We used the RR from the 2020 *Lancet* Commission,[5] together with published estimates of risk factor prevalence, and calculated RRs to apply to the population to represent those with and without each risk factor (appendix pp 5–6). We considered three stages of dementia (mild, moderate, and severe), transition rates between stages, excess mortality rates in moderate and severe stages, stage-specific costs (including health care, social services, and unpaid care by family), and stage-specific QALY levels.[23] To account for increases in life

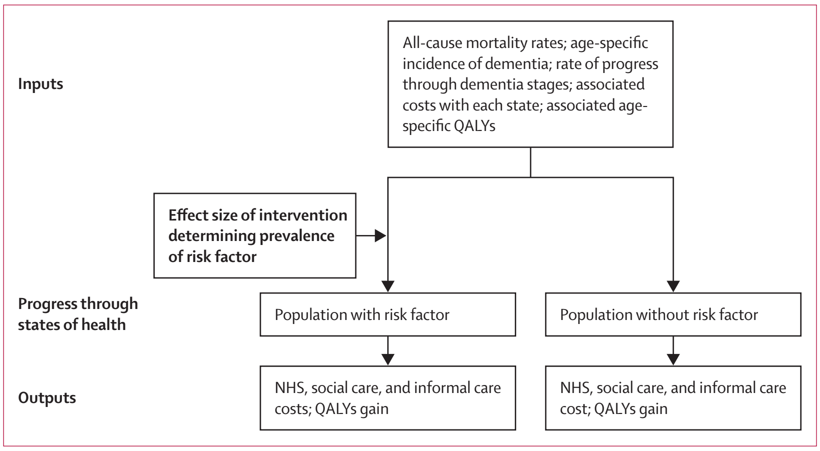

***Figure:* Inputs, process, and outputs of the Markov model**
NHS=UK National Health Service. QALYs=quality-adjusted life-years

expectancy from reductions in risk factors, such as smoking, we took these reductions in mortality into account and considered the future risk of dementia during the life-years gained. We estimated the dementia-specific year-by-year costs and health status for those with and without the risk factor and summed these over time. Further details of the model and annual rates of transition between dementia stages and death are in the appendix (p 4).

We used age-specific average UK National Health Service (NHS), social care, and unpaid care costs for dementia. These costs relate to the English population as a whole and are, in effect, weighted averages of costs for those with and without dementia.[20] To derive costs for those with dementia, we used estimates of age-specific prevalence of dementia from the Cognitive Function and Ageing Studies[23] and age-specific costs,[18] accounting for changing stage distribution of dementia with age.

As a sensitivity analysis, we selected the most conservative estimates for primary analysis where there were variations in published figures on intervention effect size or other parameters that could affect our cost and benefit analysis and modelled alternative options to illustrate the range of potential benefit. We also created tornado diagrams and carried out probabilistic sensitivity analyses (presented in the form of an incremental cost-effectiveness ratio scatter plot) for each intervention (appendix p 10).

We used TreeAge Pro 2018 (1.0) for all analyses.

For more on **TreeAge** see https://www.treeage.com/

Role of the funding source

The funders of the study had no role in study design, data collection, data analysis, data interpretation, or writing of the report.

Results

There were relevant interventions for tobacco smoking (one intervention; increase tobacco pricing[24]), excess alcohol use (two interventions; minimum unit pricing[25] and increasing alcohol price[26]), obesity (one intervention; reformulating food to reduce sugar[27]), hypertension (one intervention; reformulating food to reduce salt[28]), air pollution (one intervention; implementing low emission zones [LEZs][29]), and head injury (one intervention; compulsory bicycle helmets[30]). No relevant interventions that were not already in place in England with sufficient data were identified for the other risk factors (physical inactivity, diabetes, depression, social isolation, low educational attainment, or hearing loss).

RRs for each risk factor, prevalence of risk factors, and data on mortality are presented in table 1. The results of interventions in the five areas (alcohol, food, air pollution, smoking, and traumatic brain injury) are in table 2. Further details on assumptions and modelling for specific risk factors are in the appendix (pp 8–9).

Consumption of alcohol at the rate of more than 21 units per week in mid-life (age 45–64 years) is estimated to increase the risk of dementia by around 7%.[5] Following the 2018 imposition of a minimum price of alcohol of £0·5 per unit in Scotland, alcohol consumption reduced by 1·2 units per week per adult, with a particular reduction in those in most deprived areas.[25] The policy appears to have led to no cost to the alcohol industry and no statistically significant change in moderate drinking (only heavy drinking), and retailers appear to have complied with the policy.[25] There were no estimates of enforcement or monitoring costs of this policy, so we do not include any in our model. In England, the proportion of adults aged 45–64 years who drink >21 units of alcohol per week is 19%.[31] Introducing a minimum price per unit of alcohol in England would be expected to result in 4767 QALYs gained and a cost-saving of £280 million.

The effect of a price rise for the minimum price of alcohol intervention depends on the price elasticity of demand or how sensitive the quantity demanded is to the price, with higher numbers indicating greater sensitivity to price. For example, if a price rise of 10% causes demand to fall by 5%, the price elasticity would be –0·50. A review of the evidence by NHS Scotland indicates an elasticity of –0·50 or –0·35 in people who drink heavily.[26] We illustrate a 10% increase in the price of alcohol with an elasticity of –0·35. We estimated that the cost-savings in England would be £172 million with 2934 QALYs gained.

Hypertension in mid-life carries an estimated 22% excess risk of dementia.[5] The prevalence of hypertension in this age group (including those treated but not with adequately controlled hypertension) is estimated at 28%.[32] Hypertension also carries a 27% excess risk of mortality.[35] The 2019 Health Survey for England[31] has data on the systolic blood pressure in 1426 people in the age group 45–64 years. We modelled a reformulation policy to reduce salt content of food by 1·68 g per day,[28] which would be expected to reduce systolic blood pressure by 1·59 mm Hg,[36] leading to a reduction in the prevalence of hypertension of 5%.[31] If the reformulation policy was introduced, there would be 39 433 QALYs gained and cost-savings of £2·368 billion (despite people living longer).

Obesity in mid-life carries an estimated 21% excess risk of dementia.[5] The prevalence of obesity in the mid-life age group was 31%.[32] A systematic review has indicated a mean reduction in bodyweight of 1·04 kg if food products were reformulated to reduce their sugar content so that daily consumption falls by 11·2%.[27] We used data on height and weight from the Health Survey for England[31] for those who were defined as having obesity (BMI ≥30 kg/m^2) in mid-life to estimate the change in BMI associated with the specified amount of weight loss and, in turn, estimate those who would no longer be classed as having obesity following this weight loss. We estimated that there would be 17 985 QALYs gained and £1·046 billion cost-savings if this policy was introduced.

Air pollution in later life (aged ≥65 years) increases the risk of dementia.[5] Interventions to reduce ambient air

	Alcohol use	Hypertension	Obesity	Air pollution	Smoking	Traumatic brain injury
Mediating risk factor	Consuming more than 21 units of alcohol per week	Dietary salt	Dietary sugar	Road traffic	Low smoking cessation in mid-life	Absence of head protection
Relative risk of dementia for risk factor	1·07[5]	1·22[5]	1·21[5]	1·03[5]	1·20[5]	1·29[5]
Prevalence of risk factor in key age group	19% (mid-life)[31]	28% (mid-life)[32]	31% (mid-life)[32]	75% (later life)[33]	8% (later life)[34]	0·16% (mid-life)[30]
Risk of dementia relative to population mean*						
With the risk factor	1·060	1·148	1·135	0·990	1·181	1·290
Without the risk factor	0·987	0·943	0·936	1·00	0·984	1·00
Relative risk of all-cause mortality	1·00	1·27	1·18	1·00	1·41	1·00
Risk of mortality relative to population mean†						
With the risk factor	1·00	1·181	0·95‡	1·00	1·41	1·00
Without the risk factor	1·00	0·930	0·94§	1·00	1·07¶	1·00
Benefits per person with risk factor removed						
Cost-savings per person (2021 prices)	£645	£1884	£1977	£152	£3581	£2925
Health gain, QALYs	0·011	0·034	0·034	0·003	0·052	0·050

All estimates are net present value. All relative risks for dementia were obtained from the 2020 *Lancet* Commission for dementia prevention, intervention, and care.[5] Mid-life includes people ages 45–64 years and later life includes people ages 65 years and older. QALY=quality-adjusted life-year. *Mean population dementia risk. †Mean population mortality. ‡Obesity grade 1 (BMI 30–34 kg/m^2). §Overweight. ¶Former smokers.

Table 1: **Risk factor prevalences, relative risks, and mortality**

	Implement a minimum unit price of alcohol to match the effect seen in Scotland	Raise price of alcohol by 10% assuming elasticity of –0·35	Reformulation to reduce dietary salt	Reformulation to reduce dietary sugar	Debar cars of Euro 1 standard from 73 urban areas currently without low emission zone restrictions	Raise price of cigarettes by 10% to increase cessation in mid-life (40–64 years); elasticity of –0·375	Require children aged 5–18 years to wear a helmet when cycling
Mean reduction	1·2 units per week	0·7 units per week	1·68 g salt per day; 1·59 mm Hg systolic blood pressure	11·2% daily sugar intake; 0·37 kg/m^2 BMI	2 μg/m^3 nitrous oxides	NA	NA
Reduction in prevalence of risk factor, %	10·0%	6·0%	5·0%	2·3%	NA	0·3%	NA
People aged 45 years shedding risk, n	15 169	9335	43 130	18 514	59 727	1533	1088
Total lifetime benefits in age cohort*							
Cost-savings per age cohort (2021 prices)	£9·8 million	£6·0 million	£82·9 million	£36·6 million	£9·1 million	£5·5 million	£3·2 million
Health gain, QALYs	167	103	1380	629	179	79·7	54
Benefits summed over indefinite succession of age cohorts†							
Cost-savings for infinite succession of cohorts (2021 prices)	£280 million	£172 million	£2368 million	£1046 million	£260 million	£157 million	£91 million
Health gain, QALYs	4767	2934	39 433	17 985	5119	2277	1554

All estimates are net present value. LEZ=low emission zone. NA=not applicable. QALY=quality-adjusted life-year. *Benefit over a lifetime, for each age cohort. †Total benefits over indefinite succession of cohorts.

Table 2: **Policy interventions and their estimated effects**

pollution have been studied in a systematic review.[37] We illustrate the effects of interventions to reduce ambient air pollution if England were to adopt LEZs, based on findings from a study which thoroughly reported on effect sizes of LEZs on ambient air pollution. The study focused on LEZs in 17 cities in Germany banning cars of Euro 1 standard without appropriate retrofitting systems.[29] The study reported a mean reduction of 2 mg/m^3 in oxides of nitrogen in LEZs. The populations of the cities in question mainly exceeded 100 000 people. The LEZ mean coverage of the urban area was 19% and the coverage of the population was 38%. We applied these data to the 73 cities with a population of 100 000 or more in England that do not already impose restrictions.[38] The total population of the 73 cities was 15 023 552 people, of which the population within the LEZs would be 5 783 400 people.

A population cohort-based study in Ontario reported a hazard ratio (HR) of 1·1 for each unit interquartile range (26·7 mg/m^3) increase in $N0_2$.[29] By interpolation, the HR of a 2 mg/m^3 reduction would be 0·993. We expect 5119 QALYs gained and cost-savings of £260 million.

Smoking in later life carries an estimated 20% excess risk of dementia. There is evidence that an increase in tobacco price can enhance the rate of smoking cessation, which would otherwise not occur.[24] In later life, the excess mortality risk from smoking varies by age. People who smoked but no longer smoke retain a proportion of this excess risk.[39] By applying the prevalence by smoking status[31] to the RR by age, we inferred an age-specific risk for continuing versus discontinuing smoking to apply to the population mortality rate.

Since few people take up smoking in later life, our calculations implicitly relate to people who had smoked throughout the majority of their life and continued to smoke into later life. Since older people (aged ≥65 years) who smoke are reluctant to quit,[34] the key group for cessation is the 45–64 years age group. The prevalence of smoking in this age group was 15% and 47% of smokers quit between the ages of 45 and 64 years (3·1% per annum). We assumed that the effect of a 10% price increase in tobacco and the lowest published elasticity[24] of –0·375 would increase the rate of cessation in this age group to 48·4%, reducing prevalence from 8·00% to 7·74%. We estimated that the intervention would result in 2227 QALYs gained and cost-savings of £157 million.

Traumatic brain injury increases the risk of dementia by 1·29 times compared with those who have not had a brain injury. The risk from traumatic brain injury in mid-life is for people who have ever had a traumatic brain injury. Therefore, reducing traumatic brain injury events in children would lead to a reduction in those who had a traumatic brain injury in the key age group for dementia risk. We examined a policy of compulsory helmet use for cycling by children in the age group 5–18 years. A cost-effectiveness study from New Zealand has predicted the effects of cycle helmet legislation[30] based on reports of similar policies in Victoria, Australia,[40] and Seattle, USA.[41] We estimated that the effect in England using the New Zealand study published figures would have a 10·4 times greater effect in England due to the larger population in the 5–18 years age group,[33] meaning that the annual number of hospital admissions of cyclists age 5–18 years for serious head injuries would be 2376 in England without the policy, which would be reduced by 1100 to 1276 people with the policy. 98% of people aged 18 years in the general population survive to age 45 years in the whole population,[22] so that the reduction in the number of people with traumatic brain injuries at age 45 years would be 1088 people.

The proportion of the population with traumatic brain injury caused by cycling accidents between 5 and 18 years is small; therefore, we considered the risk of dementia without traumatic brain injury as the population rate. After the first 6 months of the event, there is no excess mortality in traumatic brain injury. There is a high RR within the first 6 months,[42] but we neglected this factor since the mortality rate in the 5–18 years age group is low. We estimated that this intervention would lead to £91 million in cost-savings and 1554 QALYs gained. We calculated the present value of dementia-related savings at age 45 years, but an alternative would be to calculate costs and benefits from the age at which the expenditure occurred, roughly age 11 years. Discounting at 3·5% per annum from ages 45 years to 11 years would reduce all the benefits by 70%, meaning £27 million in cost-savings and 466 QALYs gained.

Tornado diagrams and probabilistic sensitivity analyses found that all interventions delivered lower cost and increased QALYs in every case (appendix pp 11–17). The leading influencing variable was the QALY in stage 1 of dementia and the excess risk of dementia attributed to the intervention-specific risk factor. Sensitivity analyses using alternative price elasticity thresholds found that intervention impacts in terms of QALYs and cost-savings more than doubled for interventions tackling smoking (£489 million and 7105 QALYs) and almost doubled for interventions addressed at alcohol excess (£272 million and 4645 QALYs; appendix p 17) compared with the primary analysis.

Discussion

To our knowledge, this study is the first to estimate dementia-specific costs and benefits of population-based approaches to tackling dementia risk factors. We used a lifetime perspective with an infinite time horizon and found that, without exception, all the population-based interventions that we examined are cost-saving and have associated QALY gains. The size of the benefits is large when applied to the whole of the eligible English population. We also show how including dementia in cost-effectiveness analyses for non-communicable diseases could have implications when these interventions are evaluated, either by enhancing estimated benefits or by demonstrating benefits when calculations omitting dementia would find no benefit. For example, a cost-effectiveness review of New Zealand legislation on helmets for cyclists concluded that the benefit–cost ratio would be favourable at 2·6 in the 5–12 years age group, indicating the benefits (ie, reduction in the hospital cost of treating cycling accidents and a willingness-to-pay survey of people's aversion to a hospital stay) are 2·6 times the costs of the intervention (including cost of helmets) but are unfavourable at 0·8 in the 13–18 years age group.[43] The net cost in the 13–18 years age group was NZ$ 200 000 in 2000, equivalent to £1·5 million in this country in 2021 after adjusting for population and the purchasing power parity exchange rate. The lifetime cost-savings associated with the reduction of any traumatic brain injuries in the 45 years age cohort would be £1 million. Moreover, these cost-savings would accrue to each successive cohort indefinitely. The value of the cost-savings discounted at 3·5% per year to age 45 years would be £28·8 million. However, these cost-savings would have to be discounted further, by 27 years, to age 18 years, reducing their value to £11·4 million. Nevertheless, taking account of the impact on dementia in addition to other health benefits takes the benefit–cost ratio over unity, even without taking account of the impact on health-related quality of life, and in this way tip the scales in favour of the policy for helmet legislation.

Although there are few publications about population interventions in dementia, our findings are in line with studies in other areas. For example, a New Zealand modelling study found that food taxes and subsidies resulted in health gains and cost-savings and had positive impacts on health outcomes.[44] There is also preliminary evidence that making green spaces and roads accessible and safe increases physical activity, which, in turn, might reduce dementia incidence.[45] Similarly, population dietary interventions reduce hypertension in low-income and middle-income countries.[46]

The strengths of this study include the modelling of the costs and benefits of population-level interventions in relation to dementia for the first time, use of interventions with robust evidence of effectiveness, and the application of well established RRs with consideration of risk factor communality as well as published data on dementia progression and mortality statistics. In addition, we completed a systematic review to identify population-based interventions to target dementia risk factors.[13] However, we acknowledge the limitations of relying on observational data to estimate RRs as, while the strength of the evidence is good,[13] causality cannot be proven. Additionally, we used RRs from international meta-analyses; however, our analysis is specific to England and the RRs might differ. Our findings are likely to be generalisable to similar countries or regions but it would be advisable to replicate these analyses using country-specific or region-specific RRs and risk factor prevalence data.

Wherever possible, we have been conservative in our estimates. Therefore, the actual benefits of the interventions might be greater than those presented in this study. Our sensitivity analyses also showed that all the interventions decreased dementia-related costs and increased QALYs. The limitations of our study include the possibility that interventions might not be as effective as in published studies or might increase dementia incidence, as hypothesised in a previous modelling study assessing reduced hypertension and its impact on dementia incidence.[47] However, we found the impact on dementia-related costs with mortality risk as the comparator is to reduce them. Food reformulation is assumed to affect diet overall in terms of calorie or salt intake, but it is possible that people could source other foods and the same reformulation might not affect the whole population in the same way. However, substitution was assessed for in some of the primary studies and was found not to have occurred.[15] In many cases, the costs of interventions were not presented by published studies and this has been reflected in our analyses.

We acknowledge that debating, creating, and enforcing legislation takes time and resources. In addition, within the counterfactual scenario, we did not model changes to the risk factors from other policies, such as policies to encourage use of low emission cars or changes to smoking prevalence from other policies. Because of these factors, the costs might be higher and the benefits lower. Overall, given the savings, the interventions are still likely to be economically beneficial. There might be a lagging effect of risk factor reduction on outcomes, which could impact how quickly changes in policies have an effect, but we did not include this in our modelling as we assumed a steady-state model. Moreover, we also implicitly assumed that the *Lancet* Commission[5] findings on excess risk associated with each risk factor apply fully from the age of 45 years or 65 years. We only considered the effect of these interventions on dementia, but after including the effect that the interventions had on mortality if any (from any other causes). We did not consider the effect (positive or negative) of any intervention on other outcomes, such as on cardiovascular disease and stroke, or on overall health. Our approach means the overall societal benefits are likely to be much higher than we estimated in this study. Interventions might have important (although not directly relevant to our study) potential negative aspects, such as a reduction in the liberty of an individual. Additionally, we acknowledge that dementia incidence and mortality rates in the UK might be changing over time and the estimates we used for incidence in this study are from 2011. Although a study from the English Longitudinal Study of Ageing[48] found an increase in dementia prevalence from 2008 to 2016, their results had uncertainty as the study used imputed data;[49] therefore, we assumed static rates of dementia so there is a level of uncertainty in our estimates. We cannot rule out model misspecification bias, although we used best available estimates for inputs and assumptions. We did not model the potential cost of the interventions included in our study (as these were not available) or their impact on other conditions, such as cardiovascular disease. Therefore, we cannot comment on the overall impact of the intervention as we were focused on dementia specifically.

Overall, we have found evidence supporting the use of population-level approaches to manage dementia risk with cost-savings and QALYs gains. It is possible that policy makers are hesitant to put these interventions into place given the long lead time before the benefits of cognitive decline could be expected. However, given the effect of these interventions on vascular or brain health in general, benefits in terms of other non-communicable diseases would be expected sooner. Our analysis further strengthens the argument for implementation of effective population-level policies as soon as practicably possible.

Contributors

All authors designed the study in collaboration. RA and NM verified the data. NM wrote the first draft of the manuscript and all authors reviewed and edited the manuscript.

Declaration of interests

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Data sharing

All data used in the analysis are available from previously published work.

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References

1 American Psychiatric Association. Diagnostic and statistical manual of mental disorders (DSM-5). Washington, DC: American Psychiatric Association Publishing, 2013.
2 Wimo A, Jönsson L, Bond J, Prince M, Winblad B. The worldwide economic impact of dementia 2010. *Alzheimers Dement* 2013; **9:** 1–11.
3 Nichols E, Steinmetz JD, Vollset SE, et al. Estimation of the global prevalence of dementia in 2019 and forecasted prevalence in 2050: an analysis for the Global Burden of Disease Study 2019. *Lancet Public Health* 2022; **7:** e105–25.
4 Prince M, Ali G-C, Guerchet M, Prina AM, Albanese E, Wu Y-T. Recent global trends in the prevalence and incidence of dementia, and survival with dementia. *Alzheimers Res Ther* 2016; **8:** 23.
5 Livingston G, Huntley J, Sommerlad A, et al. Dementia prevention, intervention, and care: 2020 report of the *Lancet* Commission. *Lancet* 2020; **396:** 413–46.
6 Mukadam N, Anderson R, Knapp M, et al. Effective interventions for potentially modifiable risk factors for late-onset dementia: a costs and cost-effectiveness modelling study. *Lancet Healthy Longev* 2020; **1:** e13–20.
7 Wimo A, Handels R, Antikainen R, et al. Dementia prevention: the potential long-term cost-effectiveness of the FINGER prevention program. *Alzheimers Dement* 2022; published online July 26. https://doi.org/10.1002/alz.12698.
8 McRae I, Zheng L, Bourke S, Cherbuin N, Anstey KJ. Cost-effectiveness of dementia prevention interventions. *J Prev Alzheimers Dis* 2021; **8:** 210–17.
9 Walsh S, Brayne C. Comment on "Dementia prevention: the potential long-term cost-effectiveness of the FINGER prevention program". *Alzheimers Dement* 2023; **19:** 4758–59.
10 Kivimäki M, Batty GD, Pentti J, et al. Association between socioeconomic status and the development of mental and physical health conditions in adulthood: a multi-cohort study. *Lancet Public Health* 2020; **5:** e140–49.
11 Walsh S, Govia I, Wallace L, et al. A whole-population approach is required for dementia risk reduction. *Lancet Healthy Longev* 2022; **3:** e6–8.
12 Walsh S, Wallace L, Kuhn I, et al. Are population-level approaches to dementia risk reduction under-researched? A rapid review of the dementia prevention literature. *J Prev Alzheimers Dis* 2024; **11:** 241–48.
13 Walsh S, Brain J, Mukadam N, et al. A systematic review of the cost-effectiveness of community and population interventions to reduce the modifiable risk factors for dementia. *Maturitas* 2022; **166:** 104–16.
14 Bertram M, Banatvala N, Kulikov A, et al. Using economic evidence to support policy decisions to fund interventions for non-communicable diseases. *BMJ* 2019; **365:** l1648.
15 Walsh S, Wallace L, Kuhn I, et al. Population-level interventions for the primary prevention of dementia: a complex evidence review. *EClinicalMedicine* 2024; **70:** 102538.

16 Bravo Vergel Y, Sculpher M. Quality-adjusted life years. *Pract Neurol* 2008; **8:** 175–82.
17 Asaria M. Health care costs in the English NHS: reference tables for average annual NHS spend by age, sex and deprivation group. CHE research paper 147. York: Centre for Health Economics, 2017.
18 Personal Social Services Research Unit. Unit costs of health and social care 2018. https://www.pssru.ac.uk/project-pages/unit-costs/unit-costs-2018/ (accessed Sept 24, 2023).
19 Anderson R, Knapp M, Wittenberg R, Handels R, Schott JM. Economic modelling of disease-modifying therapies in Alzheimer's disease. London: London School of Economics and Political Science, 2018.
20 Jones KC, Weatherly H, Birch S, et al. Unit costs of health and social care 2022 manual. Canterbury: Personal Social Services Research Unit, 2022.
21 UK National Institute for Health and Care Excellence. Guide to the methods of technology appraisal. Process and methods [PMG9]. London: National Institute for Health and Care Excellence, 2013.
22 Office for National Statistics. National life tables—life expectancy in the UK: 2020 to 2022. 2020. https://www.ons.gov.uk/peoplepopulationandcommunity/birthsdeathsandmarriages/lifeexpectancies/bulletins/nationallifetablesunitedkingdom/2020to2022#:~:text=1.-,Main%20points,from%2083.0%20years%20for%20females (accessed Sept 24, 2023).
23 Matthews FE, Stephan BC, Robinson L, et al. A two decade dementia incidence comparison from the Cognitive Function and Ageing Studies I and II. *Nat Commun* 2016; **7:** 11398.
24 Wilson LM, Avila Tang E, Chander G, et al. Impact of tobacco control interventions on smoking initiation, cessation, and prevalence: a systematic review. *J Environ Public Health* 2012; **2012:** 961724.
25 Scottish Government. Alcohol (minimum pricing) (Scotland) Act 2012—operation and effect 2018 to 2023: report. Sept 20, 2022. https://www.gov.scot/publications/alcohol-minimum-pricing-scotland-act-2012-report-operation-effect-minimum-pricing-provisions-2018-2023/pages/2/ (accessed Sept 24, 2023).
26 Beeston C, Robinson M, Giles L, et al. Evaluation of minimum unit pricing of alcohol: a mixed method natural experiment in Scotland. *Int J Environ Res Public Health* 2020; **17:** 3394.
27 Hashem KM, He FJ, MacGregor GA. Effects of product reformulation on sugar intake and health-a systematic review and meta-analysis. *Nutr Rev* 2019; **77:** 181–96.
28 Collins M, Mason H, O'Flaherty M, Guzman-Castillo M, Critchley J, Capewell S. An economic evaluation of salt reduction policies to reduce coronary heart disease in England: a policy modeling study. *Value Health* 2014; **17:** 517–24.
29 Morfeld P, Groneberg DA, Spallek MF. Effectiveness of low emission zones: large scale analysis of changes in environmental NO_2, NO and NO_x concentrations in 17 German cities. *PLoS One* 2014; **9:** e102999.
30 Hansen P, Scuffham PA. The cost-effectiveness of compulsory bicycle helmets in New Zealand. *Aust J Public Health* 1995; **19:** 450–54.
31 NHS England. Health Survey for England: official statistics, national statistics, survey, accredited official statistics. https://digital.nhs.uk/data-and-information/publications/statistical/health-survey-for-england (accessed Sept 24, 2023).
32 NHS England. Health survey for England, 2021: data tables. https://digital.nhs.uk/data-and-information/publications/statistical/health-survey-for-england/2021/health-survey-for-england-2021-data-tables (accessed Sept 24, 2023).
33 Office for National Statistics. Census. 2021. https://www.ons.gov.uk/census (accessed Sept 24, 2023).
34 NHS Health Scotland, Action on Smoking and Health Scotland. A guide to smoking cessation in Scotland 2010—planning and providing specialist smoking cessation services. https://www.healthscotland.scot/media/1096/a-guide-to-smoking-cessation-in-scotland-2017.pdf (accessed Sept 24, 2023).
35 Shang X, Zhang X, Huang Y, et al. Temporal trajectories of important diseases in the life course and premature mortality in the UK Biobank. *BMC Med* 2022; **20:** 185.
36 He FJ, Li J, Macgregor GA. Effect of longer term modest salt reduction on blood pressure: Cochrane systematic review and meta-analysis of randomised trials. *BMJ* 2013; **346:** f1325.
37 Chen H, Kwong JC, Copes R, et al. Exposure to ambient air pollution and the incidence of dementia: a population-based cohort study. *Environ Int* 2017; **108:** 271–77.
38 Department for Environment, Food & Rural Affairs. Clean air zones. Jan 28, 2020. https://www.gov.uk/guidance/driving-in-a-clean-air-zone (accessed Sept 24, 2023).
39 Gellert C, Schöttker B, Brenner H. Smoking and all-cause mortality in older people: systematic review and meta-analysis. *Arch Intern Med* 2012; **172:** 837–44.
40 Cameron MH, Vulcan AP, Finch CF, Newstead SV. Mandatory bicycle helmet use following a decade of helmet promotion in Victoria, Australia—an evaluation. *Accid Anal Prev* 1994; **26:** 325–37.
41 Thompson RS, Rivara FP, Thompson DC. A case–control study of the effectiveness of bicycle safety helmets. *N Engl J Med* 1989; **320:** 1361–67.
42 Brown AW, Leibson CL, Malec JF, Perkins PK, Diehl NN, Larson DR. Long-term survival after traumatic brain injury: a population-based analysis. *NeuroRehabilitation* 2004; **19:** 37–43.
43 Taylor M, Scuffham P. New Zealand bicycle helmet law—do the costs outweigh the benefits? *Inj Prev* 2002; **8:** 317–20.
44 Blakely T, Cleghorn C, Mizdrak A, et al. The effect of food taxes and subsidies on population health and health costs: a modelling study. *Lancet Public Health* 2020; **5:** e404–13.
45 McGowan VJ, Buckner S, Mead R, et al. Examining the effectiveness of place-based interventions to improve public health and reduce health inequalities: an umbrella review. *BMC Public Health* 2021; **21:** 1888.
46 Zhou B, Perel P, Mensah GA, Ezzati M. Global epidemiology, health burden and effective interventions for elevated blood pressure and hypertension. *Nat Rev Cardiol* 2021; **18:** 785–802.
47 Chen Y, Araghi M, Bandosz P, et al. Impact of hypertension prevalence trend on mortality and burdens of dementia and disability in England and Wales to 2060: a simulation modelling study. *Lancet Healthy Longev* 2023; **4:** e470–77.
48 Chen Y, Bandosz P, Stoye G, et al. Dementia incidence trend in England and Wales, 2002–19, and projection for dementia burden to 2040: analysis of data from the English Longitudinal Study of Ageing. *Lancet Public Health* 2023; **8:** e859–67.
49 Ahmadi-Abhari S, Kivimäki M. Do age-standardised dementia incidence rates really increase in England and Wales? *Lancet Public Health* 2024; **9:** e152–53.