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Valuing the health benefits of nature-based recreational physical activity in England

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ABSTRACT

Physical activity (PA) reduces the risk of several non-communicable diseases (NCDs). Natural environments support recreational PA. Using data including a representative cross-sectional survey of the English population, we estimated the annual value of nature-based PA conducted in England in 2019 in terms of avoided healthcare and societal costs of disease.

Population-representative data from the Monitor of Engagement with the Natural Environment (MENE) survey (n = 47,580; representing 44,386,756) were used to estimate the weekly volume of nature-based recreational PA by adults in England in 2019. We used epidemiological dose–response data to calculate incident cases of six NCDs (ischaemic heart disease (IHD), ischaemic stroke (IS), type 2 diabetes (T2D), colon cancer (CC), breast cancer (BC) and major depressive disorder (MDD)) prevented through nature-based PA, and estimated associated savings using published costs of healthcare, informal care and productivity losses. We investigated additional savings resulting from hypothetical increases in: (a) visitor PA and (b) visitor numbers.

In 2019, 22 million adults > 16 years of age in England visited natural environments at least weekly. At reported volumes of nature-based PA, we estimated that 550 cases of IHD, 168 cases of IS, 1,410 cases of T2D, 41 cases of CC, 37 cases of BC and 10,552 cases of MDD were prevented, creating annual savings of £108.7million (95 % uncertainty interval: £70.3million; £150.3million).

Nature-based recreational PA in England results in reduced burden of disease and considerable annual savings through prevention of priority NCDs. Strategies that increase nature-based PA could lead to further reductions in the societal burden of NCDs.

1. Introduction

1.1. Background

Non-communicable diseases (NCDs) exert very significant burdens on people and communities, health systems and economies at multiple levels (Muka et al., 2015; World Health Organization, 2022a). The most common non-communicable diseases (NCDs) (including heart disease, stroke, cancer, diabetes and chronic lung disease) cause 74 % of global mortality (World Health Organization, 2022a).

In spite of progress in reducing age-standardised death rates, mortality attributable to NCDs is growing in most countries globally, as is the proportion of years of healthy life lost due to disability from NCDs (GBD, 2019 Diseases and Injuries Collaborators, 2020). Increasingly, these burdens are disproportionately felt by those already impacted by socioeconomic vulnerabilities (Engelgau et al., 2011; Sommer et al., 2015). Although lack of data in low- and middle-income countries has precluded reliable estimation of the absolute global impact of all NCDs

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in terms of dollars or disability-adjusted life years (DALYs), the macroeconomic burden due to major NCDs (cardiovascular disease, cancer, chronic respiratory disease, diabetes, and mental health conditions) in the US alone was estimated at approximately US$95 trillion for the period 2015–2050 (Chen et al., 2018).

Many factors drive the global increase in NCD-related burden, and the interrelationships between them are complex. However, common risk factors for several major NCDs have been identified, notably including physical inactivity (Peters et al., 2019). Physical inactivity is associated with a range of highly-prevalent NCDs, including: cardiovascular diseases, type-2 diabetes, cancers, and mental health outcomes (Kyu et al., 2016; Pearce et al., 2022; Posadzki et al., 2020; Robertson et al., 2012; Smith et al., 2016). An evaluation of the direct healthcare costs of NCDs and mental health conditions attributable to physical inactivity for 2020–30 reported that 500 million new cases will occur globally between 2020 and 2030 should physical activity (PA) remain at today's levels, incurring more than US$300 billion (US$27 billion per year) in treatment costs (Santos et al., 2022; World Health Organization, 2022b). Since prevention of NCDs is largely achievable through reducing the major risk factors, increasing population levels of PA is an increasingly important strategic goal for public health institutions globally, including the WHO (World Health Organization, 2018).

Increasing PA is a considerable challenge. The World Health Organization recommends that adults aged 18–64 years should do at least 150–300 min of moderate-intensity aerobic PA (or at least 75–150 min of vigorous-intensity aerobic PA) per week to maintain good health (Bull et al., 2020; World Health Organization, 2020). Globally, 27.5 % of adults do not meet these recommendations for healthy levels of PA (World Health Organization, 2022b). In general, the proportion of physically inactive adults increases with economic development (World Health Organization, 2018), and higher income inequality (Chastin et al., 2020). At the structural level, progress in reducing physical inactivity has been slow, chiefly due to a lack of awareness and investment (World Health Organization, 2018). Individual and social resources, environmental factors, sociocultural and personal factors, and technology use all play key roles in driving physical (in)activity (Martins et al., 2015; Spiteri et al., 2019).

Accordingly, there is considerable interest in better understanding the barriers and motivating factors relating to PA, and the value of community resources and other upstream enablers and drivers of PA at the population scale (Mackenbach et al., 2018; Rutter et al., 2017). Natural environments can be intrinsically pleasant and restorative settings in which to do exercise. They can provide the possibility of informal or incidental PA to those lacking resources, desire or confidence to engage in organised sports or fitness activities (Schutzer and Graves, 2004; Withall et al., 2011), and natural settings have been shown to provide the context for a considerable proportion of recreational PA done by adults in England, for example (White et al., 2016). Global estimates are difficult because, again, systematic data at a national level are not generally available.

However, in England, analysis of the representative Monitor of Engagement with the Natural Environment (MENE) survey (data from 2009/10–2014/15 waves) indicated that approximately 8.2 million adults, equating to 19.5 % of the population, had made at least one *active* visit to natural environments over the previous week (where 'active' was defined as doing moderate physical activity such as brisk walking for half an hour or more). Approximately 3.2 million of those adults met the recommended volumes of PA through recreation in nature. Analysis of MENE data between 2009 and 2019 has shown that health and exercise is the most common reason for spending time in nature and there has been a notable increase in the share of visits taken for health or exercise, from around a third of visits in 2009/2010 to over half in 2018/2019 (Natural England, 2019a). Whilst the evidence is mixed as to the causal drivers of recreational PA conducted in natural environments ('nature-based PA') (Garrett et al., 2020), specific types of natural setting are especially supportive of PA. For example, further analysis of additional waves (2009–2016) of the MENE data (n = 326,756) showed that coastal natural environments, for instance, supported higher volumes and different modes of activity than non-coastal ones (Elliott et al., 2018). The same research found that natural settings are supportive of activity across demographic groups, with some indication that socio-economic inequities in participation may be lower in certain environments. Nature as a setting for PA may also confer greater health benefit than that undertaken elsewhere (Mitchell, 2013): for example, reductions in the risk of poor mental health have been found to be associated with PA conducted in natural environments to a greater extent than PA in other environments (Frühauf et al., 2016; Pasanen et al., 2019, 2014). Compared to PA conducted in indoor environments, nature-based PA has been found to be associated with increased energy, feelings of revitalization and positive engagement, and with decreased levels of tension, confusion, anger, and depression (Thompson Coon et al., 2011; Wicks et al., 2022).

Natural settings are important in determining a population's overall level of PA, which has significant positive impacts on health, wellbeing and rates of NCDs, and therefore implications for health and care systems. The economic value of the human health benefits associated with nature-based PA at a national level has been crudely estimated based on the linkage between physical activity and aggregate measures (e.g. all cause mortality or total Quality Adjusted Life Years (QALYs)) and use of either the value of a statistical life or social value of a QALY (White et al., 2016). White et al (2016) calculated the QALYs associated with the physically-active visits to natural environments discussed above (Natural England, 2015). They found that over 100,000 QALYs per year could be attributed to PA across all green/blue spaces in England, with a potential health-related value of £2.2 billion per year. Results were supported by a robustness check which used the Health Economic Assessment Tool (HEAT) developed by the WHO (Kahlmeier et al., 2017), to assess the value of a subset of common physical activities, walking and cycling. A more recent study using MENE and other national data calculated that the health benefits gained from outdoor recreation for the UK in 2020 were between £6.2 billion and £8.4 billion (Office for National Statistics, 2022). It used two valuation approaches, namely an "exercise based" method, which looked at QALYs associated with active visits based on the methods of White et al. (2016), and an "exposure based" method, which looked at health benefits in terms of QALYs associated with spending at least 120 min in nature (White et al., 2019).

QALY-based valuation approaches have also been used in national-level studies that estimated the economic benefit of physical activity conducted in the marine environment using data from the Health Survey for England (Papathanasopoulou et al., 2016) and in woodlands in England and Wales (Moseley et al., 2018). However, social values such as QALYs are only part of the full economic cost of disease; and it is important to consider the wider costs of illness. There have been few estimates of impact of nature-based PA specifically for health, care and social systems via reductions in disease incidence through PA pathways (Bockarjova et al., 2020; Chen, 2020; Lynch et al., 2020; Van Oijstaeijen et al., 2020). Quantification of the value (including via economic metrics) of reductions in disease incidence through current volumes in nature-based PA may provide key support to decision-making processes and policy delivery relating to health and care systems, activity promotion, but also in regard to the management of the resource (Communities and Local Government Committee, 2017; Fields In Trust, 2018). Furthermore, quantification of the value of achieving the increases in volume of PA necessary to reduce rates of specific NCDs through different intervention scenarios (e.g. more people being active, or greater volumes of activity) achieved through infrastructural, social or population promotion programs (Hunter et al., 2015) could help guide strategies and make an argument for investment (World Health Organization, 2018).

1.2. Study aim and objectives

Our overall aim was to estimate the annual economic value of benefits to health associated with PA conducted recreationally in natural environments ('nature-based PA') in England. Our specific objectives were: (1) To estimate the annual economic value resulting from the prevention of cases of six non-communicable diseases that are known to be caused—at least in part—by low volumes of PA, at reported levels of nature-based PA; and (2) To explore the additional value of increases in nature-based PA under scenarios of (a) increased volume of PA and (b) increased visitor numbers to natural environments.

2. Material and methods

We estimated the incident cases of six non-communicable diseases that could be prevented annually through PA conducted by the English adult population on visits to natural environments. To achieve this, we required: 1) dose–response information relating volume of PA to incident cases of disease; 2) the weekly frequency of visits made to natural environment by the English adult population at risk of developing these diseases; 3) the duration of PA performed on these visits made to natural environments; 4) the intensity of PA performed during these visits to natural environments; and 5) the incidence of the selected diseases in the general population.

A model was constructed using Analytica software (Lumina Decision Systems, 2023) relating nature-based PA ('dose') to estimates of attributable health benefits ('response') via a set of six disease-specific dose–response functions.

2.1. Diseases of interest and estimates of dose–response

We selected six non-communicable diseases with high population incidence known to exert a considerable public health burden, and for which robust estimates of dose–response with PA were available from a single tool, the 'drpa' R package (Abbas, 2021), which is based on data extracted from three peer-reviewed systematic reviews and meta-analyses of epidemiological evidence (Garcia et al., 2023; Pearce et al., 2022; Smith et al., 2016). These were: ischaemic heart disease (IHD; also commonly called 'coronary heart disease') (Garcia et al., 2023), ischaemic stroke (IS) (Garcia et al., 2023), type 2 diabetes (T2D) (Smith et al., 2016), colon cancer (CC) (Garcia et al., 2023), breast cancer (BC) (Garcia et al., 2023), and major depressive disorder (MDD) (Pearce et al., 2022). For T2D and MDD, full details of articles included in each meta-analysis are described in the review articles and their supplementary materials; for IHD, IS, CC and BC, details are available at a dedicated OSF online repository https://osf.io/3nhxe (Garcia, 2021).

The "doses" of PA in the epidemiological studies included in these meta-analyses had been operationalised in terms of volumes of PA i.e. the product of metabolic equivalent of task (MET) and time over a given period. METs are an objective measure of energy expended, and are used to quantify intensities of different activities. By definition, a person completely at rest expends 1 MET. Light intensity activities are defined as > 1.5 and < 3 METs (e.g. walking slowly); moderate intensity activities are ≥ 3 and < 6 METs (e.g. brisk walking); and vigorous intensity activities are defined as ≥ 6 METS (e.g. running) (Ainsworth et al., 2011; World Health Organization, 2020).

The UK Chief Medical Officer's guidelines for adults are similar to those presented by the World Health Organization outlined above ($\geq$150 min of moderate-intensity activity, or $\geq$ 75 min of vigorous-intensity activity), but additionally suggest that equivalent benefits to health can accrue from even shorter durations of very vigorous intensity activities ($\geq$9 METs) such as sprinting (Department of Health and Social Care, Llwodraeth Cymru Welsh Government, Department of Health Northern Ireland and the Scottish Government, 2019). The product of the intensity of a given activity (in METs), its duration (in minutes), and overall frequency of activity in a given period can be expressed in MET-minutes. In the meta-analyses of these epidemiological studies, doses of PA in each component study were harmonised by conversion to *marginal* MET-hours per week. The marginal MET (mMET) is a measure of energy expended over and above the resting metabolic rate i.e. MET-1. Examples of mMET rates for various outdoor activities are provided in Supplementary Material, Table A1. The range of mMET rates for light, moderate and vigorous intensity activities are $\geq$0.5 and $<$2 mMETs, $\geq$2 and $<$5 mMETs, and $\geq$5 mMETs, respectively. In terms of volume of PA, the WHO guidelines correspond to recommending that people do at least 600 mMET-minutes (or 10 mMET-hours) per week to maintain good health.

Dose-response relationships expressed as relative risks for 1 mMET-hour/week categories were extracted from the results of the three systematic reviews and meta-analyses using the dedicated 'drpa' package (Abbas, 2021) in R (R Core Team, 2023) and RStudio (Posit team, 2023) software for between 0 and 35 mMET-hours/week (Fig. 1; Supplementary Material, Table B1). For activity above 35 mMET-hours/week, the dose–response function was assumed to take the value of the relative risk (RR) corresponding to the 34–35 mMET-hour/week category, as there was little support (insufficient *n* in the underlying studies) for dose–response relating to higher volumes of PA. 35 mMET-hours/week is equivalent to 6 MET-hours per day i.e. one hour of vigorous intensity PA (e.g. running) or two hours of moderate intensity PA (e.g. brisk walking) every day of the week.

All dose–response functions were assumed to apply equally to males and females, with the exception of breast cancer, since breast cancer in males is extremely rare and no studies of male breast cancer cases were included in the meta-analysis.

2.2. Population and time frame

The target population was defined as adults (16 years of age and older) resident in England in 2019. We only considered adults in England, as detailed information on their visits to natural environments was available from the Monitor of Engagement with the Natural Environment (MENE) survey (Natural England, 2019b), which collected data from respondents about leisure visits to natural environments in England.

We selected 2019 as our year of interest to provide up-to-date results using the most recent (and final) wave of the MENE survey (2018/2019 wave), but avoid the complications resulting from SARS-CoV-2 pandemic mitigation measures and related changes in population behaviours; including frequency of visits to natural environments and volumes of PA conducted (Burnett et al., 2021; Venter et al., 2021).

2.3. Survey data on visits to natural environments and nature-based PA

Estimates of volume of PA and visit frequency of the target population were based on data extracted from the MENE survey (see Supplementary Material C for details).

For the current study, we used data from the 2018–2019 wave. These data comprise responses to questionnaires completed by 47,580 respondents, who were asked about occasions in the last week when they spent time out of doors. Spending time "out of doors" was explained as visiting "open spaces in and around towns and cities, including parks, canals and nature areas; the coast and beaches; and the countryside including farmland, woodland, hills and rivers" (Natural England, 2017). For the purposes of this paper, we consider their responses as describing "*visits to the natural environment*". Each respondent was required to specify the number of such visits made on each of the past seven days, working backwards from the day before the interview.

Respondents who had made at least one visit in the previous week (n = 23,712; approximately 49.8 % of the total sample) were then asked more details about one visit randomly selected by the CAPI software, including visit duration and the activities undertaken. MENE data were collected using a representative sampling methodology. When

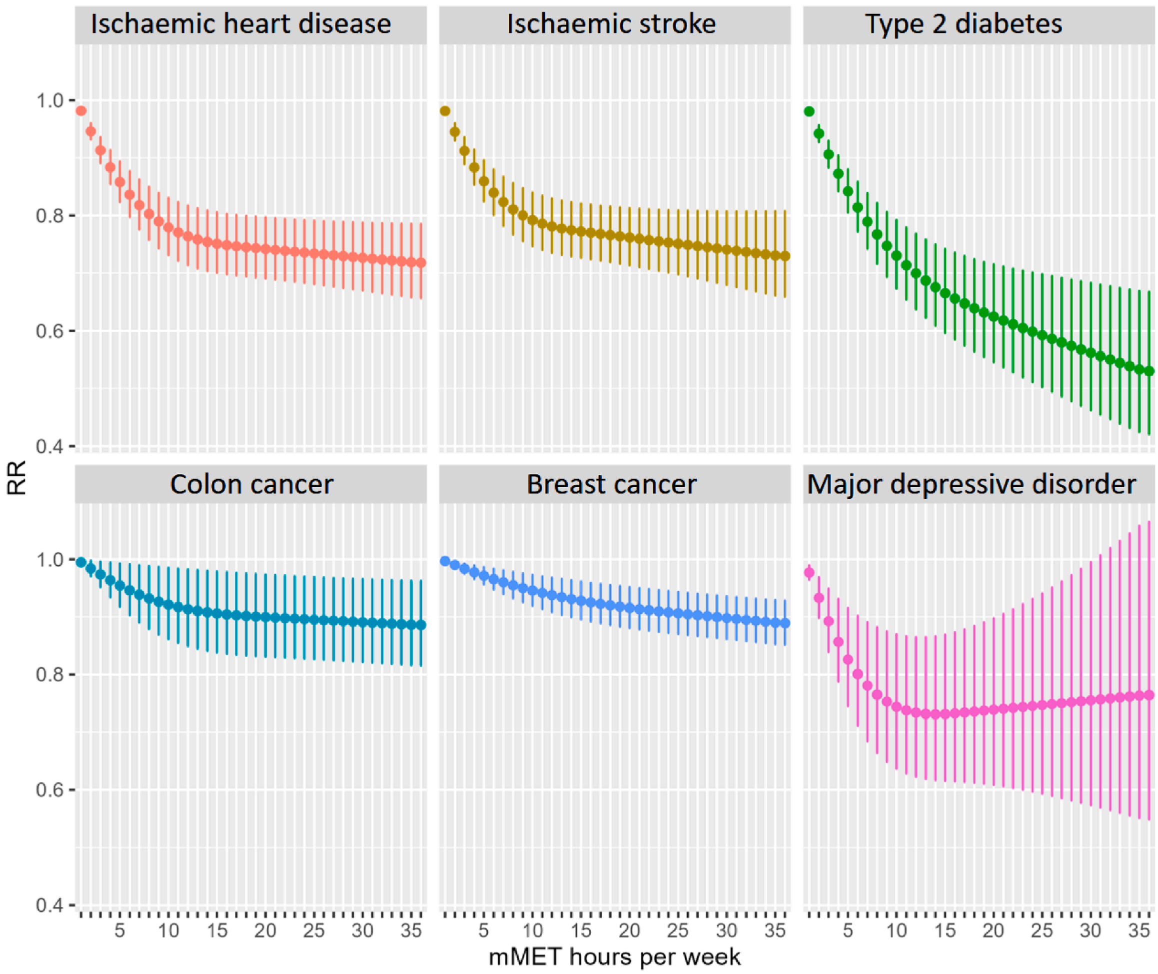

Fig. 1. Categorical operationalisations of dose–response relationships between PA and diseases of interest as estimates of relative risk for each 1 mMET-hour/week category of PA derived from 'drpa' R package (Abbas, 2021).

associated sampling weights were applied, the number of visiting respondents corresponded to 22,962,252 people in the population of England. Of the 23,712 respondents reporting at least one visit to a natural environment in the last week, we excluded: those that reported more than 14 visits per week (n = 466) as we consider such a high frequency of visits to be unrealistic; those that reported visit durations of > 12 h (n = 158) as we consider it likely they would only make such long visits less than once per week on average; and those reporting visits of zero minutes (n = 1). Application of these criteria resulted in 23,087 respondents being included in the analysis constituting 97 % of the original sample (Supplementary Material, Figure C1). For each included respondent, we used detailed visit record information to estimate the amount of PA conducted in natural environments in each week. This was done by first assigning intensities (in mMETs) to each of the activities reported based on previously published estimates (Elliott et al., 2015). For responses "none of the above" or "other outdoor activity", we assigned a value of 2.0 mMETs, which is by far the most common value for all activities as reported in MENE, and equates to—for example—walking with a dog (Supplementary Material, Table A1). We then multiplied the duration of the detailed visit by the mMETs associated with the activities reported to provide us mMET-minutes for that visit. For those that reported more than one type of activity per visit, we assigned the mean of the mMET-minutes for all activities as it was not possible to know how long was spent doing each activity during the visit.

We then multiplied the volume of PA engaged in on this single visit by the reported weekly frequency of such visits, providing an estimate of weekly volume of nature-based PA for each included respondent. We converted the weekly volume of PA in mMET-minutes to mMET-hours for congruency with the units used in the dose–response function. Due to the weekly sampling protocol across the year and random specific visit selection, we assumed that at the aggregate level the overall volume of PA reported is representative of visit activity in any given week throughout the year.

The sampling strategy used to collect MENE data provides associated weights that were used to scale up the weekly estimates of nature-based PA for each of the included respondents to the whole of the English population stratified by age category and gender. We subsequently assigned these weighted estimates to their respective 1mMET-hour categories of weekly PA as defined in the meta-analysis from which dose–response information was obtained.

2.4. Estimating the attributable cases prevented through nature-based PA

The population attributable fraction (*AFp*) is the fraction by which total incidence of a disease would be changed if the dose of a target population were reduced to the reference level (Greenland, 2001). In the context of the current study, we calculated *AFp* as the proportion by which incidence of each of the six diseases of interest would change if weekly volumes of nature-based PA were to fall to the reference level ([0, 1] mMET-hours/week). We achieved this by applying categorical relative risks (RR) corresponding to volumes of nature-based PA in the target population directly to those proportions of the population conducting those volumes of nature-based PA. Subsequently, for each disease the *AFp* was calculated according to the formula (Levin, 1953)

$$AF_p = \frac{\sum_{x=0}^{u} P_x \bullet RR_x - 1}{\sum_{x=0}^{u} P_x \bullet (RR_x - 1) + 1}$$

where RR_x is the RR in PA category x , P_x is the proportion of the target population in PA category x , and u is the uppermost category of PA. Each RR was defined as a probabilistic representation of the exponent of the coefficient, itself defined as a normal distribution with mean equal to the coefficient and standard deviation equal to the estimate of the standard error (SE) on that coefficient.

Efforts were made to maintain congruence between the derivation of dose–response estimates in the literature and the way in which these estimates were used in predicting health impacts in the current study. These required that we use a similar definition of PA (the 'dose'), the same diseases (the 'response'), and only assigning risks of breast cancer to females as no males were included in the breast cancer studies from which the dose–response information was generated.

The attributable cases (*AC)* of each disease that might be prevented through nature-based PA were estimated thus:

$$AC = \frac{AF_p \bullet N \bullet I}{100,000}$$

where *N* is the target population (England) and *I* is the incidence of the disease (rate per 100,000), stratified by age and sex. Estimates of annual incidences (central estimates with lower and upper limit values) of the diseases of interest in England for 2019 were extracted from the Global Burden of Disease tool (IHME, 2022); these incidence rates were modelled as triangular distributions, defined using the central estimates, upper and lower limit values (Supplementary Material, Figure D1).

The modelling framework allowed for key variables (dose–response functions and incidence rates) to be defined as probability distributions, and for probabilistic evaluation of the results. Details of the probabilistic simulation methods used are provided in Supplementary Material E.

2.5. Economic valuation of cases of NCDs prevented annually through nature-based PA

Firstly, we estimated the annual economic costs per case of disease prevented due to nature-based PA in England using detailed cost data derived from the literature. To do this, we searched for recent studies that presented national-level annual cost estimates for prevalent cases of each of the six diseases of interest, ideally using similar methodologies to maximise comparability, and incorporating direct costs pertaining to formal healthcare, indirect costs relating to loss of productivity, and the costs of informal care.

We did not identify any one study in which costs of all six diseases had been estimated, but did find studies for prevalent cases of ischaemic heart disease and ischaemic stroke (Leal et al., 2012) and both cancers in which the same valuation methodology had been applied (Luengo-Fernandez et al., 2013). Studies presenting costs of prevalent cases of type 2 diabetes (Hex et al., 2012) and major depressive disorder (McDaid et al., 2022) were identified which, although differing somewhat in the methodology used, had used similar component cost categories appropriate for incorporation into the current analysis. All identified studies presented estimates of costs in the UK rather than just in England.

- **Ischaemic heart disease (IHD) and ischaemic stroke (IS):** The annual costs of all prevalent cases of IHD and IS in the UK in 2009 (in euros) were obtained from an EU-wide economic valuation of cardiovascular diseases (Leal et al., 2012). These 2009 estimates included the direct costs of formal healthcare (primary care, outpatient care, emergency care, inpatient care, medications), indirect costs relating to loss of productivity (through morbidity and mortality), and the costs of informal care, all in euros.
- **Type 2 diabetes (T2D):** Annual costs of all prevalent cases of T2D in the UK in 2010/2011 (in pounds sterling) were obtained from a UK-specific health economics study (Hex et al., 2012). The costs presented therein comprised direct costs of formal healthcare (diagnosis and screening, treatment and management and complications), indirect costs relating to loss of productivity (through morbidity and mortality) and the costs of informal care. The direct costs presented included complications that stem from T2D, including cardiovascular disease (comprising IHD and IS). We therefore removed the costs of CVD from the direct costs of Type 2 diabetes, as these are accounted for in our modelling of CVD. Additionally, the Hex et al. (2012) study included costs of type 2 diabetes-related health promotion and prevention measures (e.g. education and smoking cessation programmes). We removed these costs, as they were not included in the valuation studies of CVD or cancer.
- **Colon cancer (CC) and breast cancer (BC):** Annual costs of all prevalent cases of CC and BC in the UK in 2009 (in euros) were obtained from an EU-wide economic valuation of all cancers (Luengo-Fernandez et al., 2013). This valuation presented direct costs of formal healthcare (primary care, outpatient care, accident and emergency, inpatient care, drugs), indirect costs relating to loss of productivity (through morbidity and mortality), and the costs of informal care.
- **Major depressive disorder (MDD):** Annual costs of all prevalent cases of MDD in the UK in 2019 were obtained from a UK-specific health economics study (McDaid et al., 2022), broken down into three cost categories: healthcare (primary and outpatient care); productivity loss (aggregated mortality and morbidity costs); and informal care. We excluded direct healthcare costs for child cases of MDD, but incorporated associated informal care and productivity loss costs, as these are calculated for their adult caregivers.

All costs in euros were converted into pounds sterling using the yearly Bank of England exchange rate for the appropriate year (Currency Convertor, 2022). Inflation between the relevant study year and 2019 was accounted for by multiplying study year costs by an inflation factor (Bank of England, 2022), which resulted in pounds sterling costs appropriate for 2019 (Table 1). Apart from adjusting for inflation, we assumed that healthcare costs did not change between 2009 and 2019. In the absence of more up-to-date valuation exercises for England, we are not in a position to comment on how developments in treatment, for example, might have affected direct costs, or, for example, how loss of productivity might have changed over those ten years.

Table 1
Total annual costs of all prevalent cases of ischaemic heart disease (IHD), ischaemic stroke (IS), type 2 diabetes (T2D), colon cancer (CC), breast cancer (BC) and major depressive disorder (MDD) in the UK at 2019 prices in pounds sterling.

Disease	Direct costs of formal healthcare	Indirect costs relating to loss of productivity	Costs of informal care	Total costs
IHD*	£2.4 billion	£4.2 billion	£2.3 billion	£8.9 billion
IS*	£2.4 billion	£1.3 billion	£1.3 billion	£5.0 billion
T2D†	£10.4 billion	£10.3 billion	£6.4 billion	£27.1 billion
CC‡	£714.9 million	£769.0 million	£307.6 million	£1.8 billion
BC‡	£699.3 million	£656.0 million	£371.3 million	£1.7 billion
MDD§	£3.5 billion	£8.2 billion	£8.3 billion	£20.1 billion

* Derived from data presented in Leal et al. (2009); adjusted for inflation and converted from euros into pounds sterling.
† Derived from data presented in Hex et al. (2012); adjusted for inflation.
‡ Derived from data presented in Luengo-Fernandez et al. (2013); adjusted for inflation and converted from euros into pounds sterling.
§ Derived from data presented in Daid et al. (2019).

As described above, we used dose–response data based on epidemiological studies that measured incident cases of disease in various adult populations to convert reported volumes of nature-based PA into relative risks of disease in the adult population of England. We then multiplied population attributable fractions by disease incidence in the 2019 population of England, thereby estimating attributable incident cases prevented due to nature-based PA.

Using the Global Burden of Disease results tool (IHME, 2022), we obtained central estimates of annual prevalence of ischaemic heart disease, ischaemic stroke, colon cancer[1] and breast cancer for UK adults in 2009; for type 2 diabetes, we used the prevalence data presented in Hex et al. (2012) directly; and for MDD, we obtained central estimates of annual prevalence for UK adults in 2019 (Table 2). We then calculated the cost per prevalent case for each of the six diseases by dividing total costs for the UK (converted to 2019 pounds sterling as described above) by their annual prevalence in the relevant year (Table 2).

We assumed that our estimated costs per prevalent case in the UK could be applied directly to cases in England, as the majority of UK costs are those costs incurred in England by virtue of its population making up some 84 % of the UK population. Accordingly, we multiplied our estimates of incident cases prevented in England for 2019 through nature-based PA by the cost per prevalent case in the UK.

Table 2
UK annual prevalence of ischaemic heart disease (IHD), ischaemic stroke (IS), type 2 diabetes (T2D), colon cancer (CC) and breast cancer (BC) in the years corresponding to those used in the economic assessments, and total costs per prevalent case of IHD, IS, T2D, colon cancer, breast cancer and MDD in the UK adjusted to 2019 pounds sterling.

Disease	Year	Central estimates of prevalence(number of cases) in UK population in relevant year	Source	Total cost perprevalent case (£)
IHD	2009	1,688,147	GBD results tool	£5,272
IS	2009	555,874	GBD results tool	£8,977
T2D	2010/ 2011	3,419,727	Hex et al. (2012)	£7,915
CC*	2009	247,008	GBD results tool	£7,253
BC†	2009	525,472	GBD results tool	£3,286
MDD	2019	2,283,818	GBD results tool	£8,783

* Figures were available for colon and rectum cancer combined (i.e. colorectal cancer) in the GBD results tool.
† Figures for female breast cancer cases only.

We considered that assigning costs per *incident* case (i.e. new cases of a specific disease in a population in a given period) to attributable *incident* cases would lead to an upwards bias in our cost estimates. We therefore intentionally assigned costs per *prevalent* case (i.e. number of people living with a specific disease in a population during a given period) to attributable *incident* cases in an effort to smooth out the sometimes large variations in economic costs incurred at different stages of chronic diseases (e.g. cancers, CVD and diabetes), particularly due to expensive treatments associated with medical emergencies (e.g. heart attack, stroke) and costly diagnostic procedures and treatments in newly-diagnosed patients.

Interventions relating to access and use of greenspace can have marked impacts on PA levels and rates of visiting in some contexts (Hunter et al., 2015). Therefore, as well as estimating how much disease reduction we see due to reported nature-based PA in England, we were also interested to explore two hypothetical scenarios in which: (1) visitors doing little or no nature-based PA on their visits became more active on their visits; and (2) a greater number of people visited natural environments, keeping the relative proportions of activity in that larger population the same. Under each scenario we estimated attributable cases prevented through nature-based PA and associated costs, using the methods described above.

For the first scenario, we investigated the effects on disease burden that would result from one fifth of those visitors reporting < 10 mMET-hours/week (equivalent to the 600 mMET-minutes/week in the WHO guidelines) increasing their nature-based PA to the (10, 11] mMET-hours/week category. In the second scenario, we looked at the impact on disease burden of increasing total visitor numbers by a factor of 1.2 and applied the same relative proportions of PA as in our baseline scenario (i.e. we assume the additional visitors have the same PA profile as current visitors). Whilst there is no clear evidence of the impact of specific population-level interventions that would result in changes of this magnitude, we believe that it is valuable to consider the impact and value of such hypothetical interventions.

In reality, the health benefits resulting from PA are not accrued immediately. In the case of the majority of NCDs presented in the current study, health benefits result from systemic changes in the body resulting from regular physical exercise sustained over extended periods. This has implications for how our estimates of prevented costs should be interpreted. Although we use data on PA of a specific target population in a given year, our results should be viewed as the effect we might see if that population's PA were representative of PA habits over the much longer time periods (i.e. for similar periods of time as experienced by members of the epidemiological studies upon which dose–response functions are based). Our valuation should not, therefore, be viewed as an estimate of the cost of incident cases in 2019, but rather a smoothed estimate of the cost of diagnosing, treating and managing these attributable cases (including impacts on productivity) over time. Furthermore, the estimated savings represent money not spent on these diseases every year, provided people do similar levels of nature-based PA over time. We know from MENE that levels of nature-based PA in English adults over the last decade have been moderately stable over time (Natural England, 2019a). Since the annual economic costs are adjusted for 2019, our results can therefore be interpreted as the net annual benefits to population health of doing reported volumes of PA over the past 20–40 years, the time period over which the majority of supporting epidemiological studies were run, and a sufficient time for chronic disease to manifest itself in the less physically active. We therefore calculated the long-term value of nature-based PA by applying a discounting rate to our results over 20 to 40 years.

[1] We used a dose–response function for CC to calculate PAF, but subsequently used incidence and prevalence data and associated costs related to colorectal cancer. Although the terms colorectal cancer and colon cancer are commonly used interchangeably, the former includes colon and rectal cancers. Rectal and colon cancers share a number of attributes, including many risk factors, symptoms and genetics, but they also differ in terms of prognosis, progression to metastasis, treatment modalities and postoperative complications (Lee et al., 2013; Tamas et al., 2015; Wei et al., 2004), all of which might influence costs. In clinical settings, rectal cancer has historically commonly been misclassified as cancer of the colon, partly due to the interchangeable use of the terms colon cancer and colorectal cancer (Percy et al., 1981; Yin et al., 2011), which explains why incidence and mortality statistics often use the combined term 'colorectal cancer'. We do not believe that our results have been unduly biased by using data pertaining to both colorectal and colon cancer in our model.

3. Results

3.1. Characteristics of visitors to the natural environment in England

Approximately half of the 2018/2019 MENE survey sample (n = 23,087 adults 16 years and over) made at least one visit to a natural environment per week and satisfied our criteria for inclusion. Applying survey weights, this sample corresponds to 23.0 million adults in England, comprising approximately equal numbers of women (n = 11,963, representing 11.6 million individuals) and men (n = 11,124, representing 11.4 million individuals). We calculated that the majority of visitors expend more than 10 mMET-hours/week through nature-based PA (median = 11.4 mMET-hours/week) and estimated that 53 % of those visiting natural environments achieved more than 10 mMET-hours/week of activity during visits to natural environments. We observed relatively small differences in distributions of nature-based PA across categories of age or gender (Fig. 2).

The distribution of nature-based PA in the adult population of England, operationalised as 1mMET-hour/week categories (corresponding to those employed in the categorical dose–response functions), similarly did not vary appreciably by age and gender. Across the population 11.1 % of respondents were assigned to the uppermost category for which dose–response is considered to be valid (>35 mMET-hours/week), varying among age and gender strata from 8.0 % (females 65 years and older) to 14.1 % (males between the ages of 16 and 24 years) (Fig. 3).

3.2. Incident cases of NCDs prevented by nature-based PA

Based on our analysis, we found that nature-based PA conducted by the adult population of England (reported for 2018/2019) could prevent a total of 12,763 (95 % uncertainty interval (UI): 8,328; 17,603) incident cases of the six diseases of interest annually. This comprised 550 cases of ischaemic heart disease, 168 cases of ischaemic stroke, 1,407 cases of type 2 diabetes, 41 cases of colon cancer, 37 cases of BC and 10,561 cases of MDD (Table 3). With the exception of type 2 diabetes and MDD, attributable cases prevented in those under the age of 35 were negligible, since the incidences of CVD, colon cancer and breast cancer are very low in that age group.

We found greater numbers of cases of disease could be prevented through interventions modelled in our scenario analyses. For the first scenario (modelled as an increase in nature-based PA for one fifth of those visitors doing < 10 mMET-hours/week to (10, 11] mMET-hours/week), we estimated that 15,180 (95 % UI: 10,226; 20,579) incident cases of NCD were prevented annually; some 19 % more than at 2019 reported activity levels (Supplementary Material, Table F1). For the second scenario (assuming an increase in visits to natural environments by a factor of 1.2 compared to visits reported in 2019), we estimated that 15,305 (95 % UI: 10,000; 21,127) incident cases of NCD were prevented annually; again around a fifth more than at 2019 reported activity levels (Supplementary Material, Table F2).

3.3. Economic value of prevented disease

We estimated the overall annual economic value of the incident cases of NCD possibly prevented through the adult population of England engaging in nature-based PA in 2019 at £108.7 million (95 % UI: £70.2 million; £150.5 million) (Table 4 and Supplementary Material, Table F3). The largest cost savings resulted from prevention of MDD at £92.7 million, followed by type 2 diabetes at £11.1 million, ischaemic heart disease at £2.9 million, and ischaemic stroke at £1.5 million. The smallest cost saving resulted from the prevention of breast cancer, at £120,275.

Assuming a discounting rate of 3.5 % over the next 20 to 40 years, these estimates of the net cost savings from nature-based PA translate to

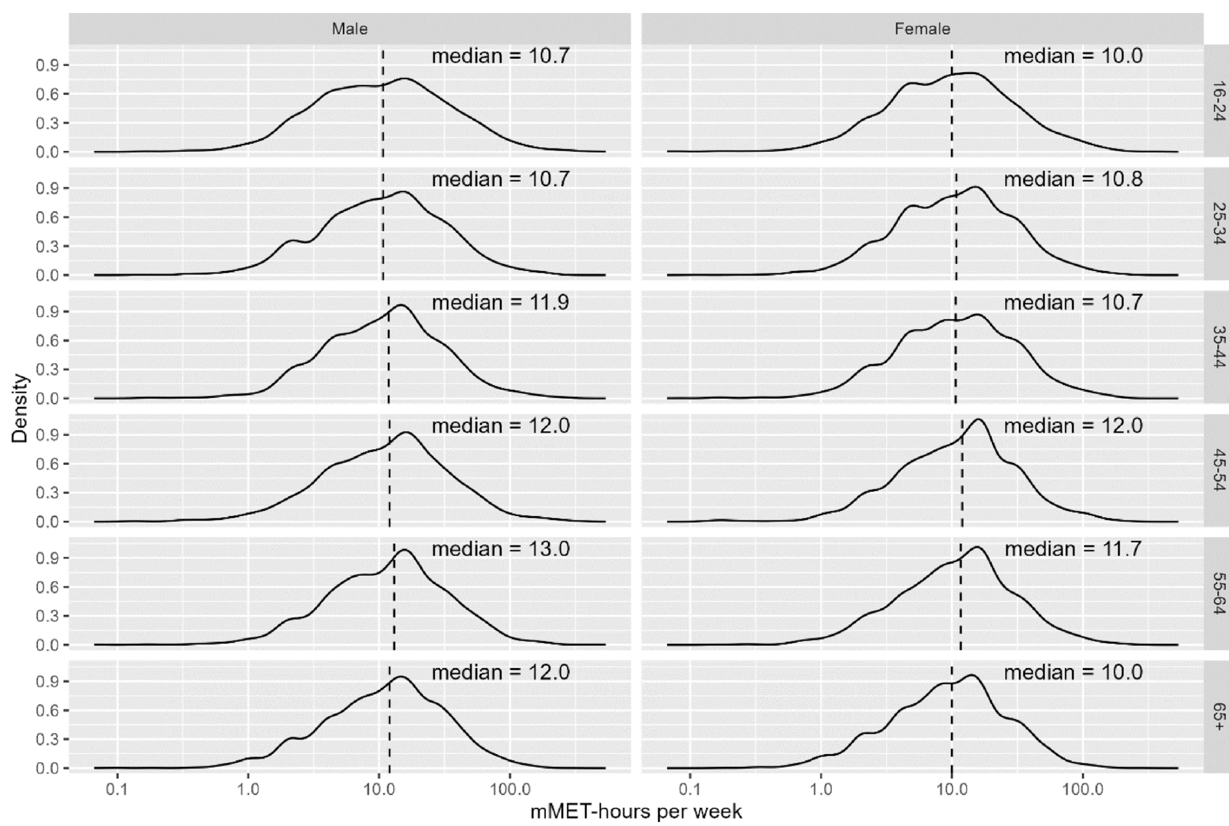

Fig. 2. Probability density functions of estimated weekly nature-based PA (in mMET-hours) for respondents of the 2018/2019 wave of the MENE survey, stratified by age and gender. Dashed lines indicate stratum-specific median nature-based PA in mMET-hours per week. ‘Density’ on the y-axis refers to the probability per unit increment of mMET-hours per week.

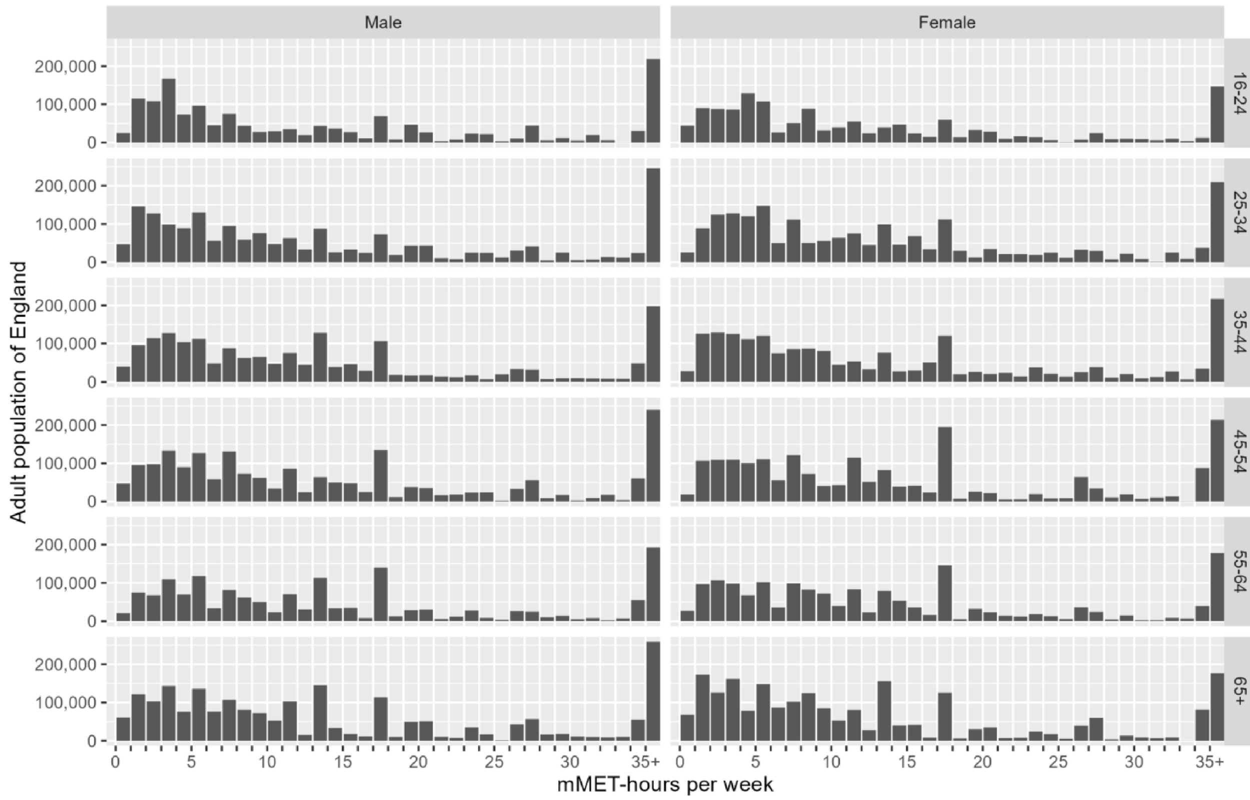

Fig. 3. The number of adults (16 years and over) in the English population engaging in each 1 mMET-hour category of nature-based PA per week, stratified by age and gender (MENE wave 2018/2019).

Table 3
Annual incident cases of ischaemic heart disease, ischaemic stroke, type 2 diabetes, colon cancer, BC and MDD potentially prevented through nature based-physical activity in England (with 95% uncertainty intervals).

Gender	Age (years)	Ischaemic heart disease	Ischaemic stroke	Type 2 diabetes	Colon cancer	Breast cancer *	Major depressive disorder
Male	16–24	1.6 (1.1, 2.2)	1.0 (0.7, 1.4)	85.4 (62.9, 112.8)	0.0 (0.0, 0.0)	0.0 (0.0, 0.0)	600.3 (285.0, 953.0)
	25–34	5.9 (4.6, 7.3)	1.9 (1.5, 2.5)	144.1 (107.9, 184.3)	0.2 (0.1, 0.3)	0.0 (0.0, 0.0)	831.1 (421.4, 1,274.7)
	35–44	15.2 (12.9, 17.8)	3.9 (3.3, 4.7)	126.1 (101.5, 152.9)	0.6 (0.4, 0.8)	0.0 (0.0, 0.0)	834.5 (535.6, 1,161.9)
	45–54	66.0 (57.0, 75.6)	10.7 (8.9, 12.7)	204.7 (164.5, 249.7)	2.4 (1.6, 3.2)	0.0 (0.0, 0.0)	934.5 (544.8, 1,340.3)
	55–64	124.8 (106.2, 145.0)	18.5 (15.6, 21.7)	221.4 (178.1, 268.4)	6.5 (4.5, 8.8)	0.0 (0.0, 0.0)	831.4 (511.0, 1,177.3)
	65+	163.8 (141.4, 188.3)	43.4 (36.6, 50.7)	27.2 (21.5, 33.5)	14.4 (9.8, 18.9)	0.0 (0.0, 0.0)	420.4 (244.6, 603.9)
Female	16–24	1.6 (1.1, 2.1)	1.1 (0.7, 1.4)	37.2 (28.2, 47.1)	0.0 (0.0, 0.0)	0.0 (0.0, 0.0)	749.7 (474.3, 1,060.7)
	25–34	5.8 (4.6, 7.1)	2.4 (1.9, 3.1)	74.2 (57.0, 93.5)	0.2 (0.1, 0.3)	1.1 (0.9, 1.4)	1,133.4 (730.1, 1,606.8)
	35–44	4.9 (3.9, 6.2)	4.7 (3.8, 5.7)	107.0 (85.4, 130.9)	0.6 (0.4, 0.8)	3.9 (3.1, 4.8)	1,210.3 (743.7, 1,722.0)
	45–54	17.8 (15.3, 20.7)	10.8 (9.0, 12.7)	182.4 (149.5, 219.0)	2.1 (1.5, 2.9)	10.4 (8.3, 12.8)	1,405.3 (935.6, 1,895.3)
	55–64	36.1 (30.6, 42.0)	14.4 (12.3, 16.7)	162.1 (130.6, 197.7)	4.1 (2.9, 5.3)	11.4 (9.2, 13.9)	1,042.7 (685.8, 1,424.1)
	65+	106.4 (94.4, 120.1)	55.3 (48.7, 62.7)	35.4 (30.0, 41.4)	10.0 (7.5, 12.4)	9.8 (8.2, 11.4)	566.9 (424.6, 723.2)
Both	Totals	550.0 (473.1, 634.3)	168.0 (142.9, 196.1)	1,407.0 (1,117.0, 1,731.1)	41.1 (28.9, 53.8)	36.6 (29.6, 44.3)	10,560.5 (6,536.5, 14,943.2)

* Attributable cases of breast cancer were only calculated for females.

between £1.7 billion and £2.5 billion, respectively, for these six NCDs alone.

In our scenario analyses, we first estimated that a strategy in which the nature-based PA of one fifth those people that reported engaging in < 10 mMET-hours/week was increased to between 10 and 11 mMET-hours/week, would result in approximately 2.1 million more people performing minimum recommended levels of PA in nature alone. This would result in total annual savings in terms of disease prevented of £129.4 million (95 % UI: £86.5 million; £176.3 million) i.e. additional savings of £20.6 million per year when compared to current reported volumes of nature-based PA (Supplementary Material, Table F4). Under the second scenario, in which overall visitor numbers are increased by a factor of 1.2 (i.e. from 22.4 million to 26.8 million visitors) at the same relative levels of nature-based PA reported in 2019, we estimated total annual savings of £130.4 million (95 % UI: £84.5 million, £180.6 million), i.e. additional savings of £21.8 million per year (Supplementary Material, Table F5).

4. Discussion

The current study provides a disease-specific, monetary assessment of the health-related value of recreational physical activity undertaken in natural environments in England. It does so by valuing the annual health benefits of reported nature-based recreational PA in terms of the prevention of incident cases of six common NCDs for which physical inactivity is a well-established risk factor, namely ischaemic heart

Table 4
Total costs associated with disease that are potentially prevented through nature-based physical activity in England for 2019 (with 95% uncertainty intervals).

Disease	Scenarios Reported visits and physical activity Based on 2019 figures from MENE	Increased physical activity 20 % of those visitors currently reporting < 10 mMET-hours/week (approximately equivalent to the 600 MET-minutes/week in the WHO guidelines) increase their nature-based PA to between 10 and 11 mMET-hours/week	Increased visits 20 % increase in visits to natural environments (at reported volumes of physical activity)
Ischaemic heart disease	£2,899,655 (£2,494,036, £3,347,684)	£3,384,433 (£2,900,608, £3,920,548)	£3,478,775 (£2,993,951, £4,017,139)
Ischaemic stroke	£1,508,976 (£1,282,384, £1,757,731)	£1,776,406 (£1,509,995, £2,074,968)	£1,810,546 (£1,538,019, £2,113,105)
Type 2 diabetes	£11,137,095 (£8,846,837, £13,702,030)	£12,768,177 (£10,243,109, £15,598,391)	£13,363,380 (£10,620,757, £16,450,220)
Colon cancer	£298,208 (£209,930, £390,496)	£298,208 (£209,930, £390,496)	£298,208 (£209,930, £390,496)
Breast cancer	£120,211 (£97,091, £145,803)	£140,546 (£111,886, £172,497)	£144,243 (£116,739, £174,714)
Major depressive disorder	£92,665,718 (£57,448,317, £131,267,367)	£110,991,048 (£71,418,070, £153,791,486)	£111,292,848 (£68,962,155, £157,409,459)
Totals	**£108,629,862 (£70,378,596, £150,611,112)**	**£129,411,936 (£86,422,733, £176,027,385)**	**£130,447,569 (£84,483,443, £180,633,115)**

disease, ischaemic stroke, type 2 diabetes, colon cancer, BC and MDD. To our knowledge this is the first such assessment conducted at the national scale.

4.1. The study findings in context

The estimated healthcare cost of overall physical inactivity in the UK in 2006–7 has been estimated previously at £900 million (Scarborough et al., 2011), corresponding to around £1.2 billion in 2019 when adjusted for inflation (13 years at an average inflation rate of 2.3 %). Assuming that these costs are homogeneously distributed across the populations of the constituent countries of the UK, the healthcare cost of physical inactivity in England (the population of which makes up 84 % of the UK population) in 2019 is approximately £1 billion.

Our study's estimate of the costs avoided through reported nature-based PA in England in 2019 constitutes approximately 11 % of this figure. Even though our estimates of the costs of disease potentially avoided through nature-based PA constitute a substantial fraction of the overall costs of physical inactivity, for several reasons we consider that we have almost certainly underestimated the true value of nature-based PA—and visiting greenspace more broadly—in terms of disease prevention. First, although we have focused on six NCDs with very high prevalence in the English population, there are other less prevalent NCDs not included in the current study that can be prevented by PA. In its guidance on PA and sedentary behaviour, the WHO states that in addition to the 6 NCDs included in the current study, PA in adults also reduces all-cause mortality, incident hypertension, incident site-specific cancers (bladder, endometrial, oesophageal adenocarcinoma, gastric, and renal), symptoms of anxiety and depression, and improves cognitive health, sleep, and measures of adiposity (World Health Organization, 2020). It was not practicable to include all these outcomes in the current study because of their different disease characteristics, and the lack of suitable data on dose–response, prevalence/incidence in the English population, and national-level costing studies. Second, although spending time in natural environments is known to benefit many facets of mental health and well-being (Bize et al., 2007; White et al., 2019, p. 120, 2017) through a range of mechanisms, we included only the effect of PA on preventing one highly prevalent mental illness in our model (MDD). In part, we made this decision based on the lack of suitably characterised dose–response information. Although evidence exists for positive impacts of PA on other outcomes (including various dimensions of mental health such as moderate depression (Mammen and Faulkner, 2013), anxiety (McDowell et al., 2019), and low self-esteem (Liu et al., 2015)),relatively few longitudinal studies having been conducted for the majority of mental health outcomes (Collins et al., 2020; McDowell et al., 2019); and a synthesis of the evidence has been hampered by incompatible operationalisations of PA, high heterogeneity in study designs, and inconsistent adjustment for potential confounders (Gianfredi et al., 2020; Schuch et al., 2018). Third, as the focus of our study was on nature-based PA, we did not attempt to include possible benefits conferred on mental health from relatively inactive visits, tacitly assuming that those who conduct very low volumes of nature-based PA achieve only very small health benefits. However, there is a compelling body of evidence that demonstrates mental health benefits from visits during which little or no PA takes place. For example, the health of those visiting natural environments without engaging in PA benefits from other functions of those spaces relating to relaxation, nature connectedness and meaningful contact with other people e.g. greater attention restoration, improved physiological stress recovery, greater social cohesion, lower heat stress, better sleep and increased happiness (Frumkin et al., 2017; Markevych et al., 2017; Yang et al., 2021).

4.2. Implications of our findings

On the basis of our results, we recommend that nature-based PA be further facilitated and promoted. Previous work suggests this can be achieved through properly targeted interventions that improve physical and social environments and deliver educational, promotional and activity programmes (Hunter et al., 2015). We modelled the effects of hypothetical increases in visitor nature-based PA and visitor numbers. In reality, strategies achieving increased uptake of PA or propensity to visit natural environments among those who are less active or not accustomed to visiting such spaces, respectively, would take considerable efforts and, importantly, some time to realise such large increases. Also, not all natural environments are equal in terms of size, proximity to large populations, factors affecting access, facilities, suitability for certain activities, or features which make them attractive destinations, for example, hence the achievability of such scenarios would be highly heterogeneous across locations and the population subgroups affected.

Importantly, while it might be argued that interventions could be designed to boost PA irrespective of the environment in which it is conducted, it has been reported that exercising specifically in natural environments is more beneficial for a range of psychological outcomes compared with urban environments (Wicks et al., 2022), and allows people to have greater focus on their surroundings rather than on individual factors such as their appearance or body image, when compared to exercising in sports or gym-based activities (Calogiuri and Elliott, 2017; Shen et al., 2021). Hence the promotion of nature-based PA may have a particularly strong role to play in preventing mental ill health, which we found to exert the largest economic burden, and which would expect to contribute substantially in reducing health and social inequalities. A range of inequalities in PA levels among those from different protected characteristic groups in the UK have been identified, and UK government recognises the need to address these challenges (Public Health England, 2021). The current study was stratified on age and sex for the purposes of accurately calculating attributable cases of disease, but not with a view to better understand inequalities in nature-based PA relating to these protected characteristics. Similarly, we did not incorporate other protected characteristics into our analyses, as this would have excessively broadened its scope. Since the MENE data contain information on various protected characteristics, it would be valuable to conduct similar analyses in future valuing the health benefits from nature-based PA in specific protected characteristic groups, in support of policy-making to address health inequalities. The 2021 Health Survey for England found considerable disparities in the proportions of those meeting the 2011 PA guidelines by age, gender and area-level deprivation (NHS England, 2023), which would be expected to exacerbate health inequalities. Coordinated efforts by planners and public health strategists to provide more accessible, inclusive, low cost nature-based PA could represent a means of addressing lower than average levels of PA among older adults, women, and those living in areas of higher deprivation. We believe that our study should motivate decision-makers seeking to increase PA in the local population to invest in natural spaces, since well-designed structural interventions in communities (e.g. parks and other natural spaces) could make it easier for individuals to be physically active (Austin et al., 2021). However, although there is some understanding of the specific characteristics of natural spaces which increase visits and levels of moderate and vigorous PA, the geographic contexts within which this research has been conducted are relatively limited (Cohen et al., 2019; Hunter et al., 2015) and relatively sparse evidence is available regarding the best means to promote PA among particular protected characteristic groups. Efforts to create more supportive environments for PA through combining data-driven approaches with community and stakeholder engagement may represent effective means of promoting a sense of ownership and satisfaction, increasing park usage and addressing health inequalities (Austin et al., 2021).

The numbers of people regularly visiting natural environments for recreation present an upper limit of the benefits to health that can be realised through visitors being physically active on their visits. Accordingly, where improvements to public health are a focus of a given policy relating to natural environments, strategies might also be considered to entice larger numbers of visitors to such spaces, and to encourage more regular visits, and visits of longer duration. However, those designing strategies that seek to draw larger visitor numbers to natural environments should carefully assess how such increases might negatively impact on characteristics of natural environments and on visitor experiences. In particular, they should aim to minimise damage to ecosystems and existing infrastructure, and ensure equitable access and safety (Association for Public Service Excellence, 2021; Hunter et al., 2019; Wolch et al., 2014). For example, although in the short term, increased visitor numbers might result in increased volumes of nature-based PA, additional visitors can result in increased degradation of habitat and decreased biodiversity (Wyles et al., 2014), which may ultimately reduce visitor satisfaction and use of the space. Negative effects of visits and certain activities on biodiversity and quality of the natural environment might also be expected to reduce the psychological restorativeness of such spaces (Wood et al., 2018; Wyles et al., 2019), potentially counteracting some of the beneficial effects associated with increased PA. Since the benefits of nature-based PA are accrued over relatively long periods, interventions should be designed to be sustained over a sufficiently long time to affect improvements in health.

Our study results are based on the combination of England-specific estimates of PA in nature, incidences of the diseases of interest, and various costs associated with each attributable case. Since any or all of these components would be expected to vary considerably even across countries exhibiting similar economic or social character to England, we would not recommend simple re-scaling of these results to other contexts. Where analysts wish to reproduce our method in another geographical context, they should identify locally relevant data on nature-based PA, disease incidence, and economic costs of healthcare, informal care and lost productivity.

4.3. Limitations

We acknowledge some limitations to the current study. First, estimates of natured-based PA were made by extrapolating information in the MENE survey on activities conducted on a single visit to all reported visits in a week. It is not known to what extent this may bias estimates of PA in the study. Since interviews were conducted with participants on a random day of the week, and sampling was conducted during 51 weeks of the year, the detailed account they gave of their most recent visit is also randomised, and so any apparent individual-level bias towards longer or more active visits being reported at weekends, or in the summer, for example, would be averaged out across the survey population.

Second, we have no information on the PA conducted by survey respondents outside of natural environments. While this allows us to estimate the value of such environments in terms of the nature-based PA they afford, it is clear from available survey statistics that some proportion of the population engages in recreational PA that is not captured in our calculation of risk reduction (NHS England, 2023; Sport England, 2023). The curvilinear character of some of the dose–response functions means that we may be applying a somewhat steeper portion of those dose–response curves (i.e. at lower volumes of PA) to individuals with higher underlying PA.

Third, although our analysis demonstrates that the vast majority (89 %) of the adult population of England do less than 35 mMET-hours/week of nature-based PA, 11 % of the population do engage in 35 mMET-hours/week or more. There is inadequate information to reliably characterise the dose–response function beyond 35 mMET-hours/week. In this analysis, we assumed that this relatively small minority receives the risk reduction seen at 35mMET-hours/week irrespective of the volume of nature-based PA they engage in. Without incorporating epidemiological evidence of populations doing much higher volumes of PA than is typical in recreational settings, it is not possible to know what shape dose–response takes at such volumes of PA or what impact this has on our study results. We found that excluding these low numbers of respondents from our analysis had a relatively small impact on our results: we estimated the annual value of cases of disease prevented only in those reporting < 35mMET-hour/week to be £85.9 million, which is well within the 95 % uncertainty interval provided for our main result.

Fourth, we did not have sufficient dose–response data to take in account potential harm that might be associated with high levels of physical activity. However, an in-depth review has found that although there are risks to health for those doing very high volumes of PA such as athletes, for the general population the benefits to health of PA far outweigh any of these potential harms (World Health Organization, 2020).

Fifth, as is common in cross-sectional health impact assessment studies, we implicitly linked annual levels of nature-based PA to incident cases of disease in the same year. In other words, we applied dose–response functions derived from longitudinal studies to cross-sectional data on PA. The categorical relative risks generated by those studies (and subsequently synthesised through meta-analysis) represent the decreased risks of developing chronic disease accrued by a population over long time periods. In using the dose–response information in this way, we are not suggesting that the PA habits of this cohort of people bring them instantaneous rewards in terms of disease avoidance. Chronic disease does not manifest itself instantaneously as the result of a single year's physical inactivity. Neither is chronic disease prevented by suddenly engaging in PA after a lifetime of inactivity. Typically, such diseases are the result of long, complex inflammatory processes which eventually interfere with regulatory functions of various systems in the body to an extent sufficient to produce clinical disease (Handschin and Spiegelman, 2008; Zotova et al., 2023). Although relatively rapid improvements in dimensions of mental health following bouts of exercise have been demonstrated in some studies, the relationships between PA and MDD are also highly complex; and the overall evidence base supporting any such instantaneous relationships is inconsistent and inconclusive (Basso and Suzuki, 2017; Ekkekakis and Brand, 2019; Liao et al., 2015). Another implication of our cross-sectional approach is that we could not assess the costs associated with the alternative health problems potentially experienced by those whose lives are prolonged by PA, or with injury experienced as a result of PA. It has been reported elsewhere that long-term avoidance of diseases caused by physical inactivity might increase longevity, which could potentially result in net increases in healthcare costs over life-years gained, albeit excluding the economic and societal benefits that adequate PA might contribute to improved quality of life (Duijvestijn et al., 2023).

Sixth, in estimating the economic value of disease prevented we were compelled to make several assumptions, in particular through collating monetary costs from different sources and across different years, adjusting for inflation and exchange rates as necessary. This is a standard approach used to bring values into a common price year, but it may lead to biases in different directions in this context. For example, treatment costs may vary differently depending on staff wages and drug costs, which may or may not increase in line with inflation. Recommended treatment pathways also may change over time, with new advances in knowledge or changes in policy, which will also affect the costs.

Seventh, the dose–response functions we used in our calculations for estimating attributable cases of all outcomes except for MDD (i.e. IHD, IS, BC, and CC (Garcia et al., 2023), and T2D (Smith et al., 2016)), were based on meta-analyses of epidemiological data of populations somewhat older at baseline than our target population. For IHD, IS, BC and CC, annual incidences in the younger two age groups of our target population (<35 years) are very low, accounting for between 2–4 % of total incidence, hence applying these dose–response functions to this group has an extremely minor impact (<1%) on our estimates of annual savings from all diseases. However, the annual incidence of T2D in < 35 year olds is around 29 % of the overall incidence. While we recognise that applying a dose–response function developed on data pertaining to those > 35 years old to a younger target population may upwardly bias our estimates of cost savings from all diseases by around 2.5 %, youth-onset T2D is largely explained by overweight and obesity in childhood, and pathogenesis in youth and older populations is believed to be broadly similar (Todd et al., 2018). It is noteworthy that the majority of our estimates of cost savings due to nature-based PA are from reduced incidence of MDD; the age ranges of the studies upon which the MDD dose–response function was based are typically similar to our target population.

Finally, being physically active can benefit the health of many of those living with certain chronic health conditions, including the diseases of interest in the current study. For example, for those living with type 2 diabetes, PA is associated with decreased risk of mortality from CVD, reduced comorbidities, lower blood pressure, reduced body mass index, and clinical parameters such as blood lipids and glycosylated haemoglobin (Gallardo-Gómez et al., 2024; Kirwan et al., 2017). Similarly, PA done by those with cancer diagnoses is related to reduced risks of mortality from both all causes and from cancer in female breast cancer survivors and colorectal cancer survivors (Bull et al., 2020). Since our estimate of savings per prevalent case was based on recent UK-wide economic valuations of all prevalent cases, the extent to which PA practiced by the population with these diseases is already reducing those costs is unclear.

5. Conclusions

In summary, we have demonstrated the potential of nature-based PA to deliver substantial, population-scale prevention of key non-communicable diseases. This prevention translates to considerable monetary savings associated with healthcare and productivity Therefore, we are able to demonstrate specific health-economic benefit to natural capital in terms of accessible natural spaces that support and promote physical activity. Given that nature-based PA constitutes only one pathway to health for visitors to natural environments, the economic value of these spaces in terms of health promotion and disease prevention is considerable, in particular given increasing prevalence of many NCDs due to factors such as an ageing population (GBD, 2019 Diseases and Injuries Collaborators, 2020; Government Office for Science, 2016). Critically, these benefits can only increase sustainably if actions are taken to simultaneously protect and improve the natural environments that provide these opportunities.

In England, comparative analysis of all ten waves of the MENE from 2009 and 2019 has shown growth in the proportion of adults that spend time in natural environments, up from 54 % to 65 % over the decade, alongside a notable increase in the share of visits taken for health or exercise reasons (Natural England, 2019a). Our study provides decision-makers with a novel approach to monetise the public health value of existing natural environments, and insight into additional societal and economic benefit that might be gained through further increases in volumes of nature-based PA conducted the adult population. The equitable provision of adequate, safe, accessible natural environments for recreation has become an important element of public health policy in recent years (HM Government, 2023; Public Health England, 2020; WHO Regional Office for Europe, 2016). Since natural environments afford opportunities for PA for people who may be reluctant to participate in formal, organised, and paid for activities (Birch et al., 2020), there is a need for evidence on how best to support, facilitate and promote such activity so that a higher proportion of the population takes up or increases PA in these environments. Understanding the substantial potential economic value of nature-based PA resulting from such strategies can be extremely helpful in their design and implementation.

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CRediT authorship contribution statement

James Grellier: Conceptualization, Formal analysis, Methodology, Software, Writing – original draft, Writing – review & editing, Visualization. **Mathew P. White:** Conceptualization, Methodology, Supervision, Writing – review & editing. **Siân de Bell:** Conceptualization, Methodology, Writing – review & editing. **Oscar Brousse:** Writing –

review & editing. **Lewis R Elliott:** Formal analysis, Methodology, Software, Writing – review & editing. **Lora E Fleming:** Funding acquisition, Writing – review & editing. **Clare Heaviside:** Funding acquisition, Writing – review & editing. **Charles Simpson:** Writing – review & editing. **Tim Taylor:** Methodology, Writing – review & editing. **Benedict W Wheeler:** Conceptualization, Writing – review & editing. **Rebecca Lovell:** Conceptualization, Funding acquisition, Supervision, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.envint.2024.108667.

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