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Health co-benefits of climate change mitigation policies in the transport sector

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Theory, common sense and modelling studies suggest that some interventions to mitigate carbon emissions in the transport sector can also have substantial short-term benefits for population health. Policies that encourage active modes of transportation such as cycling may, for example, increase population physical activity and decrease air pollution, thus reducing the burden of conditions such as some cancers, diabetes, heart disease and dementia. In this Perspective we systematically review the evidence from 'real life' transport policies and their impacts on health and CO_2 emissions. We identified a few studies that mostly involved personalized travel planning and showed modest increases in active transport such as walking, and reductions in vehicle use and CO_2 emissions. Given the poor quality of the studies identified, urgent action is needed to provide more robust evidence for policies.

Climate change is now regarded as one of the biggest threats to global human health. The direct health effects of climate change — such as those due to changes in the distribution of vector-borne diseases and more frequent and severe heatwaves — are likely to be minor compared with the indirect health consequences. Indirect health effects arise from changes in food production and availability, water shortages and associated conflict and migration. These impacts are expected to be greatest in less developed countries that have poorer overall health and have contributed least to climate change[1].

The transport sector produces 22% of world energy-related carbon emissions and is one of the fastest growing sources of emissions (see Fig. 1 for the modal distribution of energy use in the transport sector[2,3]). A large variety of interventions are available to reduce emissions in this sector[4–7]. These can be grouped into four broad categories: (1) economic policies, such as command and control and incentive-based economic policies (for example regulations around fuel standards, vehicle emissions, cap-and-trade systems, taxes, charges and subsidies); (2) physical policies, including physical infrastructure elements (such as rail infrastructure), land-use policies, public transport and infrastructure for walking and cycling; (3) soft policies, which are aimed at informing and bringing about behavioural change, such as information and advertising campaigns, including personalized travel planning, car clubs and 'teleworking'; (4) knowledge policies that support research and development[4,5].

Transport has long been known to affect human health, through pathways such as injury, physical inactivity, local and regional air pollution, and social capital[8]. In recent years, public health and epidemiology researchers have investigated these pathways, and this is reflected in the increasing number of systematic reviews that examine aspects of transport or transport-related initiatives that have an impact on health, such as shifts in travel mode[9], organizational travel plans[10], physical activity[11,12], road infrastructure[13], active travel[14–17], congestion[18] and transport initiatives and policies[19–22].

By linking health, transport and climate change, there has been increasing interest in harnessing interventions that reduce carbon emissions in the transport sector and improve population health[23–25]. Mitigation policies can potentially avoid the long-term health effects of climate change and affect health determinants such as physical activity in the short term[1]. The positive effects on health as a result of some mitigation policy options are known as co-benefits.

Figure 2 shows a simplified theoretical model of the pathways by which transport interventions could have impacts on both health and CO_2 emissions, although the precise pathways are dependent on the specific intervention. For example, a substitution of electric vehicles for existing fossil-fuel-powered vehicles could reduce air pollution but would miss the health opportunities afforded from active travel interventions that increase population physical activity[23]. An increase in diesel vehicles or a change to ethanol-blended fuel could increase urban air pollution and have associated health consequences[26,27]. Similarly, the balance of the effects of an intervention is important; for example, a congestion charge could decrease the volume of vehicles in the charging zone while increasing the volume outside the zone, and also promote the use of vehicles that are not subject to the charge (such as electric or diesel vehicles, depending on how the policy is designed). This type of information on the broader costs and benefits of policy is vital for decision makers when considering competing options. Decisions to introduce mitigation measures with very-long-term outcomes (but immediate costs) may be more palatable if there are also short-term benefits. This approach acknowledges that the economic impacts of an intervention may also affect health through other pathways, such as food poverty, and that there is a feedback loop between the reduction of greenhouse gas (GHG) emissions and the health outcomes from averting climate change.

There is a growing body of epidemiological literature modelling the health and CO_2 emission outcomes of specific transport sector policies[23,28–34]. This work has advanced the discussion about the co-benefits of such policies both by quantifying the large reductions in cardiovascular disease, respiratory disease, cancer and dementia (among others), and by clarifying that most of the health gains come from interventions that improve physical activity. Modelling consistently finds that the balance of positive health effects will substantially outweigh the harms due to the increased number of deaths caused by injury. Economic approaches to modelling also show that transport interventions are highly cost-effective, despite requiring an initial outlay of capital[35–37], and could allow for reallocation of funding within the health sector by averting ill-health[38].

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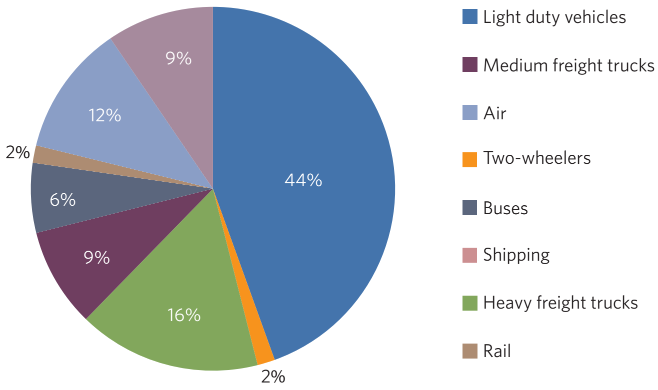

Figure 1 | Global energy use from the transport sector by mode (2000). Source: Intergovernmental Panel on Climate Change, ref. 2.

Modelling studies use the best possible information available and incorporate approaches such as sensitivity analysis and Monte Carlo simulation to explore the uncertainty around some of the parameters included in the model. There is a need, however, for observational studies of co-benefits for a number of reasons. First, thorough evaluation is needed to ensure that policy measures are actually achieving the CO_2 reductions and health co-benefits that are expected. The potential CO_2 and health gains estimated by models are a result of the implementation of large numbers of policies within society (such as congestion charges, fuel taxes and infrastructure investment). In reality, policies can be poorly implemented, fail to achieve the level of expected outcomes and/or have unintended or unexpected effects. Even a successful policy of CO_2 emission reduction implemented in one jurisdiction can have different outcomes when used in a different jurisdiction[39,40]. Second, there could also be other health pathways and outcomes that we currently do not account for in modelling owing to a lack of evidence or awareness (for example, it is possible that fuel taxes or carbon charges could decrease drink-driving related injuries[41]). Observational evidence could explore and quantify these pathways, which may alter the costs and/or balance of health and CO_2 benefits from policies. Third, the effect of these policies on inequalities in health needs to be explored. It is possible that transport policies could, depending on their design, exacerbate or mitigate existing inequalities between population groups.

We conducted a systematic literature review to bridge the knowledge gap between 'real life' experience and what modelling methodologies have suggested is, in theory, possible in terms of health and CO_2 impacts. The aim of this systematic review was to examine existing evidence on whether mitigation policies that decrease transport sector (road, rail, aviation and maritime) CO_2 emissions have a measurable effect on health determinants, population health and/or health inequalities.

Observational evidence for co-benefits

Table 1 summarizes the design, results and quality of the studies identified by our systematic review process (more detailed information on the included studies is contained in the Supplementary Information). The studies were mostly of personalized travel planning interventions and showed modest increases in walking (1–10%) and cycling (0–2%). No statistical tests were reported on these results[42–53]. One well-conducted time series analysis[54–58] of an inner-city congestion charge in Stockholm estimated a decrease in premature mortality (27 lives per year: 95% confidence interval 20–37) as a result of improved air quality in an overall population of 1.44 million. A separate evaluation of physical activity in the Stockholm population compared with controls in nearby cities that did not have congestion tax was inconclusive[59]. An evaluation of a legislated 'cash-out' of employee parking benefits showed a 1% increase in walking as a main mode of commuting[60,61]. A multifaceted intervention in three cities in England demonstrated modest increases in cycling (0–2%) and walking (1–3%), which contrasted with contemporaneous national declines in walking and cycling[62,63].

All studies estimated reductions in CO_2 emissions, which ranged from 104 tonnes eliminated over the 6-month period of the intervention in the city of York to 41,000 tonnes eliminated per annum in Greater Stockholm: the heterogeneous methods and lack of contextual information make it difficult to interpret these reductions.

Apart from the Johansson Stockholm congestion charge study[54], the quality of studies in this systematic review was poor. Common problems included limited methodological detail, poor or no justification for selection of controls, no information about the validity of measurement instruments, inadequate measurement of transport use and health outcomes, poor statistical analysis, short follow-up period and failure to consider and manage confounding. Differing methodology around calculation of CO_2 emissions also makes it difficult to compare the effectiveness of interventions in reducing emissions and improving health determinants. In short, apart from the Johansson paper[54], the validity of the results from these studies cannot be assumed.

Soft policies and their beneficiaries

Of the range of policy options that are available to decrease GHG emissions in the transport sector (outlined in the introduction), the studies included in this review were mostly 'soft policies' that encourage, but do not enforce, behaviour change. Research focus on soft policies may be because they are most commonly implemented, or because they are discrete projects that seem more amenable to evaluation.

Although projects such as personalized travel planning are in theory easier to evaluate, more attention needs to be paid to evaluating economic, legislative and infrastructure interventions. These projects, along with changes in land use, may have a greater ability to deliver larger and more enduring change, and thus greater health and CO_2 benefits, by creating an economic and physical environment that begins to redress the current pervasive favouring of unsustainable travel. This assumption, of course, needs to be tested empirically.

Experience from public health interventions suggests that targeted behavioural policies, on their own, have modest ability to achieve desired outcomes[64]. Although experience from tobacco control demonstrates that behavioural interventions have a role to play as part of a comprehensive approach to an issue, at this point attempting to change travel choices in an environment that remains deeply car-centric seems likely to have limited impact.

Interventions to reduce GHG emissions from modes of transport other than light vehicles were notably absent from the studies included in this review. While light vehicles contribute almost half of the transport sector energy use and GHG emissions (see Fig. 1)[2], a comprehensive approach requires all emitters to be included. There are potential health benefits to be gained from interventions in some of these areas, such as shipping and air travel[65–67]. Also absent from this review were studies of interventions in low- and middle-income countries. This is a gap that needs to be addressed.

There was little focus on inequalities in any of the studies: no study considered whether the intervention was likely to create or exacerbate existing socio-economic, ethnic or gender inequalities in health. Other individual-level interventions aimed at increasing sustainable travel modes have been taken up more by more advantaged groups, for example bicycle hire schemes in London and Montreal[68,69]. Reducing carbon emissions while simultaneously reducing health inequalities is one of the key challenges of the next decades[25,70], and measuring the impact of current interventions on health among different groups is crucial.

The changes in walking and cycling seen in studies in this review were modest; however, the individual-level changes required to produce meaningful population health benefits may be small[71]. Population health benefits will, however, only accrue if the physical activity is new physical activity rather than a replacement for other activity and is occurring in people who are currently insufficiently active for good health. Although the studies in this review did not address either of these issues, other evidence supports the view that changing to active transport can increase overall physical activity in adults and children[72,73].

Assessing carbon reductions comprehensively

Among the included studies, CO_2 emission changes were calculated in a number of ways, making direct comparisons difficult and precluding a meta-analysis. The basic approach used in most studies was to calculate the change in vehicle kilometres travelled (VKT) in the intervention group and apply an 'average' emission factor for CO_2 emissions per kilometre to estimate the change in emissions. Variations included (1) restricting the analysis to a subgroup of the study participants who had used a car in the preceding 7 days[47], (2) sensitivity analyses around the distribution of small and large cars in the vehicle fleets, the number of cold starts, national changes in VKT and increases in emissions that occurred because of the increase in use of buses[62], and (3) a 57% margin to account for emissions that were generated by the extraction, refining and transportation of car fuel[60]. Johansson *et al.*[54] took increases in traffic in areas outside the congestion charge zone into account when calculating the CO_2 emissions reduction.

More standardized approaches to measuring and reporting carbon emission reductions need to be adopted in future studies to aid comparisons between interventions (for example the Global Environment Facility transport emission calculators[74]). Another issue that needs to be considered is 'rebound' and 'backfire' effects: that is, changes in patterns of transport use may free up money, time or resources that result in replacement of, or increase in, other carbon-emitting activities[75].

The way forward

Evaluating transport policies in a robust manner is difficult, as is shown by the generally poor quality of the studies included in this Perspective, but options are available to improve the robustness of the evidence base that do not necessarily involve spending more money. First, there are techniques available for improving the design and analysis of quasi-experimental studies (for example non-randomized trials) to increase the ability to make causal inferences. These do not necessarily involve additional cost but do require more thoughtful planning: for example design improvements such as better selection of control areas, or statistical methods such as the use of propensity score analysis for managing confounding[76–78]. Examples of innovative, well-designed quasi-experimental approaches to answer research questions about transport interventions are available[79–81]. Second, the publicly funded TravelSmart project data could be made available to allow independent review and, if appropriate, re-analysis using better statistical techniques (confidence intervals were not reported in these studies, for example). This may allay some of the concerns expressed about the evidence for the effectiveness of the interventions[82,83]. Third, a more comprehensive range of health outcomes could be assessed: for example noise pollution, pathways to social capital/community severance or assessment of an individual's overall physical activity, rather than just transport-related physical activity. Fourth, fewer evaluations could be undertaken of personalized travel planning interventions and more studies of other interventions (for example infrastructure changes, economic interventions) and multi-faceted interventions carried out. Fifth, better measurement instruments could be used in surveys (for example validated 7-day travel diaries). Finally, existing data from studies that have looked only at air quality measures could be 'converted' into health outcomes; similarly, studies with only VKT outcome measures could calculate an estimate of CO_2 reductions.

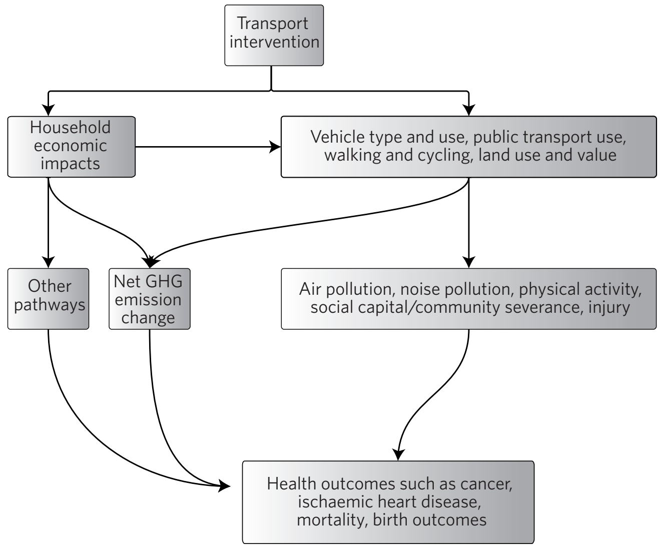

Figure 2 | Theoretical model of pathways from transport interventions to health and GHG emission changes.

There is also a role for traditional epidemiological study designs. The evaluation of staged rollouts of interventions and conducting cluster randomized controlled trials are obvious examples. These types of study have been successfully conducted in other social policy areas[84]. They will require central (that is, local or national government) coordination and support, as well as timely consideration of when they should be conducted. Additionally, the use of explicitly theorized models about the pathways between the intervention and the transport and health outcomes (as Fig. 2 illustrates) should guide decisions about which outcomes to measure. Longer follow-up periods are required to determine whether CO_2 and health benefits are sustained.

New and innovative methods are also needed to look at which national-level policy interventions reduce carbon emissions and improve health. Such interventions can often only be evaluated using uncontrolled before-and-after studies or time series analysis. International cohorts to aid cross-national comparisons, similar to the International Tobacco Control Policy Evaluation Project[85], could be used to investigate the effectiveness of national transport policies. Evaluations that involve combinations of observation and modelling could be useful when outcomes are hard to measure, rare or long-term. Recent evaluations of the Bicing bike hire programme in Barcelona and the London bicycle sharing system, for example, use this approach[86,87].

There is a need to conduct economic evaluations of observational studies. Decision makers need to be able to compare the cost effectiveness of policies and interventions that reduce carbon emissions and produce health benefits. Although ideally we would want to maximize health as well as GHG emission reductions of specific policies, there may be circumstances where one outcome is prioritized (for example a need for rapid decarbonization to meet international obligations). It is important to be explicit about these choices.

Finally, in theory, observational evidence from reviews such as this should be a foundation for modelling studies that explore the longer-term consequences and answer specific policy questions about options to reduce transport GHG emissions and improve health. Additionally, evaluation of policies being implemented is a form of monitoring how well an intervention is contributing

Table 1 | Results of included studies

Study	Intervention type	Study design	Results: Health outcomes*	Results: CO_2 emissions†	Results: Transport behaviour	Quality assessment
Bergman[59]	Inner-city congestion charge, Stockholm	RC	Increase in overall physical activity (MET) ($p = 0.015$) in intervention group. Changes not significantly different from trends in control group.	See Johanssen[54]	Not reported	Weak
Haq[47]	PTP, York, UK	NRT	*Walking mode share* **Intervention** +10% **Control** –1% *Cycling mode share* **Intervention** +1% **Control** +1%	–104t eliminated due to this intervention	**Intervention** –16% **Control** +4% (car use mode share)	Weak
Johannsen[54–58]	Inner-city congestion charge, Stockholm	TSA	27 (95% CI 20–37) premature deaths per year avoided due to decreased NOx	–41,000t ± 11,700 annually Greater Stockholm (–2.7% ± 0.8%)	–15% (road use within congestion charge zone)	Strong
Shoup[60,61]	Legislated 'cash out' (cash equivalent) of parking subsidy in Los Angeles, California	RC	*Walking mode share* **Intervention** +1% **Control** no change *Cycling mode share* **Intervention** no change **Control** no change	–0.367t per employee per year (exhaust extraction, refining and transport emissions)	**Intervention** –13% **Control** no change (solo driver share)	Weak
Sloman[62,63]	Multifaceted intervention of PTP and infrastructure in three towns in England	NRT	*Walking mode share* **Intervention** +1 to +3% **Comparison** trip stages –3% 2004–2008 *Cycling mode share* **Intervention** 0 to +2% **Comparison** trips stages –0.7% 2004–2008	–17,510t over the three towns (–0.6% per capita emissions)	**Intervention** –11.5 trips per 100 people per day **Comparison** car driver trip stages +1.7% 2004–2008	Weak
Travelsmart Exeter[44]	PTP, UK	NRT	*Walking mode share* **Intervention** +6% **Control** +2% *Cycling mode share* **Intervention** no change **Control** –2%	–6,003t annually‡	**Intervention** –4% **Control** no change (p<0.01)§	Weak
Travelsmart Lancashire-Preston/ South Ribble[45]	PTP, UK	NRT	*Walking mode share* **Intervention** +1% **Control** no change *Cycling mode share* **Intervention** +1% **Control** +1%	–2,200t annually‡	**Intervention** –6% **Control** –1% (p<0.05)§	Weak
Travelsmart Lancashire Lancaster City/ Morecambe/ Torrisholme[45]	PTP, UK	NRT	*Walking mode share* **Intervention** +4% **Control** –2% *Cycling mode share* **Intervention** +2% **Control** no change	–5,500t annually‡	**Intervention** –5% **Control** +1% (p<0.05)§	Weak
Travelsmart Lowestoft[42]	PTP, UK	NRT	*Walking mode share* **Intervention** +3% **Control** –1% *Cycling mode share* **Intervention** +1% **Control** no change	–5,5618t annually‡	**Intervention** –5% **Control** +1% (p<0.01)§	Weak
Travelsmart Melville[49,50,53]	PTP, Australia	NRT	*Walking mode share* **Intervention** +1% **Control** –1% *Cycling mode share* **Intervention** +1% **Control** –1%	–0.33t per annum per household	**Intervention** –5% **Control** +2% (p<0.01)§	Weak

Table 1 continued | Results of included studies

Study	Intervention type	Study design	Results: Health outcomes*	Results: CO_2 emissions†	Results: Transport behaviour	Quality assessment
Travelsmart South Perth[48,51-]	PTP, Australia	NRT	*Walking mode share* **Intervention** +4% **Control** –2% *Cycling mode share* **Intervention** +1% **Control** no change	–0.39t per annum/household	**Intervention** –8% **Control** +1% (car use mode share)	Weak
Travelsmart Watford[43]	PTP, UK	NRT	*Walking mode share* **Intervention** +5% **Control** + 1% *Cycling mode share* **Intervention** no change **Control** no change	–8,458t annually‡	**Intervention** –7% **Control** no change (p<0.01)§	Weak
Travelsmart Worle[46]	PTP, UK	NRT	*Walking mode share* **Intervention** +4% **Control** +1% *Cycling mode share* **Intervention** +1% **Control** no change	-660t annually‡	**Intervention** –7% **Control** –1% (p<0.05)§	Weak

RC, retrospective cohort; MET, metabolic equivalent; PTP, personalized travel planning; NRT, Non-randomized trial; TSA, Time series analysis; CI, confidence interval. Car use mode share, percentage of journeys taken in a car as either driver or passenger. Solo driver share, percentage of commuters who drive to work alone in the car. Trip stages, the parts of an overall one-way trip that has a single main purpose. *Absolute change presented where possible, unadjusted for control group effects for TravelSmart studies. †Exhaust emissions only unless otherwise specified. ‡ Compared with pre-project levels. Calculation of VKT that underpin the CO_2 emission change calculations excluded all journeys over 100 km. No information on proportion of journeys or emissions this represents. Unclear whether this adjusts for changes in control group. §Car (driver) mode share, percentage of journeys taken by people driving a car.

towards the outcome predicted in a model. In reality, the empirical evidence, in the area of health co-benefits of transport policies, is so limited that it fails to provide this foundation. Therefore, there is an urgent need to increase the quantity and improve the quality of such evidence. And there is also a need for a more nuanced discussion of how evidence from modelling and observational studies can fit together[88,89]. We suggest that, as a start, the quality assessment of epidemiological modelling should be more standardized. Papers by the ISPOR-SMDM Modelling Good Research Practices Task Force have started to address this issue[90]. More thought also needs to be put into the two-way relationship between modelling and observational evidence: for example, the parametric uncertainty estimates generated in modelling studies[86,87] could, in theory, be used as a guide to prioritize future research efforts.

Harnessing, promoting and enhancing the health co-benefits of transport sector mitigation policies — and using them to reduce inequalities — is a challenge for the twenty-first century. This systematic review has shown that there is a pressing need for more and better quality research. The rate of climate change means, however, that action to reduce emissions should not wait for this. The need for transportation planners, policy makers and the public health community to start working together on these issues is urgent.

Methods

The systematic review is reported as per the PRISMA statement[91]. A number of other cross-disciplinary systematic reviews were used as exemplars to guide the review methods[9,13,16,17,92–94]. More detailed information on the methodology, as well as a discussion of the strengths and weaknesses of the review, is contained in the Supplementary Information. Briefly, we searched for studies with any type of health or inequality outcome in 12 databases. We set no search limits on language, study design or study population. Our search syntax included search terms in four areas: climate change, health and health inequalities, travel mode, and transport policy. We also searched previous systematic and non-systematic reviews in the area of transport and health, websites and reference lists of included papers. We approached 21 experts in the field to identify any published or unpublished studies missed by our search strategy. The publication period searched was from 1 January 1992 to 31 March 2011.

We included both observational or experimental studies with a control group, and time-series studies. Studies were included if they: (1) examined a ‘real life’ intervention/policy/natural experiment in the transport sector; (2) measured health behaviours or outcomes and (3) calculated CO_2 emission change. Changes in carbon emissions and changes in health measures did not have to be reported in the same publication: we treated any papers about the same interventions/policies as a ‘set’ in our secondary screening process.

One reviewer assessed all titles and abstracts identified in the literature reviews to remove irrelevant references, with a 10% sample being verified by another reviewer. The full text of all remaining papers was obtained and assessed independently by two reviewers, and those that met our inclusion criteria were identified. For each included study, two reviewers independently extracted the data and made an assessment of study validity. We assessed the quality of the included studies using the Effective Public Health Practice Project tool for all types of quantitative study[95–97].

We identified 8,649 references from database searching, and an additional 252 references from reference lists, websites and experts. Once duplicates were removed, 6,864 studies went through the primary screening process. We reviewed the full text of 467 articles and the final review included 22 papers describing 11 interventions from four countries: United Kingdom, United States, Australia and Sweden.

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Author contributions

All authors contributed to the design of the review. C.S. executed the search strategy and undertook the primary screening and secondary screening. S.H. contributed to the primary screening and undertook secondary screening. All authors contributed to data extraction and qualitative assessment process. C.S. drafted the paper. All authors contributed to the critical review of the paper and approved the final version.

Additional information

Supplementary information is available in the online version of the paper. Reprints and permissions information is available online at www.nature.com/reprints. Correspondence and requests for materials should be addressed to C.S.

Competing financial interests

The authors declare no competing financial interests.