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Contrasts in active transport behaviour across four countries: How do they translate into public health benefits?

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Bicycling
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Health impact assessment
Active travel

A B S T R A C T

Objective. Countries and regions vary substantially in transport related physical activity that people gain from walking and cycling and in how this varies by age and gender. This study aims to quantify the population health impacts of differences between four settings.

Method. The Integrated Transport and Health Model (ITHIM) was used to estimate health impacts from changes to physical activity that would arise if adults in urban areas in England and Wales adopted travel patterns of Switzerland, the Netherlands, and California. The model was parameterised with data from travel surveys from each setting and estimated using Monte Carlo simulation. Two types of scenarios were created, one in which the total travel time budget was assumed to be fixed and one where total travel times varied.

Results. Substantial population health benefits would accrue if people in England and Wales gained as much transport related physical activity as people in Switzerland or the Netherlands, whilst smaller but still considerable harms would occur if active travel fell to the level seen in California. The benefits from achieving the travel patterns of the high cycling Netherlands or high walking Switzerland were similar.

Conclusion. Differences between high income countries in how people travel have important implications for population health.

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Introduction

Regular physical activity provides a wide range of health benefits. Active travel (primarily walking and cycling) has gained attention from the transport and environmental sectors for its advantages as low-emission and space-efficient travel modes (Banister, 2008). Active travel is also increasingly recognized for its potential to contribute to overall physical activity (Craig et al., 2012; Dora, 1999). As active travel combines mobility and activity, it may offer a lower hurdle to be active than sports or other recreational activity. Nonetheless, steps to increase active travel have generally been hesitant, although some countries (e.g. the Netherlands, Switzerland, Germany or Denmark) have been more proactive than others (e.g. UK, USA). Health impact modelling is used to quantify effects of active travel on health outcomes in a specified population and as such can support informed decision making and cost-effective investment of limited resources.

In recent years, various methods to model health impacts of active travel have been developed. These typically compare benefits of physical activity with potential harms from injury risk and increased exposure to air pollution. When modelling substantial changes at the population level, such studies have overwhelmingly found large net benefits from active travel (de Hartog et al., 2010; Rabl and De Nazelle, 2012; Rojas-Rueda et al., 2011, 2013; Woodcock et al., 2013, 2014), although this may not apply in younger age groups when injury risks are high (Woodcock et al., 2014).

Typically health impact models of transport have used hypothetical scenarios with simplistic assumptions on changes in active travel (e.g. de Hartog et al., 2010; Gotschi, 2011; Grabow et al., 2011; Kahlmeier et al., 2011). Such studies may arguably struggle to realistically reflect travel behaviour, particularly in the context of advanced models which consider distributions of physical activity across age and gender. The objective of this study is therefore to create alternative scenarios using data from major travel surveys reflecting population-wide distributions of travel behaviour, in particular across age and gender. England and Wales (E&W) served as the reference scenario. To illustrate the potential range of the magnitude of health impacts from changes in active transport, comparison areas were chosen for exceptionally high...
or low levels of active transport, respectively. Specifically, the health impacts on the urban population of E&W were modelled, assuming shifts to travel patterns of Switzerland, the Netherlands, and California.

Methods

Travel survey data

Travel survey data were used from E&W and three comparison areas selected based on substantial contrasts in travel patterns, namely Switzerland for high levels of walking, the Netherlands for high levels of bicycling, and California for high levels of car usage. As such, they were used to inform hypothetical yet realistic scenarios for the population of E&W. Table 1 shows descriptive data of E&W and the three comparison areas.

Data on travel patterns were extracted from national travel surveys (Bundesamt für Statistik et al., 2007; Department of Transport, 2013; Federal Highway Administration, 2010; Ministerie van Verkeer en Waterstaat, 2010) (Supplementary Table A.1.). To increase survey comparability, small communities of less than 10,000 inhabitants were excluded, and minimum trip duration was standardized to 3 min.

Health impact modelling

Health impacts were modelled as changes in population health due to changes in active travel time (walking, cycling) in the E&W population. The model was estimated using Monte Carlo simulation in Analytica version 4.4. (www.lumina.com), running 50,000 iterations. The current E&W travel pattern was compared against the counterfactual scenarios in which E&W would adopt the travel patterns from Switzerland, the Netherlands or California, respectively.

Travel patterns were modelled as changes in absolute terms (minutes of each mode), as well as relative terms (percent of total travel time of each mode). Travel behaviour was modelled as population wide distributions of travel times spent in different modes, stratified by sex and age groups for E&W and each comparison area. For all other variables, i.e. age distribution, background mortality and morbidity rates, age and sex-specific E&W data was used.

The study was conducted using a substantially improved and updated version of the Integrated Transport and Health Impact Modelling tool (ITHIM) (Woodcock, 2014), which now models variability and uncertainty of parameters using Monte Carlo simulation. Earlier versions were previously described elsewhere (Maizlish et al., 2013; Woodcock et al., 2013, 2014). ITHIM was used to model health benefits of physical activity using a range of non-linear dose–response functions specific to exposure domains (total physical activity, non-work physical activity, or physical activity from active travel) and outcomes (all cause mortality, morbidities). Because most previous health impact models of active travel found that associated risks are at least one order of magnitude smaller than benefits of physical activity when changes are modelled across all age groups (de Hartog et al., 2010; Rabl and De Nazelle, 2012; Rojas-Rueda et al., 2011), the approach to impact modelling presented here is only applied to impacts from physical activity.

Aggregation of background physical activities reflected intensity of specific activities, estimated in Metabolic Equivalents of Task (METs), as listed in the Compendium of Physical Activity (Ainsworth et al., 2011). Activities under 1.5 METs were excluded. METs were converted into marginal METs by subtracting 1 MET (intensity of being at rest). This approach only considers the activity over and above the metabolic activity at rest. Variation in METs for each activity was taken into account stochastically to generate distributions of METs within age and gender strata (Table 2).

Age (15+) and gender specific data on walking, cycling, household work, sport and work included estimates of variability and were available from the health survey for England (Craig and Mindell, 2013). Background physical activity was assumed to remain unchanged throughout the different scenarios (Supplementary Table A.2.).

Health benefits of physical activity were modelled using disease specific incidence and mortality of stroke, ischemic heart disease (IHD), other cardiovascular and circulatory diseases, type-2 diabetes, colon cancer, breast cancer, dementia and Alzheimer’s disease, and depression. The doses were recalculated from Woodcock et al. (2009) as marginal MET/h week. See Table 3 for dose–response parameters. As part of sensitivity analysis, two alternative approaches to model impacts on all-cause mortality were applied, using relative risks from a systematic review by Woodcock et al. (2011) and a dose–response function presented in a recent large cohort study (Wen et al., 2011), respectively (Supplementary Table A.3.).

A log-linear relationship was assumed between exposures and the health outcomes. Beyond this the exposure variables were transformed (using power transformations 0.25 to 1) (Sattelmair et al., 2011; Woodcock et al., 2011). Since the exact parameters of the non-linear dose–response function are unknown, these were stochastically allowed to vary across iterations of the model (see Supplementary Fig. B.1) and evaluated in sensitivity analyses.

Burden of disease data for the UK, including mortality rates as well as disability adjusted life years (DALYS), years of healthy life lost due to disability (YLDs) and years of life lost (YLLs), were obtained from the Global Burden of Disease (GBD) study 2010 (IHME, 2013) and adjusted to reflect E&W population size, and age and gender distribution. Supplementary Table A.4 presents size and age distribution and Supplementary Table A.5 the burden of disease for the study population.

Sensitivity of the model to selected parameters was illustrated with tornado plots (Table 2, Supplementary Table A.6 and Fig. B.2).

Results

Travel behaviour patterns

The three international comparison areas reveal substantial contrasts compared with E&W, both in terms of absolute travel times as well as relative distribution across travel modes assuming a constant travel time budget (Table 4). Overall, the data showed travel time to be highest in Switzerland at over 80 min per day, compared with fewer than 60 min in E&W. Californians drive the most, almost 1 h per day, compared with only around 35 min in E&W. The small differences for driving times between the different European settings reflect the fact that the Swiss

Table 1

<table>
<thead>
<tr>
<th>Description</th>
<th>England &amp; Wales (study area)</th>
<th>Switzerland</th>
<th>Netherlands</th>
<th>California</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area</td>
<td>151,036 km²</td>
<td>41,285 km²</td>
<td>41,543 km²</td>
<td>423,970 km²</td>
</tr>
<tr>
<td>Population density</td>
<td>370/km²</td>
<td>188/km²</td>
<td>405/km²</td>
<td>95/km²</td>
</tr>
<tr>
<td>Gross domestic product (GDP)/capita ($)</td>
<td>37 k (UK)</td>
<td>54 k</td>
<td>42 k</td>
<td>46 k (USA)</td>
</tr>
</tbody>
</table>

Sources: (Wikipedia, 2014), if not otherwise stated. See footnotes.

d http://www.clrsearch.com/Sacramento-Demographics/CA/Number-of-Vehicles-per-Household
and Dutch make fewer short but more longer trips by car, compared with E&W (data not shown).

The Dutch ranks the highest for cycling, at 12 min per day compared to only about 1 min per day in E&W. Levels of walking are highest in Switzerland at around 25 min per day.

Gender and age distributions of active travel are of interest both in planning – as indicators as to how well the environment supports active travel across the life course, and in health impact modelling (Table 4, Fig. 1 and Supplementary Fig. B.3). Walking is on balance slightly more common amongst women, whilst cycling shows a clear gender gap in favour of men in E&W and California, with almost three times lower values for women. In the Netherlands, where cycling is most popular and safest (Pucher and Buehler, 2008), there is no gender gap.

In E&W and California, walking levels are the highest amongst younger generations and decline with increasing age. In Switzerland and the Netherlands, walking levels increase with age and only drop notably in old age (80+). For cycling, the decline with increasing age is dramatic in E&W, California and, albeit somewhat delayed, in Switzerland. In the Netherlands, cycling levels only decline after age 70 (Fig. 1).

**Health impacts**

Estimated health impacts for adopting absolute travel times are presented in Table 5a, whilst Table 5b shows results for adopting portions of travel time spent in different modes but keeping total travel time as at present. Every year, approximately 2.8 million DALYs are lost in E&W due to diseases associated with inactivity, i.e. cardiovascular diseases, breast and colon cancer, type-2 diabetes, dementia, and depression. This includes 167,000 deaths. Adopting time spent walking for pleasure.

<table>
<thead>
<tr>
<th>Disease</th>
<th>RR (mean (std))</th>
<th>Corresponding exposure marginal MET h/week</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stroke; ischemic heart disease (IHD); other cardiovascular and circulatory diseases</td>
<td>0.84 (0.03)</td>
<td>5.4</td>
<td>Hamer and Chida (2008)</td>
</tr>
<tr>
<td>Type-2 diabetes</td>
<td>0.83 (0.04)</td>
<td>5.6</td>
<td>Jeon et al. (2007)</td>
</tr>
<tr>
<td>Colon cancer</td>
<td>0.80 (0.08); women: 0.86 (0.06)</td>
<td>Men 24.1; women 23.3</td>
<td>Harris et al. (2009)</td>
</tr>
<tr>
<td>Breast cancer</td>
<td>0.94 (0.01)</td>
<td>3.5</td>
<td>Momminkhof et al. (2007)</td>
</tr>
<tr>
<td>Dementia and Alzheimer's disease</td>
<td>0.72 (0.07)</td>
<td>24.5</td>
<td>Hamer and Chida (2009)</td>
</tr>
<tr>
<td>Depression</td>
<td>0.96 (0.02)</td>
<td>0.8</td>
<td>Paffenbargers et al. (1994)</td>
</tr>
</tbody>
</table>

*Means and standard deviations are based on a normal distribution. E.g. RR of 0.84 moving from no activity to 5.4 marginal MET h/week.*

**Discussion**

Findings from this study imply that large, population level shifts in travel behaviour of E&W would translate into health impacts of significant magnitude. All else equal, adoption of high rates of active travel comparable to Switzerland or the Netherlands would result in the prevention of approximately 6–10% of all deaths caused by diseases associated with physical inactivity, and about 3–4% of all deaths due to all causes. Conversely, a shift towards somewhat lower levels of walking similar to California would result in up to 3000 additional premature deaths annually.

The comparisons also show that higher levels of active travel do not automatically correspond with less driving, which suggests that achieving high levels of active travel is not likely to be sufficient in itself to reduce carbon emissions unless there is also a policy to tackle longer
comparison areas. Probably of greater importance are high quality and safe bikes also offers the potential to reduce the burden of cycling in hillier areas. The Netherlands has a favourable topography for cycling there are many differences in travel (Pucher and Buehler, 2006). Although the urban/rural mix). To what extent and how such travel patterns could be adopted remains uncertain. Climate does not provide a good explanation of the differences in travel (Pucher and Buehler, 2006). Although the Netherlands has a favourable topography for cycling there are many flat areas in E&W without much cycling. The advent of electric assist bikes also offers the potential to reduce the burden of cycling in hillier areas. Probably of greater importance are high quality and safe infrastructure (Pucher and Dijkstra, 2003), as is in place in the Netherlands for cycling, synergies with public transport, as in Switzerland where public transport is fed by a huge number of walking trips (also see Table 4), and a generally supportive culture towards active travel (Heinen et al., 2010). Robust evidence on the beneficial effects on total physical activity of provision of traffic free walking and cycling routes is emerging from the UK (Goodman et al., 2014), and studies have shown a positive increase in cycling following city level programmes in England (Goodman et al., 2013). However, overall quantitative effects of specific policies remain poorly understood (Goodman et al., 2014; Pucher et al., 2010), and depend on cultural context that may require adapted local approaches (Aldred and Jungnickel, 2014). Well documented is the correlation between levels of active transport and traffic safety (Elvik, 2009; Jacobsen, 2003; Pucher and Dijkstra, 2003). Perceived risks are a major barrier to cycling and to an extent to walking, and increasing objective and subjective safety in a manner that does not detract from mode convenience should be considered by all policies to promote active travel. Interestingly the benefits in E&W from adopting travel patterns from the Netherlands or Switzerland were similar. Based on absolute travel times, benefits from Swiss travel (mainly walking) were greater in part because the Swiss spend more time travelling than people in the other settings. If instead we assume that the English and Welsh travel time budget remains constant but is proportioned out differently, then the benefits from Dutch travel were greater.

Several methodological considerations are of importance when interpreting the presented health impacts. Because the dose-response

### Table 4

<table>
<thead>
<tr>
<th>Mode</th>
<th>England &amp; Wales</th>
<th>Switzerland</th>
<th>Netherlands</th>
<th>California</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Male</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Walk</td>
<td>10.7 (7.6%)</td>
<td>23.4 (25.4%)</td>
<td>9.3 (12.2%)</td>
<td>7.5 (9.4%)</td>
</tr>
<tr>
<td>Cycle</td>
<td>1.4 (2.3%)</td>
<td>4.5 (4.9%)</td>
<td>12.7 (16.6%)</td>
<td>2.0 (2.5%)</td>
</tr>
<tr>
<td>Public transport</td>
<td>7.1 (11.7%)</td>
<td>13.9 (15.1%)</td>
<td>8.7 (11.3%)</td>
<td>5.9 (7.4%)</td>
</tr>
<tr>
<td>Car</td>
<td>38.1 (62.5%)</td>
<td>44.7 (48.5%)</td>
<td>40.7 (53.2%)</td>
<td>61.8 (77.5%)</td>
</tr>
<tr>
<td>Other</td>
<td>3.6 (6.0%)</td>
<td>5.6 (6.1%)</td>
<td>5.1 (6.7%)</td>
<td>2.5 (3.1%)</td>
</tr>
<tr>
<td>Total</td>
<td>61.0 (100.0%)</td>
<td>92.1 (100.0%)</td>
<td>76.4 (100.0%)</td>
<td>79.8 (100.0%)</td>
</tr>
<tr>
<td><strong>Female</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Walk</td>
<td>12.4 (22.3%)</td>
<td>28.5 (36.1%)</td>
<td>10.4 (16.6%)</td>
<td>8.9 (12.1%)</td>
</tr>
<tr>
<td>Cycle</td>
<td>0.4 (0.7%)</td>
<td>2.9 (3.7%)</td>
<td>11.7 (18.7%)</td>
<td>0.5 (0.7%)</td>
</tr>
<tr>
<td>Public transport</td>
<td>7.8 (14.1%)</td>
<td>14.0 (17.7%)</td>
<td>8.7 (13.9%)</td>
<td>6.3 (8.5%)</td>
</tr>
<tr>
<td>Car</td>
<td>34.1 (61.5%)</td>
<td>31.1 (39.4%)</td>
<td>28.6 (45.4%)</td>
<td>56.8 (77.2%)</td>
</tr>
<tr>
<td>Other</td>
<td>0.8 (1.4%)</td>
<td>2.4 (3.1%)</td>
<td>3.4 (5.5%)</td>
<td>1.1 (1.5%)</td>
</tr>
<tr>
<td>Total</td>
<td>55.4 (100.0%)</td>
<td>78.9 (100.0%)</td>
<td>62.9 (100.0%)</td>
<td>73.6 (100.0%)</td>
</tr>
</tbody>
</table>

* The data is population based including people who did not travel. Communities < 10,000 and subjects < 16 years are excluded.

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**Study limitations and strengths**

ITHIM is characterized by a number of strengths, compared with other similar models. In particular, it considers morbidity and not just deaths, population wide distributions of travel times, and health relevant parameters, such as gender, age, background disease rates and physical activity. It applies more realistic non-linear dose–response functions and estimates a set of different health measures.

The presented analysis uses empirical travel survey data to inform scenarios of shifts in travel patterns, which provide realistic population wide distributions of active travel by age and gender. For example, older age groups have higher health risks and therefore benefit more from relative risk reductions due to active travel. Typically, HIA rely on average effects. For example, the WHO HEAT tool ([www.euro.who.int/HEAT](http://www.euro.who.int/HEAT)) provides an approach that is conservative in excluding effects amongst older adults but may be optimistic in not differentiating between younger and middle-aged adults. In contrast, the presented approach considers realistic age and gender distributions in its scenarios. For example, increasing cycling to levels of the Netherlands means substantial increases in cycling in elderly and women (see Figs. 1 and B.3).

The two ways how travel patterns were applied are indicative of the range of resulting benefits. Achieving absolute travel times reflects more accurately our best estimates of how people in the different countries currently behave. However, increasing total travel times may be seen as undesirable and achieving changing the relative time spent might be a more appropriate policy target. It should also be noted that differences in total travel time between the settings may in part reflect differences in survey methods. Despite attempts to standardize, the comparison data entail inherent methodological differences (e.g. survey questions and periods) as well as local differences (e.g. land use and urban/rural mix).

To what extent and how such travel patterns could be adopted remains uncertain. Climate does not provide a good explanation of the differences in travel (Pucher and Buehler, 2006). Although the Netherlands has a favourable topography for cycling there are many flat areas in E&W without much cycling. The advent of electric assist bikes also offers the potential to reduce the burden of cycling in hillier areas. Probably of greater importance are high quality and safe infrastructure (Pucher and Dijkstra, 2003), as is in place in the Netherlands for cycling, synergies with public transport, as in Switzerland where public transport is fed by a huge number of walking trips (also see Table 4), and a generally supportive culture towards active travel (Heinen et al., 2010). Robust evidence on the beneficial effects on total physical activity of provision of traffic free walking and cycling routes is emerging from the UK (Goodman et al., 2014), and studies have shown a positive increase in cycling following city level programmes in England (Goodman et al., 2013). However, overall quantitative effects of specific policies remain poorly understood (Goodman et al., 2014; Pucher et al., 2010), and depend on cultural context that may require adapted local approaches (Aldred and Jungnickel, 2014). Well documented is the correlation between levels of active transport and traffic safety (Elvik, 2009; Jacobsen, 2003; Pucher and Dijkstra, 2003). Perceived risks are a major barrier to cycling and to an extent to walking, and increasing objective and subjective safety in a manner that does not detract from mode convenience should be considered by all policies to promote active travel.

### Fig. 1

increasing physical activity than those already active. The calculation of the dose–response function is quite influential, but there is no scientific consensus on its exact shape or how it may vary by disease (Samitz et al., 2011; Sattelmair et al., 2011; Woodcock et al., 2011). A power transformation of 0.25 attributes a large part of the relationship to linear shape distributes benefits closer to no activity to low levels of activity, whereas a positive transformation resulted in an increasing risk for crashes and increased exposure to air pollution. Previous studies indicate that if a population wide change in behaviour is achieved then benefits from physical activity by far outweigh these risks either at population or individual level (de Hartog et al., 2010; Woodcock et al., 2009).

This study points to several research needs. Handling non-linear dose–response functions and non-normal distributions of key parameters remain challenges. Meta-analyses of active travel related risks and dose–response functions are needed. Travel surveys combined with objective measurements should collect improved data including intensity of walking and cycling, ideally supplemented by items on overall physical activity. Ultimately, policy evaluations should collect adequate data to link findings from health impact modelling directly to prior investments made to achieve shifts towards healthier travel patterns.

Conclusions

International surveys can be used to inform scenario calculations for increasingly sophisticated health impact models of active travel. Travel survey data would be even more valuable, if items on physical activity were included and international calibration would increase feasibility of such comparisons.

If E&W adopted walking and cycling patterns of Switzerland and the Netherlands this could be expected to confer major health benefits. As such, the presented findings provide strong support for investments in efforts to increase levels of active travel.

Conflict of interest statement

The authors declare that there are no conflicts of interest.

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Appendix A. Supplementary material

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.ypmed.2015.02.009.

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