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The health impacts of traffic-related exposures in urban areas: understanding real effects, underlying driving forces and co-producing future directions

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Abstract

The world is currently witnessing its largest surge of urban growth in human history; a trend that draws attention to the need to understand and address health impacts of urban living. Whilst transport is instrumental in this urbanisation wave, it also has significant positive and negative impacts on population health, which are disproportionately distributed.

In this paper, we bring together expertise in transport engineering, transport and urban planning, research and strategic management, epidemiology and health impact assessment in an exercise to scope and discuss the health impacts of transport in urban areas. Adopting a cross-disciplinary, co-production approach, we explore the key driving forces behind the current state of urban mobility and outline recommendations for practices that could facilitate positioning health at the core of transport design, planning and policy.

Current knowledge on the health-related impacts of urban transport shows that motor vehicle traffic is causing significant premature mortality and morbidity through motor vehicle crashes, physical inactivity and traffic-related environmental exposures including increases in air pollution, noise and temperature levels, as well as reductions in green space. Trends of rapid and car-centred urbanisation, mass motorisation and a tendency of policy to favour car mobility and undervalue health in the transport and development agenda has both led to, and exacerbated the negative health impacts of the transport systems. Simultaneously, we also argue that the benefits of new transport schemes on the economy are emphasised whilst the range and severity of identified health impacts associated with transport are often downplayed. We conclude the paper by outlining stakeholders' recommendations for the adoption of a cross-disciplinary co-production approach that takes a health-aware perspective and has the potential to promote a paradigm shift in transport practices.

1. Introduction

Today, the city is regarded as the primary settlement form, accommodating half the world's population; a trend expected to continue (United Nations 2014, Vallance and Perkins 2010). It is estimated that 75% of the European population live in urban areas (European Environment Agency 2015), which have been and are being shaped, amongst other things, by step changes in transport connectivity and related land-use practices (Eddington 2006). This is the largest wave of urban growth in human history (United Nations Population Fund 2015) and a trend which draws attention to the need to understand and address the health impacts of urban living.

Transport is instrumental in this urbanisation wave and is often envisioned as a driver for urban development and a key contributor to economic returns. By way of supporting labour markets, allowing businesses to harvest the benefits of larger catchment areas, and providing “the right connections in the right places” (Eddington 2006), urban transport networks facilitate the economic growth, competitiveness and social progress of cities (Eddington 2006, Hall et al. 2014). Yet, the transport sector also has negative impacts on the health of a population, some of which are exacerbated in urban areas. These impacts, as shown in this paper, are particularly connected to the prevalence and use of private motorised transport. In developed countries, there is a cultural and economic dependence on motor vehicles as the primary mode of transport that dominates urban transport design and planning (Gakenheimer 1999, Jeekel 2013). Although mass motorisation started much later in developing countries, it is growing rapidly, causing similar problems in many developing cities (Dargay et al. 2007).

When considered at a global level, the adverse health impacts of motor vehicle traffic are striking. Each year, over 1.3 million deaths and 78 million injuries warranting medical care are a result of motor vehicle crashes (MVC) (Bhalla et al. 2014). Traffic-related exposures including increases in air pollution, greenhouse gases, noise and local temperatures and dwindling green spaces have resulted in stressors on the environment and in turn, on the population’s health (Nieuwenhuijsen 2016, Health Effects Institute 2010). Mass motorisation, low motoring costs, convenience and the associated lack of active travel provision have resulted in reduced opportunities for physical activity and increased sedentary behaviours (Audrey et al. 2014, Mackett and Brown 2011, Lucas and Pangbourne 2014, Wanner et al. 2012). Current land-use planning and policy patterns are furthermore reinforcing the excessive use of motorised transport for short distance trips (Cervero and Duncan 2003, Giles-Corti and Donovan 2002), further contributing to increased traffic-related environmental exposures and reduced opportunities for physical activity. These trends are all associated with a significant burden of chronic disease and increased premature mortality. For example, air pollution and decreases in physical activity, both to a significant extent, caused by motorised traffic, are associated with annual estimates of 7 million and 2.1 million global deaths,

respectively (Forouzanfar et al. 2015). These impacts are disproportionately distributed, contributing further to well-established gross inequalities in health (Marmot 2005).
Although current trends are not encouraging, there is emerging evidence that health promoting and sustainable transport infrastructure and modes such as cycling, walking and transit access can be effective in promoting active travel (Heinen et al. 2015, Panter et al. 2016, Heath et al. 2006) and can potentially reduce traffic-related environmental exposures (Woodcock et al. 2009, Grabow et al. 2012). These same policies can reduce health inequalities through modifying some of the pathways by which low socioeconomic position can lead to diseases (Lindsay et al. 2011, Maas et al. 2006, Mitchell and Popham 2008).

The adverse health impacts associated with urban transport and the potential solutions that a change in transport design and planning could offer reinforce the need to develop and implement effective policies that delineate and address health consequences. To this end, a clear scoping of traffic-related health impacts is needed as part of a systematic and systemic transport design and planning approach. In this paper, we conduct a cross-disciplinary literature review to summarise the health effects and impacts of traffic-related exposures and practices considering that motor vehicles are the primary mode of transport in most urban areas. Subsequently, adopting a cross-disciplinary co-production approach (Jasanoff 2004), we explore and outline the underlying driving forces behind the accepted status-quo and make recommendations for practices that could facilitate a paradigm shift placing health at the core of transport design, planning and policy making.

2. Specific aims and methods

To effectively mirror the intended cross-disciplinary readership of this paper, we have brought together expertise in transport engineering, transport and urban planning, research and strategic management, epidemiology and health impact assessment. This work is based on a number of meetings and workshops and builds on recent reviews on this topic by some of the authors (May et al. 2016, Mueller et al. 2015, Nieuwenhuijsen 2016, Nieuwenhuijsen and Khreis 2016, Nieuwenhuijsen et al. 2016). After an initial meeting at the first International Conference of Transport and Health 2015-London, subsequent meetings amongst the authors were arranged at the Centre for Research in Environmental Epidemiology (CREAL), in Barcelona, and at the Institute for Transport Studies (ITS), in Leeds. Additionally, a number of workshops around the interactions between transport and health were undertaken including two workshops at ITS on transport policy and planning and public health and car-free cities, one at CREAL on car-free cities, and one at the second Early Career Researchers Conference on Environmental Epidemiology on how to create healthy environments in cities (Khreis et al. 2016). During these events, the concepts presented in this paper were developed further and discussed amongst the authors, and others attending, where applicable. Not all the authors attended all the meetings, but a full collaboration has been made possible through the use of online tools such as Google Docs and emails. Throughout the write-up period, we maintained co-production as a central approach to effective communication and experiential learning strategy (Jasanoff 2004). Adopting a co-production approach and maintaining dialogue amongst the authors ensured that this paper emerged from a collective rather than a solitary exercise, which enabled us to compare ideas, build new arguments from different perspectives and re-consider alternative points of view in a highly iterative process of writing. All the present text has been collaboratively discussed, edited and circulated amongst the authors several times before submission. Each author has had input with her/his expertise in specific sections as well as contributed to the definition of the recommendations for the different stakeholders; presented in Section 6. Although this collaboration represents crossing disciplines which each have a role in addressing the impacts of transport on health, bringing other disciplines and knowledge into the debate is yet necessary.

In structural terms, we adopted a modified version of the questions proposed by Meyer and Miller (2001) to analyse complex transport planning issues as applied to transport and health:

- Where are we now?
- How did we get here?
- Where do we want to go and what will guide us?
- How will we get there?

The question ‘How did we get here?’ is not part of Meyer and Miller´s original set of questions. We, however, considered it constructive to propose a possible and necessary explanation of the current state-of-affairs. The transport sector is as susceptible to path dependency as any other sector and the effect of transport infrastructure design decisions are lasting as urban form does not change rapidly or at all. Therefore, touching on the timelines and development of major transport trends is considered an important and perhaps a commonly overlooked step for improving understandings.

To address the first question, we conducted a cross-disciplinary literature review to identify and summarise the impacts of traffic-related exposures and practices on health and indicated the distribution of these impacts in different groups. The three remaining questions involved an iterative discussion and ideas comparison maintaining continuous communication amongst the authors. We acknowledge that this approach may be subjective and urge the reader to approach this paper in a critical manner. As such, the aim of this paper is not to settle the debate, but rather to raise its level by developing an informed and cross-disciplinary argument in an attempt to elicit greater attention placed on the wider range of health impacts associated with transport practices.

3. Where are we now?

This section provides a summary of the state of current knowledge on the health effects and impacts associated with traffic-related exposures and practices and their distribution amongst different socio-economic status groups - see Table 1. Where available, we give indication of how changes in transport can change the direction and magnitude of these impacts. We have considered motor vehicle crashes (MVC,) human physical inactivity and traffic-related environmental exposures including air pollution, noise, local temperature rises and reduction of green space as the most important traffic-related factors impacting human health in urban areas. In this paper, we consider these health impacts as a subset of a wider range of social impacts associated with traffic and traffic-related infrastructure including community severance, adverse effects on social cohesion, forced relocation, impaired access to goods, services and activities and uptake of public space, amongst others. These impacts are beyond the scope of this particular paper, the focus of which is to review the literature on environmental exposures and physical activity, but have been previously reviewed elsewhere (Douglas et al. 2011, Geurs et al. 2009, Markovich and Lucas 2011).

Table 1: health effects/impacts of traffic

Traffic-related factor	**Pathway**	**Quantified health effects**	**Other possible effects**
Motor vehicle crashes	Crashes	Road deaths, serious road injuries	Other impacts due to perceived unsafety including transport mode choice e.g. less active travel and less physical activity (see health effects of physical inactivity) and less outdoor activities (e.g. child play)
Physical activity reduction	Lack of active travel/ mobility	All-cause mortality, cardiovascular diseases, cerebrovascular disease, cancer (colon, breast and lung), type 2	Delaying cognitive decline and improving brain health

		diabetes, dementia, anxiety, depression, obesity	
Air pollution exposure	Motor vehicles exhaust and non-exhaust emissions, secondary pollution formation	All-cause mortality, low birth weight, cardiovascular mortality and morbidity, cerebrovascular mortality and morbidity, decreased lung function in children, diabetes, hospital admissions, infant mortality, lung cancer, obesity, pregnancy-induced hypertensive disorders, preterm birth, respiratory infections, respiratory mortality and morbidity	Cognitive function, fertility, autism. Other impacts due to perceived hazards including transport mode choice e.g. less active travel and less physical activity (see health effects of physical inactivity) and less outdoor sports activities and child play
Noise exposure	Traffic noise (engine, tyre/ road contact, honking)	All-cause mortality, annoyance and sleep disturbance, adverse reproductive outcomes, cardiovascular mortality and morbidity, cognitive function, diabetes type-2, high blood pressure in children, mental health and well-being, stroke	Aggression and stress
Exposure to local temperature rises	Heat island effects from infrastructure and greenhouse gas effects	All-cause premature mortality, cardiorespiratory morbidity, children's mortality and hospitalization, heat stress, hospital admissions, increased health service use and respiratory symptoms, preterm birth, reduced lung function, traffic accidents	Aggression and stress, fatigue
Exposure to green space reduction and biodiversity loss	Land acquisition and right of way for infrastructure and motor vehicles	All-cause mortality, cardiovascular disease, adverse birth outcomes, reduced mental health, adverse sleep patterns, slow recovery from illness, children´s behavioural problems, immune diseases related to the microbiome, childhood asthma incidence	Cognitive development, physical activity, obesity

Note that further social impacts including community severance, loss of social networks, forced relocation, access to services and activities may also have impacts on health and well-being but are beyond the scope of this paper.

3.1. Motor vehicle crashes

Motor vehicle crashes (MVC) have been one of the earliest recognised traffic-related health issues. As described by Norman (1962) in 1957, the United States death rate from MVC exceeded the number of deaths from all infectious and communicable diseases at all ages combined and it is only recently that MVC have not been amongst the top 10 causes of death in the United States (Subramanian 2012). Vulnerable populations including the elderly, children, the economically disadvantaged and vulnerable road users, including pedestrians and cyclists, were the most adversely impacted by MVC. For example, pedestrian deaths involving a motor vehicle in New York City during 1959 were estimated at 70% of all officially recorded crash deaths (Norman 1962) as opposed to 26% in 2014 (New York State 2015).

Although statistics suggest improvements in traffic safety have been taking place, MVC are still a global challenge. In 2010, MVC caused over 1.3 million global deaths and some 78 million injuries (Bhalla et al. 2014). MVC are currently the number one cause of death amongst those aged 15-29 years (World Health Organization 2015). Low-income and middle-income countries, where motorisation started later and where investments in road safety campaigns, safe infrastructure and road safety technologies are generally less, account for over 90% of the world's roads fatalities despite having 48% of the world's registered vehicles (World Health Organization 2009). The number of road death per 100,000 populations in low-income countries is now at a level of 24 (World Health Organization 2015), comparable to the level in developed countries such as the Netherlands in the 1970s (SWOV 2016). At the lower geographical scale, resource poor areas are more likely to have higher MVC rates per capita, especially for child pedestrian injuries (Abdalla et al. 1996, Hewson 2004). There are profound equity issues within these statistics, which reflect the disproportionate burden of avoidable morbidity and mortality from MVC (Nantulya and Reich, 2003). Despite the high variability between different regions, MVC rates remain highest for vulnerable road users including motorbike commuters and active travel commuters (pedestrians and cyclists), followed by public transport and car commuters (Zegeer and Bushell 2012, Steinbach et al. 2013, Wegman et al. 2012). Half of the world's road traffic deaths occur amongst motorcyclists, pedestrians and cyclists, with 31% of deaths amongst car occupants (World Health Organization 2013).

There is evidence to suggest that interventions promoting active-travel and traffic reductions can be beneficial for the reduction of MVC. Studies have suggested that incidence rates for active travel depend on the number of active travellers resulting in a rapid decline in MVC when the number of these users increase; the so called 'safety in numbers effect' (Jacobsen 2003, Elvik 2009). For instance, according to Jacobsen (2003) a community doubling its cycling can expect a 32% reduction in cycling injuries. Lower traffic volumes have also been linked to a decline in child pedestrian death rates in New Zealand (Roberts et al. 1992) and to a substantial reduction in both the number of crashes and crash rates in London as part of the congestion charging effects (Green et al. 2016).

Beyond the direct morbidity and mortality from road traffic injuries, MVC have other potential health impacts linked to perceived or an actual lack of safety, which can avert behaviours and generate pathways to less active travel, less physical activity (see health effects of physical inactivity) and less outdoor activities (e.g., child play) (Geurs et al. 2009, Granville et al. 2002).

3.2. Physical Inactivity

Physical inactivity has been described as the biggest public health problem of the 21st century (Blair 2009). Approximately, 2.1 million global deaths occur each year due to insufficient physical activity (Forouzanfar et al. 2015). Active travel can provide a sufficient level of physical activity to improve health and well-being (Chief medical officers, 2011). Compared to those who engage in at least 30 min of moderate intensity physical activity most days of the week, physically inactive people have a 20%-30% increased risk of all-cause premature mortality (Woodcock et al. 2011). Increased physical activity is associated with a reduction in risk of chronic diseases (Blair 2009, Rojas-Rueda et al. 2013) including cardiovascular disease (Hamer and Chida 2008), dementia, Alzheimer's and Parkinson's disease (Hamer and Chida 2009), type-2 diabetes (Jeon et al. 2007), breast cancer (Monninkhof et al. 2007) and colon cancer (Harriss et al. 2009). There has also been emerging evidence for the role of physical activity in delaying cognitive decline and improving brain health (Blair 2009) alongside a positive effect on pulmonary function, which can have a role in reducing the negative health effects of traffic-related air pollution (Badyda et al. 2015). Physical activity is also associated with improvements in the incidental risk of depression and general anxiety symptomatology (Dunn et al. 2001). The greatest benefits are realized by people who switch from inactive to moderately active lifestyles due to the nonlinear nature of the relationship between physical activity and associated health benefits (Woodcock et al. 2011).

In different regions around the world, 20%-50% of the population do not meet the WHO physical activity guidelines (World Health Organization 2012). Countries with higher levels of active travel have lower obesity levels suggesting that active travel could be one of the factors that explain international differences in obesity rates (Bassett et al. 2008). Recent studies have demonstrated the potential health benefits of switching to active travel modes (particularly walking and cycling) through increased levels of physical activity with minor risks expected from MVC and air pollution exposure (De Hartog et al. 2010, Mueller et al. 2015, Schepers et al. 2015, Tainio et al. 2016). Active travel has also been found to be associated with higher levels of objective and self-reported physical activity (Donaire-Gonzalez et al. 2015, Gordon-Larsen et al. 2009, Audrey et al. 2014). For example, two longitudinal studies show that increases in physical activity by way of commuting resulted in an overall increase in total level of physical activity (Sahlqvist et al. 2012, Foley et al. 2015). Further, the benefits of physical activity stemming from walking and cycling on reducing all-cause premature mortality have been documented even after adjusting for other physical activity (Kelly et al. 2014).

Active travel alone and integrated with public transport (e.g. ,walking to and from transit) can therefore be a means to build and boost physical activity patterns into one's daily routine. Several natural experimental studies have demonstrated that the construction of new high-quality infrastructure may increase active travel. Heinen et al. (2015) found that proximity to the new infrastructure was associated with an increase in active travel and a decrease in car use. Based on the same study Panter et al. (2016) concluded that living in the proximity of new infrastructure was associated with a significantly greater likelihood of an increase in weekly cycle commuting time and overall time spent in active commuting among the least active commuters at baseline. Marqués et al. (2015) showed that the development of a segregated network of cycle paths, whilst considering connectivity, continuity, visibility, uniformity, bi-directionality and comfort, has been a valuable tool for the promotion of cycling, even in a city without a tradition for cycling. Goodman et al. (2014) showed that effects of new infrastructure may not be immediate. Individuals who lived closer to new walking and cycling infrastructure did not change their time spent on active travel after one year. After two years, individuals who lived closer to the new infrastructure were spending more time walking and cycling: on average an additional 15.3 min per week walking and cycling per each kilometre closer to the intervention. The effects were found to be larger among participants with no car. The connectivity and directness of the cycling network are important factors in predicting bicycle commuting (Marqués et al. 2015, Schoner and Levinson 2014). Another study demonstrated that public transit has the potential to increase population-levels of physical activity by making walking a part of the routine travel journey (Bartels et al. 2016). However, the still predominant promotion of motorisation as the primary mode of transport, car dependent sprawl and a lack of active travel infrastructure are impeding the potential health benefits of active travel to be realized. These trends promote sedentary lifestyle choices and associated adverse health impacts (Brownson et al. 2005, Ewing et al. 2008).

As with MVC, these impacts may be disproportionately distributed according to socioeconomic factors (Crawford et al. 2008). The scientific evidence demonstrates that available resources for physical activity participation including parks and walking and biking trails vary by neighbourhood socioeconomic status with the pattern of fewer options for the more deprived (Estabrooks et al. 2003), highlighting equity issues that need to be considered. Similarly, high socioeconomic groups appear to engage in more leisure-time physical activity (Gidlow et al. 2006).

3.3. Traffic-related air pollution

In urban areas, ambient air pollution is often dominated by motor vehicles traffic (Anderson et al. 2013, European Environmental Agency 2007). Traffic-related variables such as distance to roadways, number of junctions, surrounding road length and traffic flows explain large proportions of the variability observed in air pollution levels within urban areas (Dell et al. 2014, Fuertes et al. 2013, Krämer et al. 2000, Ranzi et al. 2014, Nieuwenhuijsen and Khreis 2016). A traffic-generated plume includes particulate matter (PM) with a gaseous pollutant mixture of nitrogen oxides (NO, NO_2), carbon monoxide (CO) and multiple volatile organic compounds (e.g., benzene, ethene, ethylene and toluene). These components are associated with a range of short-term and long-term health effects; the latter including all-cause mortality (Beelen et al. 2014, Héroux et al. 2015), childhood asthma incidence (Khreis et al. submitted for publication), cardiovascular disease incidence (Cesaroni et al. 2014), cardiovascular mortality and morbidity (Héroux et al. 2015, Hoek et al. 2013), cerebrovascular mortality and morbidity (Dominici et al. 2006), decreased lung function in children (Gehring et al. 2013, Eeftens et al. 2014, Ierodiakonou et al. 2015, Barone-Adesi et al. 2015), infant mortality (Héroux et al. 2015), lung cancer (Raaschou-Nielsen et al. 2013), low birth weight (Pedersen et al. 2013), pregnancy-induced hypertensive disorders (Olsson et al. 2015), preterm birth (Sapkota et al. 2012), respiratory infections (MacIntyre et al. 2014) and respiratory mortality and morbidity (Health Effects Institute 2010, Héroux et al. 2015, Kurt et al. 2016). This emerging body of knowledge confirms previous studies based on both between and within city air pollution exposures (Brook et al. 2010, Hoek et al. 2013). Furthermore, evidence is emerging regarding a role of air pollution exposures in other increasingly prevalent diseases, such as diabetes (Krämer et al. 2010, Coogan et al. 2012, Eze et al. 2015, Bodin et al. 2015), obesity (Jerrett et al.

2014, McConnell et al. 2015), poor cognitive function (Sunyer et al. 2015), infertility (Nieuwenhuijsen et al. 2014) and autism (Volk et al. 2013).

Although tighter air quality regulations and emission controls have made improvements in air quality, ambient air pollution is still a leading cause of mortality and morbidity. Ambient particulate matter (PM) air pollution was ranked 12th in the Global Burden of Disease estimates in 2013 (Forouzanfar et al. 2015), contributing to an estimated 370,000 premature deaths and on average a 9-month reduction in life expectancy in Europe (European Commission 2007). Bhalla et al. (2014) estimated that air pollution from motor vehicles is the cause of 184,000 premature deaths globally, including 91,000 deaths from ischemic heart disease, 59,000 deaths from stroke and 34,000 deaths from lower respiratory infections, chronic obstructive pulmonary disease, and lung cancer. Using more sophisticated source models, Lelieveld et al. (2015) estimated that road traffic emissions on a country level are responsible for about one-fifth of mortality by ambient $PM_{2.5}$ and Ozone in Germany, the United Kingdom and the United States, whilst accounting globally for about 5% of the 3.3 million annual premature deaths due to outdoor air pollution. Adding the health impacts of NOx, as Walton et al. (2015) did in their London study, doubles these numbers.

Beyond the direct impacts, traffic-related air pollution has the potential to avert people's behaviour by refraining from outdoor sport or play activities and choosing not to use active travel modes (Geurs et al. 2009). In addition, traffic-related air pollution is disproportionately distributed amongst socio-economic and vulnerable groups (Havard et al. 2009, O'Neil et al. 2003, Richardson et al. 2013) including children, low-income groups and minorities, as their schools and residences are often located in high traffic exposure areas (Brandt et al. 2015, Carrier et al. 2016).

3.4. Traffic-related noise

The levels of ambient noise are associated with the road network, junctions, traffic flow, speed and load, acoustics and meteorological conditions in cities (Foraster et al. 2011, Bell and Galatioto 2013, Zuo et al. 2014). The L50 noise levels (total data) range from about 54 decibels in acoustic shadows in residential tertiary streets up to 74 decibels on the high traffic roads (Bell and Galatioto 2013); levels at which physiological effects of road noise are strongly felt (Fritschi et al. 2011). The health effects of traffic-related noise are increasingly being recognised as attributable to a large burden of disease that may be comparable to that of air pollution (Hänninen et al. 2015). In conservative estimates, one million healthy life years are lost every year from traffic-related noise in the western part of Europe alone (Fritschi et al. 2011).

Ambient noise has been associated with a range of different auditory and non-auditory outcomes (Basner et al. 2014), including all-cause premature mortality (Halonen et al. 2015), cardiovascular mortality and morbidity (Ndrepepa and Twardella 2011, Babisch et al. 2014, Münzel et al. 2014, Basner et al. 2014, Van Kempen and Babisch 2012), annoyance and sleep disturbance (Omlin et al. 2011, Laszlo et al. 2012, Basner et al. 2014), adverse reproductive outcomes (Ristovska et al. 2014), cognitive problems in children (Stansfeld et al. 2005, Basner et al. 2014), diabetes type-2 (Dzhambov 2015), high blood pressure in children (Paunović et al. 2011), mental health and well-being problems (Fritschi et al. 2011) and stroke (Sørensen et al. 2011). Ambient noise may also lead to increased levels of stress and aggression (Geurs et al. 2009).

Although long-term effects of traffic-related air pollution and noise could be mutually confounded, cardiovascular effects by ambient noise have been shown independent of air pollution exposures (van Kempen and Babish 2012, Sørensen et al. 2012, Foraster et al. 2014, Liu et al. 2014). Studies have indicated that low-income individuals and visible minorities tend to be located in the areas most polluted by road traffic noise (Brainard et al. 2004, Carrier et al. 2016, Nega et al. 2013).

3.5. Urban heat islands, greenhouse gases (GHG) and rising local temperatures

An urban heat island is observed when there are increases in local temperatures where open, wooded or green areas have been replaced by high density urban settlements where heat absorbing concrete and asphalt structures dominate the landscape (Zhang et al. 2013, Gago et al. 2013, Petralli et al. 2014). Other than traffic-related infrastructures, motor vehicles traffic also release anthropogenic heat by way of tailpipe emissions (black carbon, carbon dioxide, methane, nitrous oxide) that together with re-radiation effects of dense urban structures and long term climate change have the potential to amplify urban summer temperatures and contribute to the urban heat island effect (Rizwan et al. 2008).

High and low ambient temperatures have been associated with all-cause premature mortality (Ma et al. 2014, Guo et al. 2014, Gasparrini et al. 2015), cardiorespiratory morbidity (Turner et al. 2012, Ye et al. 2012, Cheng et al. 2014), children's mortality and hospitalisation (Xu et al. 2012), heat stress (Patz et al. 2014), hospital admissions (Hondula et al. 2014), increased health service use and symptoms for chronic diseases, including respiratory diseases, hypertension and diabetes (Feldman et al. 2014), preterm birth (Schifano et al. 2013), reduced lung function in children (Li et al. 2014) and MVC (Basagaña et al. 2015). Specifically, the urban heat island effect contributed significantly to the health impacts of the 2003 heat wave in Paris (Laaidi et al. 2012). Urban heat effects are mitigated by green space infrastructure, however, the amount of green space is often limited and varies considerably between and within cities, European cities average around 18.6% green space whilst other cities fluctuate from 1.9% to 46% (Fuller and Gaston 2009).

3.6. Green Infrastructure

Green infrastructure, often referred to as green space, includes parks, private gardens, green squares and cemeteries, hedges, trees, woodland, green roofs, green walls, rivers and ponds within urban areas (RTIP 2013). Green space has been associated with a number of beneficial health effects (Lee and Maheswaran 2010, Hartig et al. 2014, Nieuwenhuijsen et al. 2014), including decreased premature mortality and increased longevity (Takano et al. 2002, Mitchell and Popham 2008, Villeneuve et al. 2012, Gascon et al. 2016), reduced cardiovascular disease (Pereira et al. 2012, Tamosiunas et al. 2014), higher birth weight (Dzhambov et al. 2014), improved mental health (Richardson et al. 2013, Reklaitiene et al. 2014, Gascon et al. 2015), improved people's self-reported general health (Maas et al. 2006, De Vries et al. 2013), improved sleep patterns (Astell-Burt et al. 2013), recovery from illness (Ulrich 1984), reduced children's behavioural problems (Markevych et al. 2014, Balseviciene et al. 2014), reduced incidence of childhood asthma (Sbihi et al. 2015), increased social contacts (Maas et al. 2009, de Vries et al. 2013) and a better skin microbiota leading to reduced allergic disease (Hanski et al. 2012). Other effects on cognitive development (Dadvand et al. 2015), physical activity and obesity (Toftager et al. 2011, Ying et al. 2015) have also been demonstrated. Possible mechanisms for the health benefits of green space are due to increased physical activity (e.g., active travel engagement) and more space to enable social interaction, psychological restoration and stress reduction, alongside the mitigation of detrimental environmental exposures including air pollution, noise and heat (Coombes et al. 2009, Lee and Maheswaran 2010, Maas et al. 2009, Hartig et al. 2014, de Vries et al. 2013).

Transport and utilities use significant amounts of land for infrastructure and right of way, which could arguably be or be used for green infrastructure (Khreis et al. 2016) and can further cause partition and destruction of wildlife habitats (Banister 2002). The distribution of (access to) public green spaces can be differential by socioeconomic status in favour with those with resources to move to greener areas (Maas et al. 2006), contributing further to significant environmental health inequalities driven by transport and urban planning practices.

4. How did we get here?

The health impacts of traffic-related exposures and practices, as summarised in the previous section, suggest that transport design, planning and policy making are operating separately from public health delivery at some level, resulting in adverse impacts on the population's health, many of which only manifest on the long term. In this section, we highlight the role of rapid and car-centred urbanisation and mass motorisation in leading to and exacerbating the previously overviewed health impacts. We touch on (the lack of) public policies behind these trends, the influence of powerful actors in maintaining them and the weaknesses of transport investment appraisal methods in promoting healthy transport. We highlight the public's role in reversing these trends.

4.1. Rapid and car-centred urbanisation

Rapid and car-centred urbanisation and mass motorisation are two important trends which have led and continue to exacerbate the previously overviewed health impacts of motor vehicle traffic. Given the global trends towards a more urbanised world population, impacts from both these trends are forecasted to continue and intensify (Cohen 2006, Dargay et al. 2007, Gakenheimer 1999). The two trends are intractably and intricately intertwined (Merriman 2007, Schwanen, 2016, Urry 2004) and have been characterised as advancing a car-centred planning approach that has dominated urban and transport planning since post-Second World War (Banister 2002, Buchanan 1963, Handy 2002, Vigar 2000). The car has become socially, culturally, economically, politically, ethically and environmentally ingrained in most westernised countries (Merriman 2007, Urry 2004). In many regions in the world, the car-centred planning approach remains a dominant model (Litman and Burwell 2006, UN-Habitat 2012). Though the dominance and reach of a car-centred planning is may be diminishing in the developed world, its powerful legacy has multiple important features and implications.

Focusing on motorised, primarily car-based travel and a car-centred planning approach to urban design results in greater urbanisation of the natural environment (Gakenheimer 1999, Merriman 2007, Southworth and Ben-Joseph 1997, Urry 2004). The very nature of urbanisation enhances exposure to heat, air pollution, and radiation (Vanos 2015). Development of more streets flanked by buildings coupled with general increases in road traffic can create canyon effects where ventilation is reduced and air flow structures are modified. Street canyons significantly increase levels of traffic-related air pollution (Vardoulakis et al. 2003) and can cause up to a temporal tenfold increase in pollutants' levels at the sides of some urban canyons (Longley et al. 2004). Similarly, the levels of ambient noise in urban cores increase relative to increasing building and road network density (Foraster et al. 2011, Bell and Galatioto 2013, Zuo et al. 2014). Increased road and building densities can further raise local temperature via the heat island effect (O'Neill and Ebi 2009) and deplete city green space via right of way land acquisition (Vanos 2015, Nieuwenhuijsen and Khreis 2016).

In addition, urbanisation creates 'intransigent' urban systems which have long timespans, and which are not easily removed, altered or retrofitted. As such, in advancing urban (sprawl) landscapes based on meeting car travel patterns and needs, a car-centred planning approach can arguably be characterised as supporting and encouraging car-specific travel (Antrop 2004, Bansiter 2002, 2008, Newman and Kenworthy 1999, Lester 2002, Urry 2004, Vigar 2000). Normalisation of car-centred urbanisation increases the physical separation of activities and the need for motorised transport (Handy 2002, Ferreira and Batey 2007, Lester 2002, Urry 2004). Increased spatial separation of activities lowers urbanised population densities, and results in lower commuter numbers needed to support a meaningful public transport system (Lester 2002, Newman and Kenworthy 1999) and a gradual abandonment of these urbanised areas (Antrop 2004, Urry 2004). This is evident in current urbanisation trends where meaningful development and opportunities are often restricted to centres of (economic) agglomeration whilst other towns and centres do not have their needs and opportunities accessible to them (Nieuwenhuijsen and Khreis 2016). Ultimately, a car-centred planning approach fosters a self-reinforcing cycle of car dependence (Newman and Kenworthy 1999) by creating a system of 'automobility' (Urry 2004). Such automobility systems increased the fraction of the exposed population living and working in close proximity to highways and roads (Ewing et al. 2003, Health Effects Institute 2010); decreased physical activity (Hinde and Dixon 2005) and reduced the feasibility and convenience of active travel (Ewing et al. 2008, Giles-Corti and Donovan 2002) and of public transport provision (Lester 2002, Newman and Kenworthy 1999).

4.2. Mass motorisation and ethical positions towards human life

In turn, mass motorisation has played a major role in leading to the adverse health impacts of motor vehicle traffic via increasing the number of vehicles and infrastructure priorities and reinforcing car dependence. Motorised traffic in developed countries grew more or less according to an S-shaped saturation curve (Oppe 1989). Buchanon (1963) expected this curve to level off early in the 21st century. Motor vehicle kilometres in many developed countries indeed followed such a path. Upon visual inspection of Figure 1 it is clear that the number of motor vehicle kilometres in the Netherlands and a hypothetical S-curve fit the actual development. Many developing countries seem to have followed a similar pathway of rapid motorisation (Singh 2012).

In most countries, the roadway network was not designed to safely accommodate the rapid increases witnessed during the early stages of motorisation, both in terms of infrastructure demands and road user experience (Oppe 1989). This is manifest most clearly in the substantial deaths due to MVC (Section 3.1) and less clearly in the rise of chronic diseases related to traffic exposure and practices over the same periods that car traffic undergone large changes (Nicolai et al. 2003). Generally, developed countries have experienced gradual reductions of road deaths per motor vehicle kilometre, but only after the pace of growth of motor vehicle kilometres decreased in the 1970s (Oppe 1989) and with substantial policy enacted by governments with regard to vehicle crash testing and mandate of seat belts alongside other technologies. Developing countries are still experiencing a high rate of fatalities due to MVC.

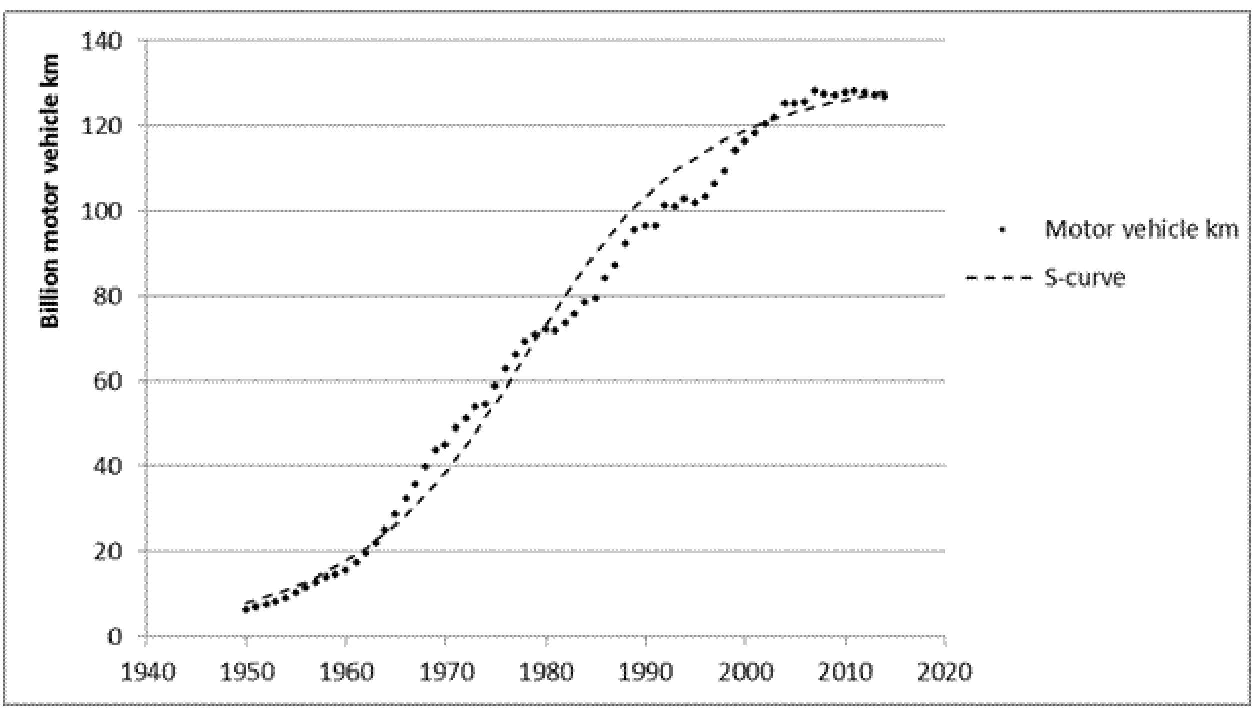

Figure 1 Development of motor vehicle km in the Netherlands (Schepers et al. 2015)

There are important differences in how successful and ultimately safe countries have become for using active travel modes, highlighting the potential causal explanations of what policies might best work for mitigating adverse health impacts of motor vehicle traffic. Examples of successful countries are Sweden and the Netherlands with crash mortality rate reductions of 70% and 82%, respectively, between 1970 and 2006 versus only 43% in the US (OECD 2009). In 2006, the number of road deaths per 100,000 populations was over three times as high in the US as in Sweden and the Netherlands (5.0 in Sweden, 4.4 in The Netherlands, 15.4 in the US; OECD 2009). Sweden and the Netherlands have amongst the lowest number of cyclist deaths per kilometre cycled in the world (Schepers et al. 2015). The Dutch cyclist fatality rate per kilometre cycled is about five times lower than in the US (Pucher and Buehler 2008).

In part, this is due to a dense Dutch motorway network that excludes cyclists and accommodates for about half of all motor vehicle kilometres in the Netherlands. On the other end of the road hierarchy are large traffic calmed areas were where cyclist and pedestrian exposure to high speed motor vehicles, traffic-related air pollution and noise is reduced (Schepers et al. 2013). A high volume of cyclists and pedestrians helps to reduce crash risk due to heightened awareness by motor vehicle drivers to the presence of cyclists and pedestrians (Jacobsen 2003, Elvik 2009, Schepers and Heinen 2013). Sweden and the Netherlands were the first two countries to base their traffic safety policies on a *systems approach*; such as the Vision Zero initiated by Sweden and Sustainable Safety in the Netherlands (Koornstra et al. 2002, PIARC 2012, Weijermars and Wegman 2011).

A systems approach is based on an ethical position in which it is unacceptable to have people seriously injured or killed on the transport network. Transport professionals are given clearly defined responsibility for designing the road system on the basis of actual human capabilities. As such, the transport infrastructure design is inherently conceived to drastically reduce crash risk. This clarity in policy and guidance may have led to a substantive influence for human life in the transport design agenda.

It is also worth noting that metropolitan areas built on a combination of transit (for longer trips that may be covered by car) and walking seem relatively safe as well and could mitigate MVC and traffic-related environmental exposures. For comparison, the four largest Dutch cities, Amsterdam, The Hague, Rotterdam and Utrecht (all with a very high bicycle modal share by international standards) had 2.0 recorded road deaths per 100,000 populations between 2010 and 2014 (SWOV 2016). Cities centred on mass transit such as Hong Kong and Paris had between 1.5 and 1.6 road deaths per 100,000 populations in the same period (Transport Department Hong Kong 2016, Préfecture de Police 2013). Excluding walking, modal share of public transport accounts for 80% in Hong Kong and 65% in Paris (Sun et al. 2014). Exchanging car driving for public transport, therefore, seems to decrease vulnerable road users' exposure to motor vehicles. As public transport is also associated with higher levels of physical activity (Dora and Phillips 2000), more attention needs to be given to the provision of quality public transport instead of trying to safely accommodate high levels of motorisation.

4.3. The Car lobby

It is important to acknowledge the role of the car industry as a powerful and diffuse force in advocating for mass motorisation through marketing strategies to increase uptake and maintenance of driving (Irwin 1987, Douglas 2011). There are numerous examples of the car industry opposing measures that may reduce car use, such as fuel duty increases (Taxpayers Alliance 2010 a), reduction in parking supply (Higginson 2013) and proposals for car-free zones in some German cities leading municipalities to delay or abandon plans (Hajdu 1988). As a powerful lobbying entity, the car industry has successfully opposed improvements in traffic safety (Taxpayers Alliance 2010 b, Sfetcu 2014) and delayed emissions regulations in Europe (Castle 2007, Taxpayers Alliance 2009, The Greens, European Free Alliance Group 2015, Neslen 2015). Politicians understand the power of the industry; which is often a factor in deterring the implementation of strict regulatory guidelines to control motor vehicle traffic (Geels 2007).

In previous work, Douglas and colleagues (2011) reviewed activities of the car industry lobby as reinforcing car dependence, ownership and motorisation. They argued that private car travel is causing significant health harms with little public support for measures to rectify their impact. The car industry with its economic reach to provide jobs including manufacturing, dealerships, hire companies, parking garages, motoring organisations, oil and gas companies, construction and engineering firms, insurance industry and others, make it difficult to regulate. The authors indicate that there are signs that the car industry is moving into new markets in low and middle-income countries, where the ability of governments and civil society to counteract their resources and marketing activities is limited, and where the levels of MVC are increasing in epidemic proportion, as these resource limited countries cannot safely accommodate the level of motorisation.

4.4. Public policy favouring car mobility

Car-centred urbanisation and mass motorisation are also a result of accepted public policies, which reflect a gap between transport design and planning and the long-term consequences of the process. Car-dependent travel in urban areas is the product of a complex history, rooted in the economics of supply and demand and a historic strong association between economic development and an increase in the demand for transportation and number of road vehicles (Banister 2002, Dargay 2007). Taking into consideration the power of the car lobby and the emergence of modern economy as a system of interrelated markets (Friedmann 1987, Douglas et al. 2011, Irwin 1987), public sector programmes seem to only be “successfully launched only when they are broadly compatible with the interests of corporate capita” (Friedmann 1987, p 21).

The preference for car-mobility amongst policy makers has had an important role in leading to the challenges of today, as the surge in motor vehicle ownership over the last 60 years (Banister 2002) is a contributing factor to the chronic health issues attributed to motor vehicle traffic. For example, infrastructure banks and governmental agencies have funded road construction for several decades (Vigar 2000, Schwanen 2016); motorised mobility remains a criterion for measuring country-level economic success, and the level of car-mobility is often seen as a function of income and/or social status (Ecola et al. 2014); economic investment in roads is seen as an important determinant of economic growth; traffic optimisation and travel time savings remain the lead principles in transport planning and core policy goals (Banister 2008) and technical-orientation in practice (mainly an engineering and economic focus) underestimate the negative externalities of transport infrastructure decisions (Banister 2008, Geels 2012). Policy decisions to dismantle personal preferences for private motor vehicles ownership and use in urban society occur in complex networks of power, which often remains clouded to the public's’ understanding and outside of the practitioner’s remit (Flyvberg 1998, Lucas and Jones 2009). As such, the dominance of car-mobility in urban society cannot be directly tied to one source, but instead reflects the co-production of dynamic relationships of power held by a wide variety of actors, both within and outside of the transport domain.

Unfortunately, in many regions around the world, road investment strategies still predominate providing continued support for private motorised travel, thereby attracting more cars (SACTRA 1994), whereas less funding is allocated to active and public transport modes or mobility management strategies, even when they are shown to be more cost-effective and environmentally and socially beneficial overall (Litman 2014 a).

4.5. The state of the practice of transport appraisal

Another key reason for car dominance is the nature of the investment appraisal in transport planning. These instruments have been designed with a great focus on the economic dimensions of transport. Amongst these, Cost Benefit Analysis (CBA) is the most commonly used instrument to determine whether a certain transport project is to be preferred over another. CBA attempts to quantify outcomes expected from projects by assigning to them a monetary value that sums up all associated costs and benefits According to the CBA rationale, a project that has the highest positive monetary value, or the highest benefit to cost ratio, and least amount of uncertainty, is the preferred project by decision-makers. Monetized items include (changes in) travel times, consumer surplus, (changes in) employment, business activity and earnings, MVC, casualties, carbon and air quality emissions and noise impacts (Geurs et al. 2009). As such, CBA and similar appraisal instruments attempt to measure many aspects of new and/or proposed transport projects in terms of financial gains and societal costs.

Despite providing a practical means to assess transport infrastructure investments based on a welfare economics perspective, the logic behind these tools is limited when applied to design and planning and policy development (as proposed by Naess 2006). First, CBA accept transport users' willingness-to-pay as an appropriate indicator factored in the calculations. This ultimately means that CBA appraisals can easily become biased towards solutions preferred by upper classes (and therefore also typically by social classes with higher car-ownership) against the interests and needs of the vulnerable and disadvantaged (and therefore those less likely to own a car).

Second, CBA are embedded in an econometric ontology that associates lower economic benefits and costs to events taking place in the future due to economic depreciation rates. As a result, short-term economic benefits (e.g. higher accessibility to jobs, lower travel costs) are likely to be overvalued when measured against more complex and distant costs such as long-term environmental and health impacts. This is likely to contribute to the establishment of positive outlooks on projects that favour motorised mobility against sustainable and active mobility.

Third, CBA assumes the outputs of transport planning models in the calculations. This is problematic because the validity, purpose and role of these models has been a highly contested topic in transport planning circles (Gudmundsson 2011, Lee 1973, Te Brömmelstroet and Bertolini 2011). Fourth, the "rule-of-half" (described and criticised in Ferreira et al. 2012) even though widely accepted in CBA calculations is not robust when applied to present day transport planning. Indeed, this rule establishes that it is acceptable to consider the time savings for existing travellers that use the services of a new transport project as benefits. It also establishes that it is valid to sum time savings to the time spent by travellers that were induced to travel by the new project (induced demand). These two assumptions are fundamentally pro-mobility and not informed by the debate on accessibility versus mobility (Ferreira and Batey 2007, Handy 2002, Litman 2003, SEU 2003). Fifth, CBA logic assumes that time savings are a benefit when time spent travelling can be positively valued by transport users, especially those using transit (Lyons et al. 2007) and active travel modes (Guell and Ogilvie 2013, LaJeunesse and Rodríguez 2012).

Finally, transport impacts on mortality are taken into account in CBA; however, impacts on morbidity are not addressed. Taking inspiration from the examples mentioned above, it may be time to consider the possibility, as partially practiced in the Netherlands and the Swedish context, to submit CBA and similar instruments to ethical principles considering adverse health impacts of a project unacceptable. It is also essential to expand the appraisal process to include health impacts as a measure of long-term sustainability. In summary, CBA and similar appraisal methods can be seen as instruments based on assumptions that do not promote human health and environmental sustainability.

4.6. Public perceptions and awareness

Public perceptions toward mobility, specifically the use of the car, and awareness of the health impacts of motor vehicle dependence are an important part of the urban mobility challenges. Historically, societal acceptance and preference toward private car ownership was celebrated as a process of democratisation fulfilling individual desires of flexibility and self-determination (Sachs 1984). It also symbolized the idea of freedom and independence (Dittmar 1994, Aldred 2010) as well as, power, superiority, and social status (Steg 2005). Behind these public perceptions are driving forces of this development such as “the leading industrial sectors and the iconic firms within 20th-century capitalism (Ford, GM, Rolls-Royce, Mercedes, Toyota, VW and so on) and the industry from which the definitive social science concepts of Fordism and Post-Fordism have emerged.” (Urry 2004). These forces are still behind a persistent car-mobility paradigm making car dependence a phenomenon that operates societally (Douglas et al. 2011). These cultural norms are reinforced by public policy and institutions that tend to exercise power to protect special interests instead of representing the public interest (Flyvberg 1998).

Whilst the health impacts of MVC have been long recognised as a public health concern, partly due to the attention to crash severity and loss of life, the ubiquitous nature of traffic-related air pollution, noise, rising temperatures and heat islands, decreases in physical activity and green space, were not widely recognised until the 1990s. This is suggested as one reason for the lack of political action. Yet, the evidence of a correlation between increased motor vehicle travel and adverse health impacts as identified in this paper is not new (Transport and Health Study Group 1991, Dora and Phillips 2000), although it is now better developed and well documented in academic circles including a wider range of impacts than previously described. In this context, a lack of public awareness of these impacts, even those which have been receiving increasing media coverage such as air pollution (Bickerstaff and Walker 2001, Kelly and Fussell 2015), reinforce the lack of political commitment and initiative to address these problems.

Arguably it is only when the general public is able to recognise the gravity of the current state of affairs that they can start to building changes in generalised attitudes and behaviours (Kelly and Fussell 2015) and express discontent with current practices. The emergence of the environmental movement since the 1960s highlights how a change in public awareness can be an important driver of policy change (Carson 2002). Increasing public awareness of the health consequences associated with transport design and planning will require some collaborative partnerships between all stakeholders involved in a transport infrastructure project in conjunction with academic research and the development of best practices (Srinivasan 2003).

5. Where do we want to go and what will guide us?

A key challenge of the transport design and planning process is to ensure that all stakeholders involved in and impacted by a project share a common perspective on ‘where we want to go’. Currently different places and sectors have different perspectives. The design and planning issues are complex and intertwined spanning different administrative boundaries. On the other hand, mitigating or preventing adverse transport-related health impacts will have long run benefits for society in terms of overall well-being, productivity, economic prosperity, reduction in healthcare costs. As such, spending in this area should be viewed as societal investments rather than societal costs.

There is a general consensus between transport and health practitioners that health should be an integrated component of the transport design and planning process. Yet, actions still need to be pushed forward by both health and transport professionals so that health becomes a cross-cutting guiding theme. Recent evidence linking traffic-related environmental exposure and practices to a wide spectrum of chronic disease and external costs to other sectors (European Parliament Research Service 2014, Santos et al. 2010), highlights an unquestionable need for a more systematic and systemic approach. International, national and local government, and the transport and health sectors have acknowledged transport planning as key to a healthier and a safer future (HM Government 2011, LGA 2013, Davis 2014, NICE 2008, Nieuwenhuijsen 2016). For this goal to be realized, an integrated cross-disciplinary planning effort should be made to move away from a car-based society and towards high quality and equitable public and active travel systems.
As it stands, transport policy options are often over-reliant on preconceived ideas (May et al. 2016); cross-disciplinary collaboration in research, policy and practice is still lacking (Sallis et al., 2004); the role of power in transport planning is not well understood (Guzman et al. 2016); and although formal networks between the transport, health and environment sectors exist, many lack real power or influence (Stead 2008). A shift toward a healthy and equitable transport design and planning process will require the courage to relinquish our dependency on predictive status quo policies and practices. This will ensure avoiding the reproduction of historical patterns of development which were constrained by sector-centric perspectives, less cognisant of the wider issues (Hall et al. 2014). There is also a need to improve our understanding and assess the role of power in transport and urban planning (Yiftachel 2001), as the same powers that pushed for car favouring technologies and land-use assets to be widely adopted, are likely to be the same actors that will impede a shift toward a sustainable transport system that includes health (Flyvbjerg 1998).

Knowledge transfer and collaboration in research, policy, and practice will play a fundamental role in promoting healthy transport practices. Knowledge transfer and collaboration in research, policy, and practice will play a fundamental role in promoting healthy transport practices. For example, the Health Economic Assessment Tools (HEAT) for Walking and Cycling is an example of good practice emerging from health expertise and translated to the terminology used in the transport world. Developed by the World Health Organisation Regional Office for Europe, HEAT aims at making the health benefits of regular cycling and walking visible to transport and urban planners, whilst addressing the importance of CBA in transport design and planning decisions. As such, the tool offers economic estimates of the health benefits of walking and cycling by estimating the economic value of reduced mortality that results from specified amounts of walking or cycling in a defined population (http://www.heatwalkingcycling.org/, 2014). HEAT emerged from a collaborative and open-ended project bringing together different expertise in health, environmental sciences, air pollution, transport planning, economics, practice and advocacy and policy making. It has been supported by a broad range of institutions and governments from across Europe and was initiated under the United Nations Transport, Health and Environment Pan-European Programme (THE PEP). It has already been used in research, making policy recommendations, advocacy and in practice. HEAT has been used in various settings and is recommended in the official toolbox for the assessment of transport projects (WebTAG, https://www.gov.uk/guidance/transport-analysis-guidance-webtag) in England and in the Action Plan for Improving the health of Londoners by Transport for London (http://content.tfl.gov.uk/improving-the-health-of-londoners-transport-action-plan.pdf).

Another example comes from the iConnect study, which was aimed at measuring and evaluating the changes in travel, physical activity and carbon emissions related to Sustrans' Connect2 programme. Connect2 was an ambitious UK-wide project that transformed local travel in more than 80 communities by creating new crossings and bridges to overcome access barriers caused by busy roads, rivers and railways thereby increasing physical activity (http://www.iconnect.ac.uk/). Initial funding for this programme came from a non-transport source, the UK Big Lottery Fund (£50 million), in which public vote demonstrating the huge amount of public support for this programme was essential. This funding was used to unlock other sources of funding necessary to complete the programme at an overall value of £175 million. The nature of the infrastructure implemented meant that there were large numbers of diverse stakeholders; notably including local communities. A range of approaches was used to engage the local constituency and other stakeholders including a range of public and private service providers, organisations operating in the area, and landowners. The principles of the approach used were to make a coherent case in the context of usage and impact and to engage a wide range of stakeholders in elements of the planning and design. Consensus was used to push implementation forward. A key part of this was almost always making the scientific case for public health improvements through increased physical activity via active travel (Goodman et al. 2014, Panter and Ogilvie 2015, Sahlqvist et al. 2013, Sahlqvist et al. 2015). The findings of the iConnect study are now being used to make a similar argument around transport infrastructure implications for public health (see report; Fit for Life).

A final example comes from Bradford Metropolitan District Council who had recently undertaken a low emission zone feasibility study, which involved stakeholders, researchers and practitioners from different disciplines including transport planning, environmental sciences, public health and health economics alongside collaboration with other city councils in the West Yorkshire region (e.g., Leeds City Council). In this study, the relative impact of several transport interventions scenarios beyond the 'business as usual' case were modelled. The impact that these scenarios may have on projected air quality concentrations, health of the local population and the costs and benefits associated with each intervention measure were calculated and presented in a final report, which was widely disseminated (see report; Bradford Low Emission Zone Feasibility Study). The study was used to provide strong evidence in support of two funding bids at an approximate value of £1 million that aim at improving air quality in the region (Jones and Crowther 2016; personal communication).

6. How will we get there?

This is perhaps the hardest of the four questions to answer. How can we move away from a long-established and powerful car-based society toward a systematic public transport and active travel network that promotes health and equity? Part of the difficulty in answering the question is based on the fact that all contexts are different and all needs are different. A common error is to try and find a common agenda and to directly transfer from one place to another. Each place has its particularities, which dynamically change as time passes. Caution should be taken before applying a "one size fits all" approach especially when taking into consideration policy transfer is a highly politicised process that seeks to justify preferred solutions (Marsden and Stead 2011).

The scale of socio-political, economic and environmental challenges faced in achieving long term sustainability of the urban transport infrastructure suggests that technological improvements, albeit important, will not be sufficient to solve transport-related health challenges. In fact, technological improvements have been shown counterproductive in instances such as the failure of the massive technology change from petrol towards diesel vehicles, initiated by the European car and oil industries, to mitigate climate change impacts (Cames and Helmers 2013), the subsequent Volkswagen diesel emission scandal (Schiermeier 2015) and its implications to public health (Nieuwenhuijsen et al. 2016). This provides justification for caution with regard to other emerging technologies including the connected city, autonomous vehicles, electric and low emission vehicles, which may have confounding effects that impact other sectors and that will only be widely realized over the longer term. Instead of solely relying on technological improvements to drive change, bearing in mind that such improvements are another component of the economy's system of interrelated markets and power relations, public transport and active travel provision alongside behavioural and societal transformations will need to be put in place (Giles-Corti et al. 2010, Thommen Dombois 2016, Banister 2008, Steg and Gifford 2005, Steg and Vlek 2009). This can be done with a parallel top down and bottom up approach to ensure that all stakeholders are aware of the environmental and health impacts of mobility choices, understand the rationale behind the policy changes and are involved in building alternatives. A change in professional culture and sector-centric perspective has the potential to create a healthy and sustainable urban transport design and planning process. The 'unlikely future' as J.H. Crawford described it in 2002, is the development of enough renewable energy to continue unrestricted auto-mobility, technical improvements to eliminate auto-related air pollution and computer-controlled cars to triple the capacity of existing freeways (Crawford 2002). These unlikely improvements will never be able to take into account the wide variety of health impacts and address inequalities, lack of physical mobility, low access and availability of green spaces and a long list of social impacts that go beyond the scope of this paper.

The active involvement and collaboration of engineers, planners, economists, epidemiologists, and medical providers is needed to ensure that health is at the top of the list of competing priorities, most notably economic growth in the research and policy making agenda. As funding is always constrained, it is imperative that all stakeholders with a role in transport and health come together to share knowledge and lessons learned from real-world experiences in an attempt to devise the most effective options and prioritise investments. Cross-disciplinary and public engagement collaboration should become a central feature of successful health-promoting urban and transport design and planning (Freeman et al. 2011, Gibson and Gilroy 2009, Hoehner et al. 2003, Jackson 2003).

Beyond the general need to prioritise health, communication and cross-disciplinary collaboration between all stakeholders, and moving beyond solely relying on technology-based solutions that we have argued for in this paper, there are a set of more specific issues which we believe need to be addressed by each individual sector/stakeholder that have emerged from our discussions. These can be targeted towards the specific actors for which they are most relevant in the form of a set of guiding principles for a move toward human health as the centralising goal of future transport policy.

A - Transport engineers and planners

- ***A1:*** In contemporary transport and urban scholarly research and policy, a disconnect remains between design, planning, economics and health (Brewer 2013, Corburn 2004, Corburn 2009) with each discipline operating in designated silos (Barton et al. 2015). This lack of cross-disciplinary communication has the potential to be altered at the lowest level of action with academics and practitioners bringing the health agenda to the table. The health impacts of planning decisions need to become more explicit criteria in the transport domain including in worked appraisal methods (e.g. Guo and Gandavarapu 2010).
- ***A2:*** Masters and undergraduate level university curriculums for planning have undergone significant change recognising the importance of environmental issues. Yet, compared to (town or urban) planning programmes (Edwards and Bates 2011, Frank et al. 2014), transport planning curriculums tend to focus on the functional quality of infrastructure (Mateo-Baniano and Burke 2013, Zhou and Schweitzer 2009). Expanding current educational curriculum to include a cause and effect relationship based on a systems approach will provide a holistic view of both positive and negative health issues of transport (e.g. Weigand 2009). It is beyond one's individual power to change school and training curriculums, but each academic in their position has the potential to deliver knowledge and tools that consider health in transport practices.
- ***A3***: The current political system sets the politician and the public constituency at opposite ends of a proposed issue due to competing priorities and limited financial resources. In the middle is the planner faced with demands from both sides whilst having to navigate the existing status quo policy and practice structure. Public engagement is an ideal opportunity for engineers, planners and local governmental leaders to come together with the public and implement publicly acceptable transport policies that consider health impacts (e.g.

Connect2 programme). Engineers and planners need to be taught to effectively engage the public and employ available tools (Cascetta and Pagliara 2012, Wagner, 2013). Khisty (1996) stress the need for them to be good communicators in addition to being technicians.

- ***A4*****:** Improving health should not be viewed by transport engineers and planners as a constraint, but rather as an additional objective considering the direct impacts of a transport project on the health of the affected community. To this end, information must be provided to transport planners and engineers about the relevance of including health in their planning and design. Easily accessible reference guides and online resources, such as the Planning Practice Guidance website (Department for Communities and Local Government 2014), are essential to prompt and support them in the incorporation of health concerns.
- ***A5***: In order to take into account health impacts in transport design and planning practice, new tools and methods need to be accepted and developed further to assist transport engineers and planners in assessing health impacts of transport design and planning (e.g. Health Impact Assessment tools; Dora and Racioppi 2003).

B - Health practitioners

- ***B1***: Health practitioners should improve their understanding of the urban and transport planning agenda (Banister 2002), play a proactive role to include health as a transport project objective and advocate for effective policies that encourage active travel and reduce car use (Douglas et al. 2011).
- ***B2***: Partnering with urban and transport planners from the start of design and planning process can ensure that health is recognised and included as a project objective (e.g. RTPI 2016). Special attention needs to be dedicated to vulnerable groups and the socially deprived so they are included as users of any proposed transport project. This is a consideration that could assist in overcoming current health inequalities (Goodman et al. 2014, Lindsay et al. 2011, Maas et al. 2006, Mitchell and Popham 2008).
- ***B3***: Health practitioners should support transport engineers and planners in conducting health impact assessments for possible transport scenarios to demonstrate the likely impacts on health to policy makers and the general public (e.g. PASTA project).
- ***B5***: Health practitioners should have an active input in developing innovative and usable health economic assessment tools to be added to existing or novel transport design and planning tools (e.g. the HEAT tool).

C - Researchers

- ***C1***: Researchers can voluntarily start appraising tools that are being used in transport planning to provide a holistic point of view in regards to impacts on health. Many of the existing tools do not currently include transport impacts on health (e.g. Nieuwenhuijsen and Khreis forthcoming, KonSULT appraisal).
- ***C2***: Researchers should advocate for co-production and cross-disciplinary work so as to become a central feature to transport design and planning.
- ***C3***: Increasing the outreach and communication between the research community and transport practitioners, local governmental entities and the public constituency in an effort to share knowledge can positively contribute to risk mitigation strategies and further inform the research and policy agendas (e.g. see workshops overviewed in methods section and International Conference on Transport and Health).
- ***C4***: Epidemiologists and health researchers can contribute to resolving open scientific issues and improving the evidence base for Health Impact Assessments (Khreis et al. 2016, Dora and Racioppi 2003). Epidemiologists should further strengthen the evidence between transport design, planning indicators/interventions and health to reduce uncertainty in policy guidance (Nieuwenhuijsen and Khreis 2016).
- ***C5***: Researchers need to follow-up to how policy guidance/recommendations will be interpreted or altered. Researchers need to become more cognizant of the political scene and the role power plays in transport planning (Albrechts 2003, Yiftachel 2001).
- ***C6***: Researchers should increase public outreach to increase awareness of health impacts of transport choices and practices. Public awareness is often a driver of change. Working in partnership with the public constituency has the potential to generate positive feedback loops in community trust and momentum for change (e.g. Connect2 programme).

D - Policy decision making

- ***D1***: Policymakers should adopt a more systemic/holistic approach that includes long-term health impacts that are difficult to grasp or measure on the short term (Litman 2006, Dotu Nyan et al. submitted).
- ***D2***: Cultural shift and reallocation of funding streams at the policy level is needed to include health assessments of a proposed transport project. CBA and other appraisal methods need to be expanded to include health outcomes beyond those related to road safety (Noland et al. 2015).

- ***D4***: The objectives of the private sector should not dominate at the expense of the public's health. Policymakers should ensure that the interest of transport users is not compromised by the interests of those who produce means of transport (Irwin 1987)
- ***D6***: Operational goals and indicators are often decided in closed circles and in a sectorial manner (Dotu Nyan et al. submitted). The rationale behind these selections should become transparent to all involved stakeholders and be discussed in larger fora.
- ***D7***: In some regions, land-use planning is increasingly being deregulated and liberalised which is causing a disconnect with transport planning and impeding planning for accessibility rather than planning for mobility (Ferreira and Batey 2007, Handy 2002, Litman 2003, SEU 2003). Policy makers should address this by ensuring that land-use planning is in public hands, or at least have strict legislation for integrated planning (Schwanen et al. 2004).
- ***D8***: Mitigation of adverse health impacts associated with a proposed transport infrastructure project should be considered and dictated by clear policy and guidance as one of the objectives transport engineers and planners need to achieve. The lack of substantive influence for health in the transport agenda may be traced back to the lack of clarity in policy and guidance.

E - Public constituency

- ***E1***: The public should improve their knowledge of the health impacts associated with traffic exposures and travel choices. This could pose new grounds for a shared understanding of the importance of and need for change.

7. Summary and conclusions

The adverse health impacts of urban transport are numerous and have been driven and exacerbated as a by-product of rapid and car-centred urbanisation, mass motorisation and a tendency of policy making to favour car mobility and undervalue health in the transport and development agenda. In this paper, we aimed to raise the level of awareness of the need to incorporate health into the fields of transport design, planning and policy making. We believe that knowledge transfer and cross-disciplinary collaboration/co-production on research, policy, and practice will play a fundamental role in promoting healthy transport practices. We have suggested practical mechanisms for paving the way forward. Now more than ever, governmental and academic systems need to become flexible and practice their capacity for self-correction. Silos of transport, environment, economic, public health departments, and most importantly, the public constituency should be avoided with all stakeholders working together to ensure quality of life in communities. A systematic approach can now be the standard to avoid the flawed sector-centric planning and decision making as we tackle the complex challenges that lie ahead in meeting the transport needs of a growing and diverse population.

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