Health impact assessment of active transportation: a systematic review

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**Abbreviations**

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<th>Abbreviation</th>
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<td>AT</td>
<td>active transportation</td>
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<td>CVD</td>
<td>cardiovascular disease</td>
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<td>DALYs</td>
<td>disability-adjusted life years</td>
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<td>DRF</td>
<td>dose-response function</td>
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<td>HEAT</td>
<td>Health Economic Assessment Tool</td>
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<td>HIA</td>
<td>health impact assessment</td>
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<td>PA</td>
<td>physical activity</td>
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<td>PM$_{2.5}$</td>
<td>particulate matter less than 2.5 micrometers</td>
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<td>RR</td>
<td>relative risk</td>
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<td>TRAP</td>
<td>traffic-related air pollution</td>
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<td>UV radiation</td>
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ABSTRACT

Objective: Walking and cycling for transportation (i.e. active transportation, AT), provide substantial health benefits from increased physical activity (PA). However, risks of injury from exposure to motorized traffic and their emissions (i.e. air pollution) exist. The objective was to systematically review studies conducting health impact assessment (HIA) of a mode shift to AT on grounds of associated health benefits and risks.

Methods: Systematic database searches of MEDLINE, Web of Science and Transportation Research International Documentation were performed by two independent researchers, augmented by bibliographic review, internet searches and expert consultation to identify peer-reviewed studies from inception to December 2014.

Results: Thirty studies were included, originating predominantly from Europe, but also the United States, Australia and New Zealand. They compromised mostly HIA approaches of comparative risk assessment and cost-benefit analysis. Estimated health benefit-risk or benefit-cost ratios of a mode shift to AT ranged between -2 to 360 (median=9). Effects of increased PA contributed the most to estimated health benefits, which strongly outweighed detrimental effects of traffic incidents and air pollution exposure on health.

Conclusion: Despite different HIA methodologies being applied with distinctive assumptions on key parameters, AT can provide substantial net health benefits, irrespective of geographical context.

KEYWORDS
Active transportation, air pollution, health impact assessment, mode shift, physical activity, traffic incident
INTRODUCTION

Contemporary car-ownership, and the vast network of roadway systems to accommodate it, adversely impact public health through environmental pathways such as air pollution, noise, greenhouse gas emissions, and traffic hazards (Haines and Dora, 2012). The convenience of motorized transportation has reduced dependence on physically-demanding travel while simultaneously increasing time spent sedentary (González-Gross and Meléndez, 2013). Today, globally, more than 30% of all adults are estimated to perform insufficient physical activity (PA) (Hallal et al., 2012). A lack of PA is associated with all-cause mortality, cardiovascular diseases (CVD), type 2 diabetes, cancer and impaired mental health (Physical Activity Guidelines Advisory Committee, 2008), and together with an energy-dense diet, the driving force of the progressing obesity epidemic (Ng et al., 2014).

The promotion of walking and cycling for transportation complemented by public transportation or any other ‘active’ mode, i.e. active transportation (AT), presents a promising strategy to not only address problems of urban traffic strain, environmental pollution and climate change, but also to provide substantial health co-benefits (de Hartog et al., 2010). Despite associated risks of exposure to traffic and to a lesser extent air pollution (de Nazelle et al., 2011), AT may best overcome car dependence while simultaneously increase PA levels (Lindsay et al., 2011).

In recent years, there has been growing interest in health impact assessment (HIA) as a method to estimate potential health consequences of non-healthcare interventions (Mindell et al., 2003). HIA aims at identifying the direction and magnitude of potential health impacts of these interventions in order to mitigate harms and increase health benefits (Mindell and Joffe, 2003). As until now, longitudinal pre-/post-intervention studies in AT are scarce, HIA in transportation has to make do with thought experiments and scenarios to study what health effects would be if changes in transportation behavior took place. To our knowledge, despite evidence of existing AT health benefits (Cavill et al., 2008; Teschke et al., 2012; Xia et al., 2013), a systematic review quantifying health benefits and risks of AT does not yet exist. Therefore, we systematically reviewed studies conducting quantitative HIA of a mode shift to AT.
METHODS

The review was performed following the PRISMA guidelines for reporting of systematic reviews (Moher et al., 2009). Systematic database searches of MEDLINE, Web of Science and Transportation Research International Documentation were conducted. Keyword combinations of “health impact assessment”, “active transportation”, “physical activity”, “traffic incidents”, “air pollution” and “noise” were used (Appendix A.1). Limits were English, Spanish, Dutch, French, or German language and abstract availability. Manual bibliographic review, internet searches and expert consultation were conducted to ensure completeness of peer-reviewed studies. Two independent researchers (NM and DR-R) performed all levels of screening and discrepancies were resolved by consensus.

Eligibility criteria

For review inclusion the study had to (1) focus on prospective or retrospective interventions in transportation, built-environment, land-use, economy, or energy that directly or indirectly produced a mode shift to or from motorized transportation to or from AT; (2) comprise of a quantitative HIA methodology of comparative risk assessment, cost-benefit analysis, risk assessment or benefit assessment; (3) report a quantitative change in the exposure distribution of at least one health pathway; (4) report a quantitative change in at least one health endpoint.

Outcome measure

The benefit-risk or benefit-cost relationship of the AT mode shift was the primary outcome of this review. If not reported by the study and if possible, the benefit-risk of benefit-cost ratio was calculated based on expected change in exposure distribution of health pathways resulting of a mode shift to AT.
Data extraction and synthesis

Essential data of eligible studies were extracted into a data extraction tool for descriptive and analytic synthesis (Appendix A.2). The literature search, study selection, data extraction and synthesis were performed between February 2, 2014 and December 9, 2014.

RESULTS

Search results

The literature search produced a list of 3594 articles. Initial title screening identified 333 candidate studies. Abstract screening identified 130 candidate studies and independent full-text reading resulted in 30 eligible studies (Figure 1).

Study characteristics

The 30 eligible studies were published between September 2001 and January 2015 (Table 1). Interventions that produced a mode shift and of which health impact were estimated were measures which make AT attractive, e.g. bike-sharing system, or discourage private vehicle use, e.g. fuel price increase. Eighteen studies assessed health impacts of AT within Europe. One study compared London (UK) and Delhi (India). Seven studies estimated health impacts of AT in the United States. Five studies assessed health impacts in Australia and New Zealand. The studies covered a range of populations consisting mostly of driving-aged adults, partially stratified by age, sex, ethnicity or population density.

Twelve studies conducted comparative risk assessment, comparing estimated health benefits and risks of changed health pathway exposure distribution resulting of a mode shift to AT (Table 2). Twelve studies used cost-benefit analysis to estimate economic health impacts. Of these, seven studies compared estimated benefits to intervention costs, while the other four studies compared savings and costs of expected health benefits and risks. Five studies were benefit assessments in which risks or costs were not considered. Two studies conducted risk assessment exclusively of traffic safety of a mode shift to AT.

Physical activity

All studies, except Stipdonk and Reurings 2012 and Schepers and Heinen 2013, assessed the health impacts of increased PA resulting of a mode shift to AT. PA risk estimates for associated health outcomes used across the studies were taken predominantly from meta-
analyses (Appendix B.1). The majority of studies assumed a linear association between PA and health. The World Health Organization’s (WHO) Health Economic Assessment Tool (HEAT) was applied in seven studies and uses a log-linear dose-response function (DRF) between PA and all-cause mortality by applying a 22% risk reduction per 29 minutes of daily walking (World Health Organization, 2011), and a 28% risk reduction per three hours of cycling per week (Andersen et al., 2000). HEAT uses a risk reduction threshold of 50%, after which no additional health benefit can be obtained. Likewise, three studies used a linear DRF with either a threshold (Jarrett et al., 2012; Woodcock et al., 2009), or a square-root function for higher PA levels (Maizlish et al., 2013). Four studies modeled PA exposure with a continuous non-linear DRF with the consideration of baseline PA levels (Dhondt et al., 2013; Rabl and de Nazelle, 2012; Woodcock et al., 2014, 2013). Six studies used PA categories assigned with distinctive relative risks (RR) (Boarnet et al., 2008; Cobiac et al., 2009; Holm et al., 2012; Mooy and Gunning-Schepers, 2001; Sælensminde, 2004; Xia et al., 2015). All 28 studies obtained estimates for PA with a mode shift to AT that resulted in reductions in all-cause mortality, CVD, type 2 diabetes, weight gain, cancer, falls, or impaired mental health.

Traffic incidents
Twenty-one studies estimated health impacts of exposure to traffic with regards to fatality and injury risk, and one study with regards to the feeling of insecurity (Sælensminde, 2004). In all 21 studies, traffic incidents were estimated directly based on local or national incident count statistics by including travel exposure data and other risk components (Appendix B.1). The majority of studies modeled traffic incident risk linearly by mode-specific distance or time travelled. Eight studies, however, assumed non-linearity of risk by including risk components of a disproportional increase in traffic incidents (‘safety in numbers’), traffic volume, modal split, conflict types and kinetic energies, speed and road type traveled, as well as age and sex effects (Gotschi, 2011; Lindsay et al., 2011; Macmillan et al., 2014; Maizlish et al., 2013; Schepers and Heinen, 2013; Woodcock et al., 2014, 2013; Xia et al., 2015). Fourteen studies estimated overall increases in traffic fatalities and injuries with increased levels of AT, while six studies estimated overall decreases in fatalities and injuries. Gotschi 2011 assumed no change in absolute number of traffic fatalities.
Air pollution

Seventeen studies estimated the health impacts of air pollution exposure. Air pollution risk estimates used across the studies were taken predominantly from longitudinal studies, but also from time-series analyses (Appendix B.1). While ten studies estimated health benefits to the general population resulting from reduced car use and associated exposure reductions, three studies estimated the active traveler’s individual exposure risk. Four studies included likewise estimations for the benefits to the population and the risk to the active traveler. Most frequently, PM$_{2.5}$ (particulate matter less than 2.5 micrometers) was used as a proxy for air pollution. Nonetheless, other traffic-related air pollution (TRAP) components were also considered, e.g. ozone, carbon monoxide, or elemental carbon. All studies, except Woodcock et al. 2009 only partially, administered a linear DRF to describe the relationship between air pollution and health, with no modification of the DRF at higher exposure levels. All air pollution estimates for the general population obtained with a mode shift to AT resulted in reductions of all-cause mortality, respiratory disease, CVD, cancer, adverse birth outcomes, activity-restriction days, and productivity-loss. Air pollution estimates for the active traveler, however, resulted in increases of described health outcomes.

Noise

Three studies considered the health impact of noise exposure. The noise associations used came from technical reports. While James et al. 2014 assessed noise exposure by changes in traffic volume, Creutzig et al. 2012 and Rabl and de Nazelle 2012 used an indirect economic assessment of traffic-related noise exposure, including health costs; relying on a cost function which was dependent on vehicle kilometers travelled, mode-type, time of day and urbanization. Noise costs were estimated to decline with a mode shift to AT, however, the noise health impact was not quantified independently (Appendix B.1).

Health endpoints

Health endpoints summarizing the overall estimated health impact of the studies were (1) all-cause or disease-specific mortality, including traffic fatalities; (2) morbidities, including CVD, respiratory disease, cerebrovascular disease, type 2 diabetes, cancer, dementia,
depression, preterm birth, low birth weight, weight gain, overweight and obesity, adipose tissue, traffic injuries; (3) life-expectancy; (3) disability-adjusted life years (DALYs); (4) activity-restriction days and; (5) monetization of health impacts, including health care costs, feeling of insecurity costs, activity-restriction costs, or productivity loss.

**Health impacts**

Estimated benefit-risk or benefit-cost ratios ranged from -2 to 360 (median=9), whereby 27 studies estimated health benefits of a mode shift to AT to outweigh associated risks or costs, irrespective of geographical context or baseline setting (Appendix B.2). The three studies that did not estimate an overall beneficial health impact were distinctive in their assessment approaches. Cobiac et al. 2009 calculated investment costs of their AT information and merchandise intervention to be excessive compared to the small change in AT behavior that the intervention produced. Stipdonk and Reurings 2012 and Schepers and Heinen 2013 assessed exclusively the risk of traffic incidents, to give a predicted overall increase in fatalities and injuries with a mode shift to AT.

Overall, however, net health benefits were estimated (Figure 2). In all studies with multiple health pathways, except for Dhondt et al. 2013, health benefits of increased PA clearly outweighed estimated detrimental effects of traffic incidents and air pollution (Appendix B.3). These benefits contributed positively to at least 50% of all estimated health impact of AT. Dhondt et al. 2013 estimated the greatest benefits (52%) from reduced traffic incidents, but assumed a mode shift predominantly to safer transportation modes of public transportation and car-sharing (as passenger) and only a small proportion (2%) of people shifting to active modes of walking and cycling (high risk modes).

**Susceptible populations**

Patterns of intra-population benefit differences were recognizable. The larger body of studies estimated older people (approximately ≥45 years) to benefit more overall from a mode shift to AT than younger people (de Hartog et al., 2010; Dhondt et al., 2013; Edwards and Mason, 2014; Rojas-Rueda et al., 2013, 2012, 2011; Woodcock et al., 2014; Xia et al., 2015). Albeit, when assessing only traffic safety, younger people (approximately ≤30 years) were
estimated to experience a road safety gain with a mode shift to AT (de Hartog et al., 2010; Dhondt et al., 2013; Schepers and Heinen, 2013; Stipdonk and Reurings, 2012). Nevertheless, when assessing traffic safety relative to baseline mortality, the proportional change in baseline mortality made AT appear especially hazardous for younger people (Edwards and Mason, 2014).

In spite of Edwards and Mason 2014 finding no sex differences, overall, males were estimated to benefit more from AT than females (Dhondt et al., 2013; Olabarria et al., 2012; Woodcock et al., 2014). Assessing only traffic safety, Stipdonk and Reurings 2012 found male cyclists to be at increased injury risk, while contradictorily Woodcock et al. 2014 found female cyclists to be at increased injury risk. Finally, disadvantaged ethnic sub-populations were estimated to benefit more from AT than the general population (Lindsay et al., 2011).

**DISCUSSION**

Consistently, the vast majority of the reviewed HIAs estimated substantial net health benefits with a mode shift to active transportation (AT). Estimated benefits were largely due to increases in PA levels, which greatly outweighed associated detrimental effects of traffic incidents as well as air pollution exposure. Noise impacts were only considered secondary. The large range of benefit-risk and benefit-cost ratios observed may be attributable to distinctive HIA modeling approaches, different assumptions on health pathways, scenario design and baseline population parameters.

**Physical activity**

Estimated gains in PA from AT constituted at least half of the total health impact, except in Dhondt et al. 2013. Uncertainties remain, however, regarding assumptions on possible PA substitution, i.e. substituting PA from another domain with PA from AT. There remains limited understanding on the relationship between transportation PA and total PA (Cavill et al., 2008). On the one hand, studies suggest independent health benefits from PA gained by AT. Adjusting for other domains of PA, a meta-analysis found significant cardiovascular risk reductions for AT (Hamer and Chida, 2008). Two cohort studies reported inverse associations between cycling for transportation and all-cause mortality (Andersen et al., 2000; Matthews et al., 2007). On the other hand, studies reported limited evidence of
additional PA from AT (Forsyth et al., 2008; Thomson et al., 2008; Wanner et al., 2012). This limited evidence was attributed to failure of detecting significant associations or the argument that total PA levels are predetermined by the social environment. Nonetheless, recent longitudinal studies estimated significant contributions of PA from AT to overall PA, without reductions of participation in other PA domains (Goodman et al., 2014; Sahlqvist et al., 2013). Thus, the assumption of a 1:1 gain in overall PA, (i.e. no substitution effect) by all reviewed HIA studies appears plausible.

The shape of the applied DRF significantly impacts the PA health benefit magnitude. As done only by a minority of studies, a more biologically plausible approach is the application of a non-linear DRF which implies that health benefits vary in magnitude for different PA levels. Non-linearity coheres with results of a meta-analysis showing a strongly curvilinear relationship between PA and all-cause mortality, with the greatest benefits occurring for inactive people becoming moderately active (Woodcock et al., 2011). However, when applying a non-linear DRF, knowledge on baseline levels of PA becomes essential. Given that in most cases data on baseline PA was not available, it may be a simplification to use a linear DRF in which case no assumptions about baseline PA are required. Nevertheless, a linear DRF assumes equal changes in health benefits for active and non-active people; this assumption can lead to under-estimations of health benefits of PA for non-active people and vice versa to over-estimations for active people (Appendix C.1) (Rojas-Rueda et al., 2013; Woodcock et al., 2011).

Traffic incidents
Estimated health risks by traffic incidents are minor compared with health benefits gained by PA. Generally, an increase of traffic incidents resulting in fatality or injury was estimated with increases of walking and cycling. Shifting to active modes may lead to risk increase as they are considered high-risk modes (Teschke et al., 2012; Wegman et al., 2012; Zegeer and Bushell, 2012). Moreover, an increases in single-mode incidents (‘slipping’) is projected (Schepers and Heinen, 2013).
A minority of studies, nevertheless, estimated that their AT mode shift scenarios would lead to reduced incidents. These findings are due to three assumptions. First, overall reduced motorized traffic volume and second, a mode shift to safer transportation modes, i.e. public transportation and car-sharing (as passengers) may reduce incidents (Dhondt et al., 2013). Third, the concept of ‘safety in numbers’ assumes a less than proportional increase in incidents, with increased walking and cycling share and acquired modal co-existence (Elvik, 2009; Jacobsen, 2003). In this context, one study found that the risk for cycling casualties decreased in communities with a higher cyclist proportion (Vandenbulcke et al., 2009). However, uncertainties remain regarding the location-specific threshold level until a ‘safety in numbers’ effect may occur (Macmillan et al., 2014). Thus, there are suggestions that traffic safety and increases in AT levels are rather due to preceding secure infrastructure measures (‘numbers in safety’) (Bhatia and Wier, 2011).

Generally, the injury burden of AT might be underestimated due to potential under-reporting of minor injuries. Two studies found that only 7% of all cycling incidents were reported in police statistics and chances for reporting increased with injury severity (Aertsens et al., 2010; de Geus et al., 2012). Another study found that single-mode incidents accounted for 40% of all bicycle incidents with 70% resulting in minor injuries (Tin Tin et al., 2010). Moreover, the incident risk is dependent on many setting-specific variables not currently comprehensively considered (Mindell et al., 2012; Wegman et al., 2012). Distance or time traveled, infrastructure provisions, traffic volume, modal split, conflict types, speed and road type traveled, kinetic energies as well as age and sex effects all affect incident risk.

Air pollution

Air pollution exposure was estimated to have small health impacts, with small benefits to the general population and small risks to the active traveler. Only two studies estimated larger air pollution improvements, but their studies assumed substantial reductions in motorized traffic volume (Dhondt et al., 2013; Grabow et al., 2012). While population health benefits emerge from reductions in motorized traffic volume and associated emission exposure decreases, the risk to the active traveler is more complex to assess. On the one hand, walkers and cyclists may experience lower direct TRAP exposure than in-traffic...
vehicle occupants, especially while travelling on segregated sidewalks or bike lanes (Boogaard et al., 2009; MacNaughton et al., 2014). On the other hand, increased ventilation rate resulting from physical strain increments the uptake of harmful pollutants at least twofold (de Nazelle et al., 2012; Zuurbier et al., 2010). Taking into account measured ventilation rate, lung deposition and potential increases in travel time while substituting motorized transportation, estimations possibly need to be revised upwards (Briggs et al., 2008; Int Panis et al., 2010).

Using air pollution risk estimates coming from elsewhere involves uncertainty because air pollution components are location and source specific (Stevens et al., 2014). PM$_{2.5}$ is a commonly-used proxy for exposure to all fossil fuel combustion sources, including motorized transportation. It has been suggested to be the most health relevant pollutant and is used in the Global Burden of Disease Study (Lim et al., 2012). Nevertheless, PM$_{2.5}$ cannot be differentiated by components, source or toxicity (Burnett et al., 2014). Thus, it has been claimed that PM$_{2.5}$ underestimates the health effects of incomplete fuel combustion (Janssen et al., 2011). All studies applied linear associations for air pollution, except Woodcock et al. 2009 for Delhi. Instead, a log-linear DRF for PM$_{2.5}$ was used as yearly average concentrations in Delhi exceeded 40 µg/ m$^3$ and a linear DRF would predict implausible risks. Recent new evidence suggests that the relationship between PM$_{2.5}$ and excess mortality does not necessarily follow a linear function for the entire human exposure range (Burnett et al., 2014).

**Noise**

So far, the health impact of noise exposure during AT has mostly been neglected in HIA. First of all, no mode-specific exposure assessment exists for noise-related burden of disease. Second, there remains inconclusive evidence to what extent health effects of TRAP and road-traffic noise are correlated (Foraster, 2013). As the majority of risk estimates applied for air pollution have not been adjusted for noise exposure, attempting to include noise as an independent health pathway can lead to confounding when estimating health impacts.

**Susceptible populations**
Uncertainties persist in intra-population benefit differences. Overall, older people are estimated to benefit more from a mode shift to AT than younger people (Appendix C.2). At older ages, effects of gained PA (and air pollution reductions) are estimated to outweigh greater detriments of traffic incidents and air pollution exposure due to increased chronic degenerative disease incidence (de Hartog et al., 2010; Dhondt et al., 2013; Edwards and Mason, 2014; Woodcock et al., 2014; Xia et al., 2015). Age is a major risk factor for chronic disease, whereas PA engagement can substantially reduce the absolute risk for disease development (Chodzko-Zajko et al., 2009; Vogel et al., 2009). This does not mean that older people benefit differently from the same PA exposure, but rather that PA has an impact on the absolute risk reduction linked to high disease incidence. Assumptions that health benefits of PA are in fact long-term benefits support the argument that older people benefit more overall from AT (Edwards and Mason, 2014).

Albeit, when assessing exclusively traffic safety of a mode shift to AT, younger people are estimated to experience a traffic safety gain, while older people yield vulnerability to traffic incidents while walking and cycling. Despite increased AT incident risk for older people, however, it has been argued that there might be more relative harm for younger people, as injury and death at younger ages translate into a larger burden of disease due to lower baseline mortality and higher statistical life-expectancy (Edwards and Mason, 2014; Woodcock et al., 2014).

While one US study did not find sex differences in benefits (Edwards and Mason, 2014), three European studies estimated males to benefit more overall than females from a mode shift to AT. First, males are assumed to less likely achieve PA recommendations (Olabarria et al., 2012). Second, sexes are predicted to have distinctive chronic disease risks (Woodcock et al., 2014). Third, males benefit more from reduced motorized traffic incident risk (especially while switching to low risk modes of public transportation and car passengers) (Dhondt et al., 2013). Despite cycling being a high risk mode for both sexes, males are said to have a higher injury risk as drivers, cyclists and pedestrians compared to females (Mindell et al., 2012). Nonetheless, one study estimated female cyclists to be at increased fatality risk
in London, but also expressed local-specificity of their results given the typically lower risk faced by females (Woodcock et al., 2014).

Likewise as for the risk factor ‘age’, pronounced benefits for disadvantaged ethnic subpopulations can be related to increased chronic disease incidence among these populations (Fang et al., 2012; Lindsay et al., 2011).
Uncertainties in health impact estimations

The reviewed HIA studies carry uncertainties in the estimations of quantitative health impacts, which emphasizes that HIA remains an indicative rather than an empirical research tool (Parry and Stevens, 2001). Presented benefit-risk and benefit-cost ratios can only be interpreted as an indication of magnitude of the expected health impact, as underlying HIA modeling assumptions varied largely across studies. As most often local risk estimates for PA, air pollution and noise were not available; a multitude of risk estimates taken from elsewhere was applied. This limits comparability across studies. Likewise, uncertainty about shapes of DRFs between health pathways and health outcomes complicates comparability of studies, despite the significant influence on the benefit magnitude.

Benefit estimations are sensitive to the contextual setting and population parameters. Health impact estimations depend on baseline prevalence of AT, baseline exposure of health pathways and the general health status of the population. Moreover, it is uncertain to what extent the mode shift scenarios reflect reality as individuals’ intrinsic motivations for AT may play a role ( Kroesen and Handy, 2013). Despite a recent meta-analysis finding no significant effect for efficacy of behavioral interventions for transportation behavior change (Arnott et al., 2014), another recent systematic review suggests that a combination of behavioral and structural (workplace, physical environment, bicycle sharing systems) interventions may best increase AT engagement (Scheepers et al., 2014). In addition, culture is said to reinforce AT behavior where it is common, but has opposing effects where it is uncommon (Pucher et al., 2010). There is also concern for decay of behavioral effects over time (Cobic et al., 2009; Hoffman et al., 2012).

In addition, health benefits for people shifting to AT may be minimal due to a ‘healthy-walker/ -cyclist effect’, assuming that only healthy people with a low baseline disease risk choose AT (Macmillan et al., 2014). To estimate longevity of AT health effects one should consider time-lags in health benefits and risks. PA benefits are predominantly long-term in nature (Chevan and Roberts, 2014; Reiner et al., 2013), whereas injuries from traffic are immediate detriments and air pollution exposure can result in short-term as well as long-term detriments. Taking age and time-lags simultaneously into consideration can alter
Benefit estimations. Delayed receipt of health benefits from PA until later in life discourages AT for younger ages, but reinforces the importance for older ages (Edwards and Mason, 2014).

Particularly, economic assessments are difficult to compare, especially, if they compare estimated health benefits with intervention costs. Recently, HEAT has been updated, correcting risk estimates for all-cause mortality (World Health Organization, 2014). Based on two meta-analyses, HEAT now proposes smaller risk reductions for walking and cycling (Kelly et al., 2014). With the new evidence given, studies need to reduce estimations for PA health benefits.

Despite net health benefits, applied stratifications suggest that people benefit differently from AT. Nonetheless, influences of demographics are not yet fully understood. Previous attempts to characterize people who benefit from AT showed uncertainty about health equity effects. On the one hand, a study found higher uptake of walking and cycling infrastructure by socio-economically advantaged people (Goodman et al., 2013). On the other hand, two studies found that especially children from lower income households were more likely to use AT and thus AT might have health inequity narrowing effects (D’Haese et al., 2014; Gray et al., 2014). Supporting the latter, two studies in adults found greatest AT health benefits for disadvantaged ethnic sub-populations (Aytur et al., 2008; Lindsay et al., 2011). Yet, AT land-use improvements are most often conducted in high income areas (Aytur et al., 2008). Additionally, high-income neighborhoods report more AT facilities, more traffic safety and less crime (Sallis et al., 2011). Albeit, differences in intrinsic motivations and intention-behavior relationships among different social classes are to consider (Conner et al., 2013).

Future research on health impacts of AT could include the effects of noise, UV radiation, dietary patterns, social capital, mental-wellbeing, happiness, crime and productivity as they are suggested to be associated with changes in transportation behavior as well as health (Xia et al., 2015). All studies, except Woodcock et al. 2009, were exclusively conducted in high income settings which leaves uncertainty about how results can be transferred to low and
medium income settings. Moreover, children have been underrepresented, even though AT is accessible for children and estimated health impacts presumably affect them the same.

While care is needed when interpreting results of HIA, the reviewed studies show net health benefits of a mode shift to AT, irrespective of geographical context and baseline setting. HIA is valuable to improve the understanding of the inter-relationship between transportation and health and can assist in optimizing health gains of non-healthcare interventions (Thomson et al., 2008).

**Limitations and strengths**

For the first time studies conducting quantitative HIA of a mode shift to AT were systematically reviewed. We provide evidence of net health benefits of AT. However, publication bias is plausible as HIA in transport is frequently conducted for intervention planning outside the peer review framework (Appendix D.1). There is also reasoning to suspect that studies with negative findings are more likely to be unpublished. Despite such limitations, the systematic search strategy and comprehensively defined inclusion criteria limit selection bias. The review of both public health and transport databases, the absence of a time restriction and limited language constraints ensure that the existing body of evidence was captured.

**CONCLUSIONS**

We conclude that net health benefits of AT are substantial, irrespective of geographical context. Projected health gains by increases in PA levels exceed detrimental effects of traffic incidents and air pollution exposure. Thus, we encourage the promotion of AT, as associated health risks are minor.
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Conflict of Interest Statement

All authors have completed the Preventive Medicine Conflict of Interest policy form and declare that there are no conflicts of interest.

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