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Bicycling for Transportation and Recreation in Cardiovascular Disease Prevention

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Abstract

Purpose of Review Bicycling as a mode of transportation can be an easy and inexpensive way of integrating health enhancing physical activity into everyday life. In the present paper, we summarize the evidence from studies on bicycling for transportation and recreation in relation to cardiovascular disease prevention. We also estimate the population impact of increasing bicycling as a mode of transportation.

Recent Findings The overall evidence from prospective cohort studies supports that bicycling for transportation or recreation is related to lower risk of development of fatal or non-fatal cardiovascular disease and premature mortality. The decreased risk of cardiovascular disease and all-cause mortality from regular bicycling is estimated to outweigh risk from additional exposure to air pollution during outdoor exercise. Also, based on experimental studies on the effect of bicycling to school or work, we report an average increase (summary effect) on cardiorespiratory fitness of 3.56 ml O_2/min/kg (95% CI 2.79 to 4.32) compared with control. Extrapolating the size of this average difference, approximately equivalent to 1 MET, then a right shift in the fitness distribution among adults in the general population would lead to substantial reductions in cases of fatal and non-fatal cardiovascular disease and type 2 diabetes. Furthermore, we estimate a significant impact on cardiovascular mortality under plausible public health intervention scenarios increasing the percentage of the population bicycling to work.

Summary Bicycling remains an underutilized alternative to motorized transport in most countries, and promoting bicycling could be a viable approach in primordial and primary prevention of cardiovascular diseases.

Keywords Bicycling · Cardiovascular · Mortality · Physical activity · Commuting · Prevention

Introduction

Regular engagement in physical activity is an essential component of cardiovascular disease prevention. A large part of populations in countries all over the world is not sufficiently physically active for optimal health promotion and cardiovascular disease prevention [1]. Many people have a desire to be more active, but prefer engagement in sedentary activities or

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dislike structured exercise. Other personal barriers typically include lack of time, work commitments, and perceived financial costs of structured exercise [2]. Bicycling for transportation can be an easy and inexpensive way of integrating physical activity into everyday life that for many people could be achieved without extra time. Bicycling as an alternative to motorized transport also has other benefits. Fewer cars on the road are associated with reduced emissions of particulates and exhaust gases that can be detrimental to the environment and health of people traveling in urban areas. Likewise, switching from car transport to bicycling will also mean less CO_2 emission, less noise, decreased traffic density, and less parking problems, which are major issues in the larger cities. The motorized transport sector is a significant source of CO_2 emissions; it is responsible for approximately a quarter of the total emissions and the expectation is that CO_2 emissions from the transport sector will increase until 2030 [3]. Yet, bicycling in urban areas with dense traffic may also be related to additional traffic noise exposure and high air pollution exposure due to a higher respiration rate when bicycling compared with driving the same distance, which could hamper the cardiovascular benefit. Another concern related to bicycling is the increased risk of fatal accidents. In this paper, we summarize the evidence of studies investigating bicycling in relation to cardiovascular disease risk and estimate the population impact of increasing bicycling as a mode of transport.

Bicycling and Risk of All-Cause Mortality and Fatal and Non-fatal Cardiovascular Diseases

Engagement in bicycling for transportation or recreation and risk of mortality and cardiovascular disease have been investigated in a number of cohort studies from Europe and China. These studies are based on data collected on bicycling and other determinants of cardiovascular risk as early as in the 1970s. To quantitatively summarize the evidence of cycling for transportation or recreation with risk of all-cause mortality and risk of fatal or non-fatal cardiovascular diseases, we extracted results from cohort studies in a literature search in PubMed to perform meta-analysis. Specifically, we extracted estimates of relative risk (RR) with 95% CI in categories of bicycling exposure. If multiple published studies from the same study cohort were available, we included only the one with the most detailed information for RR estimation. When any cycling was represented in two or more categories in the study, we then pooled these RRs with inverse variance weight and used the combined estimate to represent RR of mortality of fatal or non-fatal cardiovascular disease from engagement in any cycling versus no cycling. Random-effects meta-analyses were conducted by using DerSimonian and Laird random-effects models. Based on data available from six prospective cohort studies [4–9•] conducted in general population samples, including a total of 395,516 adult participants and 16,413 deaths from all causes, we estimated a 25% (95% CI 33 to 14%) lower risk of all-cause mortality comparing participants reporting any bicycling for transport or recreational purposes with those reporting no engagement in bicycling (Fig. 1A). Restricting analyses to cycling for transportation and risk of all-cause mortality, which was investigated in four cohort studies, the estimated pooled RR was 0.77 (95% CI 0.67 to 0.89) (Fig. 1B). Seven cohort studies [4, 6•, 7, 10–13] have reported on the relationship between bicycling and risk of fatal or non-fatal cardiovascular disease; including a total of 1,412,035 adult participants and 27,409 cases, we estimated a 16% (95% CI 12 to 20%) lower risk of fatal or non-fatal cardiovascular disease comparing participants reporting any bicycling for transport or recreational purpose with those reporting no engagement in cycling (Fig. 1C). While all cohort studies were fairly large with moderate to long follow-up and adjusted for major confounding factors including engagement in other physical activities, not all studies were carried out in populations with a widespread bicycling culture across all social classes. In particular, the reports based on the UK Biobank [6•], EPIC-Norfolk [7], and the Million Women Study [12] were carried out in populations residing in underdeveloped cycling infrastructure environments. In general, we would expect greater risk of unknown confounding in these studies since individuals reporting regularly engagement in bicycling (e.g., for transportation) from these populations may be particularly different from the general source population compared with a Danish or Dutch population. Nevertheless, the overall evidence supports bicycling for transportation or recreation to prevent development of fatal or non-fatal cardiovascular disease and premature mortality.

Bicycling in Primordial Prevention of Cardiovascular Diseases

Avoiding development of clinical cardiovascular risk factors in the first place is of major importance for cardiovascular disease prevention. Regular bicycling for transportation and recreation may represent a feasible and sustainable approach for prevention of clinical cardiovascular risk factor development including obesity, poor cardiorespiratory fitness, hypertension, and impaired glucose metabolism. While this is feasibly investigated in observational studies, a number of experimental studies have also been carried out studying the short-term effect on continues scaled cardiovascular risk factor levels.

Numerous cross-sectional studies have been carried out investigating the association of bicycling to work or school or for recreation and prevalence of clinical cardiovascular risk factors. These include large-scale population-based studies from UK, India, and Norway. These studies consistently report lower odds

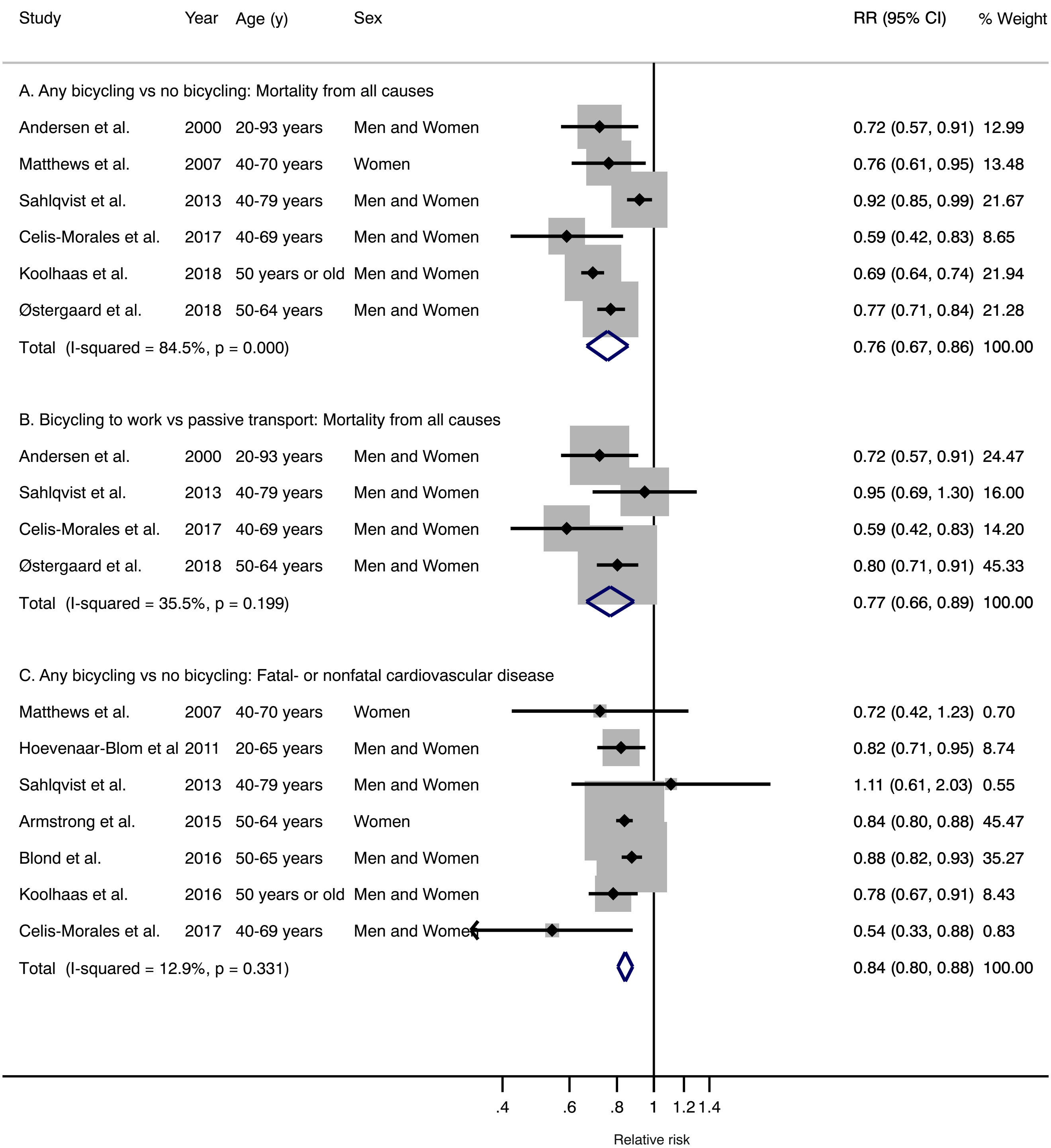

Fig. 1 Meta-analysis of bicycling and risk of mortality from all causes and fatal or non-fatal cardiovascular diseases. Diamonds represent the overall summary estimates with 95% CI from DerSimonian and Laird random-effects models

of prevalent obesity and diabetes mellitus among individuals bicycling to work compared with individuals using a passive transport mode [14–16]. In young people, bicycling to school has also been related to lower prevalence of obesity and favorable levels of metabolic risk factors [17, 18]. A limited number of prospective studies have investigated the role of bicycling to work in primordial prevention of clinical cardiovascular risk factors. In a previous cohort study among more than 20,000 Swedish men and women residing in a bicycling-friendly environment followed for 10 years, we observed that bicycling to work was associated with a lower risk of incident obesity, hypertension, hypertriglyceridemia, and impaired glucose tolerance compared with passive travel [19••]. In that study, we also found evidence of dose–response relationships between numbers of seasons spent bicycling and commuting distance for all incident cardiovascular risk factors. Due to the richness of the data in terms of the proportion individuals who were cyclist at both baseline and follow-up, we were also able to study changes in bicycling habits in relation to development of cardiovascular risk factors. We found that participants who maintained or began bicycling to work during the 10-year follow-up had lower odds of developing the abovementioned clinical risk factors, compared with participants either who did not cycle to work at both time points or who switched from cycling at baseline to other modes of transport during follow-up [19••]. In recent studies, we also examined five-year changes in bicycling habits and risk of incident obesity and type 2 diabetes in a general Danish population [20, 21•]. Maintaining bicycling habits for commuting or recreational purposes in middle and old age was associated with lower odds of incident abdominal obesity and general obesity as well as lower risk of type 2 diabetes. Overall, the observational studies suggest that men and women reporting regular bicycling for transportation or recreation have lower prevalence and incidence of multiple clinical cardiovascular risk factors compared with their peers who report no cycling after conditioning on major important confounding factors.

We are aware of five published experimental studies, which have investigated the effect of bicycling to work or school on cardiovascular risk factors among adults. In a Danish randomized trial among 48 adults not involved in regular cycling for transport or recreation or other structured leisure time exercise, an 8-week daily bicycling to work intervention had favorable effects on cardiorespiratory fitness and adiposity levels compared with control [22]. In a recent Danish randomized trial among overweight or obese and inactive adults, participants allocated to a 6-month daily bicycling to work or school intervention significantly improved peripheral insulin sensitivity, cardiorespiratory fitness, and adiposity levels compared with control [23••, 24]. Furthermore, these beneficial effects were fairly similar to those obtained among participants allocated to either a moderate or vigorous intensity leisure-time exercise intervention, which included no commuter bicycling [23••, 24]. A controlled study carried out in Belgium among 80 adults compared changes in cardiorespiratory fitness in a group allocated to a 1-year intervention that consisted of bicycling to work at least three times/week with those in a control group [25]. Compared with the control group at 6- and 12-month follow-up, the intervention group had more favorable changes in cardiorespiratory fitness. In a Finnish study, 68 men and women reporting car or bus commuting and no regular engagement in leisure-time exercise were randomly assigned to an active commuting (bicycling or walking) intervention for a period of 10 weeks or control [26]. The sub-group of participants only bicycling to and from work during the 10 weeks significantly improved cardiorespiratory fitness compared with control. Finally, in a Dutch study among 122 men and women reporting no commuter cycling or regular engagement in intensive exercise, participants were randomly allocated to cycling to work intervention including a minimum of 3 times/week during 6 months; those allocated to the cycling to work intervention significantly improved their cardiorespiratory fitness compared with control [27]. To quantitatively summarize the experimental evidence in adults, we extracted results from these randomized trials or controlled studies comparing a bicycling to school or work intervention with control on cardiorespiratory fitness (relative maximum oxygen uptake) to conduct a meta-analysis. When possible, we extracted results from intention-to-treat analysis, and when variance of within-group differences was unavailable, we estimated these based on an expected within-individual correlation between baseline and follow-up fitness of 0.925 [22]. A pooled weighted mean difference (WMD) with 95% CI with a DerSimonian and Laird random-effects model was estimated. The meta-analysis included the abovementioned five studies, which comprise a total of 441 adults. An 8-week to 6-month cycling to school or work intervention led to an average (WMD) increase in cardiorespiratory fitness of 3.56 ml O_2/min/kg (95% CI 2.79 to 4.32) compared with control (Table 1). While the effects on cardiorespiratory fitness were fairly consistent across studies ($I^2 = 54\%$ ($p = 0.054$), $Tau^2 = 0.45$ ml O_2/min/

Table 1 Controlled or randomized controlled trials of the effects of bicycling to work or school on cardiorespiratory fitness among adults

Study	Study design	Population	Duration of intervention	Effect on VO_2-max, ml O_2/min/kg (95% CI)
Blond et al. 2019 [23]	RCT	$N = 130$ physically inactive men and women with overweight or obesity	6 months	4.9 (2.2 to 7.5)
Møller et al. 2011 [22]	RCT	$N = 48$ physically inactive men and women	8 weeks	2.6 (0.9 to 4.3)
De Geus et al. 2009 [25]	Controlled study	$N = 80$ untrained men and women who did not cycle to work	6 months	3.3 (2.1 to 4.5)
Hendriksen et al. 2000 (men) [27]	RCT	$N = 84$ untrained men who did not cycle to work	6 months	4.7 (3.8 to 5.6)
Hendriksen et al. 2000 (women) [27]	RCT	$N = 31$ untrained women who did not cycle to work	6 months	3.1 (2.3 to 3.9)
Oja et al. 1991 [26]	RCT	$N = 68$ physically inactive men and women	10 weeks	3.0 (1.4 to 4.6)
			Overall summary effect	3.6 (2.8 to 4.3)

Overall summary effect is the pooled weighted mean difference with 95% CI from a DerSimonian and Laird random-effects model kg), the experimental studies had low-to-high internal validity and the size and number of studies were modest. Our confidence in the summary estimate is therefore low to moderate, and further research may change the estimates of effect of habitual bicycling to work on cardiorespiratory fitness. These experiments were carried out in perhaps the most bicycling-friendly countries, which decreases the generalizability to people living in communities with underdeveloped bicycling infrastructure. In particular, this could arise from the possible effect modification by differences in emissions of particulates from, i.e., vehicles nearby bicycling routes such as ambient fine particulate matter ($PM_{2.5}$), which is an important risk factor for cardiovascular morbidity and mortality [28, 29].

Combined Cardiovascular Effects of Bicycling and Air Pollution

Air pollution is harmful while physical activity is beneficial for cardiovascular health. Only a small number of studies have examined combined long-term health effects of long-term exposure to air pollution and physical activity and the potential interaction between the two exposures. These studies differ in a myriad of ways, including epidemiological design, how physical activity is defined, air pollutants, and health outcomes under study, as well as study settings, including both high- and low-pollution urban areas. In long-term observational studies, typically cohort or case–control design, physical activity measures are self-reported. Air pollution levels either modeled at the individual level, at the residence, measured in a given geographical area (comparing low- and high-pollution areas), or assessed by existing monitoring of daily variation in air pollution levels.

Three studies based on the Danish Diet, Cancer and Health study, with over 50,000 participants recruited between 1993 and 1997, who reported their physical activity habits (participation in sports, cycling, walking, and gardening) used a prospective cohort design to estimate long-term relationships (follow-up between 13 and 18 years) of leisure-time and utilitarian physical activities (bicycling, walking, and gardening) on overall and cause-specific mortality [30], risk of asthma and chronic obstructive pulmonary disease (COPD) [31], and risk of myocardial infarction (MI) [32]. These studies are the first to apply individual estimates of air pollution, in terms of residential estimated levels of nitrogen dioxide (NO_2), as a proxy of long-term exposure to traffic-related air pollution, and examined whether exposure to NO_2 modified beneficial effects of physical activity on mortality and cardiovascular morbidity. Furthermore, these studies are the first studies in a low-pollution setting in Denmark, where mean NO_2 concentration was 18.7 $\mu g/m^3$ at the cohort baseline (1993–1997). A study by Kubesch et al. from 2018 [32] examined whether there was effect modification of an association between physical activity and MI by NO_2 levels. The authors found inverse statistically significant associations between participation in sports (HR = 0.85, 95% CI 0.79 to 0.92), cycling (HR = 0.91, 95% CI 0.84 to 0.98), and gardening (HR = 0.87, 95% CI 0.80 to 0.95) and incident MI, while recurrent MI was statistically non-significantly inversely associated with bicycling (HR = 0.80, 95% CI 0.63 to 1.02), walking (HR = 0.82, 95% CI 0.57 to 1.16), and gardening (HR = 0.91, 95% CI 0.71 to 1.18). The authors found no effect modification of the associations between physical activity and MI by NO_2 levels. These papers document that in urban areas with relatively low air pollution levels, such as Copenhagen in Denmark, the benefits of physical activity on cardiovascular disease and overall mortality seem to outweigh the risk by additional exposure to air pollution during outdoor exercise. These results cannot be necessarily extrapolated to urban areas such as those in South East Asia, with higher magnitudes of air pollution levels, where more studies are urgently needed.

A recent randomized cross-over study among healthy participants and patients with chronic obstructive pulmonary disease or ischemic heart disease carried out in London compared the arterial stiffness and lung function response to a 2-h walk along a busy commercial street in London, England (Oxford Street) with the arterial stiffness and lung function response to a similar walk in a nearby London park (Hyde Park) with much lower air pollution [33]. Regardless of disease status, walking in Hyde Park decreased arterial stiffness and increased lung function. In contrast, these favorable effects were significantly reduced after walking along the polluted Oxford Street. This offset in cardiovascular benefit may be similar when comparing effects of bicycling in high dense vs. low dense traffic areas, yet additional studies are needed to confirm this.

Population Impact of Bicycling to Work

Compared with other countries, cycling is widespread in countries such as Denmark. Based on data from the regional health profile survey, which includes a large representative sample for the Region of Southern Denmark, cycling is the primary mode of transport to work or school for 18% of adult men and women [34]. By comparison, the proportion of people bicycling to work in the USA, Australia, UK, and Canada is about 2% [35]. In most countries around the world, there is a large potential for increasing the proportion of people using a bicycle for transportation. Based on the summary effects obtained in our meta-analysis of observational studies, we calculated the potential impact fraction (PIF) [36], which is the proportional difference between the observed number of fatal cardiovascular diseases under current levels of bicycling and the number expected under alternative scenarios of prevalent bicycling use. Under a plausible public health intervention scenario increasing the percentage of the population cycling to work from 3.5 to 18% in the UK and 0.5 to 18% in the USA, we estimate that 3.4% or 5,648 new annual deaths from cardiovascular diseases and 4% or 33,788 of new annual deaths from cardiovascular diseases could be prevented in the UK and USA, respectively [37–40]. These estimations assume that the RRs from the meta-analysis represent causal relationships and also assume no compensatory changes (i.e., a decrease) in other habitual physical activities among people taking up cycling to work.

From prior meta-analysis of prospective cohort studies, it has been estimated that a 3.5-ml O_2/min/kg increase in cardiorespiratory fitness is related to 13% and 15% lower relative risk of all-cause mortality and fatal or non-fatal cardiovascular disease, respectively [41]. Also, we have recently estimated that a 3.5-ml O_2/min/kg increase in cardiorespiratory fitness is related to an 8% lower risk of type 2 diabetes and a 3.5-ml O_2/min/kg right shift in the fitness distribution in the US middle-aged population could prevent 8% of all new annual cases of type 2 diabetes [42]. Thus, the average summary effect of 3.6-ml O_2/min/kg improvement in fitness from swapping passive travel, such as car commuting, with bicycling to school or work may represent a clinical meaningful benefit in relation to prevention of cardiovascular diseases, type 2 diabetes, and premature mortality.

Conclusion and Perspectives

Bicycling for transportation and recreation may be a feasible way of integrating fitness and health enhancing physical activity into everyday life. It is related to lower risk of cardiovascular morbidity and mortality and to lower risk of developing risk factors including obesity, hypertension, and impaired glucose metabolism. The estimated impact on cardiovascular mortality is substantial under plausible public health intervention scenarios increasing the percentage of the population cycling to work. However, unfortunately bicycling remains an underutilized alternative to car transport in many populations around the globe. For bicycling to be preferred over car transport, it must be safe and convenient to ride. Although many people might be interested in taking up bicycling, the majority feels uncomfortable making trips in traffic with poor bicycling infrastructure and in some urban areas it may also be unpleasant to bicycle due to high levels of air pollution. Improving bicycle infrastructure with separate bike lanes and paths in combination with traffic calming measures (e.g., reducing speed levels), easy and affordable integration of bicycles with public transit, and improving bicycle parking are essential measures for increasing bicycling for transportation. Implementing such structural interventions is extensive and requires political action. A first step for nations to promote bicycling is the development of a bicycling strategy on a national level. Over the last few years, many countries have developed a national bicycling strategy. An example from a country with a recently developed cycling policy and plan for implementation is the UK. It is aimed at promoting cycling and walking as the natural choice for shorter journeys, or as part of a longer journey [43]. With a government investment of £1 billion available to local bodies that will be invested in cycling and walking over a 5-year period, planned implementation actions include investments to improve the road network and road safety, enable cycling proficiency training for children, and offer cycling promotion programs [43]. Despite being one of the leading cycling nations, Denmark launched a new national bicycle strategy to encourage more people to cycle in 2014 [44]. While the Danish government historically has had an important role in bicycling promotion, the local municipalities have made most initiatives as the majority of roads are administered locally. The municipality of Copenhagen is a good example of bicycling being highly prioritized with big investments in road infrastructure to increase safety for cyclists and improve opportunities for commuting by bicycle over two decades. The municipality of Copenhagen continues their investments and has successfully increased the number of trips all to work and education done by bicycle to 49% in 2018 [45]. Such extensive structural policy interventions require political action at the national, regional, and municipal level to succeed building a bicycling infrastructure competitive to motorized transport that will remove the major barriers to bicycling.

Future research needs include (i) investigating the effects of bicycling for transportation in secondary prevention of cardiovascular diseases and comparing this with more structured exercise-based interventions, (ii) investigating the possible effect modification of air pollution and bicycling on cardiovascular risk in areas with low and high air pollution levels, which could be pursued in both observational and experimental studies, (iii) comparing the fitness and cardiovascular effects of e-bike with those of regular bicycling, and (iv) investigating the effect of structural interventions to promote bicycling in communities with underdeveloped bicycling infrastructure.

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