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Exchanging car trips by cycling in the Netherlands

A first estimation of the health benefits

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Abstract

Exchanging car trips by cycling in the Netherlands
A first estimation of the health benefits

As commissioned by the Dutch Ministry of Housing, Spatial Planning and the Environment, we assessed the possible health benefits of the substitution of short-distance car trips with short-distance cycling trips. To this end we used existing methods for Health Impact Assessment and evaluated the availability and quality of data, models and tools that were needed.

In our assessment not only the classic environmental pollutants noise and air pollution were taken into account, but also the effects on road safety and physical activity. Application shows that the disease burden related to physical activity reduces at a maximum of 1.3% after one year. As expected, the health benefits due to reduction in road traffic noise levels and traffic-related air pollution are relatively small. Furthermore, it appears that an exchange of short-distance car trips by cycling is only beneficial for young male drivers.

Since a lot of information was unavailable and/or unknown and because a lot of choices and assumptions were made, the results have to be seen as a first estimate of what can be expected of interventions that cause an exchange between short-distance car trips with cycling. This study is a follow-up on earlier exemplary assessments of transport interventions.

The reliability of our assessment can be improved if we can obtain better information on population exposure distributions of noise and air pollution; it is also important to validate the modelled decrease in traffic noise, air pollution and changes in behaviour by means of measurements.

Trefwoorden / Key words:
Health Impact Assessment, cycling, traffic-related air pollution, road traffic noise, transport, road safety, physical activity

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Rapport in het kort

Het vervangen van korte autoritten door fietsritten
Een eerste schatting van de gezondheidsbaten in Nederland

In opdracht van het ministerie van VROM is onderzocht hoe de mogelijke gezondheidsbaten van het vervangen van korte autoritten door fietsritten geschat kunnen worden. Hiervoor zijn bestaande methoden voor Health Impact Assessment gebruikt en is bekeken of de benodigde data, modellen en instrumenten aanwezig en van voldoende kwaliteit zijn.

In de studie worden niet alleen de klassieke milieufactoren als geluid en luchtverontreiniging meegenomen, maar ook verkeersveiligheid en bewegen. Toepassing laat zien dat de ziektelast door lichamelijke inactiviteit na 1 jaar met maximaal 1,3% wordt gereduceerd als volwassenen meer fietsen. Zoals verwacht, zijn de gezondheidsbaten ten gevolge van een afname van de niveaus door geluid van wegverkeer en verkeersgerelateerde luchtverontreiniging relatief klein; verder bleek het vervangen van korte autoritten door fietsritten alleen voordelig te zijn voor jonge mannen.

Gezien het grote aantal aannames en onzekerheden, moeten de resultaten worden gezien als een eerste inschatting van wat mogelijk kan worden verwacht van interventies die ervoor zorgen dat mensen de fiets nemen in plaats van de auto. Deze voorbeeldstudie is een vervolg op eerdere studies waarin de effecten van snelheidsreductie en de aanleg van een nieuwe snelweg werden geëvalueerd.

Uit de studie blijkt dat de betrouwbaarheid van de berekeningen kan worden verbeterd wanneer er betere informatie is over de verdeling van verkeersgerelateerde luchtvervuiling en geluid over de populatie. Ook is het belangrijk om de gemodelleerde vermindering van verkeersgeluid en luchtvervuiling en de gedragsveranderingen te valideren door middel van metingen.

Trefwoorden / Key words:
gezondheidseffectschatting, fietsen, verkeersgerelateerde luchtverontreiniging, geluid van wegverkeer, bewegen, verkeersveiligheid, transport

Acknowledgement

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Contents

Summary

Background
As a follow-up to earlier exemplary assessments of transport interventions, the Dutch Ministry of Housing, Environmental and Spatial Planning (VROM) commissioned the National Institute for Public Health and the Environment (RIVM) to evaluate the health benefits of bicycle interventions. For the purposes of this study, we estimated the health benefits of a substitution of a fraction of car trips by bicycle trips in the Netherlands. Thereby, we only included short car trips: trips with a distance up to 7.5 km.

Objectives
The main objectives of the present study were:

- to assess the possible health benefits of the substitution of short-distance car trips with short-distance cycling trips in the Netherlands; and
- to evaluate the availability and quality of data, models and tools that were necessary to estimate the health benefits of this transport scenario.

Method
In order to estimate the health benefits of substituting short-distance car trips by short-distance cycling trips, we compared the disease burden resulting from the following two scenarios:

1. Reference situation: the disease burden at the moment that none of the short distance-car trips was substituted by cycling: which is in fact the current situation.
2. Alternative scenario: the disease burden at the moment that a specific fraction of the short distance-car trips is substituted by cycling trips. Different sub-scenarios with alternative fractions were evaluated.

In both scenarios, we evaluated the impact of the change in traffic-related air pollution, road traffic noise, road safety and physical activity on the disease burden expressed in Disability-Adjusted Life Years (DALYs). The methodology used to assess the effects of both scenarios was based on common procedures for environmental health risk assessment.
For estimating the burden of disease due to road traffic noise, transport-related air pollution, physical activity and road safety, several types of data were needed such as population exposure distributions, exposure-response relations and morbidity and mortality data for the different transport-related health endpoints. For the calculation of the number of years lived with disease (YLD), data were needed on the duration of the disease and disability weights expressing the severity of the different health endpoints.

Results and conclusions
Substitution of short-distance car trips with cycling can improve public health: it is estimated that the disease burden related to physical (in)activity reduces at a maximum of 1.3% after one year, this is a large effect compared to the effects of achieving the aims of the Dutch National Action Plan for Sports and Physical Activity. As expected, the health benefits due to reduction in road traffic noise levels and traffic-related air pollution are relatively small. A possible health deficit could come from a higher risk of accidents; it appears that an exchange of short-distance car trips by cycling is only beneficial for young male drivers. Since a lot of information was unavailable and/or unknown, the results have to be seen as a first estimate of what can be expected of interventions that cause an exchange between short-distance car trips with cycling.

The integrated approach used in the present study links up with Dutch policy documents such as 'The National Action Plan on Environment and Health', and 'Opting for a healthy life' in which the Dutch government presents a number of targets that can contribute to the promotion of public health and the prevention of public health problems in the Netherlands.

The reliability of our assessment can be improved if we obtain better information on population exposure distributions of noise and air pollution; it is also important to validate the modelled decrease in traffic noise, air pollution and changes in behaviour by means of measurements.

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Samenvatting

Achtergrond
In opdracht van het ministerie van VROM is onderzocht hoe de mogelijke gezondheidsbaten van het vervangen van korte autoritten door fietsritten geschat kunnen worden. Dit is een vervolg op eerdere studies waarin de effecten van snelheidsreductie en de aanleg van een nieuwe snelweg werden geëvalueerd.

Doel
De belangrijkste doelstellingen van deze studie waren:

- het schatten van de gezondheidsbaten die in Nederland optreden ten gevolge van het vervangen van korte autoritten door fietsritten;
- beoordelen in hoeverre de benodigde data, modellen en instrumenten aanwezig zijn en van voldoende kwaliteit zijn

Om een schatting te maken van de gezondheidsbaten die optreden ten gevolge van het vervangen van korte autoritten door fietsritten, is de ziektelast van de twee onderstaande scenario's met elkaar vergeleken:

1. Referentie situatie: de ziektelast op het moment dat nog geen van de korte autoritten is vervangen door fietsritten.
2. Alternatief scenario: de ziektelast op het moment dat een fractie van de korte autoritten is vervangen door fietsritten.

Omdat het moeilijk is te bepalen welk deel van de korte autoritjes nu door fietsritjes kan worden vervangen zijn verschillende fracties bekeken. Om een schatting van de ziektelast (uitgedrukt in Disability-adjusted Life Years) te maken zijn bestaande methoden voor Health Impact Assessment gebruikt. In de studie worden niet alleen de klassieke milieufactoren als geluid en luchtverontreiniging meegenomen, maar ook verkeersveiligheid en bewegen. Voor de berekening van de transportgerelateerde ziektelast zijn verschillende soorten gegevens nodig: populatie blootstellingverdelingen, blootstellingrespons relaties, en morbiditeits- en mortaliteitsgegevens van de verschillende transportgerelateerde gezondheids eindpunten. Voor de berekening van het aantal jaren doorgebracht in verminderde gezondheid, waren behalve wegingsfactoren die de ernst van de verschillende gezondheidstoestanden uitdrukten, ook gegevens nodig over de duur van deze gezondheidstoestanden

Resultaten en conclusies
Toepassing laat zien dat de ziektelast door lichamelijke inactiviteit na 1 jaar met maximaal 1,3% wordt gereduceerd als volwassenen meer fietsen. In vergelijking met de effecten van het 'Nationaal Actieplan Sport en Bewegen' is dit een groot effect. Zoals verwacht zijn de gezondheidsbaten ten gevolge van een afname van de niveaus door geluid van wegverkeer en verkeersgerelateerde luchtverontreiniging relatief klein; verder bleek het vervangen van korte autoritten door fietsritten alleen voordelig te zijn voor jonge mannen. Gezien het grote aantal aannames en onzekerheden, moeten de resultaten worden

gezien als een eerste inschatting van wat mogelijk kan worden verwacht van interventies die ervoor zorgen dat mensen de fiets nemen in plaats van de auto.
De integrale aanpak in deze studie sluit goed aan bij het 'Nationale Aanpak Milieu en Gezondheid, 2008-2012' en de 'Preventienota Kiezen voor Gezond Leven' waarin het kabinet een aantal speerpunten presenteert ter verbetering van de volksgezondheid en ter preventie van volksgezondheidsproblemen in Nederland.

Uit de studie blijkt dat de betrouwbaarheid van de berekeningen kan worden verbeterd wanneer er betere informatie is over de verdeling van verkeersgerelateerde luchtvervuiling en geluid over de populatie. Ook is het belangrijk om de gemodelleerde vermindering van verkeersgeluid en luchtvervuiling en de gedragsveranderingen te valideren door middel van metingen.

1 Introduction

As a continuation of the fourth Ministerial Conference on Environment and Health [1], the Dutch Ministry of Housing, Environmental and Spatial Planning (VROM) commissioned the National Institute for Public Health and the Environment (RIVM) to start a project on 'Sustainable traffic', which aims to assess and integrate the potential health aspects of transport interventions for air pollution, noise, physical activity and road safety in order to identify measures that most effectively reduce the traffic-related disease burden in the Netherlands.

The qualification and quantification of transport-related health aspects can be carried out by means of a Health Impact Assessment (HIA), which is a 'combination of procedures, methods and tools by which a policy, programme or project may be judged as to its potential effects on the health of a population, and the distribution of those effects within the population' [2, 3].
Although it has been widely agreed upon that HIA can be a useful tool for evaluating and comparing transport policies and interventions, studies quantifying the transport-related disease burden [4, 5] and/or the health benefits of transport interventions [6-10] are scarce. In most cases only the effects of the more classical environmental exposures such as air pollution are included or studies are looking more at lifestyle aspects such as physical activity.

Despite the fact that several reviews have been published describing adverse and beneficial health effects of motorised transport – ranging from loss of life expectancy by air pollution to social effects related to mobility [11-13], it is difficult to compare the different health effects resulting from specific policy options. In addition, it becomes more and more clear that physical and social aspects are interwoven and as such strongly affect our living environment. Think of, for example, the possibilities for cycling and walking, the opening up of a neighbourhood and the conjugated traffic-related emissions.

Following Figure 1, health behaviour, such as cycling and walking, is determined by an interrelated set of personal and environmental factors. The model is based on Fishbein and Ajzen's model of reasoned behaviour and Bandura's concept of self-efficacy [14]. In this theoretical model, attitudes, social norms and self-efficacy predict the intention to behave in a certain way, which in turn predicts the behaviour. Personal characteristics (for example gender, age and educational level) influence these determinants of behaviour. Barriers and skills determine if, when or why the intention is turned into behaviour [14]. An important set of barriers lies within the environment or moreover, in the interaction between individuals and their environment. Both the actual environmental factors and the perception of these factors are of importance [15].

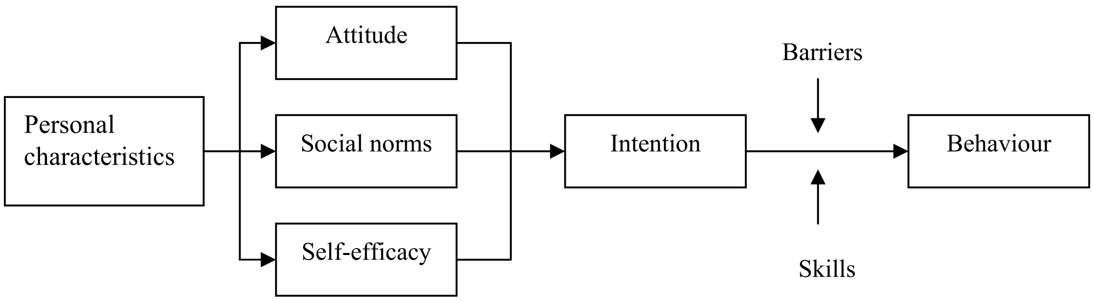

Figure 1: The determinants of behaviour model [14].

The underlying report is a follow-up study on an earlier exemplary assessment of a transport intervention carried out in 2005: an estimation of the possible health benefits of speed limit reduction at nine highway sections in urban areas [16]. At the same time, the effects of traffic re-allocation from a densely to a less densely populated area by the introduction of a new highway section were evaluated [17]. One of the recommendations in these earlier assessments was to evaluate the health benefits of another transport (policy) intervention in the Netherlands: the health benefits of bicycle interventions. This was considered meaningful because it was expected that this intervention not only affects levels of traffic-related noise and/or air pollution, but also road safety. One of the important benefits from cycling comes from its contribution to overall levels of physical activity [18]. As such, the importance of cycling as a means to achieve greater sustainability of public health is more and more recognised [11 in: 18].

1.1 Aim

The primary objective of the present study was to assess the possible health benefits of the substitution of short-distance car trips with short-distance cycling trips in the Netherlands. We estimated the impact on traffic-related air pollution, road traffic noise, road safety and physical activity in several theoretical scenarios. By doing so, we furthermore evaluated the availability and quality of data, models and tools that are necessary to estimate the health benefits of these transport scenarios.
The outcome of this report can be helpful since there is a need to promote healthy and sustainable transport alternatives as a way to prevent the negative impacts of transport systems on human health. One important way to do this is to ensure that health issues are clearly on the agenda when transport decisions are being made and policies formulated [87]. Furthermore, the integrated approach used for our assessment links up with Dutch policy documents such as ‘The National Action Plan on Environment and Health’ (‘Nationale Aanpak Milieu en Gezondheid 2008-2012’ in Dutch) [19], and ‘Opting for a healthy life’ (‘Preventienota Kiezen voor Gezond leven’ in Dutch) [20] in which the Dutch government presents a number of target areas that can contribute to the promotion of public health and the prevention of public health problems in the Netherlands. Important spearhead areas that are mentioned in these policy documents are: healthy design and layout of the living environment, healthy mobility and obesity (physical activity and nutrition). One of the ways to contribute to these

spearheads is the improvement and extension of existing instruments such as health impact assessment (HIA). In addition, the Dutch Government wishes to promote ‘the healthy choice’ by arranging society in such a way that the healthy choice indeed becomes the easy one. This means, for example, that our living environment should invite people to be more physical active.

As one of the inputs for our assessment, we commissioned SWOV Institute for Road Safety Research to estimate the effect of a mobility shift from the car and the bicycle on road safety. The main results are presented in this report. More details on the traffic safety-related part of this assessment can be found elsewhere [21].

Before we present the different steps of our assessment (chapter 3), we give an overview of the potential health benefits of cycling in relation to the environment (chapter 2). Results are presented and discussed in chapters 4 and 5. Finally, recommendations are given for future assessments and the continuation of this project.

2 Cycling and health

2.1 Some facts about cycling in the Netherlands

In the Netherlands, cycling is one of the most important means of transportation. In 2005, on average, the Dutch population chose to use their bicycle for 27% of their journeys. Women cycle somewhat more often than men; on average, men cycle longer distances. After the age of 18 years, the use of the bike decreases (see also Figure 2). A possible reason might be the fact that the driving licence comes within reach. Until the age of 70, the use of the bicycle is rather stable; only among middle-aged people there is a small pick up. Among people of 70 years and older, the use of the bike decreases drastically [22].

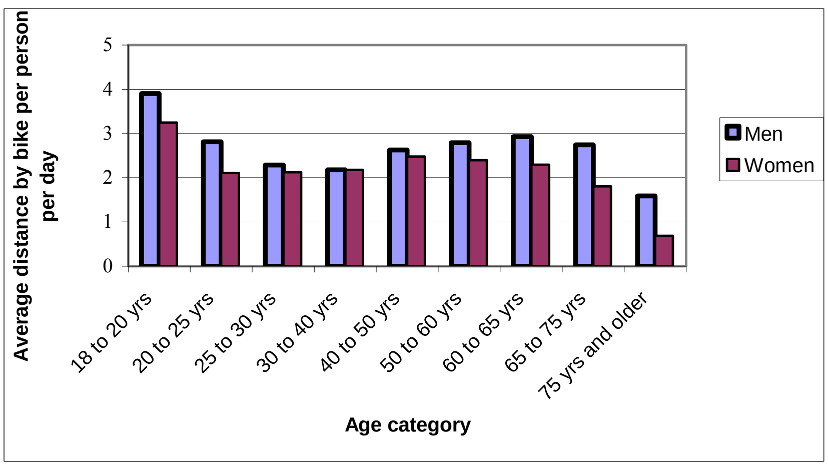

Figure 2: The average distance travelled per person per day by bike in the Netherlands in 2005 (derived from MON 2005 [23]).

Together with Denmark and Germany, which have a bicycle share of 19% and 10% respectively, the Netherlands has the highest bicycle use in Europe. In countries such as France and the United Kingdom, the bicycle share is approximately 5% and 2%, respectively [24].
Although cycling is a very popular activity in the Netherlands, it is not equally prevalent all over the country. In cities with the highest bicycle usage rates (e.g. Groningen and Zwolle), inhabitants chose the bicycle for 35-40% of their journeys; in cities with the lowest bicycle use rates (e.g. Rotterdam and Heerlen) inhabitants chose the bicycle for 15-20% of their journeys [24].

For short distances, the contribution of the bicycle is high: In 2005, 35% of all trips up to 7.5 km were made by bicycle (see also Figure 3).

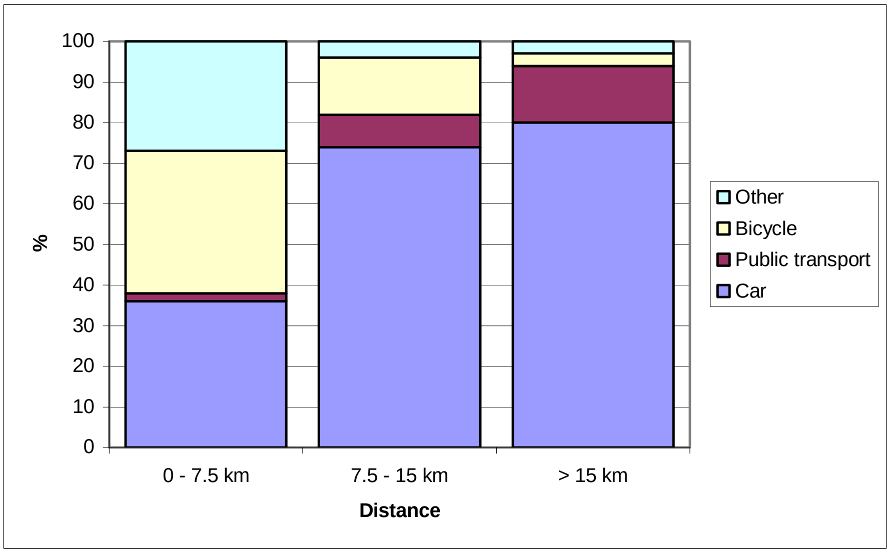

Figure 3: Journeys according to transportation means and distance category in the Netherlands in 2005 (Source: MON, 2005 in: [24]).

Most short distance bike trips are made by persons aged 35-49 years. Among persons of 65 years and older, the number of short-distance bike trips decreases drastically.

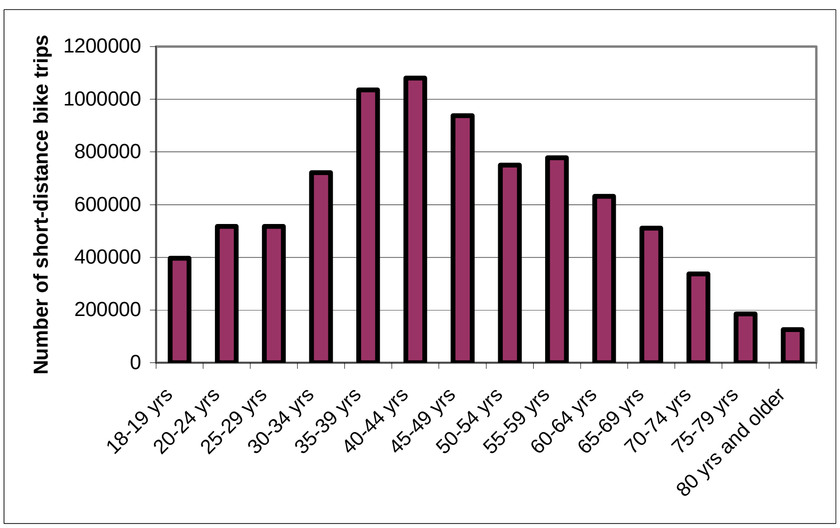

Figure 4: The number of short-distance bike trips (0-7.5 km) in the Netherlands in 2005 in relation to age (derived from MON 2005 [23]).

2.2 Car mobility in the Netherlands

People in the Netherlands use their cars more and more: in 2005 car drivers travelled almost 95 milliard kilometres on Dutch roads; this is almost 6 milliard kilometres more than in 2000 [25]. In 2005, the Dutch car driver travelled 16 kilometres per day [25]. Figure 5 shows the distance travelled per day by car drivers for men and women separately. After the age of 18 years, the use of the car increases; between the ages of 30 and 50, people's car use is highest.

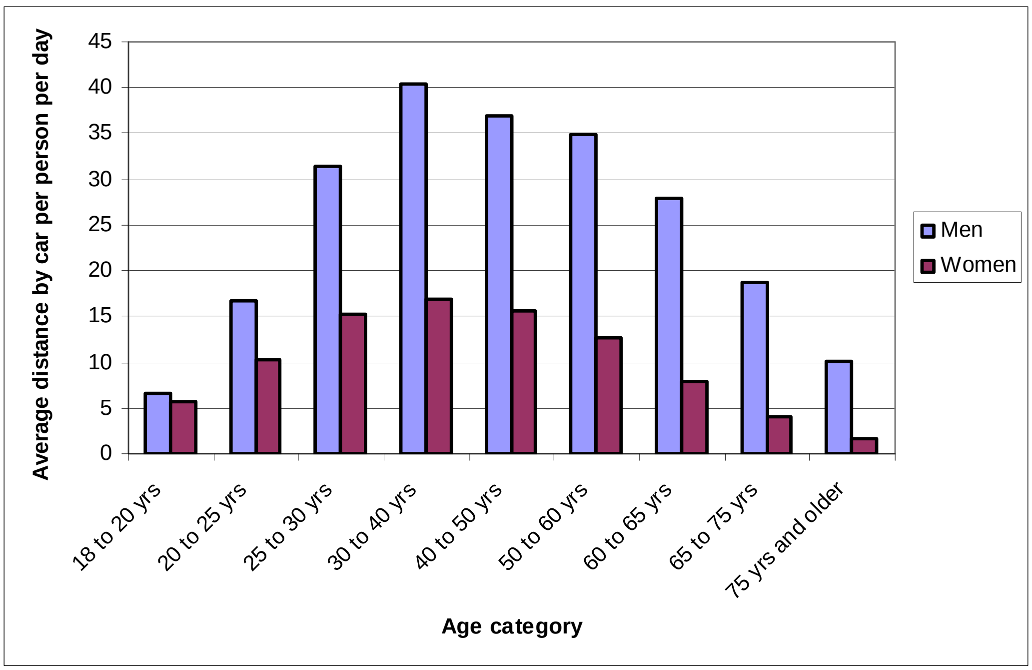

Figure 5: The average distance travelled by car per person per day for men and women in the Netherlands in 2005 (derived from MON 2005 [23]).

A relatively large proportion of car trips have a distance shorter than 7.5 km. Figure 3 shows that in 2005, almost 35% of all trips up to 7.5 km were made by car. Between 1986 and 2006 the number of short-distance car trips has hardly changed: on average, a person makes about 220 short-distance trips per year [22]. The number of short distance car trips is still higher among men compared to women. However, since more women have a driving license, this difference is becoming smaller [22].
As far as age is concerned, most short-distance car trips are made by persons aged 30-49 years (see also Figure 6). Among persons of 65 years and older car use decreases drastically. At the same time, Figure 6 also demonstrates that during the last 20 years the number of *short-distance* car trips has been increased extensively among people of 65 years and older. This increase is partly associated with the increase in the number of elderly people and with the fact that elderly drive more kilometres per day

[25]. A striking observation is the fact that the number of short-distance car trips increases among people aged 40-49 years, while this decreases among people aged 30-39 years.

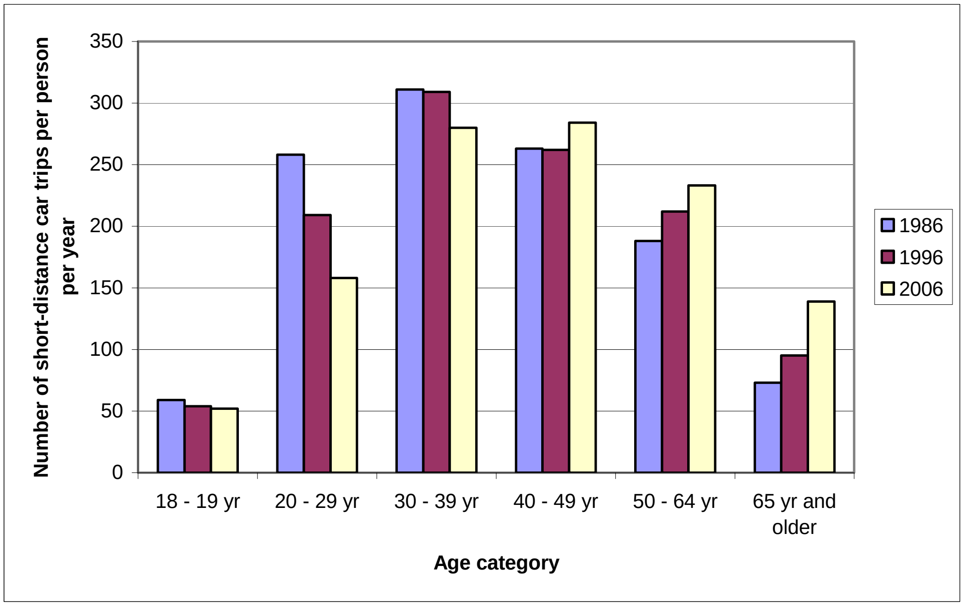

Figure 6: The number of short-distance car trips per person per year for the different age categories in 1986-2006 (Source: Olde Kalter, 2007 [22]).

2.3 The potential health benefits of cycling

The main health benefits of cycling come from its contribution to overall levels of physical activity. However, the benefits of cycling do not stop at improving physical and mental health but also extend to benefits to the wider public health, by reducing the adverse impacts associated with motor traffic [18], e.g., health effects related to air pollution and noise or road crashes.

2.3.1 Traffic-related air pollution

Pollution from motorised traffic is an important health hazard: it is responsible for the release of hundreds of chemical compounds that can affect health into the atmosphere. From a health perspective, important pollutants stemming from traffic are particulate matter, nitrogen dioxide, carbon monoxide, polycyclic aromatic hydrocarbons, benzene and metals emissions.

Transport-related air pollution is associated with a number of health outcomes [26]: it increases the risk of both morbidity and mortality, particularly from cardiopulmonary causes; furthermore, transport-related air pollution has been associated with several other adverse health outcomes, including cancer and birth outcomes.

The replacement of short-distance car trips can have a greater impact on air pollution than would be expected at first sight, as in the first kilometres travelled after starting a cold engine, more pollutants are emitted than at the equivalent distance driving with a warm engine [22].

2.3.2 Road traffic noise

Most types of motorised transport generate noise. As such, road transport is one of the most important sources of community noise. With regard to noise emitted by motorised vehicles, noise arises from 3 sources: propulsion noise (engine, power train, exhaust and intake systems), tyre/road contact noise (rolling noise) and aerodynamic noise. The first is dependent on the operation and speed of the engine and includes noise related to the combustion process, gas flow and mechanical noise. The second refers to the speed of the vehicle and is mainly related to the noise generated by the tyre/road interaction. Propulsion noise is the dominant source at lower speeds (under 30 km/hr for passenger cars), and under conditions of acceleration when engine speeds tend to be relatively high. Tyre/road surface interaction noise tends to dominate at moderate and high road speeds; aerodynamic noise becomes louder as a function of the vehicle's speed [27].

Noise is considered an environmental stressor that is purported to have adverse effects on health and well being. These include not only community responses such as annoyance and sleep disturbance, but also physiological effects resulting in, for example, cardiovascular disease [28].

2.3.3 Physical activity

There is international consensus on the value of regular, moderate-to-vigorous intense physical activity [29-31]. Cycling is an example of an activity with such intensity. Therefore, cycling is considered to be the ideal way to meet the necessary levels of activity, as it is one of the few activities of sufficient intensity that may be incorporated into the activities of daily life [18, 32]. In the Netherlands, cycling is already the activity that contributes most to the total time spent on moderate-to-vigorous physical activity [33].

Many benefits could theoretically be expected from, for example, the realisation of amenities at walking and cycling distance, the construction of sufficient safe footpaths and cycle tracks in the neighbourhood, making it more attractive to travel (part of) the distance between home and work by bike or on foot. It appears that in an environment with a lot of cycle tracks, short cycling distances and low hills, people cycle more [34]. Studies investigating people's travel behaviour show that an infrastructure where the distance between shops and other amenities and people's homes is short, people are more willing to visit these amenities by walking and/or cycling [35]. Since there is a substantial increase in car dependency for travelling short distances, there is considerable capacity to increase physical activity through substituting short car journeys with cycling and/or walking [1].

2.3.4 Road safety

Determining the effect on road safety of a mobility exchange between car and bicycle may not be all that straightforward. Firstly, many properties of short distance car and bicycle trips that predict the risk on injury and/or fatality are unknown: which type of roads are used by cars and/or bicycles (e.g., 50 km/hr, 30 km/hr roads, cycling lanes), what time of day and what kind of people engage in short-distance car and/or cycling trips. Secondly, a given car trip will probably not be replaced by a bicycle trip along exactly the same route. Thirdly, it may be expected that the substitution of short-distance car trips with short-distance bicycle trips will be more successful in regions where there (already) is a good bicycle infrastructure (Stipdonk et al., in prep). In addition, there are people who think that increasing cycling can improve safety among cyclists because it is assumed that cycling becomes safer when it becomes more common [18].

3 Methods

For the purposes of this study, we estimated the health benefits of a substitution of a fraction of car trips by bicycle trips in the Netherlands. Thereby, we only included short car trips: trips with a distance of up to 7.5 km. In order to estimate the health benefits of substituting such short-distance car trips by short-distance cycling trips, we compared the disease burden resulting from the following two scenarios:

1. Reference situation: the disease burden at the moment that none of the short distance-car trips was substituted by cycling: which is in fact the current situation.
2. Alternative scenario: a specific fraction of the short distance-car trips is substituted by cycling trips. Different sub-scenarios with alternative fractions are evaluated.

The outcomes of the alternative scenario were compared with the reference situation. In all scenarios, we evaluated the impact of the change in traffic-related air pollution, road traffic noise, road safety and physical activity on the disease burden.

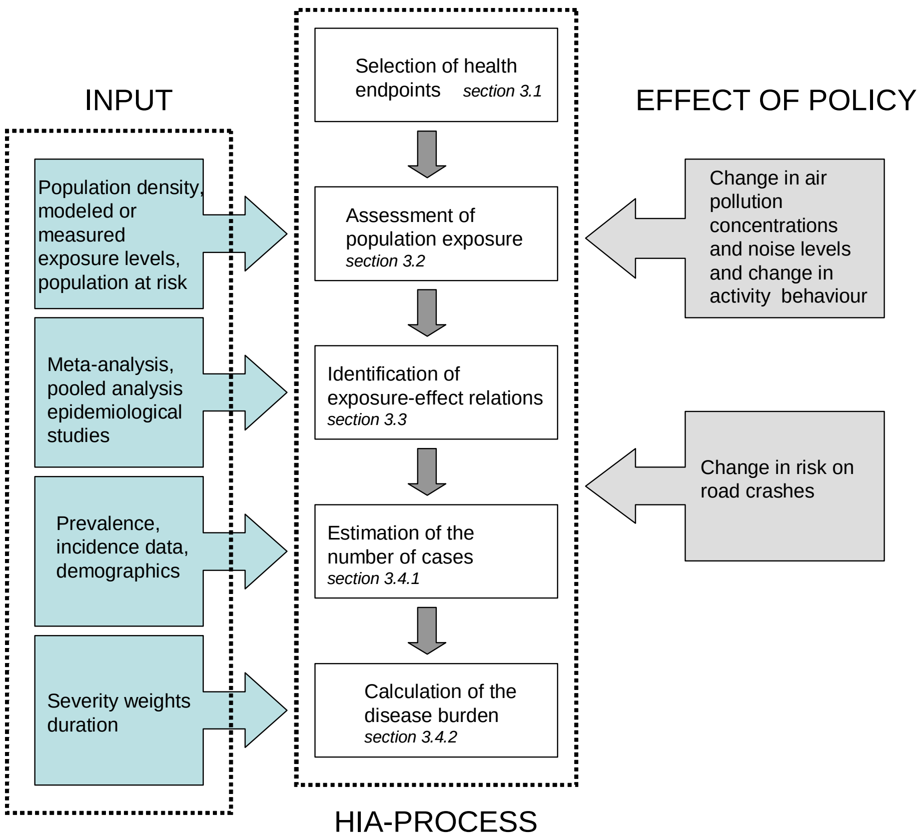

Figure 7: Scheme of data used, calculations made and steps taken in order to assess the disease burden due to the substitution of short-distance car trips by cycling trips (adapted from [36] and [16]). The numbers indicate the section in this report that describes the step briefly.

Figure 7 summarises the methodology and data which was used to assess the effects of both scenarios. It is based on common procedures for environmental health risk assessment [36] and adapted for transport-related health impact assessment [16]. We identified five steps in our assessment, which are described briefly below; more details can be found in Appendices I, II, III and IV. Steps 2 to 5 were performed twice, to estimate the disease burden before and after the substitution of short-distance car trips by cycling trips.

3.1 Selection of health endpoints

As indicated earlier, we evaluated the effects of traffic-related air-pollution, road traffic noise, road safety and physical activity. However, the benefits of cycling extend beyond that. Examples are the benefits caused by the reduction of the adverse impacts associated with climate change and the most associated psychological and social impacts [13]. However, changes in these elements are difficult to quantify and were therefore not included in this assessment. For our assessment we included health endpoints

1. of which the World Health Organisation and the Dutch Health Council concluded that there is sufficient evidence for a relationship with traffic-related air pollution, road traffic noise or physical activity [26, 28, 29, 30, 37, 38]; and
2. that impair people's daily functioning.

Table 1. Overview of the selected health endpoints

Traffic-related exposure/risk factor	Selected health endpoint
Traffic-related air pollution‡	Mortality (ICD-10 < V01)** Wheezing in children
Road traffic noise‡	Severe annoyance Severe sleep disturbance Ischemic heart disease (ICD-10: I20-I25)
Road safety	Mortality* Injury†
Physical activity	Mortality and morbidity from Coronary heart disease (ICD-20: I20-25) Stroke (ICD-10: I60-69, G45) Type II Diabetes (ICD-10: E11) Colon cancer (ICD-10: C18) Breast cancer (women) (ICD-10: C50)

*) Fatalities: deceased within 30 days after a road crash;

†) Hospitalised severely injured: taken to a hospital for treatment and at least a one night stay, after a road crash;

‡) Referring to long-term exposure;

**) this includes all natural causes.

Since the relation between transport activities and deaths and injuries has been clearly and unambiguously identified, we decided to include outcomes of crashes that are commonly used: the number of killed and injured. In accordance with the criteria mentioned above, elevated blood pressure by road traffic noise exposure, for example, was excluded because it does not necessarily impair daily functioning. On the other hand, we did include severe annoyance and severe sleep disturbance because they affect well-being, which is included in the WHO's definition of health.[1]

As an indicator for all traffic-related air pollutions we used NO_2, which is widely accepted [26]. In epidemiological studies, PM_{10} has also been used as an indicator but is less specific for *traffic-related* air pollution [26]. Since the scenarios deal with *long*-term rather than *short*-term changes, health effects of short-term increases in air pollution, such as myocardial infarction, were not included.

3.2 Assessment of population exposure

3.2.1 Population at risk

Traffic-related air pollution and road traffic noise

With regard to traffic-related air pollution and road traffic noise, we estimated health effects for the whole Dutch population (all ages), regardless of where they live in relation to roads and/or how they participate in traffic (by car or bike). We realise that this is rather crude, since the highest traffic-related air pollution exposures, for example, are usually found within the first 100 m from roadways and exposures often fall to background levels by 300 m distance or more from a road [26]. Only a small part of the Dutch population lives close to a major road. To give an indication: in the Dutch cohort of Hoek et al. (2002), 5% of the population lived close to a major road [40]. Although several studies have investigated the exposure of cyclists and car drivers to traffic-related air pollutants and noise [41-46], the results of these studies cannot be used to assess the exposure to traffic-related air pollution and/or road traffic noise of groups of cyclists or car drivers in the Netherlands.

Physical activity

In relation to physical activity, we estimated the health effects for all persons in the Netherlands of 18 years and older. However, since physical activity guidelines imply the most health gain is achieved by persuading the least active groups in the population to become moderately active [29], the population *at risk* of being affected by a health effect are those who are the least active. Health gain can be expected by increasing the proportion of the population that cycle and/or by increasing the time spent cycling among those who cycle.

Road safety

For our assessment, only the trips of drivers aged 18 years and older were replaced, since car trips always relate to drivers aged 18 years and older; the consequences of replacing trips of passengers of the drivers, were left out of the assessment. Health effects were estimated for road users aged 18 years and older, involved in crashes where either a car or a bicycle is involved. Since we assume that the number of crashes where neither a car nor a bicycle is involved is not influenced by a change in car and

[1] WHO definition of health: 'Health is a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity' [39].

bicycle mobility, these were not included in our assessment. Detailed backgrounds to the calculations for road safety can be found in Appendix I.

3.2.2 Population exposure in the *reference* situation

Traffic-related air pollution and road traffic noise

We assessed population exposure to traffic-related air pollution (NO_2) and road traffic in the *reference situation* by linking data on the place of residence of the population to modelled NO_2 concentrations and road traffic noise levels (expressed in L_{den}).

Data on the place of residence (postal code level) were obtained from Statistics Netherlands (CBS). Modelled NO_2 concentrations (µg/m^3) in the Netherlands were calculated by means of the Luvotool module from the EMPARA[2] model. The resolution of the resulting maps with total NO_2 concentrations was 25*25 m [47].

For the calculation of road traffic-noise exposure levels, the module Noisetool [48] of the EMPARA model was used. The resolution of the resulting maps with road traffic-noise levels was 25*25 m [47]. From the L_{den}, the other noise indicators ($L_{Aeq,\ 16hr}$ and the L_{night}) were derived using the distribution of road traffic on the roads over 24 hours provided by the Netherlands Environmental Assessment Agency (PBL) [49].

Physical activity

To estimate the physical activity pattern at the moment that *none* of the short-distance car trips were substituted by cycling, we needed to know the physical activity pattern of the Dutch population at that moment. To this end, the fraction of the population that meets the Dutch guideline for physical activity (the so-called Nederlandse Norm Gezond Bewegen (NNGB)) was estimated.[3] This was done on the basis of data from Statistics Netherlands (CBS). Participants were categorised as 'inactive', 'semi-active' or 'active'. Those who were categorised as 'inactive' spent 30 minutes of moderately intense physical activity on none of the days of the week. 'Active' participants spent 30 minutes of moderately intense physical activity on 5-7 days of the week. 'Semi-active' participants spent 30 minutes of moderately intense physical activity on 1-4 days of the week.

Road safety

For road safety, the distance travelled by car or by bike (indicated as mobility) was the exposure metric. Mobility data were obtained from Statistics Netherlands (see also section 3.2.3 and Appendix II).

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[2] EMPARA (Environmental Model for Population Annoyance and Risk Analysis) is a compilation of modules that are being used by the Netherlands Environmental Assessment Agency to assess the magnitude of the effects of local air quality due to road traffic and noise levels due to industry and road, rail and air traffic on a national scale.

[3] The NNGB prescribes a minimum of 30 minutes of at least moderately intense physical activity at 5–7 days a week. In addition, the definition of 'at least moderately intense' differs between adults up to 55 years of age (≥ 4.0 Metabolic equivalents) and adults aged 55 years or over (≥ 3 Metabolic equivalents) [50].

3.2.3 Change in exposure

Traffic-related air pollution and road-traffic noise

To estimate the reduction in the concentration of traffic-related air pollution we used the estimate of Vermeulen and Den Boer (2005) who have estimated the change in traffic-related air pollution levels due to a substitution of a fraction of short-distance car trips for the Rijnmond region [51]: a substitution of 10% of the short distance car trips was estimated to decrease the NO_2 concentration by maximal 1-2 $\mu g/m^3$. For the purposes of this report, we have applied the estimate of Vermeulen and Den Boer (2005) on all dwellings in the Netherlands, assuming an equal decrease in exposure for every inhabitant. We realise that this it is a rather crude assumption, since only a part of the Dutch population lives close to a major road. To put it into perspective: suppose that the estimation of Hoek et al. (2002) [40] is true for the Dutch population, indicating that 5% of the Dutch population lives close to a major road. If we suppose that the reduction in traffic-related air pollution due to an exchange of short-distance car trips with cycling is 4 $\mu g/m^3$ for those 5% and
1 $\mu g/m^3$ for the other 95% of the people, this would mean an average reduction 1.2 $\mu g/m^3$ for the whole population. A reduction of 10 $\mu g/m^3$ for the people living close to a major road and 1 $\mu g/m^3$ for the other part of the population would imply an average reduction of 1.5 $\mu g/m^3$; and a reduction of 20 $\mu g/m^3$ for the people living close to a major road and 1 $\mu g/m^3$ for the other part of the population would imply an average reduction of almost 2 $\mu g/m^3$.

To estimate the reduction in road traffic-noise due to a reduction in the number of cars, we modelled the change in road traffic-noise levels by means of the standard Reken- en Meetvoorschrift Wegverkeerslawaai [52] assuming that a reduction of the number of car movements causes a reduction in noise levels. The estimated reductions in noise levels are presented in Table 2 and were processed in EMPARA, assuming that all short-distance car trips took place on the municipal roads and not on other roads: the estimated reductions in road traffic-noise level were applied to all dwellings exposed to municipal roads. Subsequently, this was generically applied to the general noise load for road traffic, not taking into account any differences in traffic composition.

Table 2. Change in road traffic-noise levels due to the reduction of the number of cars estimated by means of Reken- en Meetvoorschrift Wegverkeerslawaai [52]

Reduction of the number of cars (%)	Reduction in noise level (in dB(A))
10	0.5
20	1.0
30	1.5

Figure 8 shows how the exposure distribution for the Dutch population for exposure to road traffic noise could be affected due to the substitution of short-distance car trips by bike trips in the Netherlands. The exposure distributions for cumulative road traffic noise changed little: when 30% of the short car trips is substituted by bike trips, the percentage of the Dutch population that is exposed to cumulative road traffic noise levels over 55 dB(A) (L_{den}) decreased from 36% to 32%.

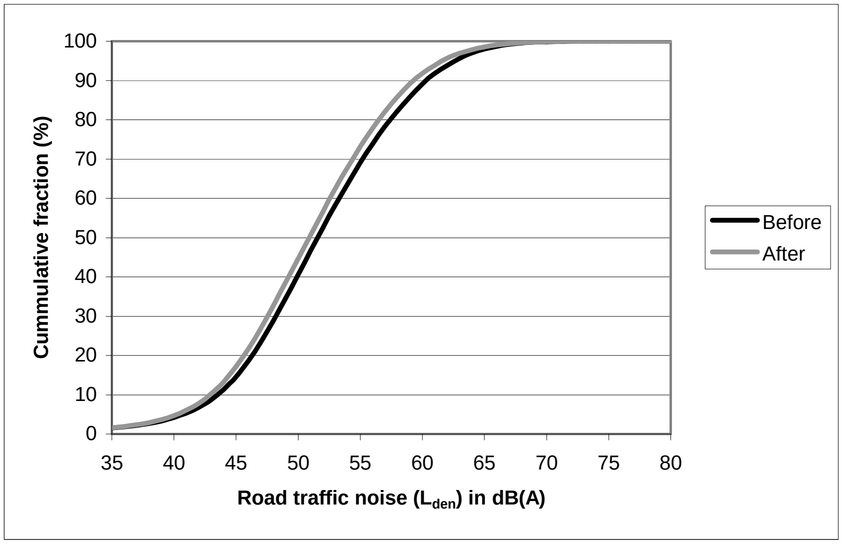

Figure 8: Exposure distribution of cumulative road traffic noise (L_{den}) levels before (*reference* situation) and after the substitution of 30% of the short car trips by bike trips. Included was the whole Dutch population of 2004.

Physical activity

As already indicated in section 3.2.1, health gain with regard to physical activity can be expected by increasing the proportion of the population that cycles and/or by increasing the time spent cycling among those who cycle. As a consequence, the physical activity pattern of the population will change: the proportion of ‘inactive’ is expected to *decrease* while the proportion of ‘active’ is expected to *increase*.

Because the duration of short-distance bike trips varies, we assumed that the whole adult population (in theory the population that drives cars) would increase their cycle behaviour by one day more and respectively 5, 10, 15, 20, 25 and 30 minutes longer in the *alternative scenario*. The 5-minute intervals represent the various sub-scenarios. Changes in the distribution over the physical activity categories ‘inactive’, semi-active’ and ‘active’ among these sub-scenarios and the reference scenario were calculated based on data from the second ‘National Survey in General Practice’ (DNSGP-2) [53]. The resulting activity patterns of the population are presented in Appendix III. It appears that the largest effect can be found in the group aged 18-55 years: when everybody cycles one day more and 30 minutes longer, the percentage of inactives and semi-actives decreases by 2.5% and 7.0%, respectively; at the same time, the percentage of actives increases by 9.5%.

Road safety

The change in car mobility was estimated using National Travel Survey data [54-56][4]. These data were gathered for two periods of two years (1999-2000 and 2005-2006), 6 years apart [21].[5] Since the

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[4] This is an ongoing study that aims to describe the mobility patterns of the Dutch population. By means of the study, information was collected on trip origins and destinations, time of day, mode of transport, purpose, distance and time travelled.

[5] Hospital data were available for the period 1997–2005 (see also section 3.4.1) and for the beginning and end of this period, mobility data were available.

fraction of short trips will not be equal for men and women and for driver age (see also Figures 2, 4, 5 and 6), the National Travel Survey data were stratified by age and gender.
Figure 9 demonstrates the reduction in car mobility in case 10% of the short-distance car trips are replaced by short-distance bicycle trips. Figure 5 already demonstrated that the distance travelled by car decreases from the age of 30-40 years, for both males and females. For women, this effect is larger than for men. Because the total amount of mobility related to short-distance car trips is a small fraction of total car mobility (10-20%), an exchange of 10% of the short-distance car trips to cycling trips reduces car mobility by just 1 or 2%.

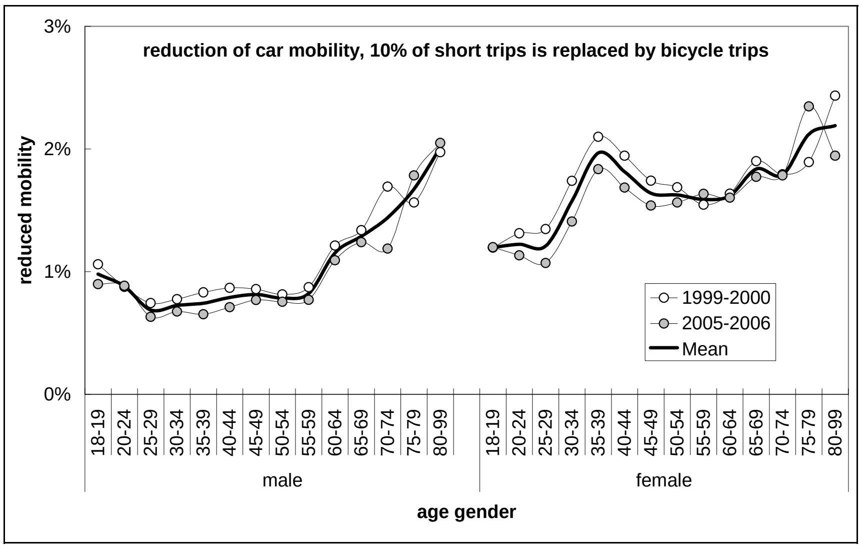

Figure 9: The reduction of total car mobility (in %) by age and gender, when 10% of the short passenger car trips (< 7.5 km trip length) are exchanged for bicycle trips. The data are gathered for two periods of 2 years, 6 years apart. The mean of the two is shown as a solid line [21].

This is different for the amount by which bicycle mobility is enhanced by this exchange. When comparing Figures 9 and 10, it appears that the relative increase in bicycle mobility (maximal 16%) is much larger than the relative decrease in car mobility (maximal 2%). Figure 2 already demonstrated that bicycle mobility is highest for young people and lowest for people aged
65 years and older; people between 30-50 years old make the most short-distance trips by bike (see also Figure 4). As a consequence, the relative increase in bicycle mobility is highest for 30 to 40-year old men and women, and lowest for young drivers (18-20 years) and elderly drivers.

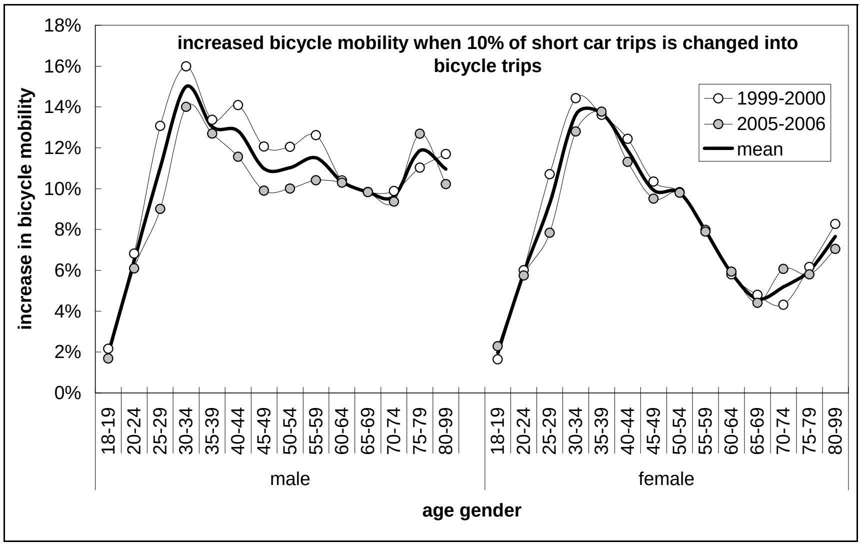

Figure 10: The increase (in %) of total bicycle mobility by age and gender, when 10% of the short passenger car trips (< 7.5 km trip length) are exchanged for bicycle trips. The data are gathered for two periods of 2 years, 6 years apart. The mean of the two is shown as a solid line [21].

3.3 Identification of exposure-effect relations

For the selected health endpoints in relation to traffic-related air pollution, road traffic noise and physical activity (see also Table 1) we identified exposure-effect relations that are known up to today, using data published in the epidemiological literature. We were interested in relationships that were derived either from a quantitative summary of published data (pooled analysis or meta-analysis) or, if not available, from single epidemiological studies, preferably recently performed in the Netherlands. Table 3 shows which exposure-effect relations we have used in our assessment for traffic-related air pollution and road traffic noise.

Table 3. Selected exposure-effect relations for traffic-related air pollution, road traffic noise and road safety.

Exposure	Health outcome	Exposure-effect relation	Source
Traffic-related air pollution	Mortality (ICD-10 < V01)	RR = 1.08 (95%CI: 1.00-1.16) per 30 $\mu g/m^3$	[56]†
	Wheezing in children	RR = 1.74 (95%CI: 0.99 – 3.05) per 17.6 $\mu g/m^3$	[57]
Road traffic noise	Severe annoyance	$\%SA = 9{,}868 x 10^{-4} (L_{den} - 42)^3 - 1{,}436 x 10^{-2} (L_{den} - 42)^2 + 0{,}5118 (L_{den} - 42)$	[58]
	Severe sleep disturbance	$\%HSD = 20{,}8 - 1{,}05 x L_{night} + 0{,}01486 x L_{night}^2$	[59]
	Myocardial infarction	$RR_{5\ dB(A)}$ = 1.06 (95%CI: 1.01 – 1.11) *	[49]
Road safety	Fatalities Injured	‡	[21]

*) For this relation the $L_{Aeq,16\ hrs}$ is used;
†) Since the study population that was used in this study was relatively old, we decided to extrapolate the results of this study only to older age groups;
‡) these age- and sex specific formulas describe the relation between the number of fatalities or hospitalised injuries and mobility as a function of the risk of being involved in a crash; they are presented in section 3 of Stipdonk and Reurings [21].
Abbreviations: RR = Relative risk; 95%CI = 95% confidence intervals; SA = Severe annoyed; HSD = Highly sleep disturbed; L_{den} = Day-evening-night level; L_{night} = Equivalent sound level averaged for the period from 23 to 7 hours;

Except for road safety, the relations that were presented in Table 3 were extrapolated to other age ranges than the ones covered in the underlying epidemiological study: for the effect of traffic-related air pollution on mortality, the age range was extended from people aged 60-67 years to people aged 60 years or older. Since the study population that was used in Beelen et al., (2008) [56] was relatively old, we decided to extrapolate the results of this study only to older age groups. For the effect of traffic-related air pollution on wheezing in children, the age range was extended to people aged 0 to 18 years. The relation describing the association between road traffic-noise exposure and severe annoyance and severe sleep disturbance and myocardial infarction was applied to people of 18 years and older.

Table 4 shows the relative risk (RR) per category of physical activity (active persons are the reference). Depending on whether someone is ‘semi-active’ or ‘inactive’, a person has a certain (additional) chance to become ill or die. For example, a relative risk of 1.09 means that the chance to die prematurely is 9% higher for a ‘semi-active’ person compared to an ‘active’ person [29]. Unfortunately, no 95% confidence intervals were available for these exposure-effect relations.

Table 4. Selected exposure-effect relations for physical activity ('active' is reference category)

	Semi-active				Inactive			
	< 60 years		≥ 60 years		< 60 years		≥ 60 years	
	Men	Women	Men	Women	Men	Women	Men	Women
Total mortality	1.09	1.09	1.09	1.09	1.40	1.40	1.40	1.40
Coronary heart disease	1.16	1.16	1.21	1.21	1.80	1.80	2.00	2.00
CVA	1.21	1.21	1.25	1.25	2.00	2.00	2.20	2.20
Type II Diabetes	1.14	1.18	1.14	1.18	1.53	1.36	1.53	1.36
Colon cancer	1.14	1.14	1.14	1.14	1.70	1.70	1.70	1.70
Breast cancer	-	1.06	-	1.06	-	1.25	-	1.25

3.4 Estimation of the attributable number of cases and the disease burden

3.4.1 The attributable number of cases

Traffic-related air pollution and road traffic noise

In this step, the attributable burden, i.e., the number of cases that can be related to exposure to traffic-related-air pollution or road traffic noise, was calculated. In short, the attributable burden is a function of the exposure-effect relations (relative risks), baseline prevalence or incidence rates of the health endpoints under study and the number of people exposed [60], for more details see Knol and Staatsen (2005) [61]. Baseline prevalence rates and incidence rates of the health endpoints and mortality rates were obtained through the National Public Health Compass of RIVM and Statistics Netherlands (see Table 5).

Because a linear relation is assumed between traffic-related air pollution and wheezing and mortality (ICD-10 < V01), we have calculated the disease burden attributable to traffic-related air pollution without a threshold value for NO_2. However, we realise that health effects can occur at all levels of exposure and that a zero exposure level is neither realistic nor feasible to achieve.

With regard to the effects of road traffic-noise exposure on myocardial infarction, the value of a 'no effect level' is uncertain and still under debate. For our assessment, the theoretical minimum level for road traffic noise was set at 60 dB(A) (L_{den}).

Since no baseline prevalences were required, the numbers of people severely annoyed and severely disturbed in their sleep were calculated directly by using the exposure-effect relations and the estimated population exposure distribution, see also [61] for more details.

Physical activity

The number of cases resulting from changes in physical activity was modelled using the RIVM Chronic Diseases Model (CDM). The RIVM-CDM is a dynamic Markov-type multi-state transition model in which the population is categorised according to diseases and risk factors [62, 63]. More details about the calculation can be found in Appendix IV.

Table 5. Base prevalence data used for the calculation of the attributable number of cases

Stressor	Health outcome	Prevalence (per 1,000)
Traffic-related air pollution (NO_2)	Mortality (ICD10 < V01) Wheezing	36.9* 50-200†
Road traffic noise	Severe annoyance Severe sleep disturbance Myocardial infarction	‡ ‡ 1.73$
Physical activity	Total mortality Coronary heart disease CVA Type II Diabetes Colon cancer Breast cancer	§
Road safety	Fatalities Hospitalised, serious injuries	**

* = CBS Doodsoorzakenstatistiek, Mortality 2005;
† = Smit et al., 2006 [64]; $ = this is the incidence of acute myocardial infarction for the Netherlands in 2003 [65]; ‡ = No baseline prevalences were required; § = The base prevalences that were included in the RIVM Chronic Diseases Model were used;
** Data on fatalities in 8 years (1999-2006) stratified by age and gender were based on police reports [66]; data on hospitalised serious injuries in 8 years (1999-2006) stratified by age and gender were based on police reports [66], and hospital data [67].

Road safety
The number of fatalities and hospitalised injuries at the moment none of the short-distance car trips was substituted by short-distance bike trips (*reference situation*) was assessed directly by taking the mean of the number of fatalities and hospitalised injuries per year for the period
1999-2006. For most of the conflict types that were addressed in section 3.2.1, the numbers of fatalities and hospitalised injuries were obtained from police records data. However, for hospitalised cyclists in crashes with no motor vehicle involved, these numbers are grossly underestimated by police registration, possible because they are often not reported to the police in the first place. They were, however, derived from hospital data (LMR, Prismant).
When the actual car mobility to be exchanged (stratified by age and gender) was known, we calculated the expected number of fatalities and hospitalised injuries related to crashes with cars by means of the formulas presented in Stipdonk and Reurings [21]. The expected number of bicycle casualties was calculated similarly.

3.4.2 The disease burden

For each health endpoint, the disease burden was calculated by multiplying the attributive number of cases with a severity weight and an estimate of the duration of the disease, or years of life lost for mortality [61]. For details of these calculations, see also Appendix III.

3.5 Uncertainty analysis

Since this is a first-order estimation with the main focus on the *method* instead of the exact outcome and because it was not always possible to estimate confidence intervals, our results are presented without confidence intervals. Instead we have tabulated for every step of our assessment the uncertainties and/or assumptions and how these might have possibly affected our results (see also Table V-1 of Appendix V).

As sections 3.1 to 3.4 have shown, our assessment involves many different input variables and assumptions. To give an indication of the relative importance of some of the input variables and/or assumptions, we investigated the sensitivity of the results by changing one input variable or assumption at a time, *ceteris paribus*. Examined were the sensitivity of our results a) in case we used the exposure-effect relation between road traffic noise and myocardial infarction derived by Babisch (2006) [68] instead of the relation derived by Van Kempen and Houthuijs (2008) [49];

b) in case we assessed the effects attributable to traffic-related air pollution using a minimum level of 22.7 $\mu g/m^3$ (background concentration in 2003 in the Netherlands) instead of 0 $\mu g/m^3$; c) in case we used a minimum level of 55 dB(A) when assessing the number of incident cases of myocardial infarction attributable to road traffic noise exposure instead of 60 dB(A).

Finally, we estimated the average loss of life expectancy due to exposure to traffic-related air pollution instead of attributable numbers of deaths. This is more appropriate, since we assume that traffic-related air pollution does not cause death but accelerates it [69, 70]. Therefore, for mortality attributable to traffic-related air pollution, we also estimated the population average ‘years of life lost’ [17]. Average loss or gain of life expectancy can best be calculated by using life tables, which take population dynamics into account. At the moment, this method is in progress and considered outside the scope of this report. Therefore, it was only included as a kind of sensitivity analysis.

4 Results

4.1 The possible health benefits of cycling

Figure 13 presents the disease burden (DALYs) for the Dutch population due to exposure to traffic-related air pollution (NO_2), road traffic noise, and traffic injuries in the Netherlands at the moment that *none* of the short-distance car trips was substituted by cycling (*reference situation*) and the disease burden *after* the substitution of short-distance car trips by cycling. In addition, the figure presents the disease burden due to the physical activity pattern of the Dutch population aged 18 years and older at the moment that *none* of the short-distance car trips was substituted by cycling (*reference situation*) and at the moment that everybody cycles one day more and
30 minutes longer.

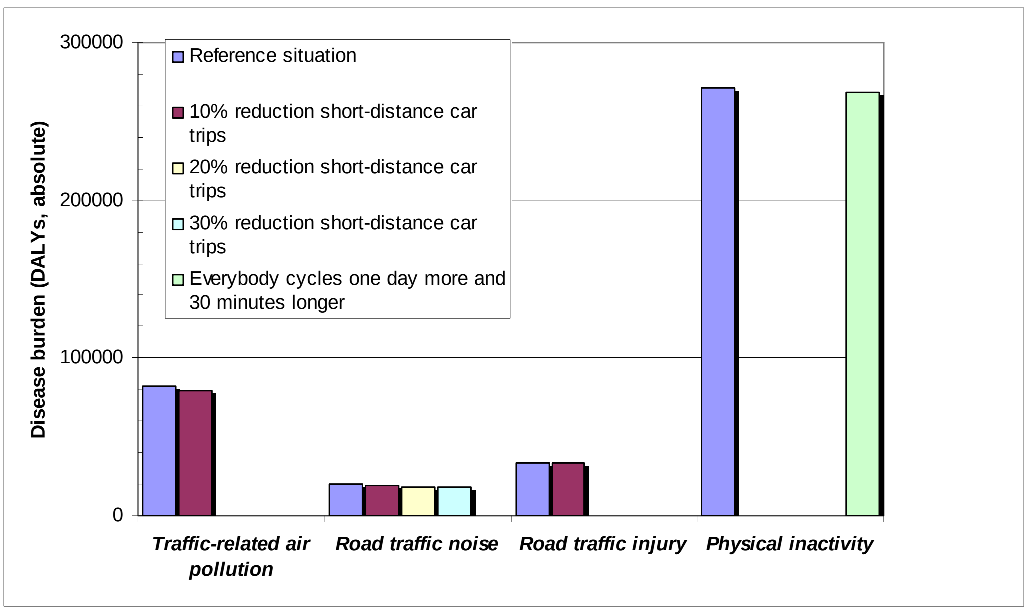

Figure 11: The estimated changes in burden of disease, expressed in Disability-Adjusted Life Years (DALYs), grouped by exposure.

Firstly, Figure 11 shows the balance in disease burden of the different traffic-related impacts at the moment that none of the short-distance car trips was exchanged. However, the figure is *not* representative of the actual traffic-related disease burden in the Netherlands, since the picture is incomplete: the estimated disease burden due to road safety is an underestimation and is mainly driven by male drivers aged 18-39 years, who died or were severely injured in a crash where at least one car was involved but no bicycles; emergency-room admissions, e.g., were not included. The estimations for road traffic noise mainly consisted in the number of people with severe annoyance and sleep disturbance.

Secondly, Figure 11 shows that the health benefits of an exchange between short-distance car trips by cycling appear to be modest: we estimated that a reduction of the traffic-related air pollution concentration of 26.5 to 25.5 μg/m^3 (assumed to be equivalent to a reduction of 10% of the short-distance car trips) results in a reduction of almost 4% of the disease burden. The effect in terms of average loss of life expectancy was estimated to be negligible.
It was estimated that the disease burden attributable to road traffic noise in the Netherlands decreased by about 5% in case 10% of the car trips on municipal roads is substituted by cycling; in case 30% of the car trips on municipal roads is substituted, the disease burden is estimated to decrease by more than 10%.

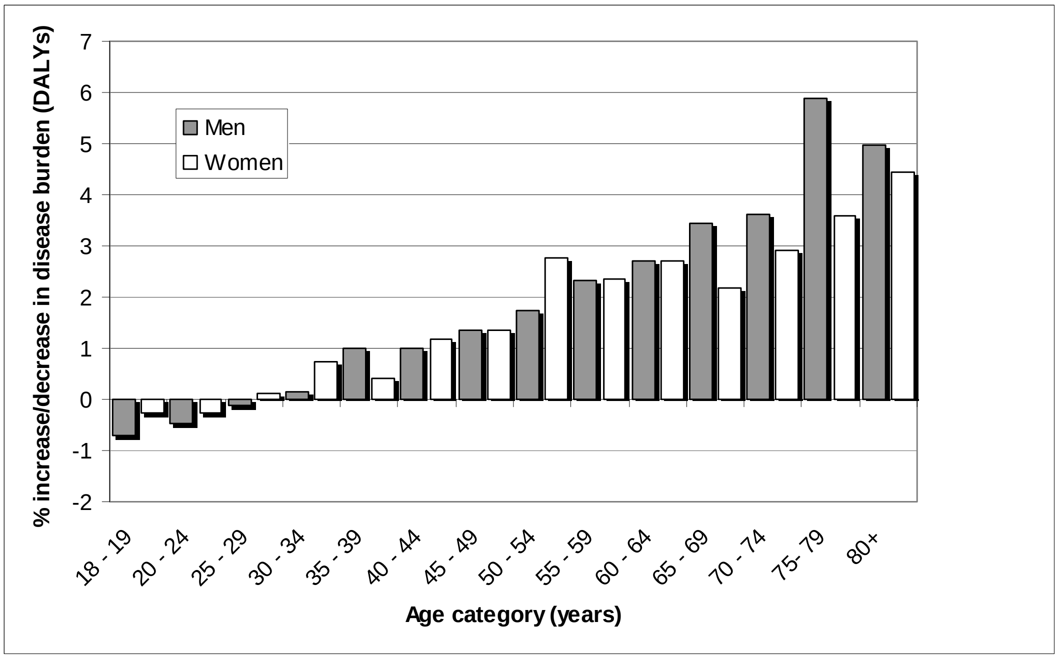

Figure 12: The relative (%) increase and/or decrease in disease burden (DALYs) attributable to traffic injury due the exchange between short-distance car trips and short distance bicycle trips.

The disease burden due to road crashes caused by road traffic is estimated to increase by 0.7% due to the exchange between short-distance car trips and short-distance bicycle trips. Figure 12 however, shows a more complete picture: it appears that an exchange between short-distance car trips and cycling is only beneficial for young (especially male) drivers. Since due to an increase in bicycle mobility, relatively more males and females die and/or were admitted to a hospital than due the decrease in car mobility, the disease burden among drivers of 35 years and older increases due to an exchange between short-distance car trips and cycling.

For physical activity, the disease burden decreases almost 1.5% in case everybody cycles one day more and 30 minutes longer. This increase in cycling is estimated to correspond with a reduction in the inactive persons by 2.5% in the group of people of 18-55 years old; at the same time, the amount of inactives decreases by 0.6% among people older than 55 years (see also Appendix III). The strongest decrease in disease burden can be expected in case everybody cycles one day more and at least 20 minutes a day longer. Figure 15 shows the corresponding change in activity patterns for the other scenarios that were run for physical inactivity.

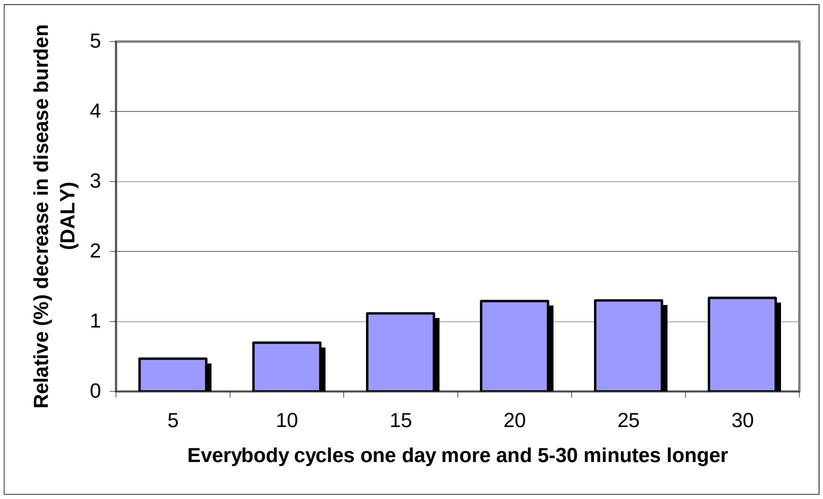

Figure 13: The relative change (%) in disease burden (DALYs) after one year when everybody cycles one day more and 5-30 minutes longer.

4.2 Sensitivity analysis

In our calculations with regard to traffic-related air pollution, we estimated the disease burden due to an average reduction of 1 μg/m^3 for the whole population. This is rather a crude method, since only a part of the Dutch population lives close to a major road. According to Hoek et al. (2002) [40] 5% of the Dutch population is estimated to live close to a major road. If we suppose that the exchange of short-distance car trips causes a reduction of 10 μg/m^3 for those 5% and 1 μg/m^3 for the other 95% of the population, this would mean an average reduction of almost 1.5 μg/m^3. This would result in a reduction of the disease burden attributable to traffic-related air pollution of around 5%; in case we suppose that the exchange of short-distance car trips causes a reduction of 20 μg/m^3 for the people that live close to a major road (implying an average reduction of almost
2 μg/m^3), the disease burden decreases by almost 7%.

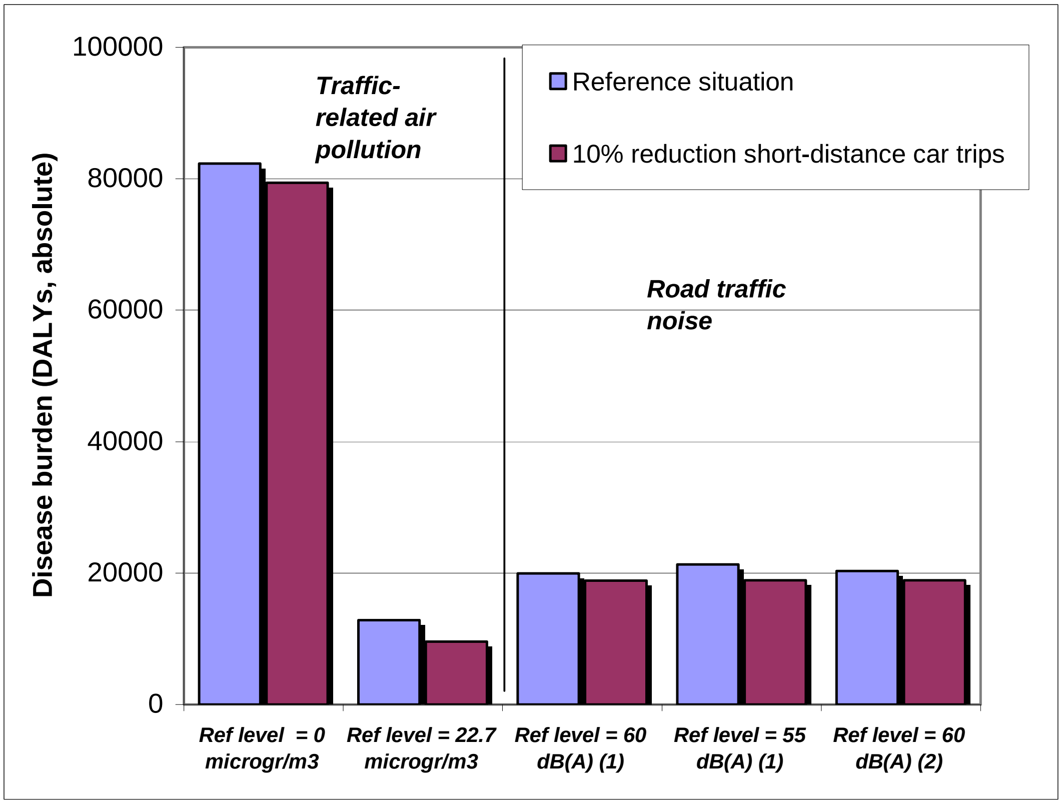

Figure 14: The estimated change in disease burden (DALY) due to exposure to traffic-related air pollution (NO_2) and road traffic noise using different reference levels; and for the change in disease burden due to road traffic noise the effect of the application the exposure-effect relation derived by Van Kempen and Houthuijs (1) and Babisch (2) [49, 68].

Figure 14 shows how the reference levels used for traffic-related air pollution and road traffic noise affect the disease burden before and after exchange of short-distance car trips. The number of estimated incident cases of myocardial infarction using the relation derived by Van Kempen and Houthuijs (2008) [49] differed from the number of incident cases estimated using the relation derived by Babisch (2006) [68]; since the disease burden attributable to road traffic noise is mainly driven by the number of severely annoyed and severely sleep disturbed, this did not really affected the absolute (difference) in the disease burden attributable to road traffic-noise exposure.

The presented burden of disease of traffic-related air pollution consisted of wheezing and cardiovascular mortality. However, since we assume that traffic-related air pollution does not cause death but accelerates it, we realise that it is more appropriate to calculate the average loss of life expectancy due to exposure to traffic-related air pollution instead of attributable numbers of cardiovascular deaths. Analogous to Schram-Bijkerk et al. (2009) we have estimated that instead of postponing 275 deaths (results not shown but included in Figure 11), the reduction in air pollution would result in a life gain of approximately 7 hours for the total population at risk (about 3.1 million people). Presented this way, the air pollution-related health effects of our simulations seem negligible because they are spread out over the entire population, but this estimate is based on the same data as the numbers used for Figure 11, though put into a more appropriate form. Average loss or gain of life expectancy can best be calculated by using life tables, which take population dynamics into account [109, 110], which facilitates the simulation of effects of aging and latency time of effects. However, this advanced method was considered outside the scope of this report.

5 Discussion

5.1 Traffic-related disease burden and health benefits attributable to cycling

In this report we have presented a first assessment of the possible health benefits of the substitution of a fraction of short-distance car trips by cycling in the Netherlands. The objective was to assess the associated possible change in disease burden related to road traffic noise, traffic-related air pollution, physical activity and injuries due to road transport in the Netherlands. The identified gaps and uncertainties are presented in Appendix V. The most important ones will be discussed below.

5.1.1 Traffic-related air pollution

Assuming that a substitution of 10% of the short-distance car trips decreases the traffic-related air pollution concentrations by 1 μg/m^3, we estimated that a reduction of the NO_2 concentration from 26.5 to 25.5 μg/m^3 results in a reduction of about 4% of the disease burden.

Comparison with other studies

At the time, no other studies are known that have investigated the traffic-related health effects of a reduction of short-distance car trips by cycling. The recent intervention studies investigating the effects of congestion charging in London and Stockholm provide some support for efforts to reduce local air pollution and improve health via reductions in motor vehicle traffic. After the city's Congestion Charge scheme was established, the annual average NO_2 concentrations in the areas within or adjacent to the congestion zone decreased from 54.7 μg/m^3 in 2003 to 54.0 μg/m^3 (1.3% reduction) in 2007. Between 2003 and 2007, the number of vehicles entering London's congestion zone decreased from 378,000 to 316,000, which is equal to a decrease of 16%. These falls are predicted to have saved 183 years of life per 100,000 in wards with charging as compared with 18 years in other wards [71]. It was estimated that due to the Stockholm congestion charge in 2007, the inner city traffic declined substantially by approximately 20%. As a consequence, the estimated mean levels of nitrogen oxides arising as a result of emissions from road traffic decreased: the contribution of road traffic to the levels of nitrogen oxides declined from
8.41 μg/m^3 to 7.60 μg/m^3. Using the exposure-effect relation for the association between long-term exposure to NO_2 and mortality (ICD-10 A00-R99) derived by Nafstad et al. (2004) [73], it was estimated that the improvements in air quality Stockholm will lead to approximately 20-25 fewer early deaths per annum for Stockholm's inner-city [72].
Despite the fact that both Tonne et al. (2008) [71] and SLB Analys (2006) [72] used stronger risk estimates in order to estimate health benefits[6], both the Congestion Charging Scheme in London and Stockholm resulted in smaller health benefits when comparing them with our findings. This is probably due to the smaller difference in exposure levels and corresponding number of vehicles that were found before and after the introduction of the Congestion Charging Schemes. In London they found that a reduction of 16% of the number of vehicles resulted in a reduction of 0.7 μg/m^3 (1.3%) [71]; in our

[6] For the association between long-term exposure to NO_2 and mortality, Tonne et al. (2008) applied an RR of 1.10 per 10 μg/m^3 (95% CI 1.04 – 1.16), while SLB Analys applied an RR of 1.08 per 10 μg/m^3 (95% CI 1.06 – 1.11)) [71, 72].

assessment we assumed that a reduction of 10% of the number of vehicles caused a reduction of 1 μg/m^3 (4%). This could mean that our assumption was a little too optimistic. Another difference is that in the analysis of Stockholm, SLB Analys (2006) distinguishes between background concentrations and the contribution of the road traffic to the total concentration [72], something that was not done in our analysis (with the exception of our sensitivity analysis), nor by Tonne et al. (2008) [71].

Gaps and uncertainties

Since we were not able to model the change in traffic-related air pollution levels at a national scale, we applied the estimate of Vermeulen and Den Boer (2005), who have estimated the change in traffic-related air pollution levels due to a substitution of a fraction of short-distance car trips for the Rijnmond region. They estimated that a substitution of 10% of the short-distance car trips decreases the PM_{10} concentration with maximally 0.5 μg/m^3 and the NO_2 concentration with maximally 1-2 μg/m^3 [51]. Although the studies regarding the congestion charging in London [71] and Stockholm [72] give us some information about what happens with air pollution concentrations in case of traffic flow decreases, it is still difficult to say whether a substitution of 10% of the short-distance car trips indeed decreases the NO_2 concentration with 1 μg/m^3. Apart from the question whether the situation in Rijnmond is representative for the Netherlands, we realise that this might differ from what happens in reality: a given car trip will hardly be replaced by a bicycle trip along exactly the same route. Due to the fact that not only modal shift will be affected but probably also the routes taken, the average decrease in concentration will be associated with no decreases in some streets and decreases in other streets.

Reducing the number of cars nationwide on municipal roads will not only influence the local contribution of each road to the total concentration but could also alter the national background concentration. Although in local situations this influence on municipal roads on the background concentrations is likely to be negligible [74], no clear indications can yet be made on a nationwide scale.

The estimated (change in) disease burden attributable to traffic-related air pollution might be an underestimation of the real effect, since we did not take into account traffic participants such as cyclists and car drivers. As is already addressed in section 3.2.1, people may also receive substantial exposure during travelling time. Since many transport microenvironments are relatively more heavily polluted than others and since most journeys are made during rush hours, when the increased volume of traffic results in higher ambient pollution levels, journey-time exposures often contribute disproportionately to the total and account for the main peaks in exposure for many people. For car drivers, traffic conditions (speed, road type and traffic intensity), weather conditions and the cars themselves are the main determinants of exposure levels. While cyclists are exposed to lower average concentrations than car drivers, this might be misleading: different modes imply different journey times and many travellers spend time in transport at the expense of time in less polluted environments. The longer journey times by bicycling may thus compensate to a great extent for the reduced average exposures. In addition, increased breathing rates while bicycling may mean that larger volumes of pollutants are inhaled [26]. However, this might not take into account that especially in city centres, where most cycling trips are made, the travelling speed of cars is often comparable or (in case of congestion) even lower than that of bicycles. In addition, time spent in cars to find a parking space is often not taken into account.

At the moment of our assessment, it was not possible to estimate the exposure of cyclists and car drivers at the population level; exposure-response relations describing the association between air pollution exposure and health in traffic participants (car drivers and/or cyclists) were also not available. We could have made an approximation by making assumptions about how much commuting would contribute to the overall exposure to traffic-related air pollution including time, level and activity and express the difference in exposure between cyclists and car drivers in a difference in the yearly average concentration. Still, the question remained which exposure-response relation could be best used.

5.1.2 Road traffic noise

With regard to road traffic noise, the health benefits were estimated to be modest but proportional to the average reduction in road traffic-noise levels. An exchange between car and bike will probably only affect the highest exposure levels. As demonstrated in Figure 8, there will be a small effect on the population exposure distribution, resulting in a small reduction in disease burden.

Since the substitution of car trips by cycling is in fact a measure that influences the amount of noise producing traffic, our results were to be expected: generally measures which reduce traffic volume are unlikely to significantly influence the noise levels of an overall area, unless these measures lead to dramatic changes; the logarithmic nature of the dB scale means that a 50% reduction of the traffic volume results in a 3 dB reduction in noise level, providing that traffic composition, speed and driving patterns are unchanged [75]. Thus, such measures are not generally applicable as a means of noise abatement but they may have an effect on selected roads.

Only on minor roads with small traffic volumes, the exchange of cars with bikes might be effective in reducing noise levels. Since it is generally unlikely that a given car trip will be replaced by cycling along exactly the same route, it is possible that a reduction in the number of cars on a road leads to increases in speed and hence, increased noise levels because the remaining cars can drive more unhindered (unless measures are taken to keep speed down). On the other hand, if traffic flows more freely, decreases in the number of accelerations and decelerations are likely to result in lower noise levels.

Comparison with other studies

The few studies that have investigated the effects of measures that encourage bicycling (e.g., the development of cycling lanes) show that noise reductions will be negligible unless the changes also significantly influence driving patterns, which seems unlikely [76-78].

If we assume that the substitution of car trips by cycling is a measure that influences the amount of noise-producing traffic in an urban area, the results of our study are confirmed. Studies where the amount of traffic was reduced, such as the Congestion Charges in Stockholm and London, indicate that such a measure has only a small effect on noise levels [71, 72]. For example, it appeared that due to the Congestion Charge, the traffic noise situation in Stockholm was only affected to a small extent. Monitoring data showed reductions in traffic noise levels of 1-4 dB(A) in several locations in the city, while at other locations in the city, a rise in traffic noise levels of 1-4 dB(A) was observed [79].

Gaps and uncertainties

The report of the Netherlands Environmental Assessment Agency [47] extensively describes gaps and uncertainties of the model that we have used for our road traffic-noise exposure estimates. Relevant for our study was the impact of the different noise levels from the different types of vehicles. The model that was used to estimate road traffic-noise levels, takes account of differing noise levels from different types of vehicles. The vehicles are consequently placed in three classes: light vehicles, medium-heavy vehicles and heavy vehicles. The distribution among the classes determines the results of the calculation. For motorways, this distribution is well known; for secondary roads there is reasonable data available. For municipal roads, the location where we assume that the exchange between short-distance car trips and cycling takes place, these values are however not available. Modifications of these values can therefore lead to higher or lower emissions from the road and therefore, to a different noise load on the houses and residents.

Analogous to the estimates for traffic-related air pollution, the estimates for road traffic noise did not take into account traffic participants such as cyclists and car drivers. However, many people may also receive substantial exposure during travelling time. Due to inconsistencies in noise level documentation and a tendency to focus on the highest possible exposures, little is known about the exposure levels associated with typical daily activities such as travelling [80]. Recently, Boogaard and Hoek (2008) assessed total noise levels during cycling in 11 Dutch cities. It appeared that the average noise levels varied from 62 to 66 dB(A); the lowest noise levels measured were 48 dB(A); the highest noise levels measured were 92 dB(A). These levels are high, if one knows that in 2004 about 15% of dwellings in the Netherlands is situated in areas with road traffic-noise levels of 60 dB(A) (L_{den}) and more [46].

We assumed that car trips were replaced by bicycle trips along the same route. However, the exchange of car mobility by bicycle mobility is more likely where there is sufficient specific, bicycle-friendly infrastructure. It is unknown how this has affected our outcomes.

5.1.3 Physical activity

The estimated change in disease burden related to physical activity was estimated as the reduction after one year at a maximum of 1.3%. At first sight, this reduction does not seem to be large. However, in comparison with the effects on traffic-related air pollution, road traffic noise and road safety, the effect was large. Secondly, it has to be kept in mind that the present study looked at the reduction after 1 year; we have looked at the impact on the prevalence of disease. It is, however, more common to look at the effect on the incidence of the disease during a very long period. Based on the experience of calculations estimating the effect of public health interventions on the incidence of disease, it can be expected that the health gain will be larger when taking into account a period of 10 or 20 years. One of the likely explanations is that the people in the cohort that is needed to investigate the effect on the disease incidence, die [35].

The figures in Appendix II show that the activity patterns in the alternative scenario do not seem to change very much: it was estimated that in case everybody cycles one day more and 30 minutes longer, the percentage of active persons in the group aged 18-55 years increases by 9.5%. However, this is a large effect compared to the effects of public health programmes such as the ‘Hartslag Limburg Project’ [81, 82] and the Study on Lifestyle Intervention and impaired glucose tolerance Maastricht’ (SLIM) [83]. The effects of these interventions were used to calculate health benefits for achieving the aims of the National Action Plan for Sports and Physical Activity [35]. Both projects included interventions to stimulate the population to be more physically active, such as the release of walking and cycling guides, the development of a special programme that was broadcasted on the local television, explaining the possibilities of the different sporting clubs. After five years, these projects have achieved a shift of 1-2% from inactive to semi-active.

Comparison with other studies

For our analysis we defined three categories of physical activity: inactive, semi-active, and active, assuming that cycling represents a 'step up' in the level of exercise, rather than moving from no exercise to cycling five days a week. When applied to new cyclists, it assumes that by cycling each person takes a step up in the amount of physical activity they do. The key question is whether our assumption that cycling one day more and 5 to 30 minutes a day longer is sufficient to generate this 'step up'. Our approach was rather comparable with the analyses of the National Heart Forum (NHF) [84] and of Pitches and Kemm (2003) [9] but differed from the approach applied by MacDonald (2007) [85]: NHF defines four categories of physical activity: vigorous, moderate, light and sedentary [84]; Pitches and Kemm (2003) define three categories of physical activity: Sedentary, moderate and vigorous [9]. In his report, MacDonald (2007) estimated that 39% of deaths in England from coronary heart disease, stroke and colon cancer, among over 16-year-olds, can be attributed to a lack of regular physical exercise. For his calculation he assumed that new cyclists were previously active [85]. This however, restricts the way in which the values can be applied. Many people encouraged to cycle will already be active, while those that were inactive to begin with may not achieve the necessary amount of cycling to be defined as 'active'. In addition to the analyses from NHF [84], Pitches and Kemm (2003) [9] and MacDonald (2007) [85], only a few studies are known that have investigated the effects of cycling on health. Since the methods that were used in these studies differed from the methods that were used in our analysis, comparison of the results is very difficult: For example, the British Medical Association (BMA) (1992) estimated that by cycling an average of 97 kilometres per week for about 30 years, individual lives would be extended by over 2 years. Their calculations were based on the survival rates of very large samples of respondents who had and had not adopted a regular physical exercise regime over a long period of time [88]. For his recent estimate, Rutter (in: [85]) uses data collected as part of the Copenhagen Heart Study by Andersen et al. (2000) [89] to calculate the health benefits for cycling commuters. His estimate is then adjusted downwards to allow for an estimate of the excess deaths from cyclist accidents to obtain a net benefit of 50 prevented deaths per 100,000 cyclists; equivalent to around 1660 life years. Rutters' approach produces estimates that are specifically related to cycling, rather than general physical activity, as is more or less the case in this report, since we assume that an increase in cycling automatically leads to an increase in total physical activity. Rutters' estimate is also directly related to people of cycling age (commuters) rather than across the population as a whole [85].

Gaps and uncertainties

Our assessment is concerned with the health impact of a transport intervention that is expected to result in increasing rates of cycling, assuming an observed increase in cycling leads to an increase in physical activity. However, as people cycle more and do less of another activity as a result (e.g., people may have stopped jogging when they started cycling; a new cycle path may have meant their new journey was actually shorter), this might not always be the case. As a consequence, our benefits might be an overestimation.

For our calculations we have assumed that the effect of the intervention will remain in the long term. However, we also realise that a shift in peoples' behaviour is difficult to accomplish and that it is questionable whether the effect of the intervention will remain very long, since it seems likely that people will relapse into their old behaviour. People's behaviour will be affected by several impacts:

their age, impacts at population level such as changes in price levels, new scientific insights and campaigns in the mass media. These impacts will also take place if short-distance car trips are not exchanged by cycling.

In our assessment, children are not included. It is, however, not quite clear how much health gain can be expected: according to Statistics Netherlands (2008) in 2007 only 27% met the Dutch guideline for physical activity [90]. And although children nowadays are often called the 'back-seat generation', this is not supported by numbers. According to a study from Traffic Test, it appeared that on average, 14% of primary school children (aged 4-12 years) is fetched and delivered to school; 49% of children cycles to school [91]. These findings are consistent with National Traffic Survey data, which state that in 2001, 15% of children (aged 6-11 years) are delivered to school. In Amsterdam, 9% of the children in the three highest grades of primary schools, often goes by car to school [92]. Recent numbers are even lower: a survey among

1000 children (aged 7-12 years) visiting 6 primary schools in Delft, showed that 4% of the primary school children travels to school by car [93]. One of the main reasons for parents fetching and delivering their child to and from school is road safety [91].

5.1.4 Road safety

It appears that an exchange of car trips by cycling is only beneficial for young, especially male, drivers. Since due to an increase in bicycle mobility relatively more males and females died and/or were admitted to a hospital than due the decrease in car mobility, the disease burden among drivers of 35 years and older increases, due to an exchange between short-distance car trips and cycling.

These results can be expected if one keeps in mind that cyclists of 55 years and older are relatively vulnerable due to their physical vulnerability and their relatively retarded observation. Our results do not mean that policy makers should not encourage cycling; they rather mean that the prevention of road crashes should be targeted at the reduction of accident risks for cyclists ([94] in: [95]).

Comparison with other studies

Our results are not supported by the results of other studies [96-99]. In most of these studies, increased active transport appears to be linked to an overall reduction in the road crash rates, implying that increasing presence of cyclists improves the awareness of motor vehicle drivers and/or that policies to separate motorised from non-motorised transport are effective. In these studies, however, only the number of casualties that is registered by the police was taken into account. In our study, we also used hospital data for our calculations: a recent analysis showed that there is a large number of injured cyclists that are not registered by the police [100]. These are mainly crashes where cyclists crash with other cyclists, pedestrians or objects such as bollards.

Another important improvement compared to earlier calculations is the fact that we took into account not only the crashes where either the car occupant or the cyclist was injured or killed, but also the crashes where the other party was injured or killed. Furthermore, we stratified on age and gender for both the change in mobility and the number of fatalities and hospitalised injuries, revealing a more realistic and complete picture of what happens when exchanging short-distance car trips by cycling.

Gaps and uncertainties

The assumptions on which the presented calculation is based may give an incomplete picture of what actually happens with regard to road safety. As demonstrated in the table in Appendix V, several effects were not taken into account. Firstly, there was no stratification of crashes and mobility by road type applied. Secondly, analogous to road traffic noise, we assumed that car trips were replaced by bicycle trips along the same route. Thirdly, effects due to a change in travelling time were not taken into account. Although bicycle trips are often shorter than the car trips they replace, cycling often takes more time than driving a car. As a consequence, an exchange from car mobility to bicycle mobility could lead to longer travelling times [111]. Since in the long run, the total time spent in traffic in the Netherlands is constant, it may be expected that other trips would be omitted as well (to reduce total travelling time again).

A possible limitation that might have affected our outcomes with regard to road safety might be the fact that not all types of hospital admissions or emergency room admissions were included.

Our assessment is limited to car drivers, cyclists and other road users who risk becoming involved in a crash; car passengers who have to go by bike if the driver goes by bike were not included. In 2005, more than 23% of all short-distance trips in the Netherlands were made by car drivers, while about 12% was made by car passengers [23]. Since the passenger does not have to be of the same age and gender as the driver, it is difficult to say how the results of our calculations would change if passengers were included. More information, such as the reason for the car trips with passengers, is required for an accurate calculation.

6 Conclusions and recommendations

6.1 Conclusions

In this report we have presented a first assessment of possible health benefits of the substitution of a fraction of short-distance car trips by cycling in the Netherlands. The objective was to assess the associated possible change in disease burden related to traffic noise, traffic-related air pollution, physical activity and injuries due to road transport in the Netherlands. The following can be concluded:

- our study demonstrates that a substitution of short-distance car trips with cycling can improve public health. Although it was estimated that the disease burden related to physical activity reduced at a maximum of 1.3% after one year, this is a large effect compared to the effects of achieving the aims of the Dutch National Action Plan for Sports and Physical Activity. As expected, the health benefits due to a reduction in road traffic-noise levels and traffic-related air pollution are estimated to be relatively small. A possible negative effect could come from a higher risk of crashes; it appears that an exchange of short-distance car trips by cycling is only beneficial for young male drivers.
- for our assessment we were forced to make a lot of assumptions with regard to exposure indicators, age groups, models, etc. As a consequence, the results have to be seen as a first estimate of what can be expected of interventions that cause an exchange between short-distance car trips and cycling.

6.2 Recommendations

Based on the findings in our report, we recommend the following:

- the present study is a calculation at national scale; a calculation for a local situation might reveal another picture. It is therefore recommended to repeat this assessment for some specific local situations to obtain a better feeling for where and how an intervention, such as the substitution of short-distance car trips with cycling, can best be implemented;
- as was the case in other traffic-related health impact assessments, we were forced to make a lot of assumptions. It is therefore recommended to take a better look at the input data that are necessary for traffic-related health impact assessments: e.g., the distribution of the population over traffic-related air pollution levels and road traffic noise.
- since the presented estimates were based on modelled reductions of road traffic-noise exposure and traffic-related air pollution and mobility and modelled behavioural changes, measurements have to make clear whether the estimated reductions really take place. The best option for rapidly improving the evidence base is applying prospective study methods to the natural experiments offered by the developments and changes in transport systems.

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Appendix I. The effect of an exchange of short-distance car trips on road safety: basic backgrounds

In order to estimate the effect of an exchange of short-distance car trips with bike trips, we assumed that the risk of becoming involved in a crash is constant and only depends on the distance travelled by car or bike (indicated as mobility). We realise that this assumption is not quite realistic, since many factors determine the risk of becoming involved in a crash. For example, car mobility is not equally dangerous for every road, day of week, age of driver, etc. The same holds for bicycle trips. However, since a lot of the properties of car and bicycle trips are unknown (such as which roads, what time of day, what kind of people (old or young, male or female)), we had to make this assumption.
Because we defined mobility as the sum of the lengths of all trips travelled by car or bike, it was possible to calculate what part of the car mobility was exchanged by bicycle mobility in case 10% of the short-distance car trips was substituted by short-distance bike trips. To this end, we assumed that except for age and gender, the distance travelled by car *decreases* with the same percentage and the distance travelled by bike *increases* with the same percentage: every road type loses the same percentage of car mobility and gains the same percentage of bicycle mobility. Since we assumed that the risk of becoming involved in a crash is constant, we were able to calculate the expected number of fatalities and hospitalised injured after an exchange of 10% of the short-distance car trips with short-distance bike trips. For a detailed description of the formulas used, see also [21].
Because car trips always relate to drivers of 18 years and older, only the trips of these drivers were replaced. The consequences of replacing the trips of passengers of the drivers whose mobility was to be exchanged[7] were left out of the assessment. Health effects were estimated for road users of 18 years and older, involved in crashes where either a car or a bicycle is involved. To be specific, we distinguished between three types of crashes of which we considered the casualties: 1) crashes where at least one car is involved but no bicycles (e.g., a car and a lorry); 2) crashes where at least one bicycle is involved, but no cars (e.g., a cyclist and a pedestrian); and 3) crashes where at least one bicycle and one car are involved (e.g., a car and a cyclist). The first two categories contain single vehicle crashes and two-party crashes, where either the car occupant, the cyclist or where the other party is injured or killed. The third category contains crashes where the car occupant or the cyclist is injured or killed. Since we assume that the number of crashes where neither a car nor a bicycle is involved is not influenced by a change in car and bicycle mobility, these were not included in our assessment.

[7] One car trip could possibly be replaced by multiple bicycle trips.

Appendix II. The second National Survey in General Practice and change in activity patterns

The second National Survey in General Practice (Tweede Nationale Studie) (DNSGP-2) is a countrywide representative survey in which all diseases from approximately 400,000 patients presented to approximately 200 General Practitioners (GPs) (104 practices) and all the activities of these GPs (e.g., diagnostics, prescriptions, references to specialists) were documented [53].
As part of the DNSGP, a health interview was conducted among a sub-sample of patients, resulting in approximately 14,000 interviews. Participants were representative for the population of Dutch GP patients [101]. Physical activity was part of the interview for only a part of the subset involved in the health interviews. Information was available for 4567 adults (≥ 21 years of age). Physical activity was assessed using the short questionnaire to assess health-enhancing physical activity (SQUASH), which allows calculation of the proportion of the population adhering to the physical activity guideline [102].
In the DNSGP, adults spent an average of 35 minutes bicycling on the days they indeed cycle. Moreover, it appears that more than 85% of the short trips by bicycle in 2005 lasted a maximum of 20 minutes [55].
In the *alternative scenario*, it was therefore assumed that the whole adult population (in theory the population that drives cars) would increase their cycle behaviour by one day more and respectively 5, 10, 15, 20, 25 and 30 minutes longer. The 5-minute intervals represent the various sub-scenarios. Changes in the distribution over the physical activity categories 'inactive', semi-active' and 'active' among these sub-scenarios and the reference scenario were calculated based on data from the second DNSGP. The resulting activity patterns of the population are presented in Figures II-1 and II-2.

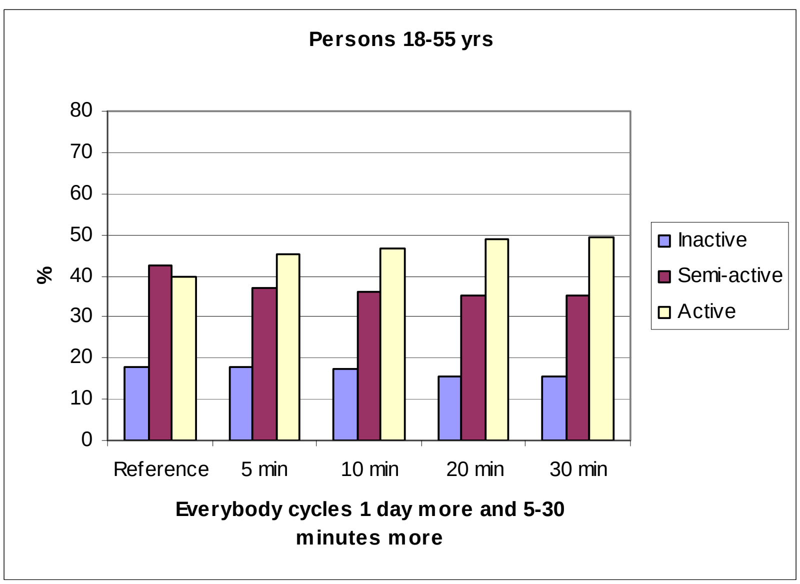

Figure II-1 Change in physical activity patterns when persons in the Netherlands aged 18-55 years cycle one day more and 5-30 minutes longer, due to the substitution of short-distance car trips by cycling trips.

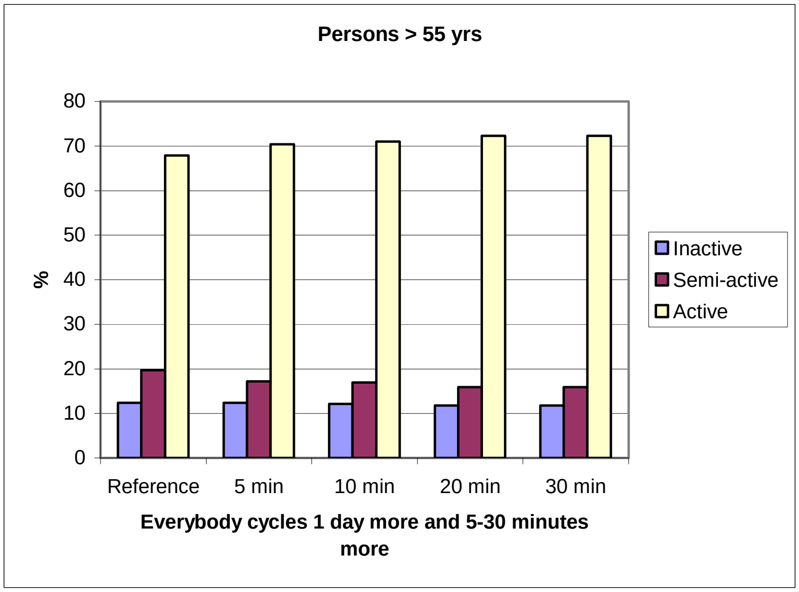

Figure II-2: Change in physical activity patterns when persons in the Netherlands older than 55 years cycle one day more and 5-30 minutes longer, due to the substitution of short-distance car trips by cycling trips.

The figures show that the largest effect can be found in the group of 18-55 years: when everybody cycles one day more and 30 minutes longer, the percentage of inactives and semi-actives decreases by 2.5% and 7.0%, respectively; at the same time, the percentage of actives increases by 9.5%.

Appendix III. Calculation of the disease burden

For each health endpoint, the disease burden was calculated by multiplying the attributive number of cases with a severity weight and an estimate of the duration of the disease or years of life lost for mortality [61]. In this Appendix, we describe the details of these calculations.

Traffic-related air pollution

Similar to the calculation of Knol and Staatsen (2005) [61], we assumed that long-term exposure to traffic-related air pollution is associated with a reduction in life expectancy per victim in the order of about 10 years. The years of life lost attributable to mortality due to traffic-related air pollution before and after the exchange of short-distance car trips with cycling was subsequently calculated by multiplying the attributive number of deaths by the reduction in life expectancy per victim.
For wheezing we used a severity factor for ‘mild asthma’, which was derived as part of the Dutch Disability Weights Study by Stouthard et al. (1997) [103]. Since we have used prevalence data for wheezing (see Table 5), the duration is one year. The years lived with disability attributable to wheezing due to traffic-related air pollution before and after the exchange of short-distance car trips with cycling was subsequently calculated by multiplying the attributive number of wheezers by the severity factor. The disease burden due to traffic-related air pollution was computed by adding up the estimated years of life lost and years lived with disability.

Since we assume that traffic-related air pollution does not cause death but accelerates it, we realise that it is more appropriate to calculate the average loss of life expectancy due to exposure to traffic-related air pollution instead of attributable numbers of deaths [69, 70]. Therefore, for mortality attributable to traffic-related air pollution, we have also estimated the population average ‘years of life lost’ [17]. Average loss or gain of life expectancy can best be calculated by using life tables, which take population dynamics into account. At the moment, this method is in progress and considered outside the scope of this report. Therefore, it was only included as a kind of sensitivity analysis (see also section 3.5).

Road traffic noise

Since there is no base prevalence, we estimated the prevalence for severe annoyance and severe sleep disturbance by combining population exposure with exposure-effect relations (see also Table 3 of section 3.3). The duration of these health endpoints is one year. Because of the limited information of the meaning of severe annoyance and severe sleep disturbance for the daily functioning of humans we have used a severity factor of 0.02. This is similar to the calculation of Knol and Staatsen (2005) [61]. The years lived with disability attributable to annoyance and sleep disturbance due to road traffic-noise exposure before and after the exchange of short-distance car trips with cycling were subsequently calculated by multiplying the number of severely annoyed and severely sleep disturbed by the severity factor.
For our calculations we assume that the duration of the incidental cases of myocardial infarction attributable to long-term exposure to road traffic noise is 6 weeks [104]. We realise that using this duration might give an overestimation of the years lived with disability due to myocardial infarction. Analogous to the Global Burden of Disease Study, we have used a severity factor of 0.3954 [105]. The years lived with disability attributable to the incidence of myocardial infarction due to road traffic-

noise exposure before and after the exchange of short-distance car trips with cycling was subsequently calculated by multiplying the estimated number of attributable cases of myocardial infarction by the above-mentioned duration and severity factor. The ‘total’ disease burden due to road traffic noise was computed by adding up the estimated years lived with disability.

Physical activity

DALYs for physical activity were calculated using the RIVM Chronic Diseases Model (for formulas see Appendix IV). Since prevalence data were used, the duration of the diseases was one year. All severity factors have been derived from the Global Burden of Disease study [105].

Road safety

We computed Years of Life Lost by multiplying the age-specific mortality by age-specific life expectancy based on standard life table analysis, with Dutch life tables for 2004 used as the reference. Years lived with disability were estimated by multiplying the reported age-specific hospitalised injuries per year by the corresponding disability weight (0.172), which was derived by Stouthard et al. (2000) [106]. Given the fact that only the severely hospitalised injured (MAIS2+)[8] were included in our assessment, experts considered this disability weight as more appropriate [104]. After consultation with an expert, we additionally assumed that 4.5% of the hospitalised injuries had permanent damage. For the duration of this permanent damage we assumed a duration of 25.8 years. This is similar to the National Public Health Compass [95, 107]. The disease burden due to road safety was computed by adding up the years of life lost and the years lived with disability.

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[8] Maximum Abbreviated Injury Scale is a severity scoring system that classifies each injury according to its relative importance on a 6-point ordinal scale: MAIS0 = no injury, MAIS1 = minor injury, MAIS2 = moderate injury, MAIS3 = serious injury, MAIS4 = severe injury, MAIS5 = critical injury and MAIS6 = unsurvivable [108].

Appendix IV. The Chronic Diseases Model

The number of cases resulting from changes in physical activity were modelled using the RIVM Chronic Diseases Model (CDM), a dynamic Markov-type multi-state transition model in which the population is categorised according to disease and risk factors [62, 63]. For the purposes of the present study, the following formulas for a certain individual with a certain age and of a certain gender were used:

(1) $DALY(scen) = \left[1 - \left\{\Pi_d \left(1 - p_d(scen) DALY_d\right)\right\}\right]$

(2) $p_d(scen) = \sum_{ri} RR_d(pac) p_r(pac, scen) \Big/ \sum_{ri} RR_d(pac) p_r(pac, emp) p_d(emp)$

where

scen	=	index for scenario
d	=	index for disease
pac	=	index for physical activity category
DALY(scen)	=	calculated quality of life loss for scenario scen
P_d(emp)	=	the given, empirical prevalence risk for disease d
P_d(scen)	=	calculated prevalence risk for disease d in scenario scen
$DALY_d$	=	DALY disability weight for disease d
RR_d(pac)	=	relative risk for physical activity category pac for disease d
P_r(pac,emp)	=	the given, empirical prevalence risk for physical activity category pac
Pr(pac,scen)	=	prevalence risk for physical activity category pac according to scenario scen

The outcomes for a certain individual were aggregated for all age categories for people of 20 years and older and for both men and women.

Appendix V. Gaps and uncertainties

Table V-1a. Valuation of data and tools used, and gaps that were encountered for the selection of health end points with regard to the estimation of the effect of the exchange of car trips by cycling

Environmental exposure/risk factor	Methods/tools used	Gaps and uncertainties
TRAP	Literature review and expert judgment	Only long-term effects related to NO_2 are considered → possible underestimation
RS	Literature review and expert judgment	Emergency-room admissions were not included → possible underestimation
Other*	Literature review and expert judgment	Since it is not possible to quantify these effects, these were not included → underestimation

* This refers to climate change effects, social effects, etc. Abbreviations: TRAP = Traffic-related air pollution, RS = Road Safety

Table V-1b. Valuation of data and tools used, and gaps that were encountered for the assessment of population exposure with regard to the estimation of the effect of the exchange of car trips by cycling

Stage in HIA-process	Methods/tools used per environmental exposure/risk factor	Gaps and uncertainties
Selection population at risk	*Expert judgement*	
	TRAP	Effects estimated for parts of the general population; no distinction made between people living near roads on the one hand and traffic participants such as cyclists, car drivers and their passengers → underestimation
	RTN	Effects estimated for the general population of 18 years and older; no distinction made between people living near roads on the one hand and traffic participants such as cyclists, car drivers and their passengers → underestimation
	RS	Only car drivers, cyclists and other road users whose risk of becoming involved in a car crash were supposed to be at risk. Not included were car passengers such as children (and those who have to go by bike if the driver goes by bike) → underestimation
	PA	Only the population 18 years and older is included; children are not included.
Population exposure in reference scenario	*Modelled exposures*	
	TRAP	We limited our assessment to NO_2 for traffic-related air pollution; the impact of the intervention on concentrations of ultra fine particles, soot and possible PAH is not included → possible under effect
	TRAP, RTN	It is not possible to estimate exposure to noise and traffic-related air pollution for traffic participants (cyclists, car drivers, etc.); in comparison to car drivers, the internal dose due to exposure to

		traffic-related air pollution might be higher, due to a higher timed vital capacity; this might be compensated by lower exposure levels → underestimation
Population exposure in reference scenario	*Monitoring data*	
	PA	
	RS	Mobility (distance traveled) was used as indicator; effects due to a change in travelling time were not taken into account
	RS	No stratification of crashes and mobility by road type
Change in population exposure/behaviour due to the intervention	*Modelled change*	
	TRAP	Due to a lack of (measurement) data about the effects of the intervention on national traffic-related air pollution concentrations, the effect of an average reduction of 1 μg/m^3 was estimated; no distinction was made between people living close to roads and the rest of the population
	RTN	We assumed that all short car trips take place on municipal roads and not on other roads. This may have deviations at local level (urban areas), where local traffic also may use the highway and/or motorway → underestimation of the effect The reduction of the number of vehicles was made for all motorised traffic without distinguishing between heavy lorry traffic and car traffic → overestimation of the effect
	PA, TRAP, RTN, RS	Real change in behaviour is unknown: e.g., how much more per week will people make a short bike trip and how long will this behaviour remain → unclear direction of the effect
	PA	It is assumed that an increase in cycling always leads to an increase in physical activity; this might not always be the case, as people cycle more and do less of another activity as a result → possible overestimation
	RS, TRAP, RTN	Because information about where and when short trips take place was lacking (e.g., on what type of roads, time of day), it was assumed that car trips were replaced by bicycle trips along the same route → unclear direction of effect
	PA, TRAP, RTN, RS	Unclear what kind of people make short trips → unclear direction of effect

Abbreviations: TRAP = Traffic-related air pollution, RTN = Road traffic noise, RS = Road Safety, PA = Physical activity

Table V-1c. Valuation of data and tools used, and gaps that were encountered for the identification of exposure-effect relations with regard to the estimation of the effect of the exchange of car trips by cycling

Environmental exposure/risk factor	Methods/tools used	Gaps and uncertainties
TRAP, RTN, PA, RS	Expert judgement and literature review	No methodology to estimate the effect of combined exposures is available → unclear direction of effect
TRAP, RTN	Expert judgement and literature review	No exposure-effect relations available for traffic participants for the relation between TRAP and/or RTN and health → underestimation

Abbreviations: TRAP = Traffic-related air pollution, RTN = Road traffic noise, RS = Road Safety, PA = Physical activity

Table V-1d. Valuation of data and tools used, and gaps that were encountered for the assessment of the disease burden with regard to the estimation of the effect of the exchange of car trips by cycling

Stage in HIA-process	Methods/tools used per environmental exposure/risk factor	Gaps and uncertainties
Estimation of attributable number of cases: population attributive fraction	TRAP	More logical to estimate loss of life expectancy instead of number of deaths; however, this method was in progress during our study
	PA, RS	Not possible to estimate the effect of the variability of the input data on the disease burden → unclear direction of effect
Estimation of attributable number of cases: base prevalence national registries	RS	The number of cyclists in crashes with no motor vehicle is underreported in police registries and hospital registries → underestimation of effect
Estimation of disease burden: YLD and YLL	Expert judgement	Unknown whether disease attributable to road traffic lasts as long as disease attributable to other risk factor (e.g., smoking) → unclear direction of effect
Severity factor	Expert judgement	Unknown whether disease attributable to road traffic is just as severe as disease attributable to other risk factor (e.g., smoking) → unclear direction of effect

Abbreviations: TRAP = Traffic-related air pollution, RTN = Road traffic noise, RS = Road Safety, PA = Physical activity, YLD = Years of Life lived with a Disability, YLL = Years of Life Lost

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