SSD

SCIENCE FOR A SUSTAINABLE DEVELOPMENT

# Particles, Mobility, Physical activity, Morbidity and the Environment Network

## PM²-TEN


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**SCIENCE FOR A SUSTAINABLE DEVELOPMENT (SSD)**

FINAL REPORT

# PARTICLES, MOBILITY, PHYSICAL ACTIVITY, MORBIDITY AND THE ENVIRONMENT NETWORK

## PM²-TEN

SD/CL/02


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# ACRONYMS, ABBREVIATIONS AND UNITS

| | |
|---|---|
| BDNF | Brain derived neurotrophic factor |
| CNS | Central nervous system |
| IL-1 | Plasma interleukin-1 |
| IL-6 | Plasma interleukin-6 |
| LEZ | Low emission zones |
| MCA | Multi criteria analysis |
| MRI | Magnetic Resonance Imaging |
| NO | Nitrogen oxide |
| PM | Particulate Matter |
| R&D | research and development |
| UFP | Ultrafine Particles |

# 1 SUMMARIES

## 1.1 Executive summary in English

This is the final scientific report of the PM²TEN cluster project, a collaboration between SHAPES and PARHEALTH with links to ANIMO and SCOPE.

The PM²TEN cluster has three major objectives:

1. the organisation of a scientific workshop enabling a peer review of the intermediary results of SHAPES and PARHEALTH by international experts

2. the planning and execution of a common experiment

3. the organisation of a policy oriented workshop to disseminate results to policy makers

Most of the activities in PM²TEN were successfully completed in 2008 and 2009. The final scientific analysis of the experimental results of this cluster continued in 2010 after which the policy workshop was organised. This document reports on the activities and results of the workshops and also presents the results of the common experiment.

More detailed information on the experimental results can be found in the final reports of the SCOPE, SHAPES and PARHEALTH projects and in the scientific literature (http://www.ehjournal.net/content/9/1/64). Information in the papers has priority over the results presented in this document.

### 1.1.1. Part 1: summary of the workshops

***The Scientific workshop***

The scientific workshop was held in Leuven on 18 November 2008 under the title *"Health impacts of PM and traffic noise"*. On that occasion the researchers involved in SHAPES and PARHEALTH presented their mid-term results and preliminary conclusions to a selection of national and international experts. The final results of SHAPES and PARHEALTH have meanwhile been published in reports and papers in peer-reviewed scientific journals. Based on the results of the projects and the knowledge of the international state of the art, the experts identified a number of questions that need to be solved scientifically in order to improve the efficiency of policy measures; e.g. the lack of knowledge on the toxicity of different PM fractions, the uncertainty on the contributions of noise and PM to the observed health impacts, the uncertainty on the effects of brief exposures to high peaks in traffic, etc.

The first two points were also discussed with policy makers in the second workshop. The third point was integrated into the design of the common experiment.

***The Policy workshop***

Initially a number of interviews and written consultations on 10 years of air quality policy (focused on PM) were collected among researchers and policy makers. A list of policy actions, plans and measures was distilled from these on-line consultations in collaboration with the SCOPE project. This list was then scored by means of an on-line inquiry including several criteria:

- was the measure crucial to achieve the air quality targets?
- how well was it implemented?
- is it feasible to implement the measure in the future?

Achieving PM air quality standards and improving scientific knowledge were considered equally important objectives.

The results of this preparatory exercise were presented on the second workshop in Antwerpen on 22 January 2009 under the title : *"Advancement and knowledge transfer and with regard to fine particles in Flanders"*. Selected air quality experts, policy scientists and policy makers were present. Unfortunately policy makers active in the mobility domain were not present although many measures are relevant for or directly concern the transport sector. There was a very open discussion between all the members of the group. Furthermore some subjects were separately discussed in breakaway sessions to get a more detailed picture of old problems and new opportunities after 10 years of PM policy.

From the discussions in the workshop it was concluded that not everyone supports the current network of fixed measurement stations as the best tool to monitor specific sources and to protect public health. It was proposed to organize mobile and personal measurement campaigns to provide more information on exposure to different specific (transport related) fractions.

In the field of knowledge development, research programmes on PM must be coordinated better. A sustainable vision on R&D in the field of PM and public health is necessary. This will provide support to refine the air quality standards on the one hand, but also open up the possibility for exposure and health related aspects (which were always the basis for air quality policy)to play a role in devising and implementing new policies. New detailed scientific studies are necessary on (among other things); identifying sources of PM (attribution of fine fractions to several sectors), on the composition of PM fractions and on the impact of the composition on public health taking into account time activity patterns.

This new knowledge on exposure related aspects must then further be opened up to everyone, so that this information is useful for reflection and policy preparation (e.g. see MIRA).

Finally we conclude that this type of workshops can lead to a better communication between scientists and policy makers. As a result the air quality standards and improving the knowledge needed to achieve them have been brought a little step closer.

### 1.1.2. Part 2 summary of the experimental research in the cluster

Epidemiologic studies have consistently shown that air pollution has detrimental effects on public health. In addition the lack of physical activity (linked to increased motorized traffic) presents us with even more important challenges in the field of public health. SHAPES and other projects have shown that the average mortality impacts of air pollution are less important than the mortality impacts of accidents and sedentary lifestyle for people who take up cycling to increase their level of physical activity. However some concerns have not been completely solved. Because physical activity contributes to increased inhalation of polluting substances, it is not clear if cycling to work in polluted surroundings must be encouraged or not. It is not clear whether a brief exposure to short high peaks of air pollution has any effect on the health of cyclists (or car drivers for that matter).

For this reason PM²TEN examined if a short bicycle ride along a very busy motorway, changes biomarkers for pulmonary and systemic inflammation and BDNF in a group healthy cyclists. Thirty-eight volunteers (average age: 43 (8.6 year, 26% women) cycled for approximately 20 minutes, next to a busy ring road in Antwerp (test; average exposure to ultrafine particles: 28, 867 particles by cm $^3$) and in a laboratory with filtered air (clean room; average exposure to ultrafine particles: 496 particles by cm $^3$). The intensity of cycling was for each volunteer the same in both experimental settings. Exhaled nitrogen oxide (NO), plasma interleukine-6 (IL-6), platelet function, Clara cell protein in serum and number of white blood cells were measured before and 30 minutes after cycling. The percentage of neutrophylic granulocytes increased significantly ($p=0.004$) after cycling next to the ring road (3.9%; 95% CI: 1.5 to 6.2%; $p=0.003$) compared to cycling with the same intensity in the clean the room (0.2%; 95% CI: -1.8 to 2.2%, $p=0.83$). Levels of exhaled NO were significantly lower after cycling in polluted air. Levels of plasma IL-6, platelet function, Clara cell protein in serum and total number of white blood cells was not different between the two experiments. The results for BDF were inconsistent because the levels of BDNF at the start of both experiments were different. We conclude that exposure to particles during cycling, caused a small decrease in exhaled NO and a change in the fractions of white blood cells in healthy people. The link between these changes and the consequences for health remain unclear. We hypothesize that exposure to air pollution may inhibit the exercise induced increase in BDNF and recommend that similar studies repeat this experiment to confirm our results.

# 2 INTRODUCTION

## 2.1 International Context

Many different studies examine health risks. The types of risks studied are sometimes very different, but many are related to transport and how people move from one place to another. The PM²TEN initiative wants to look for common solutions to common problems within this group of Belspo projects and studies, especially with respect to the design of experiments. In that way the results of each participating study will ultimately be more clear if they can be presented in a context that includes all of the other risk factors.

Traffic related and particulate air pollution is arguably the most studied risk factor today. There is a strong association between daily variation in levels of air pollution and daily variation in mortality. At this moment there is a lack of information and knowledge on the specific components in air pollution that can be blamed for this excess mortality and which groups in the population suffer the highest risk. At this point we can only speculate on e.g. a stronger association between mortality and PM in summer, taking into account higher levels of PM in wintertime. All of these uncertainties hamper the implementation of a targeted, effective and efficient policy in the domains of air quality and traffic.

Nevertheless policies are designed and implemented at many different levels (Global, European, National, Local) to reduce air pollution levels and the impact on public health. Taking into account that many important studies are based on annual average concentrations of PM10 or PM2.5, "proximity to traffic" has nevertheless been identified as a risk factor. A conclusion that has been widely accepted by policy maker although there is no strict scientific certainty on this point.

In 2009 the European Commission denied Belgium's appeal to postpone compliance with the PM10 air quality standards until 2011. This has led to a public debate on the elements that had caused or contributed to this failure. Was all of the scientific knowledge adequately and correctly transferred to policy makers and were the most crucial actions effectively taken? This immediately made the third objective of PM²TEN very timely and topical.

On the other hand there are scores of other risks that threaten life expectancy of people and those too need to be dealt with by policy makers. Noise, traffic accidents and sedentary life style are three priority health risks that can have important economic and social consequences. Given the strict budgetary limits that policy makers have to take into account, it is well worthwhile investigating how different policy domains can cooperate to derive comprehensive policy measures in order to achieve synergistic effects rather than taking the risk that individual measures counteract each other. This is especially the case in the domains of health, environment, traffic safety and mobility.

The fact that new scientific information is not transferred efficiently between scientists and policy makers exists not only in Belgium but also in other member states and in Europe. Part of the problem is that there is often also a poor understanding between scientists that prefer a toxicological or clinical approach and scientists that measure or model air pollution to analyze policy scenarios.

The PM²TEN cluster was therefore primarily designed to formally organize the cooperation SHAPES and PARHEALTH in the SSD programme.

SHAPES (Systematic analysis of Health risks and physical Activity associated with cycling Policies) is a project that focuses on the systematic analysis of the health risks and benefits of a modal shift

from passenger cars to cycling (exposure to air pollution, accident risks, and physical activity). In this way SHAPES wants to enable policy makers to make clear and science-based choices related to commuter cycling and transport modal shift in cities. Therefore SHAPES decided to collect the data needed to build an integrated framework to evaluate the costs and benefits of commuter cycling. The outcome of the project was a distinct set of policy options that can be used to promote a modal shift to cycling and substantially improve public health in a cost-efficient manner while taking in account the physical capabilities of different groups and spatial constraints in different regions.
More information can be found at www.shapes–ssd.be and http://www.belspo.be/belspo/ssd/science/pr_health_envir_fr.stm

The PARHEALTH project (Health effects of particulate matter in relation to physical-chemical characteristics and meteorology) on the other hand attempted to quantify the health risks and costs of PM by identifying the components responsible for the observed health effects. More info on PARHEALTH can be found in http://www.belspo.be/belspo/ssd/science/pr_health_envir_fr.stm

By joining the forces of SHAPES and PARHEALTH the knowledge can be presented in a much more comprehensive way to policy makers than either project would achieve standing on its own. Also this creates the opportunity to execute an experiment which combines simultaneous exposure measurements with clinical parameters.

## 2.2 Objectives

PM2-TEN has two general objectives:

- to promote the dialog between research groups which investigate the relation between the environment and health from a human or physical point of view.

- to promote the dialog between researchers and policy makers. This should result in a set of recommendations which take into account the inherent uncertainties of scientific analysis.

This was translated to the following more specific objectives:

1. Discuss with scientists, air quality experts and policy makers:
   a. The short term effects of particulate matter (mass as well as physical and chemical properties) and ozone in two sensible segments of the population (children and elderly)
   b. The component specific toxicity of particulate matter together with meteorological data en the importance for air quality modelling.
   c. The interpretation of the results for environmental impact studies and importance for policy makers taking into account the uncertainties.
   d. The relation between the behaviour of certain groups and the risks related to inhalation pollutants, exposure to noise, traffic accidents, physical inactivity, sleep disturbance and their interactions.
2. The realization of a common experiment by both groups of researchers leading to common publications which put previously obtained results in a new perspective.
3. Permit SHAPES and PARHEALTH to propose efficient measures which contribute to a safer and healthier environment and lead to lower expenses for public health on the long term (although the knowledge is incomplete).
4. Anticipate international trends and possibly participate in European research programs.

# 3 SCIENTIFIC METHODOLOGY

## 3.1 Introduction

Within this cluster project time was reserved to bring partners from different but related research projects into contact with each other. It concerns a selection of projects, both within and outside of PODO I&II (SSD) and both national and international expert related to environment, health and transport.

Two methods were used to achieve this integration of knowledge:

1. The organization of two workshops in which researchers have the opportunity to present the preliminary results of their research to national and international colleagues. This peer review will result in a synergy which will be beneficial for their own research as well as their colleagues'. In the first workshop the focus was on the scientific aspects. The second focused on the relevance for the policy. Policy makers were invited which forced researchers to present their message in a completely different way.

2. The researchers of PARHEALTH and SHAPES performed a common experiment.

**Interaction between the different partners**
The partners in the PARHEALTH project perform fundamental scientific research on one of the three risks which are the pillars of the SHAPES project. PARHEALTH will provide new information from about effects, causal factors and specific components. SHAPES will translate this input in policy measures.

**Experiment**
During the simultaneous measurements of air quality, effort and respiration in SHAPES - phase 2, also blood samples were taken to determine a variety of health outcomes. Whereas initially only the risk for thromboses formation would be determined, it was decided that also white blood cell counts, inflammation markers, exhaled NO and BDNF would be studied. These extra analyses were paid for by the researchers outside of the PM²TEN budget.
A group of cyclists was recruited from the SHAPES participants to cycle a predetermined tour with specific exposure characteristics. A blood sample was drawn before and after cycling. The difference between a situation with high exposure and a control situation was be investigated. In this way the acute effect of brief exposures could be assessed with limited means.

## 3.2 Detailed Design and Organisation of the scientific Experiment

### 3.2.1. Aim of the scientific experiment

To study respiratory, cardiovascular, and neurological effects of short-term exposure to traffic related air pollution in healthy subjects.

### 3.2.2. Design of the scientific experiment

All subjects taking part in the 'SHAPES injury surveillance system' (for more details, see Aertsens et al, 2010) who had filled out at least two week books (N = 1048) were sent an email asking if they were willing to participate in this experiment. Additional exclusion criteria were: smoking and the use of anti-platelet medication. Finally 62 healthy non-smokers were randomly selected and stratified based on their place of residence (relative to one of the three case-study locations). After this preliminary selection, test persons were subjected to a medical examination (excluding heart problems and asthma among others). None were rejected based on the medical examination. From these 62 people, 55 participated in the experiments and 7 failed to show up for various reasons. Some descriptive characteristics of these 55 test persons are summarized in Table 3.

In a randomized, crossover study, participants cycled for ~30 minutes near a busy road with high PM exposure or either cycling in a room with filtered air (Genano Benelux, www.genano.be) to reduce the levels of particles smaller than PM2.5 to the level of approximately a clean room. This provided a maximal contrast in exposure. The time of the examinations was the same in the field as well as in the clean room to prevent the possible influence of circadian variation in the studied parameters.

**Summary of experimental outline:**

- Questionnaire at baseline
- Clinical measures at baseline
- Cycling for 30 minutes
- Resting for 30 minutes
- Clinical measures after exposure
- Repeating in 'clean room' at least 7 days apart

### 3.2.3. Exposure assessment

A bicycle equipped with a number of different assembled instrumentations (collectively called AeroFlex II) was used to measure size resolved aerosol concentrations in the ambient environment (SHAPES; Int Panis et al., 2010). In the present study an updated AeroFlex II system was used as a tool for evaluating and personal exposure because it can capture the time-activity exposure patterns of individuals in an urban transport microenvironment. It consists of 4 different instruments: a TSI P-TRAK, a TSI DustTrack a commercial GPS and a video camera. The TSI DustTrack is a portable optical dust monitor which can simultaneously measure PM1.0, PM2.5, PM10 and TSP. The size range covered by the instrument is 0.3-20 $\mu$m. Standard calibration by the manufacturer (factory settings) was used. Particle number concentrations (PNC) at 1-second resolution were made using P-track Ultra fine Particle Counters (TSI Model 8525), for particles in the size range 0.02–1 $\mu$m with a (maximum limit of: 500,000 particles.cm-3). The P-TRAK was chosen over other instruments because it is hand-held with high data-logging resolution and a fast response time. It is battery-powered and has a relatively robust performance whilst in motion provided that it is housed in a shock absorbing case, custom built for this study, to prevent the tilt sensor from switching off the instrument. More details on the instrumentation used can be found in the final SHAPES report.

During the field test, subjects were asked to cycle at the same intensity or average speed as during their daily trips to and from work which were recorded in weekly web-based diaries for approximately 1 year prior to this experiment.

### 3.2.4. Clinical Measurements

A questionnaire was administered to update recent medical history, life-style habits including the use of alcohol. Endpoints of interest includes standard cardiovascular function (arterial blood pressure), blood parameters of inflammation (leukocytes, Il-6 ), endothelial activation (E-selectin, ICAM, VCAM), and platelet activation (P-selectin, Platelet Function Analyzer, PFA100®). Exhaled NO was measured as a parameter of lung inflammation and was recorded with a chemiluminescence analyser (time: 2 minutes). PFA-100 tests the platelet function. The equipment mimics thrombus formation ex-vivo by evaluating the closure time of the blood (2 minutes). Markers for respiratory health also include plasma Clara cell protein level (marker of lung permeability) and exhaled NO. Brain Derived Neurotrophic Factor a protein that has many effects on the nervous system such as neuronal growth, differentiation and repair was also measured.

**Sample size for an unpaired two sample Student t test**
Alpha = 0,05
Power = 0,8
Difference between means = 16
Standard deviation = 41
Controls per experimental subject 1

Estimated minimum sample size = 105 experimental subjects and 105 controls.
Degrees of freedom = 208

**Sample size for a paired sample Student t test**
Alpha = 0,05
Power = 0,8
Difference of mean from zero = 20
Standard deviation = 41

Estimated minimum sample size = 35 pairs
Degrees of freedom = 34

A paired design was therefore adopted. The detailed planning of the experiment is shown in the table on the next page.

| | 8:00 | 8:30 | 9:00 | 9:30 | 10:00 | 10:30 | 11:00 | 11:30 | 12:00 | 12:30 | 13:00 | 13:30 | 14:00 | 14:30 | 15:00 | 15:30 | 16:00 | 16:30 | 17:00 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **P1** | quest | pre | cycling | rest | post | | | | | | | | | | | | | | |
| **P2** | | quest | pre | cycling | rest | post | | | | | | | | | | | | | |
| **P3** | | | quest | pre | cycling | rest | post | | | | | | | | | | | | |
| **P4** | | | | | | | quest | pre | cycling | rest | post | | | | | | | | |
| **P5** | | | | | | | | quest | pre | cycling | rest | post | | | | | | | |
| **P6** | | | | | | | | | quest | pre | cycling | rest | post | | | | | | |
| **P7** | | | | | | | | | | | | | quest | pre | cycling | rest | post | | |
| **P8** | | | | | | | | | | | | | | quest | pre | cycling | rest | post | |
| **P9** | | | | | | | | | | | | | | | quest | pre | cycling | rest | post |

| code | explanation |
|---|---|
| quest | questionaire |
| pre | preliminary clinical measurements |
| cycling | |
| rest | |
| post | posterior clinical measurements |

**Table 1 Chronology of the PM²TEN experiment in Antwerp**

# 4 RESULTS

## 4.1 Results from the workshops (BUEKERS et al, 2011)

### 4.1.1. Introduction

The scientific workshop served mainly to discuss preliminary results and the design of the experiment and to prepare for the policy related workshop. Based on the results of the projects and the knowledge of the international state of the art, the experts identified a number of questions that need to be solved scientifically in order to improve the efficiency of policy measures; e.g. the lack of knowledge on the toxicity of different PM fractions, the uncertainty on the contributions of noise and PM to the observed health impacts, the uncertainty on the effects of brief exposures to high peaks in traffic, etc. This remainder of this section therefore focuses exclusively on the policy related workshop.

The detailed results of this workshop were already published by Buekers et al. (2011). In this report we therefore only provide a general summary and we refer to the paper for more details.

Air pollution is a systemic risk embedded in environmental, political, social and economic systems. Risk assessments on air pollution therefore involve communication between several stakeholders at multiple scale levels (Buekers et al, 2011). This joint SCOPE & PM²TEN workshop focuses on a small part of the risk assessment, to evaluate actions or decisions on both policy and research fields using an importance-performance/feasibility analysis as a scoring methodology.
The results were discussed by researchers and policy makers at a closed workshop to guarantee a safe place for knowledge integration. The composition of the expert panel is therefore not disclosed in this report.
New insights prove useful for future scenarios on air pollution policy. Although PM²TEN is a cluster of Belgian science projects, this particular study was performed in Flanders, because Flanders is the European hot spot for air particulate matter. After 10 years of policy efforts in Flanders, the daily air particulate matter PM10 standard, which was enforced by the European Commission (EC) in 1999, is still being exceeded more frequently than allowed. No exemption for not achieving this standard was granted by the EC.

So what went wrong on policy and research fields in Flanders? And how can this situation be prevented in the future taking into account the new PM2.5 standard that will be implemented in 2015 (European Directive 2008/50/EC)?

We briefly discuss the methodology and the results of the importance-performance/feasibility analysis on actions related to PM research and policy and discussions at the workshop, improving the communication between researchers and governmental stakeholders. More details can be found in Buekers et al, 2011.

### 4.1.2. Methods

In order to create a safe place for research policy interaction, a closed workshop with a restricted number of selected key players active in the Flemish region was set up to debate on past and future policy actions related to particulate matter air pollution and research development. Policy makers were selected on the basis of their prominent role in the preparation of policy measures or the monitoring of air pollution. The researchers who participated were active in policy supporting research, funded by the Belgian federal science policy or Flemish government. The debate was structured by actions that were scored in advance by an importance-performance analysis.

The importance-performance analysis tool is an evaluative technique used in several disciplines, originally as a tool to aid management in making marketing decisions. A feature that makes importance-performance analysis an explicit evaluative tool is that results can be displayed graphically and information can be communicated in a clear way. The first step in importance-performance analysis involves developing a workable list of actions. Therefore, in-depth interviews and written consultations of several policy makers as well as researchers active in the air pollution domain were carried out. Out of these interviews and consultations, 40 actions related to PM policy or knowledge development were distilled. These actions were introduced in an internet questionnaire that was preceded by a cover letter in which the goal of the study was explained and an example of scoring was illustrated. Actions were rated by a 5 point scale in terms of importance for achieving the PM10 standard, importance for developing knowledge and their performance (for past issues) or feasibility (for future issues) (Figure 1).

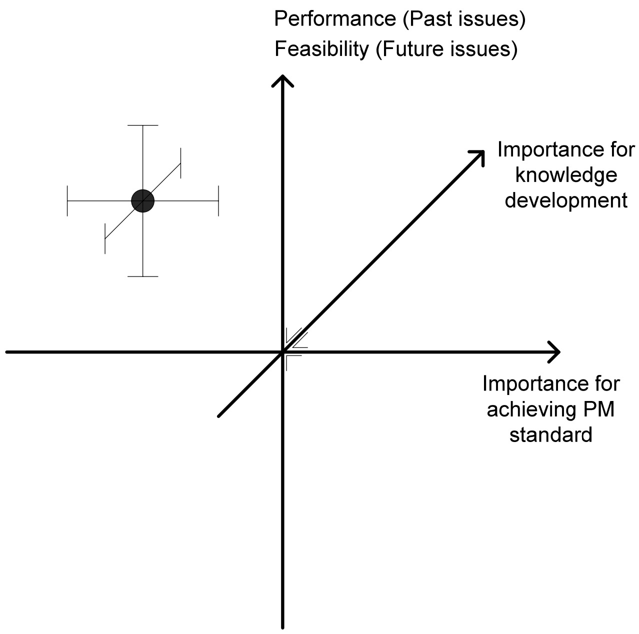



**Figure 1 (Buekers et al, 2011)**

The classic importance-performance analysis was thus extended towards an importance-performance/feasibility analysis. Different quadrants of the graphically displayed analysis may be labelled as e.g. ″concentrate here″, ″keep up the good work″, ″low priority″, ″possible overkill″ and this in terms of importance for achieving the PM standard or knowledge development on PM.

In total 10 respondents (with equal numbers of policymakers and researchers) were invited to fill in the internet poll. The number of participants was restricted in order to promote open discussions at a following workshop.

After analysis of the poll, a research policy expert workshop was organized and aimed at building, transferring and using knowledge on air particulate matter in Flanders. All participants that filled in the internet poll were invited. The workshop was setup to:

- evaluate results of the preceding internet poll on actions related to PM policy and research by an importance-performance analysis
- to improve knowledge on PM policy and research and
- to promote the communication between different stakeholders.

The workshop was a closed session with several key players. This approach was chosen to create an open and interactive forum for discussions. Results were discussed in a plenary session and breakaway sessions (2 mixed groups of policymakers and researchers) were used as a creative process to structure the day, and to free participants of the intimidating necessity of addressing the full audience; although the total number of participants was already limited.

### 4.1.3. Results

Results of the analysis were split up in 4 two-dimensional graphs (Figures below). Only actions with explicit scores or actions which were discussed at the workshop are presented. This input was used as the leitmotiv to organize the discussion at the workshop. In this section, the most important actions are presented, accompanied by observations from the workshop.

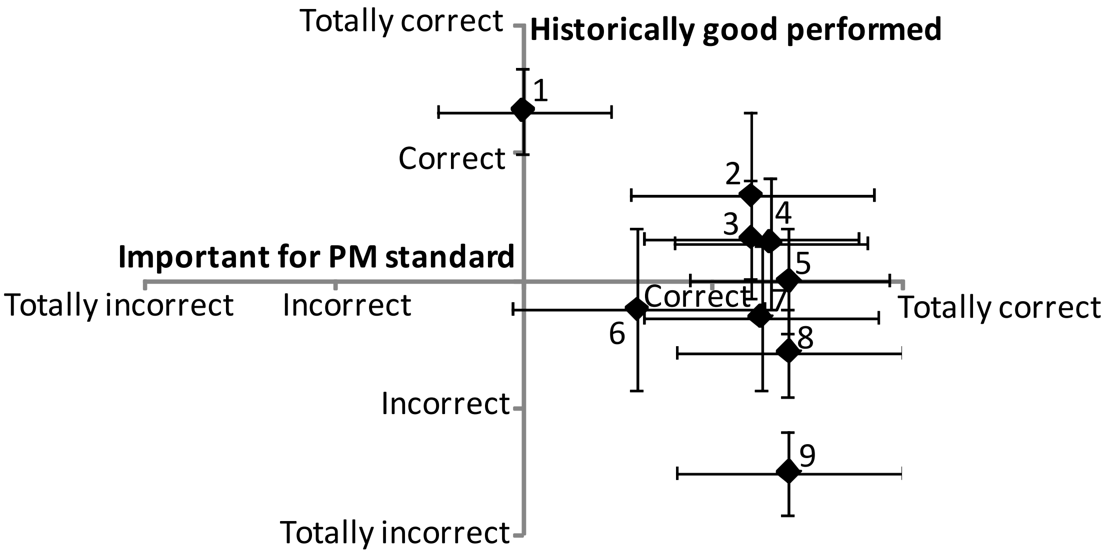



**Figure 2 (Buekers et al, 2011)**

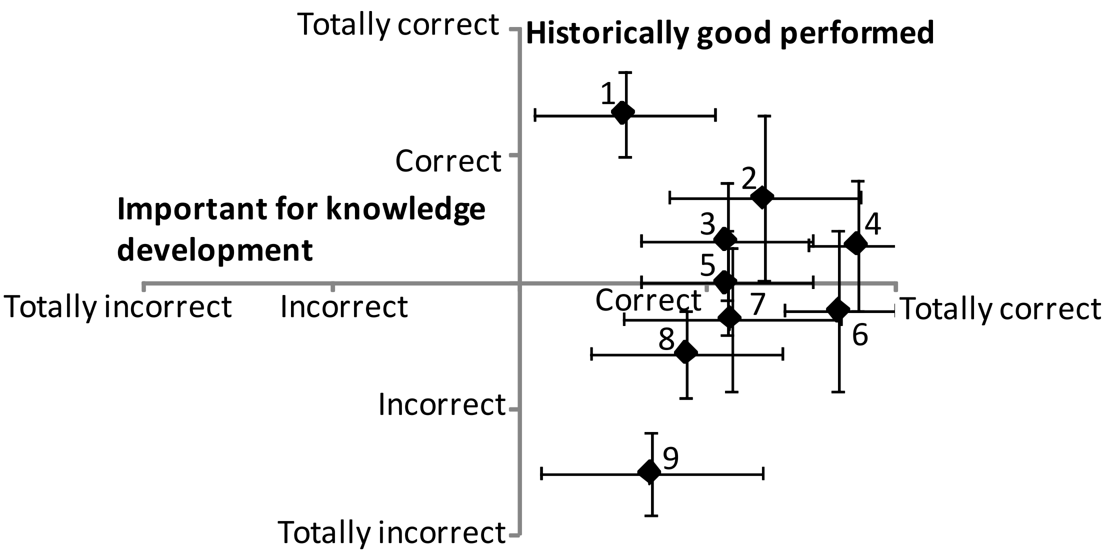



**Figure 3 (Buekers et al, 2011)**

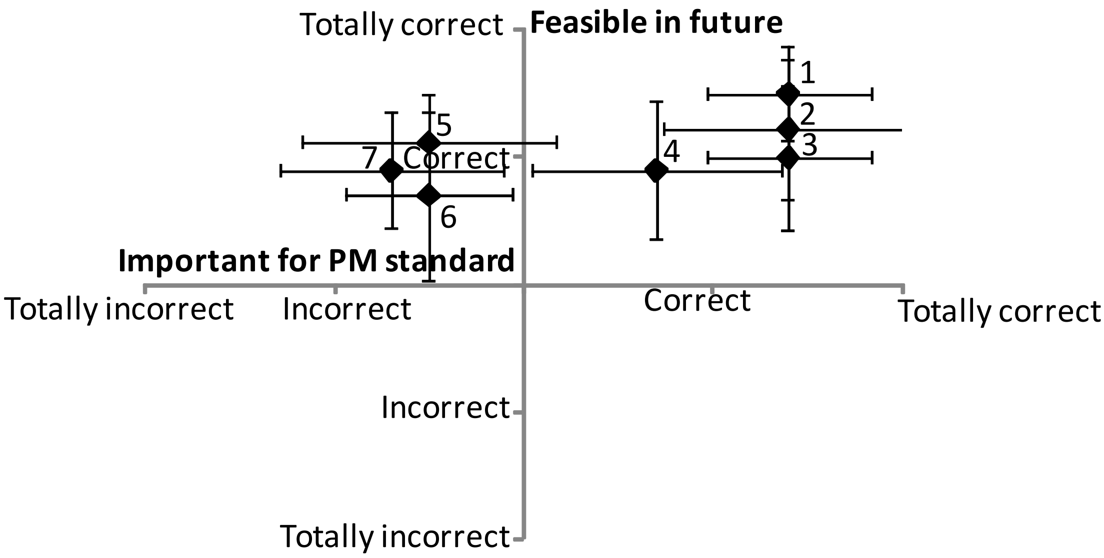



**Figure 4 (Buekers et al, 2011)**

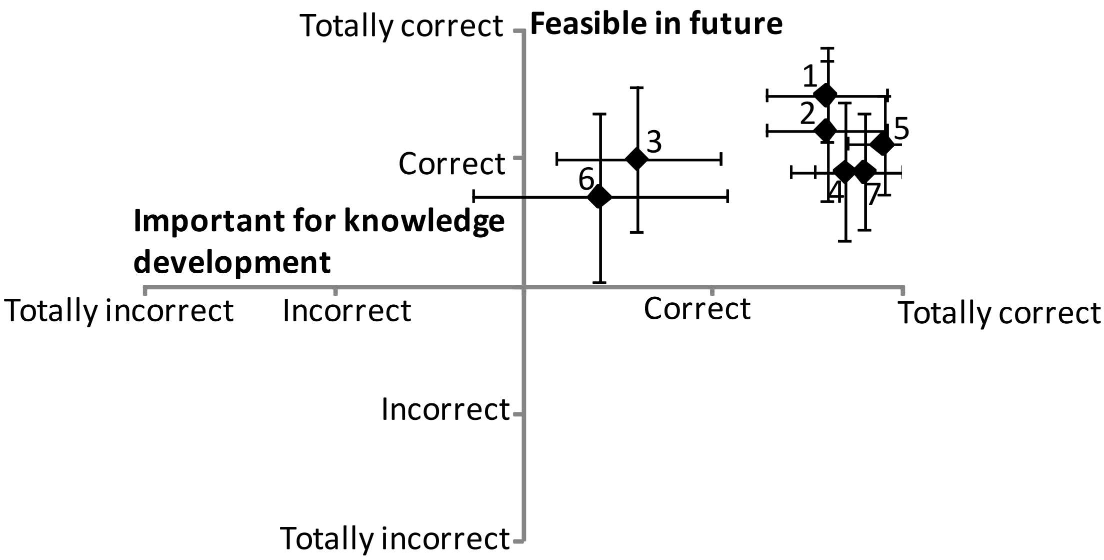



**Figure 5 (Buekers et al, 2011)**

### 4.1.4. Some Highlights

***The Air pollution measurements and monitoring network***

The participants at the workshop emphasized the importance of the implemented monitoring network to measure PM concentration levels, but questions were raised about the locations of the official fixed monitoring network. In the past, monitors were located in an ad hoc fashion, favouring the placement of monitors in hot spots or in areas deemed subjectively to be of interest. By consequence, present locations of some measurement posts are focused on micro-situations and are not relevant for general PM exposure. Although the EU guidelines do clearly indicate that the limit values have to be respected over the entire territory, some participants felt that territory-wide PM standards ignore the relative health relevance of some PM fractions and do not adequately reflect differences in human exposure. However, new methods have now been developed for systematically locating air pollution monitors to maximize coverage in relation to socio-demographic characteristics, likely pollution variability and activity level.

***Car speed reduction limit***

The car speed reduction limit during smog episodes was scored high for its good implementation in the past, but was not seen as crucial for achieving the PM standard. The participants agreed that this measure mainly serves to increase public awareness for the air pollution problem.

***PM interpolation models***

The quality of PM measurements and the application of models for interpolation of PM concentrations were scored as good implemented in the past and crucial for achieving the PM standard. Real-time assessment of the ambient air quality has gained an increased interest in recent years. A drawback is the resolution applied in interpolation models, which can make it difficult to draw conclusions for specific locations such as street canyons.

***Communication between researchers and policy makers***

The communication between researchers and policy makers was scored as crucial for achieving the PM standard, but there was a rather neutral opinion on the implementation, without extreme notions or division in groups.

When risk communication is considered, literature shows that an evolution can be traced from traditional, one-way communication, to more modern, more-way communication, with a focus on participation and cooperation between researchers, policymakers and the public. VITO's Environment and Health unit incorporates risk communication in the day-to-day practice of e.g. human bio-monitoring research.

***Pro-active policy***

Setting up a pro-active policy was scored as crucial for achieving the PM standard but the participants agreed that this was not well implemented in the past. At this moment, the problem of particulate matter air pollution is not a priority on the political agenda. This becomes evident in the poor attention given to the accountability of measures taken and the fact that Flanders is not losing any sleep over not achieving the PM10 standard. Moreover, the Flemish government established the "Flanders in Action Plan 2020" and the ambition to become the European logistic hub for transport. This may increase PM emissions.

***Car/fuel taxation***

Flanders is a transport region with still increasing traffic. In 2009, 60% of the Belgian fleet of cars consisted of diesels. The recent increase in diesels is partly due to the difference in fuel taxation, gasoline versus diesel. Moreover, diesel cars are promoted to reduce the impact on the climate change. It is noted that if soot emissions would be taken into account in the debate on climate change, it may have a large influence. Therefore it's necessary that political focus on fuel prices changes.

Some actions were scored as being crucial for knowledge development and implementation in the past (Figure 3).

***Coordinated research program***

The most drastic change between Figures 2 and 3 is the shift of action 6 (setting a coordinated research program) going from less important to achieve the PM standard towards highly crucial for knowledge development. In the past, a lot of fragmentary ad hoc research on air pollution was performed. The coordination and synchronization of research programs was not adequate. During the last decade, this has been improved by e.g. the development of focus or supporting points, indicative programs for yearly planned research projects on environment but a long term vision may be missing.

Some actions we scored as being crucial for achieving PM standard and feasibility in future (Figure 4).

- knowledge improvement on sources of PM
- the implementation of Low Emission Zones (LEZ)

- the quantification of measures to reduce PM concentrations (accountability)
- knowledge improvement on sources of PM

***Low Emission Zones (LEZ)***
At the workshop, there was a discussion on the implementation of low emission zones (LEZ), which was scored by the attendants as a very effective measure to obtain the PM standard. It was remarked that several political parties consider this measure as antisocial e.g. some polluting vehicle types, belonging to different socio-economic classes, may be restricted to enter a specified area. The general tendency shows that it should be possible to correct for this antisocial aspect by e.g. providing inhabitants of a LEZ a free annual ticket for public transport or providing free parking places or applying the revenue that a LEZ generates for reducing taxes.

***Accountability of measures to reduce PM exposure***
In the Commission's decision on the notification by Belgium for an exemption from the obligation to apply the limit values for PM10, it was stated that *"some information on the observed and planned effects of certain measures to improve the air quality situation was not included"*.
This means that more attention has to be given to the impact of certain measures; thereby modelling of PM air concentrations may help to predict or rather project emissions for future situations after implementation of new measures. Recent scientific research helps to develop methods to quantify the effect of policies and measures. Projections for future PM air concentration levels in relation to e.g. human activities such as transport, provides a valuable contribution to establishing efficient and effective policies and measures. Recently, the Health Effect Institute (HEI) funded eight studies on accountability, which cover near-term interventions to improve air quality. These studies include e.g. measures to reduce traffic, replacing old wood stoves with cleaner ones, longer term wide-ranging actions or events (such as complex changes associated with the reunification of Germany).

***Actions scored by crucial for knowledge development and feasibility in future (Figure 5)***
The most achievable action was knowledge improvement or development on the sources of primary and secondary PM. The most crucial action was gathering more information on the composition of PM and the effect of individual components of this composition on public health. There remains uncertainty about which chemical components of PM are most harmful to human health. But mass alone is not deemed a sufficient metric when evaluating health effects of PM exposure.

### 4.1.5. Conclusions on the policy workshop

Systemic risks characterized by complexity require the collaboration between different stakeholders and the interaction on several levels. The communication exercise described in the joint SCOPE & PM²TEN workshop, included a collaboration of researchers and policy administrators and expected a large input or effort but resulted in a fruitful discussion on the policy and research topics on particulate matter (PM) air pollution in hot spot Flanders.

A multi criteria analysis (MCA), where several alternatives are weighed according to several criteria, can be carried out on the workshop results for e.g. to review which type of studies should be conducted in the future and which measures can be taken to cope with current levels of air pollution.

## 4.2 Published experimental results

Of the 41 persons that completed the field test in Antwerp, 38 also cycled in the clean room. Thirty-one men and ten women participated (table 1) with a mean age of 43 years and mean BMI of 24.

**Table 1 Patiënt characteristics (N=38)**

| | Mean (SD) or number (%) |
|---|---|
| **Anthropometrics** | |
| Women | 10 (24%) |
| Age, years | 43 (8.6) |
| BMI, kg/m² | 23.9 (3.2) |
| **Lifestyle** | |
| Former smoker | 19 (46%) |
| Exposure to environmental tobacco smoke | 4 (10%) |
| Regular alcohol use | 23 (56%) |
| **Medication use** | |
| Antiplatelet medication | 0 (0%) |
| Lipid-lowering medication | 1 (2%) |
| Antihypertensive medication | 3 (7%) |

### 4.2.1. Exposure measurements

The average concentration of particles the participants were exposed to, during the field test and in the clean room are given in table 2. Concentrations of particles were significantly increased while cycling along the Antwerp ring (Figure 1). Average temperature was higher in the clean room and relative humidity was lower. The duration of the cycling, the heart rate and the average ventilation per minute did not differ significantly between the two test scenarios (Antwerp ring and clean room).

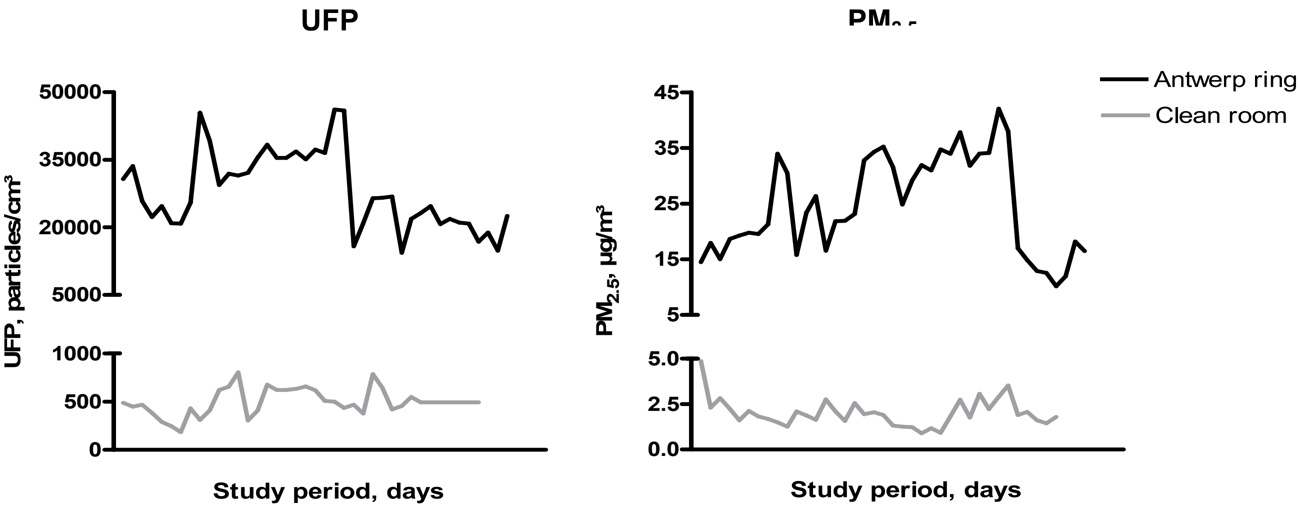



**Figure 6 UFP and PM2.5 concentrations in both experimental settings**

**Table 2 Exposure measurements during cycling along the Antwerp ring and in the clean room**

| Endpoint | Antwerp ring | Clean room | P-value |
|---|---|---|---|
| **Average $PM_{10}$, µg/m³** | 64.9 (24.6) | 7.7 (3.3) | <0.0001 |
| **Average $PM_{2.5}$, µg/m³** | 24.6 (8.8) | 2.0 (0.76) | <0.0001 |
| **Average UFP, particles/cm³** | 28180 (8584) | 496 (138) | <0.0001 |
| **Total $PM_{10}$, µg/m³** | 71.8 (31) | 8.3 (3.8) | <0.0001 |
| **Total $PM_{2.5}$, µg/m³** | 27.7 (11.4) | 2.2 (0.91) | <0.0001 |
| **Total UFP, particles/cm³** | $3.3 \times 10^{10}$ ($1.3 \times 10^{10}$) | $5.5 \times 10^{8}$ ($1.9 \times 10^{8}$) | <0.0001 |
| **Temperature, °C** | 15.3 (1.7) | 21.6 (1.0) | <0.0001 |
| **Relative humidity, %** | 56.3 (9.6) | 45.7 (6.6) | <0.0001 |
| **Duration of cycling, min** | 20.7 (1.7) | 20.2 (1.9) | 0.20 |
| **Heart rate** | 131 (14.8) | 131 (14.6) | 0.88 |
| **Ventilation, L/min** | 55.4 (12.7) | 55.2 (13.1) | 0.88 |

**Table 3 Comparison of baseline values between Antwerp and the clean room before cycling**

| Endpoint | Median (IQR) |
|---|---|
| **Exhaled NO, ppb** | |
| Antwerp | 26 (20) |
| Clean room | 22 (24) |
| **PFA closure time, s** | |
| Antwerp | 160 (62) |
| Clean room | 156 (51) |
| **Il-6, pg/mL** | |
| Antwerp | 1.32 (1.35) |
| Clean room | 1.46 (0.69) |
| **Leukocyte counts, per µL** | |
| Antwerp | 5250 (1220) |
| Clean room | 4645 (1340) |
| **Neutrophil counts, per µL** | |
| Antwerp | 2990 (1090) |
| Clean room | 2820 (1230) |
| **Percentage neutrophils, %** | |
| Antwerp | 57 (11) |
| Clean room | 61 (11) |

### 4.2.2. Clinical endpoints

Baseline values (before cycling) were not significantly different between the Antwerp ring and the clean room except for BDNF(Table 3).
When we compared the values of the clinical parameters before and after cycling, separately for the two locations (Antwerp and clean room), we observed a decrease in exhaled NO when the persons were exposed to polluted, but not filtered air (Table 4). Platelet function, Il-6 and total leukocyte counts did not differ significantly before and after cycling, neither in Antwerp, not in the clean room.
The percentage of blood neutrophils, however, increased after cycling in polluted, but not filtered air.

**Table 4 Differences in clinical endpoints per location**

| Endpoint | Difference | P-value |
|---|---|---|
| **Log Exhaled NO, ppb** | | |
| Antwerp | -0.025 | 0.01 |
| Clean room | -0.006 | 0.60 |
| **Log PFA closure time, s** | | |
| Antwerp | +0.026 | 0.10 |
| Clean room | +0.024 | 0.08 |
| **Log Il-6, pg/mL** | | |
| Antwerp | +0.062 | 0.20 |
| Clean room | -0.013 | 0.74 |
| **Leukocyte counts, per µL** | | |
| Antwerp | +0.035 | 0.66 |
| Clean room | +0.25 | 0.05 |
| **Neutrophil counts, per µL** | | |
| Antwerp | +0.021 | 0.02 |
| Clean room | +0.023 | 0.08 |
| **Percentage neutrophils, %** | | |
| Antwerp | +2.11 | 0.002 |
| Clean room | +0.61 | 0.33 |

## 4.3 Unpublished experimental results

The analysis of exercise-induced increase in plasma BDNF after cycling near a major traffic road is still ongoing. The final analysis will be published later in Bos et al.. (in prep) In this report we present a detailed overview of the intermediate results because they have not been published in another form.

### 4.3.1. Introduction

SHAPES has concluded that commuting by bike has a clear health enhancing effect. Here we focus on the fact that, regular exercise is also known to improve brain plasticity, which results in enhanced cognition and memory performance. Animal research has clearly shown that exercise upregulates Brain-Derived Neurotrophic Factor (BDNF – a neurotrophine) enhancing brain plasticity. Studies in humans found an increase in serum BDNF concentration in response to an acute exercise bout. Recently, more evidence is emerging suggesting that exposure to air pollution (such as particulate matter (PM)) is increased during commuting. Furthermore, it has been shown that enhanced exposure to PM is linked to negative neurological effects, such as neuroinflammation and cognitive decline.

There is now extensive research showing that exercise also has substantial benefits for psychological health and cognition. Exercise not only improves cognitive function in normal individuals, but is also associated with a lower risk for depression, Alzheimer's disease and other types of neurodegenerative diseases. Study results from the National Long Term Care Survey data provide evidence supporting the potential for exercise to lower the risk of cognitive impairment and dementia. In a sample of more than 5000 subjects, they found at 10-year follow-up, that the number of different types of exercises performed was inversely associated with the onset of cognitive impairment as was the number of exercise sessions lasting at least 20 minutes (refs in Bos et al, in prep).

Both clinical and animal studies have repeatedly demonstrated that exercise benefits neuronal function, promotes brain vascularisation, stimulates neurogenesis and enhances learning. Exercise elevates levels of neurotrophic factors, factors that regulate the proliferation and differentiation of cells in the central nervous system. Among these factors Brain-derived neurotrophic factor (BDNF) is a molecule that is consistently demonstrated to be upregulated with exercise treatments. BDNF has been shown to be necessary for long-term potentiation, a neural analogue of long-term memory formation, and for the growth and survival of new neurons. Both animal and human studies have demonstrated that BDNF increases with exercise (see Bos et al, in prep for references corroborating these claims).

However, most of the bike commuting is performed in urbanised environments suffering from air pollution. Several epidemiological studies link air pollution with human illnesses. Air pollution from vehicle exhaust and its possible effects on health of people living and cycling near heavy traffic have raised concerns since in certain cities inhaled $\mu$g PM2.5/km and $\mu$g PM10/km is significantly higher while cycling compared to driving a car [SHAPES: Int Panis et al 2010]. Information indicates an inverse dose–response relationship between air pollutants and lung function at constant workloads, as well as an inverse dose–response relationship between lung function and breathing frequency at constant pollutant levels above previously identified thresholds. Exercise increases ventilation, and it is known that an athlete running at 70% of maximal oxygen uptake for the length of a marathon (~ 3 hours) inhales the same volume of air as a sedentary person would in 2 days. We calculated that minute ventilation while cycling is on average 4.3 times higher compared to driving a car. In addition to the elevated ventilation rate, the switch from nasal to mouth breathing during intensive exercise, and an increased airflow velocity carry pollutants deeper into the lungs, and further amplify the subject's dose of pollutants.

It is now reasonably well established that both short-term and chronic air pollution exposures are related to cardiovascular diseases, but there is also mounting evidence that exposure to air pollution can cause brain damage and neurodegeneration. Calderon-Garciduenas have previously shown that negative health effects of long-term exposure to air pollution causes neuroinflammation and a disruption of the Blood-Brain Barrier. These authors documented with MRI prefrontal lesions and cognitive deficits in children exposed to ambient air pollution in Mexico city. They showed a possible link between cognitive dysfunction and structural alterations to children's brain and chronic exposure to significant concentrations of air pollutants, including particular matter. Clinically healthy children with no known risk factors for neurological or cognitive disorders residing in a highly polluted urban environment exhibited deficits in fluid cognition, memory, and executive functions, relative to children living in a less polluted urban environment. Other studies demonstrated an association between long-term exposure to traffic related air pollution and mild cognitive impairment. Another study found that the brain tissue of mice in Mexico City had higher levels of several inflammatory factors, as well as the principal proinflammatory cytokines, compared with those from non polluted areas; Furthermore, it has been shown that children in a school in a polluted area had lower scores in all items for cognitive testing than did those from a school in a clear area.
The molecular toxicity of air pollution and especially diesel exhaust is suggested to include oxidative stress-mediated inflammation. Inhaled PM are able to translocate to the brain via olfactory nerves, or through inhalation and systemic inflammation. We recently found that cyclists that were briefly exposed to traffic –related air pollution showed an increase in inflammatory blood cells [see above and Jacobs et al 2010].

From the above it is clear that exercise has positive effects on brain health, and that air pollution can negatively impact on cognition. Since exposure during commuting may represent an important fraction of the daily exposure to air pollution, we used the PM²TEN controlled cross-over experiment to measure exercise-induced levels of BDNF in healthy subjects while cycling near a major motorway with busy traffic compared to a room with filtered air. We hypothesize that the exercise-induced increase of serum BDNF will be lost while cycling in polluted air.

### 4.3.2. Methodology

The set-up of the experiment is described in detail in Jacobs et al. 2010 (http://www.ehjournal.net/content/9/1/64)

BNDF was determined based on a venous blood sample that was drawn, before and after exercise for 20 minutes. After the exercise participants rested for 30 minutes in a seated position followed by the post-exercise blood collection.

### 4.3.3. Statistical analysis

We first present some graphs (figure 7) in which we look at each of the effects separately (Average of the differences for each person; before/after for exposure and cycling). The p-value is for a paired t-test.

- Left upper graph: effect of cycling in the clean room. The graph shows a significant increase due to cycling ($p = 0.02$)
- Right upper graph: effect of cycling in Antwerp (exposed). No significant difference before or after cycling
- Left bottom graph: there is a significant difference between the clean room and Antwerp (exposed) before cycling
- Right bottom graph: The difference between the clean room and Antwerp (exposed) after cycling is not significant.

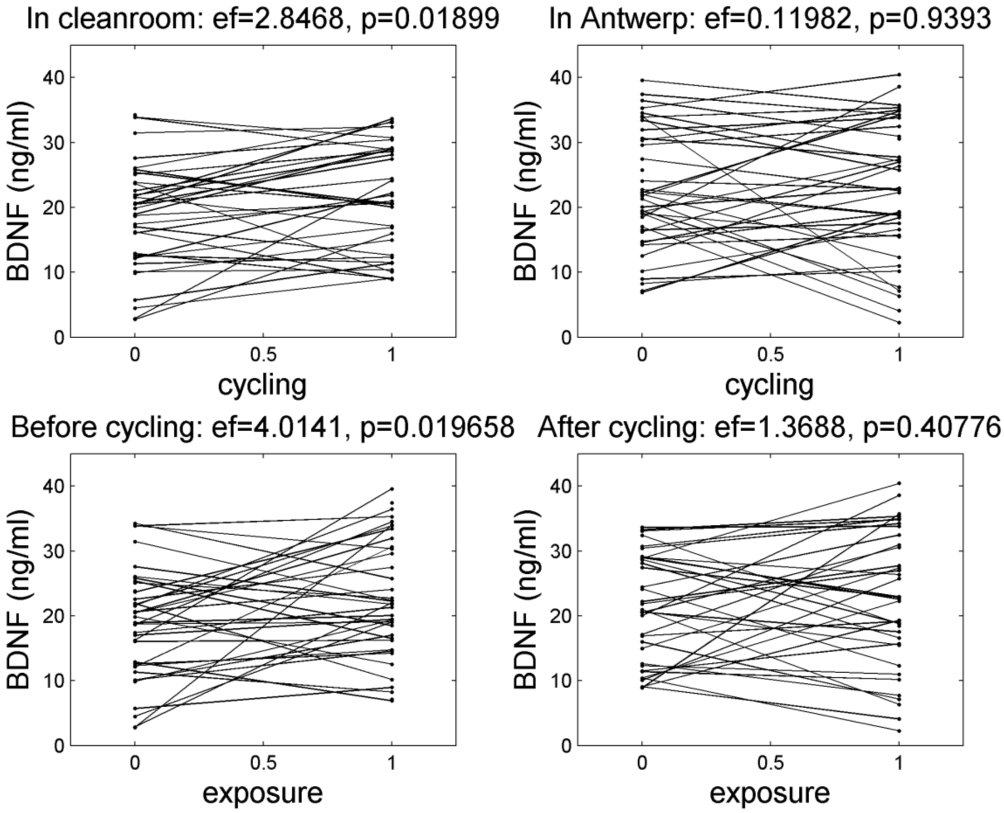



**Figure 7 Statistical analysis of the BDNF measurements**

To summarize the situation: BDNF was significantly lower before cycling in the clean room compared to Antwerp. This is different from the situation with all the other biomarkers (see previous section) where the baseline values (before cycling) were not significantly different between the Antwerp ring and the clean room.

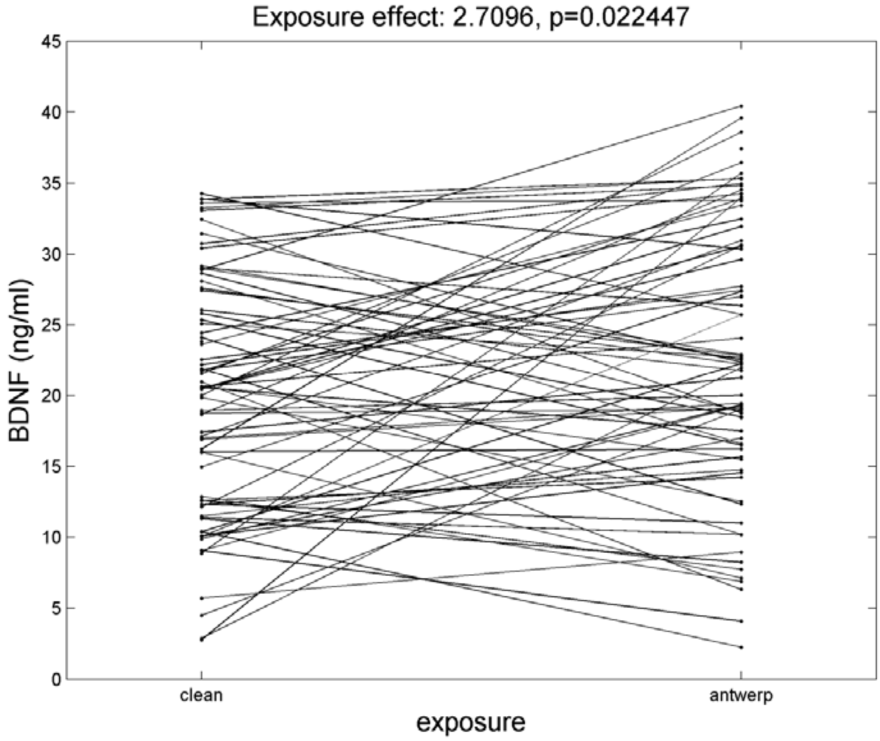
The increase in BDNF after cycling was significant in the clean room but not in Antwerp. Therefore the difference between the clean room and Antwerpen after cycling is not significant.

The overall effect of exposure (combined measurements before and after cycling) is significant. But the overall effect of cycling (combined measurements of both locations) is not significant (see figures below).

Because of the possible interaction between exposure and cycling, we are therefore forced to construct a more complicated Mixed effects linear model.

Our current best hypothesis is that exposure to air pollution prevents or inhibits the BDNF increase induced by cycling. Unfortunately the effect of cycling only is not significant and neither is the interaction (although there seems to be a trend in the data).

The effect of exposure is significant but because the measurements in the clean room and in Antwerp were done with a lag of several weeks, this is a weak results that could also be attributed to other factors.



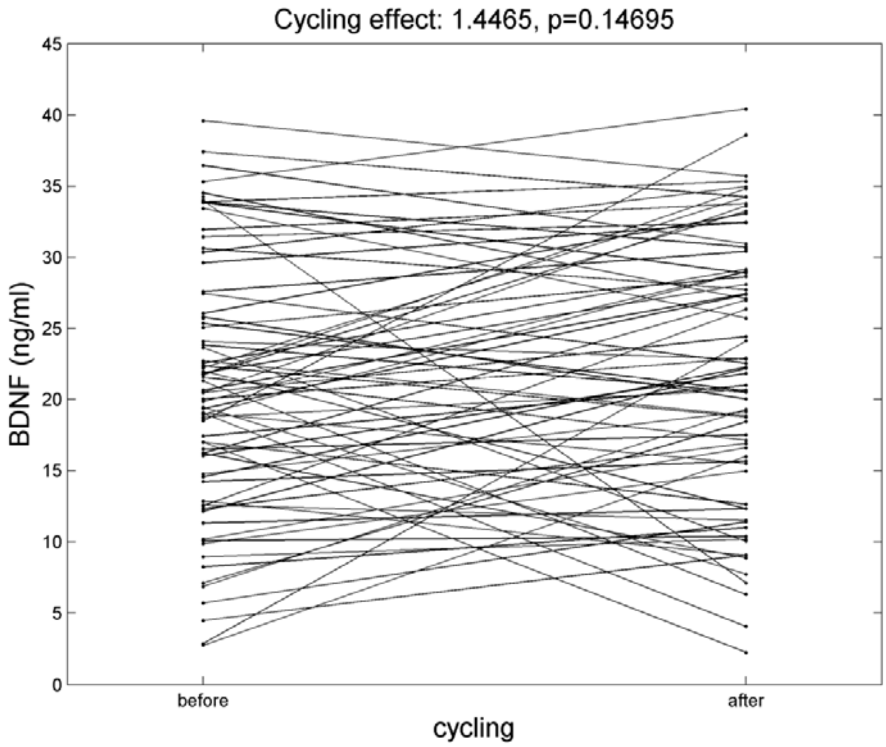




**Figure 8 Statistical Analysis of Exposure and Cycling effects on BDNF**

An anova gives the same result. Only the exposure is significant.

**Table 5 ANOVA of the BDNF concentrations by exposure and cycling**

| Source | Sum Sq. | d.f. | Mean Sq. | F | Prob>F |
|---|---|---|---|---|---|
| id | 7569.5 | 39 | 194.089 | 4.57 | 0 |
| expo | 260.3 | 1 | 260.324 | 6.13 | 0.0149 |
| cyc | 95.7 | 1 | 95.734 | 2.25 | 0.1362 |
| expo*cyc | 56.4 | 1 | 56.434 | 1.33 | 0.2517 |
| Error | 4631.5 | 109 | 42.49 | | |
| Total | 12608.8 | 151 | | | |

## 4.3.4. Results and discussion

As expected, exercise significantly increased plasma BDNF concentration after cycling in the air-filtered room (18.30 vs. 20.93 ng/mL; p=0.036). In contrast, plasma BDNF concentrations did not increase after cycling near the major traffic route (22.14 vs. 22.25 ng/mL; p=0.94).

Exercise significantly increased serum BDNF concentration after cycling in the air-filtered room (+14.4%; p=0.036). In contrast, serum BDNF concentrations did not increase after cycling near the major traffic route (+0.5%; p=0.94) (Figure 2).

As expected, exercise significantly increased plasma BDNF concentration after cycling in the air-filtered room (18.30 vs. 20.93 ng/mL; p=0.036). In contrast, plasma BDNF concentrations did not increase after cycling near the major traffic route (22.14 vs. 22.25 ng/mL; p=0.94).

The most remarkable result of this study is that the exercise-induced increase of serum BDNF seems to be absent when exercising in a polluted environment. One important difference between both environments was the concentration of air pollution. In the clean room, the ultrafine particles as well as PM2,5 and PM10 were filtered out of the air. Particle concentrations were therefore substantially higher when cycling along the Antwerp Ring but other differences cannot be ruled out.

Acute exercise is the key intervention to trigger the processes through which neurotrophins mediate energy metabolism and, in turn, neural plasticity. Serum BDNF level is known to increase during and immediately after an acute exercise bout. The mild increase of serum BDNF (+14%) after exercise in the clean room is consistent with literature, where a transient enhancement of BDNF in serum is found in response to a single exercise bout. Most studies on human subjects found a increase in BDNF (increase ranging from 11.7% to 410.0%) following acute exercise, with acute high intensity exercise protocols having larger increases in BDNF concentrations than acute low intensity exercise protocols. The exercise intensities in both experimental settings was mild, being 75% of maximal heart rate, also the duration of exercise was the same (20 min), nevertheless peripheral BDNF did not increase while cycling next to a busy highway.

There are reproducible findings that exercise has a positive effect on cognitive function in humans. Living in a polluted area, however, can be the cause of cognitive decline. Epidemiological studies linking air pollution with human illnesses demonstrate an association between long-term exposure to traffic-related air pollution and mild cognitive impairment in elderly people, but also in children (see Bos et al, in prep. for refs). The ability of exercise to improve cognitive function by engaging neurotrophic action may also rely on an interface with metabolic processes, which alter the amount of oxidative stress. Studies have shown that a regular exercise regimen retards the accumulation of cell damage and physiologic dysfunction characteristic of the ageing process. BDNF can protect CNS neurons from oxidative stress and may target the source of free radical production as BDNF addition has been shown to impact mitochondrial activity. In contrast, injection of a substance known to disrupt mitochondrial metabolism into the right hippocampus (1,25–dihydroxyvitamine), fully blocked the exercise-induced effect on BDNF. The authors suggest that exercise modulates BDNF by decreasing oxidative stress, because oxidative stress decreases DNA-binding ability of CREB, a prominent regulator of BDNF. It might be that exposure to air pollution while cycling next to the Antwerp ring could acutely have enhanced oxidative stress and inflammatory processes in the brain, whereby the positive effect of exercise on oxidative stress is neutralized and BDNF is not increased.

While diverse environmental factors have been implicated in neuroinflammation leading to CNS pathology, air pollution may rank as the most prevalent source of environmentally induced inflammation and oxidative stress. UFP may induce inflammatory and pro-thrombotic responses in the organism, which could promote atherosclerosis, thrombogenesis and the occurrence of cardiovascular events. Furthermore, UFP may directly act on cells in various organs inducing oxidative stress and eventually heritable mutations. Nanosize particles can cross the BBB and physically enter the central nervous system. Respiratory tract inflammation may lead to brain inflammation by altering levels of circulating cytokines, such as TNF-α and IL-1. Cytokines (e.g. IL-1) are produced by respiratory epithelia in response to PM exposure and by activated microglia in the CNS. Furthermore, inhaled nano-size PM particles quickly exit the lungs and enter the circulation where they distribute to various organ systems, and damage to these secondary targets occurs though oxidative stress pathways. The brain is vulnerable to oxidative stress damage because of its high energy use, low levels of endogenous scavengers (e.g., vitamin C, catalase, superoxide dismutase etc.), high metabolic demands, extensive axonal and dendritic networks, and high cellular content of lipids and proteins (see Bos et al, in prep. for refs). Recently Wu et al, found that inducing systemic inflammation by injecting LPS intraperitoneally caused, within 3 hours, an inflammatory status in the substantia nigra and striatum and reduced the BDNF levels in the substantia nigra (not in striatum). These events were followed by extensive loss of dopaminergic neuron. In contrast, 4 weeks of exercise before the inflammatory insult significantly enhanced BDNF levels and hereby the loss dopaminergic neurons could be prevented, although the inflammatory status still appeared. Both the acute inflammation caused by ultra fine particles entering the body by cycling in a polluted environment as well as the subsequent oxidative stress could be reasons for the loss of exercise-induced increase in BDNF, especially because we reported from the same study that white blood cell count increased significantly when cycling next to the Antwerp ring, compared to values in the clean room [Jacobs et al 2010]. As air pollution is known to induce systemic as well as neurologic inflammation, we suggest that air pollution could act in the same way as the LPS-injection and trigger similar actions. In that way, neuroinflammation could be the underlying cause of the difference in effects of cycling in clean versus polluted air.

### 4.3.5. Conclusions on BDNF

This study showed that exercise-induced increase in BDNF is absent while cycling near a busy road where the concentration of PM & UFP is much higher than in a controlled clean room. Although it is tempting to speculate that the inflammation caused by PM and the subsequent oxidative stress could be the primary explanation for these results, further research is necessary to detect the possible mechanism.

Although active commuting is considered to be beneficial for health, this health enhancing effect could be negatively influenced by exercising in an environment with high concentrations of PM. Whether this effect is also present with chronic exercise and chronic exposure must be further elucidated.

# 5 PUBLICATIONS

## 5.1 Publications of the teams

### 5.1.1. Peer review

*Lead by KUL*

Lotte Jacobs, Tim S Nawrot, Bas de Geus, Romain Meeusen, Bart Degraeuwe, Alfred Bernard, Muhammad Sughis, Ben Nemery and Luc Int Panis. Subclinical responses in healthy cyclists briefly exposed to traffic-related air pollution. **Environmental health** http://www.ehjournal.net/content/9/1/64. Published 25/10/2010. http://dx.doi:10.1186/1476-069X-9-64

*Lead by VITO*

Jurgen Buekers, KristienStassen, Luc Int Panis, Kim Hendrickx, RudiTorfs, 2011. Ten years of research and policy on particulate matter air pollution in hotspot Flanders. **Environmental Science and Policy** (accepted 2/11/2010) http://dx.doi:10.1016/j.envsci.2010.10.012

### 5.1.2. Others

*Lead by VUB (in preparation)*

Bos I., Jacobs L., Nawrot T., De Geus B., Degraeuwe, B., Int Panis L., Meeusen R. No exercise-induced increase in plasma BDNF after cycling near a major traffic road (in preparation)