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# Short-term effects of physical activity, air pollution and their interaction on the cardiovascular and respiratory system

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ABSTRACT

Physical activity (PA) in urban environments may lead to increased inhalation of air pollutants. As PA and air pollution (AP) have respectively beneficial and detrimental effects on the cardiorespiratory system, the responses to these exposures can interact. Therefore, we assessed the short-term effects of PA, AP and their interaction on a set of subclinical cardiovascular and respiratory outcomes in a panel of healthy adults: heart rate variability (HRV), retinal vessel diameters, lung function and fractional exhaled nitric oxide (FeNO).

One hundred twenty two participants measured their PA level and exposure to black carbon (BC), a marker of AP exposure, with wearable sensors during an unscripted week in three different seasons. The study was part of the PASTA project in three European cities (Antwerp: 41 participants, Barcelona: 41 participants, London: 40 participants). At the end of each measurement week, the health outcomes were evaluated. Responses to PA, BC and their interaction were assessed with mixed effect regression models. Separate models were used to account for a 2-h and 24-h time window.

During the 2-h time window, HRV and lung function changed statistically significantly in response to PA (METhours) and logarithmic BC (%change). Changes in HRV marked an increased sympathetic tone with both PA (logarithmic LF/HF: +7%; $p < 0.01$) and BC (logarithmic HF: −19%; $p < 0.05$). In addition, PA provoked bronchodilation which was illustrated by a significant increase in lung function ($FEV_1$: +15.63 mL; $p < 0.05$). While a BC %increase was associated with a significant lung function decrease (PEF: −0.10 mL; $p < 0.05$), the interaction indicated a potential protective effect of PA ($p < 0.05$). We did not observe a response of the retinal vessel diameters. Most subclinical outcomes did not change in the 24-h time window (except for a few minor changes in LF/HF, FeNO and PEF).

Our results on the separate and combined effects of short-term PA and AP exposure on subclinical markers of the cardiorespiratory system are relevant for public health. We provide insights on the physiological responses of multiple, complementary markers. This may move further research towards elucidating potential pathways to disease and the long-term clinical impact of the observed physiological changes.

## 1. Introduction/background

Particulate matter air pollution provokes over three million annual deaths worldwide and contributes to the onset and development of cardiovascular and respiratory conditions (Lim et al., 2012; Brook et al., 2010; Health Effects Institute, 2010). Epidemiological studies frequently study non-invasive outcomes such as heart rate variability (HRV), retinal vessel diameters, lung function and fractional exhaled

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nitric oxide (FeNO) to assess subclinical responses to air pollution (AP) that may be on the pathway of disease development (Sarnat et al., 2014; Weichenthal et al., 2011; Louwies et al., 2013; De Prins et al., 2014; Zuurbier et al., 2011).

Increased sympathetic tone, indicated by decreased HRV, and responses of the retinal vessel diameters are recognized as early markers of cardiovascular conditions (Schuster et al., 2014). In healthy individuals, the sympathetic and parasympathetic branch form the autonomic nervous system and are in dynamic balance (Thayer et al., 2010). Sympathetic domination provokes reductions in HRV which induces arrhythmias potentially leading to sudden death (Brook et al., 2010; Brook and Rajagopalan, 2009). In addition, microvascular narrowing as quantified through retinal image analysis is related to elevated blood pressure potentially leading to hypertension and cardiovascular diseases (Wong et al., 2006; Wong et al., 2002). Airway inflammation, as estimated with FeNO, and lung function are used to diagnose respiratory conditions (Dweik et al., 2011; Quanjer et al., 2012; Miller et al., 2005). High FeNO concentrations are associated with eosinophilic airway inflammation and impaired lung function indicates pulmonary diseases such as asthma or COPD. Elevated AP exposure has been associated with increased FeNO, reduced HRV, narrowed retinal arteriolar lumen and impaired lung function (Brook et al., 2010; De Prins et al., 2014; Adar et al., 2010; Rice et al., 2015). In contrast, better cardiovascular fitness is related to increased HRV (Kenney et al., 2011), wider retinal arterioles (Hanssen et al., 2011), and improved respiratory function (Cheng et al., 2003).

An adequate amount of physical activity (PA) prevents premature mortality and increases quality of life, yet 31% of the world's adult population does not reach the WHO recommended level of 600 metabolic equivalent (MET) minutes per week (Hallal et al., 2012). Active mobility (e.g. walking and cycling) has been introduced as an innovative and accessible measure to promote PA (Dons et al., 2015; Gerike et al., 2016). However, when PA takes place in urban outdoor settings, individuals may be exposed to elevated AP concentrations and higher ventilation rates during PA could increase the inhaled pollutant dose (Dons et al., 2015; Gerike et al., 2016; Nieuwenhuijsen, 2016; Dons et al., 2017). PA and AP exposure activate biological pathways that provoke subclinical changes in the cardiovascular and respiratory system (Brook et al., 2010; Huang et al., 2013; Gleeson et al., 2011). Hence, the responses may interact. A recent study in 135 older adults, with and without pre-existing COPD or ischaemic heart disease, assessed acute cardiorespiratory responses after a 2-h walk in high versus low AP concentrations (Sinharay et al., 2017). They found that the beneficial effects of walking on arterial stiffness and lung function were lost in a polluted environment. This illustrates that AP may attenuate the cardiorespiratory benefits of PA in vulnerable populations. Such results need to be complemented with studies of physiological responses in healthy volunteers. An experimental study in 29 healthy participants found that PA may protect against the short-term blood pressure increase associated with AP (Kubesch et al., 2014; Cole-hunter et al., 2016). Lung function improved with PA, while reductions were observed in association with AP (Kubesch et al., 2015). The adverse effects of AP on respiratory markers were negated by PA in a comparable study in Barcelona (Matt et al., 2016).

Considering the fact that many people are physically active in an urban environment, more evidence is needed to disentangle the short-term physiological responses to PA and AP. Assessing subclinical changes in healthy individuals may provide relevant information on the development of cardiovascular and respiratory diseases. The aim of the current study was to evaluate the short-term subclinical, cardiorespiratory effects of real-life PA, AP and their interaction in a sample of healthy adults.

## 2. Methods

### 2.1. Study design and participants

This study was part of the FP7 PASTA project (Physical Activity through Sustainable Transport Approaches) in which data on PA and travel behavior was collected in seven European cities (Antwerp, Barcelona, London, Örebro, Rome, Vienna and Zürich) (Dons et al., 2015; Gerike et al., 2016). Data was collected through online, longitudinal surveys that were completed by over 12,500 volunteers across a period of up to two years. From this sample, 122 participants took part in a real-world monitoring study between February 2015 and March 2016 in three cities: Antwerp (41 participants), Barcelona (41 participants) and London (40 participants). The participants collected high-resolution data on PA level and AP exposure with wearable sensors during seven consecutive days while performing their habitual activities. A battery of non-invasive measurements were used: HRV, retinal vessel diameters, FeNO, and lung function. These outcomes were measured at a research center in each of the three cities at the end of each measurement week. Each participant repeated the measurement week three times: in the mid-season (autumn or spring), in the summer and in the winter. Eligible participants were non-smoking, 18–65 years old with a self-reported BMI below 30 and no self-reported cardiovascular, respiratory or neurological condition. The study was approved by the ethics committee of each research center involved and all participants gave written informed consent prior to participation.

### 2.2. Physical activity assessment

PA was measured with the SenseWear armband (model MF-SW, BodyMedia, USA). This multi-sensor body monitor measures heat flux, galvanic skin response, skin temperature and 3-axis accelerometry on a one-minute basis. Participants wore the armband on the triceps muscle of the left arm and only removed it during contact with water (bathing, showering, etc.). Wearing time was 96 ± 4% (mean ± SD) of total participation time. Age, sex, body weight and height were provided to the SenseWear professional software (version 8.0) that calculates energy expenditure and METs (Metabolic Equivalent of Task, used to express exercise intensity) using proprietary algorithms based on pattern recognition (Bassett et al., 2012). The total amount of METhours (an integrated measure of PA intensity and duration) was calculated in R version 3.3.1 for each time window. Only bouts of at least 10 consecutive minutes with an intensity ≥3 METs were considered for the METhour calculations, in accordance with the WHO recommendations on PA for health (WHO, 2010). According to the updated compendium of physical activities by Ainsworth et al. (2000), 3 METs is the amount of energy required to e.g. walk the dog (Ainsworth et al., 2000). Doing this for one hour results in 3 METhours.

### 2.3. Personal air pollution exposure assessment

Personal AP exposure was assessed by measuring black carbon (BC). A major element of diesel exhaust emissions and therefore abundantly present in urban areas (Janssen et al., 2011). Since BC consists of particles that are mostly smaller than one micrometer, they have a high pulmonary penetration capacity. Therefore, such small particles are believed to be more harmful than larger ones, which makes BC a valuable marker to study the physiological effects of AP (Janssen et al., 2011; Seaton et al., 1995).

Exposure to BC was measured on a personal level using the microAeth (model AE51, Aethlabs, USA). Air was drawn over a Teflon-coated borosilicate glass fibre filter at a flow rate of 100 mL/min, resulting in BC accumulation on the filter. The microAeth detects the changing optical absorption of light transmitted through the filter at wavelength of 880 nm. The microAeth logs the average BC concentration on a five-minute basis. Participants were instructed to always carry