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Acute respiratory response to traffic-related air pollution during physical activity performance

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ABSTRACT

Background: Physical activity (PA) has beneficial, whereas exposure to traffic related air pollution (TRAP) has adverse, respiratory effects. Few studies, however, have examined if the acute effects of TRAP upon respiratory outcomes are modified depending on the level of PA.

Objectives: The aim of our study was to disentangle acute effects of TRAP and PA upon respiratory outcomes and assess the impact of participants TRAP pre-exposure.

Methods: We conducted a real-world crossover study with repeated measures of 30 healthy adults. Participants completed four 2-h exposure scenarios that included either rest or intermittent exercise in high- and low-traffic environments. Measures of respiratory function were collected at three time points. Pre-exposure to TRAP was ascertained from land-use-modeled address-attributed values. Mixed-effects models were used to estimate the impact of TRAP and PA on respiratory measures as well as potential effect modifications.

Results: We found that PA was associated with a statistically significant increases of FEV_1 (48.5 mL, $p = 0.02$), FEV_1/FVC (0.64%, $p = 0.005$) and $FEF_{25–75\%}$ (97.8 mL, $p = 0.02$). An increase in exposure to one unit (1 $\mu g/m^3$) of PM_{coarse} was associated with a decrease in FEV_1 (−1.31 mL, $p = 0.02$) and FVC (−1.71 mL, $p = 0.01$), respectively. On the other hand, for an otherwise equivalent exposure an increase of PA by one unit (1%Heart rate max) was found to reduce the immediate negative effects of particulate matter (PM) upon PEF ($PM_{2.5}$, 0.02 L/min, $p = 0.047$; PM_{10}, 0.02 L/min $p = 0.02$; PM_{coarse}, 0.03 L/min, $p = 0.02$) and the several hours delayed negative effects of PM upon FVC (PM_{coarse}, 0.11 mL, $p = 0.02$). The negative impact of exposure to TRAP constituents on FEV_1/FVC and PEF was attenuated in those participants with higher TRAP pre-exposure levels.

Conclusions: Our results suggest that associations between various pollutant exposures and respiratory measures are modified by the level of PA during exposure and TRAP pre-exposure of participants.

1. Introduction

Worldwide, in urban environments, millions of people are exposed daily to air pollution levels well above national and international standards (Chen and Kan, 2008; WHO, 2006). One major source of the observed air pollution is the high traffic-density of cities (Chen and Kan, 2008). Long-term exposure to traffic-related air pollution (TRAP) is associated with adverse health impacts such as respiratory symptoms, as well as increased morbidity and mortality (Hoek et al., 2013; Peters et al., 2012; Raaschou-Nielsen et al., 2012; Strak et al., 2010; Willers et al., 2013). TRAP contributes to these health outcomes among others by mechanisms involving oxidative stress and inflammation (Anderson et al., 2012; Delfino et al., 2009).

Health co-benefits of physical activity (PA) are well known and are often promoted in public health measures (Haskell et al., 2009; Kohl et al., 2012; Warburton et al., 2006). Among the adaptations of the respiratory system in response to exercise are an increase in ventilation rate and bronchodilation lasting beyond the exercise period (Anderton et al., 1979; Cheng et al., 2003; Crimi et al., 2002; Freedman et al., 1988;

Abbreviations: PA, physical activity; TRAP, traffic-related air pollution; LT, low traffic; HT, high traffic; T_0–T_2, time points of lung function measurements; HR, heart rate.

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Scichilone et al., 2010). Due to these respiratory adaptations, the volume of inhaled air and the fraction of air-suspended particles deposited in the respiratory tract are considerably higher during exercise compared to rest (Daigle et al., 2003; Jakob and Massling, 2007). Indeed, studies have shown that individuals deciding to perform PA in an urban environment risk a higher exposure to TRAP compared to sedentary individuals or people exercising indoors or in rural environments (van Wijnen et al., 1995; Watt et al., 1995).

Besides the above, a change from private-automobile usage to active mobility like cycling or walking is often promoted as a means of reducing TRAP levels in urban areas. However, opting for active transportation has been found to increase exposure to TRAP (Knibbs et al., 2011; Zuurbier et al., 2010), which could lead to a decrease in lung function in susceptible and healthy adults (McCreanor et al., 2007; Mu et al., 2014), and to a substantial increase in the inhaled dose of TRAP (Int Panis et al., 2010; Zuurbier et al., 2010; Zuurbier et al., 2009). To date, despite some previous studies (de Hartog et al., 2010; Kubesch et al., 2015), there is still reasonable doubt as to whether the conjunction between performing PA and being exposed to high levels of TRAP is either beneficial or detrimental for lung function.

It is therefore of scientific and public health interest to understand whether the respiratory effects of PA are modified when it is performed in an urban, highly-polluted environment. Moreover, since studies suggest that air pollution pre-exposure modifies respiratory function (Giles et al., 2012), the influence of participants pre-exposure is of interest. Many epidemiological studies assessing the acute respiratory effects of air pollutants only examine susceptible subpopulations (Bentayeb et al., 2012; Delfino et al., 2008; Lee et al., 2007; Lewis et al., 2005; McCreanor et al., 2007; O'Connor et al., 2008; Peacock et al., 2011; Qian et al., 2009; Weinmayr et al., 2010) and whether findings of these studies can be transferred to healthy individuals remains questionable. Furthermore, studies examining the respiratory short-term effects of an exposure to elevated levels of air pollution are still rare and not designed to examine effect modifications on a single pollutant level (Cole-Hunter et al., 2015a; Cole-Hunter et al., 2013; Mu et al., 2014). A large Danish cohort study found beneficial health effects of regular PA not to be moderated by the long term exposure to urban levels of air pollution (Andersen et al., 2015). However, whether this can be transferred to the short term effects of PA remains questionable. As such, our study was intended to assess the impact of PA on the acute relationship between respiratory function and surrounding levels of air pollution and to contribute to the growing body of evidence from studies examining healthy subpopulations. Identifying potential interdependent effects of air pollution and PA can help to advise public health measures such as encouraging active mobility.

The type of interaction terms we use in our models to examine the interdependence of the effects of two factors, assume that each factor modifies the effect of the other. Hence, for example, we cannot say what the effect of PA will be (to increase, decrease, or have no effect on the respiratory measure) unless we know that person's value for the level of TRAP exposure (and conversely, we cannot know the effect of TRAP exposure without knowing that person's level of PA).

2. Methods

2.1. Study design

Our study was conducted in Barcelona, Spain, between November 2013 and February 2014. A well-controlled crossover study design, comprising of four exposure scenarios performed in a random order, was chosen to disentangle the short-term effects of TRAP and PA on participants' respiratory function. These scenarios were defined by a combination of the exposure status (low or high TRAP environment) and the PA-status (rest or intermittent exercise). Each participant took part on four study days (turns), completing one exposure scenario a day. Six subjects were studied simultaneously on each study day, with three of them performing intermittent (moderate) PA (as 15-min intermittent cycle ergometry) while the other three volunteers rested. To avoid a diurnal effect, all experiments and measurements were scheduled at the same time during the day. On study days, participants arrived to the clinic at 06:45 for baseline measurements (T_0); afterwards, from 08:00 to 10:00 (i.e. morning traffic “rush hour”) they were exposed to either low TRAP in a quiet seaside park (low traffic (LT) site) or high TRAP at a pedestrian overpass of a highway (high traffic (HT) site). Study sites were selected due to them representing low and high traffic-density areas and also their close proximity to the clinic where baseline health measurements were taken, and thus in-transit exposure of participants (and consequent exposure-response effect prior to study period) is minimized when moving from the clinic to the study site. These low and high definitions were confirmed by describing the sampled data while the study progressed – full exposure descriptions of each site are presented later as results (Table 2). To minimise prior exposure to TRAP and performance of PA, participants were requested to arrive prior to rush hour and via underground rail. Volunteers were transported by van (cycle-ventilated, windows closed) to either exposure site, which were of equivalent distance (approximately a one kilometre or five minute drive) from the clinic. The study days were scheduled on Tuesdays, Wednesdays, and Thursdays to avoid atypical weekend-related (commuting) TRAP levels. A two-hour exposure period was chosen as this was found to be a typical local average time spent in-transit over the course of a day (De Nazelle et al., 2013). Immediately after the two-hour exposure participants returned to the clinic to have the post-exposure (T_1) health measurements taken. Participants were then free to live their day normally for a period of 7 h, before returning to the clinic for the 7-hour-post-exposure (T_2) health measurements. We chose the free-living period to see whether acute effects observed immediately after exposure sustain and/or change over a period of 7 h if people were free to live their day normally, rather than as a scripted study procession. During the free-living period participants were carrying a Cambridge Personal Environmental Monitor (PEM) recording exposure data for NO, NO_2 and CO. Furthermore, heart rate (HR) was monitored with an ambulatory electrocardiography monitor (ModelCardioLight, Gem-Med, ESP).

Eligible participants were required to be: (1) in the age range of 18–60 yrs.; (2) non-smokers or ex-smokers (minimum one year without smoking); (3) not taking any medication (except contraception pill), nor any vitamins, nor any kind of allergy medication/treatment (at least for the last three months); (4) not being pregnant and not suffering from any chronic illness (high blood pressure, diabetes, pulmonary or cardiovascular diseases, etc.). Participants were required to abstain from high-intensity exercise, from alcohol, and from caffeine for at least 48, 24 and 4 h, respectively, before baseline measurements. The Ethic Review Committee of the Institut Municipal d'Investigatió Mèdica (IMIM) approved the study and prior to participation all participants gave written informed consent.

2.2. Physical activity monitoring

During the experiment, moderate PA performance was checked continuously by a fingertip pulse oximeter (Konica Minolta, Japan), being defined as a heart rate (HR) between 50 and 70% of an individual's predicted maximum HR, according to participant age and sex [males: $HR_{max} = 220 - (age)$; females: $HR_{max} = 206 - 0.88 * (age)$] (Gulati et al., 2010). Further, HR during the experiment (in parallel to oximetry) and free time was monitored with an ambulatory electrocardiography monitor (ModelCardioLight, Gem-Med, Spain).

2.3. Environmental exposure monitoring

Exposures at either study site were continuously monitored for ultra-fine particle (UFP; 0.01–1.0 μm) counts using a condensation particle counter (CPC, Model 3007, TSI, Minnesota, USA) (applied