Environmental Research 158 (2017) 286–294

Contents lists available at ScienceDirect

Environmental Research

journal homepage: www.elsevier.com/locate/envres

Validating novel air pollution sensors to improve exposure estimates for epidemiological analyses and citizen science

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ARTICLE INFO

Keywords:
Low cost
Personal air pollution sensor
Exposure
CO
NO
NO_2

ABSTRACT

Low cost, personal air pollution sensors may reduce exposure measurement errors in epidemiological investigations and contribute to citizen science initiatives. Here we assess the validity of a low cost personal air pollution sensor. Study participants were drawn from two ongoing epidemiological projects in Barcelona, Spain. Participants repeatedly wore the pollution sensor − which measured carbon monoxide (CO), nitric oxide (NO), and nitrogen dioxide (NO_2). We also compared personal sensor measurements to those from more expensive instruments. Our personal sensors had moderate to high correlations with government monitors with averaging times of 1-h and 30-min epochs ($r \sim 0.38$–0.8) for NO and CO, but had low to moderate correlations with NO_2 (~0.04–0.67). Correlations between the personal sensors and more expensive research instruments were higher than with the government monitors. The sensors were able to detect high and low air pollution levels in agreement with expectations (e.g., high levels on or near busy roadways and lower levels in background residential areas and parks). Our findings suggest that the low cost, personal sensors have potential to reduce exposure measurement error in epidemiological studies and provide valid data for citizen science studies.

1. Introduction

Efforts to characterize air pollution exposure in epidemiological and public health studies have typically estimated ambient air pollution levels based on the nearest routine monitor or a prediction model such as disperson or land use regression models (Jerrett et al., 2005). These estimates are then usually assigned to an individual through their home address. Although important health risks have been revealed, reliance on proxy methods may impart large exposure-measurement error. Depending on the exposure-error type, health effect estimates may be attenuated and biased toward a null result, obscuring the true benefits of air pollution control measures (Zeger et al., 2000). This is particularly important for pollutants with high spatial variability, such as traffic-related air pollutants (Suh and Zanobetti, 2010).

Innovations in science and technology such as mobile, personalised sensing now provide opportunities to overcome limitations that have led to exposure-measurement errors. These innovations also provide opportunities to understand multiple exposures in time and space and are now spurring fields known as "ubiquitous" and "participatory" sensing that have substantial relevance to the future of environmental epidemiology in particular, but more generally for public health protection (National Academy of Science Committee on Human and Environmental Exposures, 2012).

We define ubiquitous sensing as a network of sensors, such as a

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http://dx.doi.org/10.1016/j.envres.2017.04.023
Received 23 August 2016; Received in revised form 17 March 2017; Accepted 20 April 2017

dense array of air pollution monitors, that have wide spatial coverage and are embedded in urban areas. Participatory sensing is defined as a means of obtaining detailed information on personal and population exposures via citizens volunteering to carry sensors to supply this data (as citizen scientists) – often in exchange for useful information that might allow them to better understand and prevent harmful exposures they face (Lahoz, 2014; Castell et al., 2017). Such definitions have invariably fuzzy boundaries, where an exposure information gained from participatory sensing may be used in tandem with information from a ubiquitous network to develop more precise estimates of exposure (Turner et al., in press). Ubiquitous and participatory sensors can improve air pollution exposure estimates in both epidemiological studies and empowerment exercises where citizen scientists seek to understand how ambient exposures could be affecting their health (Liu et al., 2014). Such improvements in exposure assessment may refine the estimates of health effects from air pollution or give citizens better information on the health risk they face from ambient exposures. In both instances, better exposure assessments from sensors could result in improved public health protection.

While this kind of sensing shows excellent promise, there have been few published attempts to validate how well the sensors function when deployed on free-living human participants. Recent studies have demonstrated the utility of having personal measurements of exposure and location to assess air pollution exposures, but these efforts have used expensive, commercially-available sensors that in most instances cannot be deployed en mass in larger epidemiological studies because of relatively high cost ($2000-10,000 USD per unit) (Nieuwenhuijsen et al., 2015). In this paper we report on a series of validation studies for a novel, low-cost personal air pollution sensor (i.e., less than $600 USD per unit).

2. Methods

2.1. Sensor design

The personal sensors used here were designed and built at Cambridge University, UK (for short we call them “CamPerS” for **Cam**bridge **Per**sonal **S**ensors). The CamPerS were designed to be compact and lightweight and thus convenient for participants to carry. Electrochemical sensors from Alphasense Ltd. (UK) were incorporated for carbon monoxide (CO), nitric oxide (NO), and nitrogen dioxide (NO_2) along with a temperature sensor, a Global Positioning System (GPS) and General Packet Radio Service (GPRS) transmittor. All of the sensors are mounted behind a metal mesh opening at one end of the unit (Fig. 1 illustrates the version used in this validation study). The sensors weigh ~450 g with the batteries and ~ 330 g without batteries.

Earlier work by Mead et al. (2013) gives more details on sensor design and laboratory and field performance.

2.2. Field studies

Field deployments occurred in two ongoing case-crossover studies undertaken in Barcelona, Spain: (1) Positive Health Effects on the Natural Outdoor Environment in Typical Populations of different regions in Europe (PHENOTYPE), and (2) Transportation Air pollution and Physical ActivitieS (TAPAS) II Experimental Study Extension.

The PHENOTYPE study involved 26 adults with poor mental health who visited three environments: green (i.e. natural park), blue (i.e. beachfront) and urban (i.e. mixed-use neighborhood). Psycho-physiological measures were taken before, during (at 30 and 210 min), and after each visit. Study participants were asked to stay in each of the environments behaving as they would normally in that environment (while avoiding swimming, vigorous physical activity and only eating or drinking what was provided). Participants were repeatedly monitored for air pollution with CamPerS, geographic location, and physical activity (see Nieuwenhuijsen, 2013, for more details) (Donaire-Gonzalez et al., 2013).

The TAPAS II study involved 30 healthy, non-smoking adults who rode stationary bicycles or sat resting in two contrasting environments – a high traffic zone on a bridge above a major highway with substantial automobile and truck traffic and a low traffic environment in a park with few immediate emission sources. Physiological measures were taken before and after riding or resting in each setting. Study participants were allowed to go about their normal lives in the interval between the scripted exposures and their follow-up physiological measurements six hours later.

In both studies, numerous other research-grade instruments measuring similar parameters to the CamPerS were arrayed in proximity to the study participants during scripted exposures.

Field data were collected between September 2013 and February 2014 by trained technicians. CamPerS measured NO_2, NO and CO on 10-second intervals. Participants wearing the CamPerS also carried a cellular phone with software for measuring geographic location and physical activity assessment (see de Nazelle et al., 2013 and Donaire et al., 2013 for details of this assessment).

2.3. Validation protocol

With our validations we sought to determine how well the CamPerS could replicate measurements taken by either ratified government monitors or more expensive, larger research-grade instruments. We also sought to determine whether the monitors could classify meaningful differences among ambient and indoor microenvironments based on samples collected by our study participants. To conduct our validation, we followed four steps:

1. We calibrated the CamPerS in chamber experiments to determine the zero value for each sensor. This involved constructing a pollution chamber and filling it with purified zero air and running controlled experiments. We also conducted bump tests where higher levels were introduced into the chamber to evaluate responsiveness and drift back to lower levels. This work was conducted in the Cohen Atmospheric Chemistry lab at University of California, Berkeley.

Fig. 1. Cambridge Personal Sensor (CamPerS) with essential components shown (approximate weight 450 g with batteries and 330 g without batteries).