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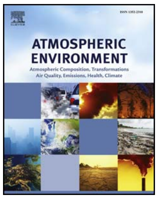

Short communication

Accuracy and practicality of a portable ozone monitor for personal exposure estimates

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ABSTRACT

Accurate measurements of personal exposure to atmospheric pollutants such as ozone are important for understanding health risks. We tested a new personal ozone monitor (POM; 2B Technologies) for accuracy, precision, and ease of use. The POM's measurements were compared to simultaneous ozone measurements from a 2B Model 205 monitor and a ThermoScientific 49i monitor, and multiple POMs were placed side-by-side to check precision. Tests were undertaken in a controlled environmental facility, outdoors, and in a private residence. Additionally, ten volunteers wore a POM for five days and answered a questionnaire about its ease of use.

The POM measured ozone accurately compared to the 49i ozone monitor, with average relative differences of less than 8%. In the controlled environment tests, the POM's ozone measurements did not change in the presence of additional atmospheric constituents with similar absorption lines to ozone, though there may have been a small decrease in precision and accuracy. Precision between POMs varied by environment ($r^2 = 0.98$ outdoors; $r^2 = 0.3$ to 0.9 in controlled lab conditions). Volunteers reported that the POM was reasonably comfortable to wear, although all reported that they felt that it was too noisy. Overall, the POM is a viable option for personal ozone monitoring.

1. Introduction

Ozone (O_3) is one of the United States Environmental Protection Agency's criteria pollutants. Increased concentrations of ozone are associated with decreased lung function (Brauer and Brook, 1997) and an increase in daily morbidity and mortality (Bell et al., 2014; Ito et al., 2005; Sunyer et al., 2002; Weisel et al., 2002) at elevated levels. However, characterization of the level and pattern of personal ozone exposure with a resolution of minutes has been limited due to lack of personal ozone monitors. Rather, integrated ozone measurements, ambient ozone concentration and model approaches have been used as a surrogate for personal exposure in health studies (Bell, 2006; Jerrett et al., 2009). Quantifying personal exposure to ozone is thus important for understanding health effects, which may be a result of peak concentration, short term excursions or repetitive average daily exposures measured as an integrated concentration, which has led to changes in the ozone standard in the United States (Rombout et al., 1986). Exposure to ozone changes throughout a day due to its production, removal processes and transport in ambient air, its losses when transported indoors and people's movement between indoor and outdoor locations (Weschler et al., 1989). These changes will not be identified from a long term integrated sample. Personal sampling, in which a person wears sampling equipment for a period of time, provides a more accurate representation of the amount of a pollutant that is inhaled than stationary or central point ambient air monitoring, since peak values differ over small spatial regions (Monn, 2001) and there are losses of ozone when it is transported indoors (Liu et al., 1993; Weschler, 2006). Furthermore, central point ambient air monitoring does not account for indoor ozone concentrations, which have been measured to be 3–60% of the ambient concentration depending upon the ventilation system and air exchange rate (Lee et al., 2004; Liu et al., 1995; Zhang and Lioy, 1994). Ozone personal samplers based on passive badges have been successfully used in exposure studies (Demirel et al., 2014; Koutrakis et al., 1994; Liard et al., 1999; Liu et al., 1995) but only provide average concentrations over extended time periods and require chemical laboratories to analyze the badge. Recently, several small continuous ozone monitors have been proposed or developed for incorporation into personal samplers based on: semi-conductions sensors (Cao and Thompson, 2016; Piedrahita et al., 2014), electrochemical cells (Cho, 2015; Pang et al., 2017), dispersive surface acoustic wave (SAW)

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Table 1
Summary of study design.

Test purpose	Location	Ozone source	Additional variables	POM(s) used	Comparison instruments used	Averaging Time for Measurement	Duration of full test(s)	Section in paper
Precision between POMs	Controlled Exposure Facility (CEF)	Corona Discharge Ozone Generator; see text	Challenge compounds	1 and 2	None	1 min averages	30 min to 6 h	3.1.1
Precision between POMs	Outdoors (rooftop)	Ambient Air	Rain	Commercial	None	5 min averages	24 h	3.1.2
Precision between POMs	Indoors (private residence)	Ambient Air Penetration Indoors	Stir-fry cooking, worn by person	1 and 2	None	1 min averages	8 h	3.1.3
Accuracy of POM	Controlled Exposure Facility (CEF)	Corona Discharge Ozone Generator; see text	Challenge compounds	1 for ozone only; 1 and 2 for tests with challenge compounds	205 Monitor, 49i	1 min averages	30 min to 6 h	3.2.1
Accuracy of POM	Outdoors (rooftop)	Ambient Air	Rain	Commercial	205 Monitor	1 min averages	24 h	3.2.2
Accuracy of POM	Indoors (private residence)	Ambient Air Penetration Indoors	Stir-fry cooking, worn by person	2	205 Monitor	1 min averages	8 h	3.2.3
Practical use of POMs	Various (POMs worn by volunteers)	n/a	None	1 and 2	None	n/a	5 days	3.3

(Westafer et al., 2014) and ultraviolet light adsorption (Andersen et al., 2010). Several strengths and weaknesses of these systems have been reviewed (e.g., McKercher et al., 2017; Snyder et al., 2013).

The Personal Ozone Monitor (POM; http://www.twobtech.com/model_POM.htm) was developed by 2B Technologies to address the need for a lightweight, portable, battery operated, and moderately-price ($4500) way to measure personal exposure to ozone using a similar premise to the 2B Technology 205 ozone monitor (Andersen et al., 2010). In this study, we evaluate POM precision and accuracy 1) within a controlled environmental of ozone alone and in the presence of additional compounds, 2) outdoors in the ambient environment, and 3) indoors in a private residence. Additionally, the POM was evaluated by volunteers for practicality for everyday personal use. The study design is summarized in Table 1.

2. Methods

2.1. Instrument description

Similar to 2B's 205 ozone monitor, the POM uses the absorption of UV light at 254 nm to determine ozone concentrations, but with a curved optical path, thus reducing the size of the instrument (10 cm × 7.6 cm × 3.8 cm, 0.45 kg, power requirements of 2.9 W supplied by a Lithium Ion 7.4 V battery which operates up to 8 h on a charge). The POM operates at a flow rate of 0.8 L/min and records ozone concentrations at a resolution of 10 s, with the option to store data as 1-min, 5-min, or 1-h averages. We operated the POM with a 1-min average. The limit of detection is 4 ppb, which is below the ozone concentration typically encountered in ambient air. Two POMs (subsequently referred to as POM 1 and POM 2) were received from 2B Technologies during their evaluation phase of the POM development and were used for evaluation tests in the Controlled Environment Facility (CEF; see additional details below) at Rutgers University, indoors and subject evaluation. The outdoor tests were done on POMs that were purchased once they became commercially available.

2.2. Experimental design

To evaluate the accuracy of the POM, we compared its measurements to a 2B Technology Model 205 ozone monitor and a ThermoScientific 49i ozone monitor. The ThermoScientific monitor and the 2B Technology Model 205 are Federal Equivalent Methods (FEM) for ozone measurement (# EQOA-0410-190). These comparisons were carried out in three different settings: the CEF, in which ozone concentrations, temperature (21 ± 2 °C), and relative humidity (45 ± 10%) were closely controlled; outdoors; and inside a private residence (Table 1). Two POMs were also run simultaneously in these settings to assess inter-unit precision.

One set of experiments took place in the CEF at Rutgers University in Piscataway, New Jersey. The CEF is a 25 m^3 steel-walled chamber in which atmospheric constituents can be closely monitored and controlled. The CEF has a single-pass through ventilation system with inlet air filtered through a HEPA filter and a charcoal filter. Ozone and other test compounds can be added to the air stream in a baffle system to facilitate mixing and released into the CEF through a series of diffusors. Further air mixing in the CEF is accomplished using a series of 6 small fans located near the ceiling at corners/wall edges of the CEF. The air exchange rate was set to 45 ACH. Each instrument was placed inside the CEF with their inlets within 1 m of each other. Ozone was produced using an Ozone Research and Equipment Corporation (OREC) generator to create a concentration range of 50–170 ppb in the CEF. It was introduced into the CEF to provide both steady-concentration periods and periods with rapid increase or decrease in ozone concentration.

Potential interferences from other compounds on ozone measurements were evaluated by introducing a series of “challenge” compounds in the CEF while ozone was held constant at 65–90 ppb. This allowed