Environmental Research 107 (2008) 401–411

Contents lists available at ScienceDirect

Environmental Research

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

Public perception and behavior change in relationship to hot weather and air pollution ☆

Jan C. Semenza [a,*], Daniel J. Wilson [b], Jeremy Parra [c], Brian D. Bontempo [b], Melissa Hart [d], David J. Sailor [d], Linda A. George [c]

[a] School of Community Health, Portland State University, P.O. Box 751, Portland, OR 97207-0751, USA
[b] Mountain Measurements, P.O. Box 12274, Portland, OR 97212, USA
[c] Environmental Sciences and Resources Program, Portland State University, P.O. Box 751, Portland, OR 97207, USA
[d] Mechanical and Materials Engineering Department, Portland State University, P.O. Box 751, Portland, OR 97207-0751, USA

ARTICLE INFO

Article history:
Received 3 September 2007
Received in revised form
7 March 2008
Accepted 12 March 2008
Available online 7 May 2008

Keywords:
Heat wave
Hot weather
Climate change
Temperature
Humidity
Air pollution
$PM_{2.5}$
Ozone
Air conditioning
Advisory
Health behavior

ABSTRACT

Background: Changes in climate systems are increasing heat wave frequency and air stagnation, both conditions associated with exacerbating poor air quality and of considerable public health concern.
Objectives: Heat and air pollution advisory systems are in place in many cities for early detection and response to reduce health consequences, or severity of adverse conditions. Whereas the ability to forecast heat waves and/or air pollution episodes has become increasingly sophisticated and accurate, little is known about the effectiveness of advisories in altering public behavior.
Methods: Air quality and meteorological conditions were measured during advisory and control days in Portland, OR and Houston, TX in 2005 and 2006 and 1962 subjects were interviewed by telephone about their perception and response to these conditions.
Results: Elevated ambient temperatures were accurately recognized regardless of air conditioning use; in Portland, respondents resorted to active cooling behavior (AC, fan, etc.), while in Houston no such change was observed. More heat-related symptoms were reported in Portland compared to Houston, probably due to low air conditioning use in the northwest. One-third of study participants were aware of air quality advisories but only ~10–15% claimed to have changed activities during such an episode. Not the advisory, however, drove their behavior change, but rather the perception of poor air quality, which was not related to $PM_{2.5}$ or ozone measurements.
Conclusions: Messages are not reaching the public during potentially hazardous weather and air quality conditions. Climatic forecasts are increasingly predictive but public agencies fail to mount an appropriate outreach response.

1. Introduction

The need for a rapid public health response to weather-related disasters has become apparent in recent years (Epstein, 2005). Catastrophic events such as Hurricane Katrina and the 2003 heat wave in Europe have triggered accelerated developments in public health to respond to these challenges. Real-time surveillance, syndromic surveillance, or interoperable heat health warning plans are part of this new research agenda (Broome, 2005; Leonardi et al., 2006). The goal is to provide rapid alerts of emerging epidemics or unusual (weather) conditions to assure timely intervention. A particular problem arises for early detection and prediction of meteorological conditions threatening public health, such as excessive heat or poor air quality. Because they are invisible, silent, and underrated, they tend to be insidious killers.

Heat waves are sporadic but recurrent, and are considered a mere annoyance, rather than a threat; however, on average, in the United States, heat kills almost 700 people each year (CDC, 2006). Numerous studies of historical heat waves have documented excess morbidity and mortality (Semenza et al., 1996, 1999). In addition, every year millions of people in the US are exposed to elevated levels of urban air pollutants that have been linked to adverse health outcomes. Urban air pollution is a complex

Abbreviations: AC, air conditioning; PM, particulate matter; ODEQ, Oregon Department of Environmental Quality; RDD, random-digit-dial; TCEQ, Texas Commission on Environmental Quality; PSU, Portland State University; CMAQ, Community Multiscale Air Quality.

☆ Human Participant Protection: The institutional review board of Portland State University approved the protocol for this study. Oral informed consent that briefly described the study with all the procedures and activities was obtained from study participants prior to the completion of the phone surveys.

* Corresponding author. Current address: European Centre for Disease Prevention and Control (ECDC), Tomtebodavägen 11A, S-171 83 Stockholm, Sweden. Fax: +46 8 58 60 1001.
E-mail address: semenzaj@pdx.edu (J.C. Semenza).

0013-9351/$ - see front matter © 2008 Elsevier Inc. All rights reserved.
doi:10.1016/j.envres.2008.03.005

mixture of hazardous and toxic gaseous and particulate matter (PM). Health effects of individual pollutants have been documented including ozone (Schildcrout et al., 2006), PM_{10} and $PM_{2.5}$ (Gauderman et al., 2004) and can have synergistic effects with heat (Filleul et al., 2006). In addition, interaction effects have been noted for multiple pollutants making it particularly important to improve overall air quality and reduce human exposure in urban environments (Samet and Krewski, 2007).

In response to these public health challenges, warning systems have been developed that aim to predict at which point meteorological and air quality conditions become sufficiently hazardous to trigger an alert. Forecasting methods for triggering advisories have become increasingly sophisticated and accurate. Health impacts of excessive heat and poor air quality are well documented. However, there are few studies that examine human perception of ambient conditions or behavioral response to advisories either to reduce personal risk or to reduce one's contribution to the adverse conditions.

This study examined public perception of hot weather and poor air quality in two test bed cities, Portland, Oregon and Houston, Texas, in order to assess the effectiveness of such advisories. Monitoring meteorological conditions and epidemiologic intelligence will increasingly be part of public health practice aiming to protect the health of the public (Kaiser et al., 2006). The effectiveness of these multisectorial efforts remains to be documented and this study aims to assess the response and perception to these measures. In Portland no heat warning systems had been established until 2006 when the first warning was enacted in July 25–28, during a record setting episode. Clean air action days were also enacted in response to poor air quality. In contrast, Houston experiences regularly very high temperatures and poor air quality and was included in this study as a comparison city.

In Portland, the air quality advisory system is triggered by the Oregon Department of Environmental Quality (ODEQ) who alerts the media, sends out e-mail notices to citizens who have previously requested this information and places messages on electronic freeway message boards. The ODEQ air pollution advisory requests voluntary change in behavior to reduce "pollution from cars, mowers, paint, and aerosol sprays" with specific instructions about how to reduce such emissions (e.g. reducing idling). Information about potential health impact of smog is also provided. Citizens are referred to their health providers to obtain specific advice.

In Houston, the Texas Commission on Environmental Quality (TCEQ) e-mail alert only contains information about health impact and states: "Active children and adults as well as people with respiratory disease, such as asthma, should limit prolonged outdoor exertion." There is no request to change activities that may affect emissions of ozone precursors.

In order to assess the reach and benefits of these advisories to the general population a random sample of individuals was called in the two test bed cities. Portland and Houston differ in their climatic conditions and air conditioning (AC) usage and in many ways serve as two extremes on the continuum of air quality and meteorological conditions in the US. Thus, the aim of this study was to assess whether such a passive system of outreach to the public is reliable enough to trigger a change in behavior in relationship to these environmental conditions.

2. Methods

2.1. Survey

Human activity levels in response to oppressive atmospheric conditions (heat and air quality) and health advisories was assessed in two test bed cities, Portland, OR and Houston, TX. Cross-sectional surveys were conducted at the conclusion of selected heat waves and poor air quality episodes, as well as control days, during the summers of 2005 and 2006. These surveys were administered in some instances during less severe conditions than those needed to trigger an ozone or heat advisory in order to isolate response with and without the presence of advisories. This trigger was based on specific predetermined meteorological criteria according to analysis of 3–5 years of historical data with a high probability of triggering multiple non-advisory surveys each summer.

Subjects were enrolled using random-digit-dial (RDD) telephone surveys with geographic specificity of numbers in the RDD sampling frame. Once the predetermined meteorological criteria were met, interviewers at the state-of-the-art Computer Assisted Telephone Interviewing system in Portland State University (PSU)'s Survey Research Laboratory randomly called individuals in the area. In each city, we enrolled approximately 125 individuals per episode that met the inclusion criteria, representing a cross-section of the population. The surveys were conducted shortly after episodes of poor air quality and/or oppressively hot conditions, and encompassed both weekday and weekend episodes as well as episodes with and without accompanying health advisories.

The interviews were designed to seek information on the following topics: age, sex, and self-reported health status; location; typical driving/commute patterns (car, bus, carpool, distances, #'s of trips); type of residence (house, apartment, etc.); availability of AC (history of installation, mode of operation); perceptions of poor air quality and extreme heat; and awareness and attitudes toward advisory systems.

The surveys triggered by weather/air quality conditions were designed to identify changes in activity patterns that are a direct result of weather/air quality conditions and/or health advisories. These surveys also aimed to identify the way in which respondents obtain information regarding adverse health conditions, and their perceptions of the reliability of such information.

2.2. Air quality and meteorological data

Temperature, relative humidity, wind speed, solar radiation, ozone, nitric oxide, nitrogen dioxide, and $PM_{2.5}$ data were collected by the TCEQ (for Houston, TX), the ODEQ and a network of PSU monitoring stations (for Portland, OR) during the survey periods. In Houston, TCEQ maintains a large number of multi-parameter monitoring stations and we were able to gather data necessary for our analysis from this network. In Portland, ODEQ maintains only one comprehensive air quality monitoring station. There are three ODEQ ozone monitoring stations in Portland. We supplemented this network by installing our own equipment at ODEQ ozone sites (with nitrogen oxide monitoring), installing ground-based temperature loggers at 12 sites in the Portland area and collecting air quality data at our downtown PSU station. Our rooftop monitoring station measures ozone (Dasibi Model (1003AH) ± 2 ppb), nitrogen oxides (Thermoelectron Model (42C xxx) ± 2 ppb) and b_{scat} or light scatter extinction (Radiance Research Nephelometer M903). These instruments were calibrated with ODEQ. Temperature data was gathered from ground-based temperature loggers (HOBO-PRO 8 calibrated accuracy $\pm$.25 C) in radiation shields mounted on telephone poles 3 m above ground. Temperature sensors were calibrated with a NIST-traceable temperature sensor. Quality assurance measures were conducted by ODEQ, TCEQ, and PSU. The data was reviewed further in this study to determine if there were any outliers or inconsistencies in the dataset.

Heat index was calculated from ground-based downtown temperatures and relative humidity in both cities using National Oceanic and Atmospheric Administration's Heat Index formula (Rothfusz, 1990; Steadman, 1984). $PM_{2.5}$ filter measurements are made daily in Houston, but in Portland, $PM_{2.5}$ is collected on every 3rd day. The measurement coincided with one Portland survey date. However, there are continuous nephelometer scattering data available from ODEQ and PSU sites. ODEQ has correlated Portland area b_{scat} levels to $PM_{2.5}$ Federal Reference Method levels resulting in a relationship of 18.7 $\mu g/m^3$ per 100 m/M ($r^2 = .85$, $N = 1707$). We used this relationship to calculate $PM_{2.5}$ levels in the Portland area.

"Downtown" data for Portland are from PSU measurements. PSU is located in downtown Portland within the I-405 beltway surrounding the city center. "Downwind" data for ozone was gathered from the ODEQ Spangler Road site, which is about 20 miles SSE of PSU. During the summer in Portland, the wind direction is predominantly from the NNW or is stagnant. "Downtown" data from Houston was gathered from a TCEQ monitoring station located within the Sam Houston Beltway (C411). The site of maximum ozone depends on the timing of the start of the re-circulation of the Houston air mass due to the afternoon sea/gulf breeze (Darby, 2005). The "downwind" data for ozone was the maximum ozone level for the air-shed but could be from a number of sites 10 miles or more from the center of the city. Downwind and downtown values are considered separately since ozone is at a maximum downwind of precursor sources and is the quantity used for regulatory purposes. For the two cities under consideration, downwind sites are much less populated than downtown areas. Measures of the perception of air quality relative to actual air quality should be based on what the majority of the population actually experiences. On the other hand, downwind ozone levels are a function of the emissions of ozone precursors, such as nitrogen oxides and volatile organic compounds. Therefore, downwind ozone levels are indicative of the overall air emission activity and photochemical processing.