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Temperature, traffic-related air pollution, and heart rate variability in a panel of healthy adults

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ABSTRACT

Background: Both ambient temperature and air pollution have been associated with alterations in cardiac autonomic function, but the responsive patterns associated with temperature exposure and the interactive effects of temperature and air pollution remain largely unclear.
Objectives: We investigated the associations between personal temperature exposure and cardiac autonomic function as reflected by heart rate variability (HRV) in a panel of 14 healthy taxi drivers in the context of traffic-related air pollution.
Methods: We collected real-time data on study subjects' in-car exposures to temperature and traffic-related air pollutants including particulate matter with an aerodynamic diameter $\leq 2.5\ \mu m$ ($PM_{2.5}$) and carbon monoxide (CO) and HRV indices during work time (8:30–21:00) on 48 sampling days in the warm season (May–September) and cold season (October–March). We applied mixed-effects models and loess models adjusting for potential confounders to examine the associations between temperature and HRV indices.
Results: We found nonlinear relationships between temperature and HRV indices in both the warm and cold seasons. Linear regression stratified by temperature levels showed that increasing temperature levels were associated with declines in standard deviation of normal-to-normal intervals over different temperature strata and increases in low-frequency power and low-frequency:high-frequency ratio in higher temperature range ($> 25\ ^\circ C$). $PM_{2.5}$ and CO modified these associations to various extents.
Conclusions: Temperature was associated with alterations in cardiac autonomic function in healthy adults in the context of traffic-related air pollution.

1. Introduction

Significant changes in ambient temperature have been found to have adverse effects on human health as well as the air pollution (Kan et al., 2012), and studies during recent years have associated changes in both ambient temperature and air pollution with increased morbidity and mortality of cardiovascular disease (Goldberg et al., 2006; Guo et al., 2011; Ito et al., 2011; Ren et al., 2006; Stafoggia et al., 2008; Zanobetti and Schwartz, 2008). Several biological mechanisms linking environmental exposures to the development of cardiovascular disease have been proposed with alterations in cardiac autonomic function as one of the mechanisms that received much attention (Hampel et al., 2012; He et al., 2011; Jia et al., 2011, 2012; Ren et al., 2011; Riediker et al., 2004; Wu et al., 2010; Zanobetti et al., 2010). Heart rate variability (HRV) is a noninvasive and sensitive measure of cardiac autonomic function and has been frequently used in previous studies to assess the cardiac effects of environmental exposures. However, compared with the robust literature focusing on the cardiac autonomic dysfunction associated with air pollution exposure, few studies have examined this mechanism in light of ambient temperature changes, and most of them have been conducted under experimental conditions (Bruce-Low et al., 2006; Sollers et al., 2002; Yamamoto et al., 2007; Yao et al., 2009). Previous epidemiologic studies have examined the cardiovascular effects of ambient temperature under various settings (Adamopoulos et al., 2010; Brook et al., 2011;

Abbreviations: CO, Carbon monoxide; HRV, Heart rate variability; $PM_{2.5}$, Particulate matter with an aerodynamic diameter $\leq 2.5\ \mu m$

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Pope et al., 2004a; Ren et al., 2006, 2011; Stafoggia et al., 2008; Zanobetti and Schwartz, 2008), whereas only one of them has reported the association of ambient temperature with HRV as well as modification of this association by air pollution in an aging population (Ren et al., 2011). This study found that higher ambient temperature was associated with decreased HRV in the aging population in the warm season but not in the cold season. In fact, ambient temperature in the cold season would be a poor surrogate for real temperature exposure because people spend most time inside home and use heating in the cold season, and this inconsistency would conceivably conceal the association of ambient temperature with health outcomes. To date, the change patterns of human cardiac autonomic function in response to simultaneous exposures to temperature and air pollution and their interactive effects still remain largely unclear.

Recently we have reported the association of personal exposure to traffic-related air pollution with HRV in a panel of healthy taxi drivers around the Beijing 2008 Olympic time, a period that underwent significant air quality changes due to the implementation of air pollution control measures by the government (Wu et al., 2010, 2011a, 2011b). In addition to the air pollution changes, we also observed significant ambient temperature changes over the study with the highest daily mean air temperature of 25.0 °C during the Olympics and the lowest daily mean air temperature of 2.6 °C during the winter period (heating season) (Wu et al., 2011a). The real-time, personal exposure measurements conducted in our study provide better estimation for subjects' real exposures to temperature and air pollutants especially in the cold season. These give us the excellent opportunity to investigate the relationship between temperature exposure and HRV as well as the interactive effects of temperature and air pollution exposures. In the present analysis, we examined the effects of personal temperature exposure on HRV in the context of air pollution changes.

2. Methods

2.1. Study design and subjects

We recruited 14 eligible subjects from 44 voluntary taxi drivers based on the following criteria: age $<$ 45 years, nonsmoking, no history of physician-diagnosed cardiovascular, pulmonary, neurological or endocrine diseases, body mass index $\leq$ 30, drive taxicab during daytime hours, employed as a taxi driver for at least one year, and normal physical and blood examination results. We collected the following personal information using a self-administered questionnaire: name, sex, age, years of employment as a taxi driver, smoking status, education, and history of cardiovascular diseases or other diseases. Taxi drivers were then physically examined and tested for their seated blood pressures, resting electrocardiogram, blood cholesterol, triglycerides, and high- and low-density lipoproteins. Eligible subjects were followed for four time periods around the Beijing 2008 Olympic Games, which were before (late May to mid June, 2008), during (mid August to early September, 2008) and after (late October to mid November, 2008) the Beijing 2008 Olympic Games, and a subsequent winter period (late February to mid March, 2009), respectively. Each driver was measured for his/her ambulatory electrocardiogram and real-time, in-car exposures to temperature, relative humidity and two major traffic-related air pollutants ($PM_{2.5}$ and CO) using specific instruments and materials for a separate daily work shift (08:30–21:00) during each of the four time periods on weekdays (Monday to Friday). The study was approved by the Institutional Review Board of Peking University Health Science Center, and informed consent was obtained from each subject before the study began.

2.2. Exposure data

Instruments and materials for exposure measurements were placed on the front passenger seat parallel to the driver, and the sampling inlets or sensors were about 35–50 cm above the seat base. The drivers were asked to keep the status of taxi windows of both sides consistent with each other (open/closed) throughout the measurement periods for the equilibrium of air flow. Therefore, the measurement results could well represent the driver's real exposure in personal levels. In particular, real-time temperature and relative humidity were measured by a HOBO Pro V2 temperature/relative humidity logger (Onset Corp., Pocasset, MA, USA). Real-time $PM_{2.5}$ concentrations were measured by a Grimm Model 1.109 Portable Aerosol Spectrometer (Grimm Technologies Incorporation, Douglasville, GA, USA), and real-time CO concentrations were measured by a Model T15n Enhanced CO Measurer (Langan Products Inc., San Francisco, CA, USA). Instruments used in the study were all calibrated or checked for measurement accuracy according to the manufacture's specifications before the measurement began. The exposure measurements commonly began about half-hour (at 08:30) before the commencement of the electrocardiogram measurements, and all real-time exposure variables were logged in 1-min intervals and aggregated as 5-min averages. During the measurement periods, traffic routes of the taxicabs were recorded using a global positioning system device and the drivers were asked to record their personal activities in work diaries. Both drivers and passengers were not allowed to smoke inside the taxicab throughout the measurement periods.

2.3. Heart rate variability data

Subjects were fitted with a standard 5-lead ambulatory electrocardiogram recorder (model MGY-H7; DM Software Inc., Stateline, NV, USA). Each subject's skin was carefully cleaned with alcohol pads by a trained technician before the electrodes were connected. Each subject wore the recorder throughout the daily work shift (09:00 to 21:00) along with the exposure measurements. Data obtained from the recorder were processed using specific software (Holter System Ver 12.net, DM Software Inc., Stateline, NV, USA) according to standard criteria (Task Force, 1996). In the present analysis, we used the following four representative HRV indices which were commonly used to examine the effects of environmental exposures on cardiac autonomic function in previous studies (Jia et al., 2012; Hampel et al., 2012; He et al., 2011; Ren et al., 2011; Wu et al., 2010; Zanobetti et al., 2010): (a) standard deviation of normal-to-normal intervals; (b) low-frequency power (0.04 to 0.15 Hz); (c) high-frequency power (0.15 to 0.40 Hz); and (d) low-frequency:high-frequency ratio: the ratio of low-frequency power to high-frequency power. The standard deviation of normal to normal intervals is an index in time-domain which reflects all the cyclic components responsible for variability in the period of recording, and the other three HRV indices low-frequency power, high-frequency power and low-frequency:high-frequency ratio are indices in frequency-domain (Task Force, 1996). Among the frequency-domain indices, low-frequency power is an index reflecting both sympathetic and parasympathetic (vagal) influences whereas high-frequency power is an index reflecting parasympathetic tone, and low-frequency:high-frequency ratio is a method of assessing sympathetic and parasympathetic balance for the cardiac autonomic function (Task Force, 1996; Zanobetti et al., 2010). Previous clinical studies have demonstrated that these HRV indices were strong predictors of mortality in cardiac patients (La Rovere et al., 2003; Nolan et al., 1998), and air pollution exposure may induce increased cardiovascular mortality through the cardiac autonomic dysfunction pathway as reflected by changes in HRV (Pope et al., 2004b). In the present study, all the HRV indices were calculated in standard 5-min segments throughout the measurement periods. Data when drivers were out of their taxicabs were identified according to their work diaries and global positioning system records, and were excluded before analysis.

2.4. Statistical analysis

The overall database was stratified by a warm season (with data from periods of before and during the Olympics: May–September) and a cold season (with data from periods of after the Olympics and the winter period: October–March) according to the previous literature (Ito et al., 2011). HRV indices were $\log_{10}$-transformed to improve the normality and stabilize the variance. Exposure metrics of 5-min, 15-min, 30-min, 1-h, 2-h, 3-h and 4-h moving averages for real-time levels of temperature, relative humidity and air pollutants were used in the present analysis as previously shown to best capture the cardiac effects of environmental exposures on the same study subjects. Log_{10}-transformed 5-min HRV indices were regressed on these moving averages in the mixed-effects models, and typical results based on the exposure metrics that best capture the exposure effects were selected for presentation. Potential confounders including age, time of day, $\log_{10}$-transformed heart rate and relative humidity were included as fixed-effect terms, and day of the year was included as a random-effect term in the models based on our previous analyses (Wu et al., 2010). The following variables were also examined for their potential confounding effects: gender, body mass index, years as a taxi driver, day of week, status of cab windows and status of cab air-conditioner. Regression coefficients of these variables were not statistically significant in any of the models, and therefore these variables were not adjusted in the final models. To account for the nonlinear relationships between weather variables (temperature and relative humidity) and HRV indices, we included both linear and quadratic terms of weather variables in base models (Pope et al., 2004a; Wu et al., 2010). We included a random intercept for each subject and a first-order autoregressive covariance structure in the models to account for the repeated HRV measurements on the same subjects (Delfino et al.,