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Effects of commuting mode on air pollution exposure and cardiovascular health among young adults in Taipei, Taiwan

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ABSTRACT

The association between traffic-related air pollution and adverse cardiovascular effects has been well documented; however, little is known about whether different commuting modes can modify the effects of air pollution on the cardiovascular system in human subjects in urban areas with heavy traffic. We recruited 120 young, healthy subjects in Taipei, Taiwan. Each participant was classified with different commuting modes according to his/her own commuting style. Three repeated measurements of heart rate variability (HRV) indices {standard deviation of NN intervals (SDNN) and the square root of the mean of the sum of the squares of differences between adjacent NN intervals (r-MSSD)}, particulate matter with an aerodynamic diameter ≤2.5 μm ($PM_{2.5}$), temperature, humidity and noise level were conducted for each subject during 1-h morning commutes (0900–1000 h) in four different commuting modes, including an electrically powered subway, a gas-powered bus, a gasoline-powered car, and walking. Linear mixed-effects models were used to investigate the association of $PM_{2.5}$ with HRV indices. The results showed that decreases in the HRV indices were associated with increased levels of $PM_{2.5}$. The personal exposure levels to $PM_{2.5}$ were the highest in the walking mode. The effects of $PM_{2.5}$ on cardiovascular endpoints were the lowest in the subway mode compared to the effects in the walking mode. The participants in the car and bus modes had reduced effects on their cardiovascular endpoints compared to the participants in the walking mode. We concluded that traffic-related $PM_{2.5}$ is associated with autonomic alteration. Commuting modes can modify the effects of $PM_{2.5}$ on HRV indices among young, healthy subjects.

Introduction

The association of short-term exposure to traffic-related air pollution with mortality (Madsen et al., 2012) or adverse cardiovascular effects (Krishnan et al., 2013; Peters et al., 2004; Riediker et al., 2004; Wu et al., 2010) has been well documented in epidemiological studies. Short-term exposure to traffic-related pollutants can be a major contributor to total air pollution exposure among commuters during rush hour traffic times. It has been reported that air pollution levels are high and commuters are close to traffic emissions during rush hours when commuting (Kaur et al., 2007). The World Health Organization reported that individuals in Europe may spend 1 to 1.5 h commuting daily (World Health Organization, 2005). Therefore, exposure to traffic remains a major public health issue in urban areas with heavy traffic around the world.

Exposure levels of traffic-related air pollution vary according to the route, the various traffic loads and the mode of commuting. Previous studies have shown that walkers (Kaur et al., 2007) and cyclists (Kaur et al., 2007; McNabola et al., 2008; Thai et al., 2008) had higher particulate matter (PM) exposures on routes with high traffic loads compared to those on low traffic routes. Bus commuters experience three to four times higher PM concentrations in diesel-powered buses than in gas-powered buses (Hammond et al., 2006). Moreover, higher PM levels were demonstrated among commuters walking on sidewalks compared to commuters driving in cars (Briggs et al., 2008).

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Although previous studies have investigated the effects of traffic-related air pollution on cardiovascular events or air pollution levels associated with different modes of commuting, few studies have evaluated the differences in air pollution levels and cardiovascular endpoints related to traffic between different commuting modes. Heart rate variability (HRV) is a quantitative biological measurement of cardiac autonomic function and is analyzed in the time or frequency domains. It reflects autonomic modulation of the rhythmic activity of the sinus node (Task Force, 1996). Decrease in HRV has been demonstrated to be associated with increased risk of mortality in healthy subjects and cardiac patients (Dekker et al., 1997; Gerritsen et al., 2001; La Rovere et al., 2003). Moreover, air pollution has been reported to be associated HRV reduction (Chuang et al., 2007; de Hartog et al., 2009; Huang et al., 2013; Wu et al., 2010; Zanobetti et al., 2010). Therefore, we conducted a panel study that simultaneously compared traffic-related air pollution levels with HRV indices between different commuting modes to elucidate the associations between traffic-related air pollution exposure and traffic-induced cardiovascular effects. The aim of this study was to explore air pollution exposures and the adverse cardiovascular effects of air pollutants encountered during different modes of transport among commuters.

Methods

Participants and study design

We recruited a panel of 120 young, healthy students from universities in Taipei, Taiwan. The following study participant selection criteria were used: no history of smoking and no cardiovascular diseases such as coronary artery disease, arrhythmia, hypertension or diabetes mellitus. Each student was classified with different commuting modes according to his/her own commuting style. Three repeated measurements of HRV indices {standard deviation of NN intervals (SDNN) and the square root of the mean of the sum of the squares of differences between adjacent NN intervals (r-MSSD)}, particulate matter with an aerodynamic diameter $\leq$2.5 μm ($PM_{2.5}$), temperature, humidity and noise level were conducted for each student during 1-hour morning commutes (0900–1000 h) in four different commuting modes, including an electrically powered subway, a gas-powered bus, a gasoline-powered car, and walking. Air conditioning systems were used in the bus, car, subway and subway station. Each of the 120 students underwent three 1-hour measurements (each measurement for each ride for a total of three rides per participant), resulting in a total of 360 1-hour measurements between January and March in the years 2012 to 2014. All of the students' age, sex, body mass index (BMI) and time-activity pattern information was recorded with a questionnaire during their measurements. This study was approved by the ethics committee of St. Mary's Medicine Nursing and Management College. Written informed consent was obtained from each participant before the study.

HRV indices

We performed the 1-hour electrocardiography monitoring using a PacerCorder 3-channel device (model 461A; Del Mar Medical Systems LLC, Irvine, CA, USA). A complete 5-min segment of the NN interval was taken for the HRV indices analysis, including the standard deviation of the normal-to-normal (NN) intervals (SDNN) and the square root of the mean of the sum of the squares of differences between adjacent NN intervals (r-MSSD). A total of 36 5-min HRV indices were recorded for each student during the three repeated measurements (12 segments for each measurement) for data analysis. We obtained 4320 5-min segments of HRV indices from the 120 students in our data analysis.

Air pollution, noise and climate conditions

We performed a 1-hour continuous air pollution monitoring during each measurement for each participant. PM <10 μm in aerodynamic diameter (PM_{10}), PM <2.5 μm in aerodynamic diameter ($PM_{2.5}$), temperature, and relative humidity were measured continuously using a personal dust monitor (DUST-check portable dust monitor, model 1.108; temperature and humidity sensor, model 1.153FH, Grimm Labortechnik Ltd., Ainring, Germany), which measured and recorded 1-minute mass concentrations of PM_{10} and $PM_{2.5}$ and temperature and relative humidity. The detection limit for mass concentration is 0.1 μg/m^3. Rupprecht and Patashnick 1400a tapered element oscillating microbalance samplers (Thermo Electron Corporation, East Greenbush, NY, USA) were used to calibrate the mass concentrations of PM_{10} and $PM_{2.5}$ measured by DUST-check monitor before and after each measurement. Total volatile organic compounds (TVOCs) were measured continuously using a TVOCs monitor (SeeAiR, model M5-201, Chen-Wei VR International Co., Ltd., Kaohsiung, Taiwan). The detection limit for TVOCs concentration is 1ppb. Isobutylene was used as the calibration gas before and after each measurement. The noise level was measured using a portable noise dosimeter (Logging Noise Dose Meter, Type 4443, Brüel & Kjær, Nærum, Denmark) that reports 1-minute continuous equivalent sound levels (Leq) and time-weighted-averages (TWA) of noise doses. A range of 30–100 dBA was used to measure noise exposure with 1-minute readings conducted over 1 h. After sampling, the raw data for the 1-minute PM_{10}, $PM_{2.5}$, TVOCs, temperature, humidity and noise data were matched with the sampling time of the HRV monitoring and then computed to 5-minute averages.

Statistical analysis

We used mixed-effects models to examine the associations between air pollutants and $\log_{10}$-transformed HRV indices by running R statistical software version 2.15.1. The independent variables were the 5-minute mean PM_{10}, $PM_{2.5}$, and TVOCs values, whereas the dependent variables were the $\log_{10}$ 5-minute mean SDNN and r-MSSD values. The mixed-effects models of the four different commuting modes including an electrically powered subway, a gas-powered bus, a gasoline-powered car, and walking were adjusted for age, sex, body mass index (BMI), order of the measurement, 5-minute temperature, 5-minute relative humidity and 5-minute noise level. The participant identity number was fitted as a random intercept term in all of the mixed-effects models. Inter-individual and intra-individual variations in HRV were examined by using autocorrelation function (ACF) and partial autocorrelation function (PACF). No significant autoregressive pattern or moving average pattern was observed in all models. A one-way analysis of variance (ANOVA) using Scheffe's mean comparison test was used to compare air pollution, noise, climate conditions and HRV indices at 5-minute means between the four commuting modes. The air pollution effects are expressed as percent changes by interquartile range (IQR) changes using the formula: $[10^{(\beta \times \text{IQR})} \times 1] \times 100\%$ for the log 10-transformed HRV indices, in which β is the estimated regression coefficient.

Results

The average age of the 120 participants was 21.3 years (SD = 1.2 years), the average BMI was 22.7 kg/m^2 (SD = 1.8 kg/m^2), and the male/female ratio was approximately 1:1. The mean values (SD)