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Short-term exposure to noise, fine particulate matter and nitrogen oxides on ambulatory blood pressure: A repeated-measure study

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ABSTRACT

Exposure to road traffic noise, fine particulate matter (aerodynamic diameter ≤ 2.5 μm; $PM_{2.5}$) and nitrogen oxides (NO_x) has been associated with transient changes in blood pressure, but whether an interaction exists remains unclear. This panel study investigated whether noise, $PM_{2.5}$ and NO_x exposure were independently associated with changes in 24-h ambulatory blood pressure. We recruited 33 males and 33 females aged 18–32 years as study subjects. Personal noise exposure and ambulatory blood pressure were monitored simultaneously in 2007. During the data collection periods, 24-h data on $PM_{2.5}$ and NO_x from five air-quality monitors within 6 km of participants' home addresses were used to estimate their individual exposures. Linear mixed-effects regression models were used to estimate single and combined effects on ambulatory blood pressure. Exposure to both noise and $PM_{2.5}$ was significantly associated with increased systolic blood pressure (SBP) and diastolic blood pressure (DBP) over 24 h; NO_x exposure was only significantly related to elevated DBP. Twenty-four-hour ambulatory blood pressure increased with the current noise exposure of 5 A-weighted decibels (dBA) (SBP 1.44 [95% confidence interval: 1.16, 1.71] mmHg and DBP 1.40 [1.18, 1.61] mmHg) and $PM_{2.5}$ exposure of 10-μg/m^3 (SBP 0.81 [0.19, 1.43] mmHg and DBP 0.63 [0.17, 1.10] mmHg), as well as the current NO_x exposure of 10-ppb (DBP 0.54 [0.12, 0.97] mmHg) after simultaneous adjustment. These findings suggest that exposure to noise and air pollutants may independently increase ambulatory blood pressure and the risk of cardiovascular diseases.

1. Introduction

Road traffic is a major environmental pollutant that generates both annoying noise and contaminated air. Epidemiological studies have reported that exposure to road traffic noise, fine particulate matter (aerodynamic diameter ≤ 2.5 μm, $PM_{2.5}$) and nitrogen oxides (NO_x) was associated with transient blood pressure effects. Noise exposure above 55 A-weighted decibels (dBA) may increase systolic blood pressure (SBP) and diastolic blood pressure (DBP) in young and middle-aged adults (Chang et al., 2009, 2015). Short-term exposure to $PM_{2.5}$ was associated with increased SBP (Brook et al., 2011; Dvonch et al., 2009). Doubling NO_x exposure during one year preceding enrollment was associated with decreased SBP (Sorensen et al., 2012).

Residents who live along roadsides are always exposed to noise, $PM_{2.5}$ and NO_x simultaneously; they come from the same sources and make similar contributions to the development of cardiovascular diseases. However, their interactions with ambulatory blood pressure remain unclear. The possible biological mechanisms for the effects of $PM_{2.5}$ on blood pressure have been suggested to include local and systemic inflammation and

Abbreviations: DBA, A-weighted decibel; Leq, equivalent sound level; NO_x, nitrogen oxides; $PM_{2.5}$, particulate matter with aerodynamic diameter ≤ 2.5 μm; TWA, time-weighted average

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oxidative stress, autonomic imbalance and endothelial dysfunction (Brook and Rajagopalan, 2009; Brook et al., 2010; Mills and Snabre, 2009). Noise may activate the autonomic nervous and endocrine systems to produce the irregular endocrine and metabolic dysfunction that leads to hypertension (Babisch, 2011; Ising et al., 1999). Because $PM_{2.5}$ exposure and noise exposure may affect the same target system, the autonomic nervous system, it is worthwhile to investigate whether these agents have independent effects on blood pressure. Therefore, the purpose of this study was to explore whether noise, $PM_{2.5}$ and NO_x exposure independently affected adults' 24-h ambulatory blood pressure readings.

2. Materials and methods

2.1. Subjects

The participant recruitment and selection processes are described in detail elsewhere (Chang et al., 2009, 2012). Before the recruitment of study subjects, a commercial software (PASS, Kaysville, UT, USA) was used to calculate the minimum size of number for estimating the effect. Briefly, young adults were recruited through an on-campus advertisement at the China Medical University in 2007. A total of 69 students responded to the advertisement, but only 66 volunteers were included because three respondents reported having diagnosed hypertension on a questionnaire. No participants had any cardiovascular or pulmonary diseases. The major source of environmental noise came from road traffic; all study subjects lived at least 10 km from an airport.

In addition, a standardized questionnaire was used to collect individual information related to potential hypertension risk factors during the study period. These factors included age, height, weight, exercise habits, cigarette smoking, alcohol consumption, tea consumption, coffee consumption and a family history of hypertension. Cigarette smokers were defined as those who had smoked at least 3 days per week for more than 6 months. The same criterion was applied to define alcohol, tea and coffee drinkers. In addition, regular exercisers were defined as those who had participated in a sporting activity at least 3 times per week for 6 months or more (Chang et al., 2009, 2011, 2012). Each participant's height and weight were also gathered to calculate each individual's body mass index (BMI). During the study period, each subject was required to refrain from certain activities to prevent interference between the noise exposure measurements and the ambulatory blood pressure monitoring; prohibited activities were cigarette smoking, alcohol, tea and coffee consumption, drug use, regular exercise and the use of portable media players (Chang et al., 2009, 2012). This study was approved by the Institutional Review Board of the School of Public Health (China Medical University) before the study began, and informed consent was obtained from each participant.

2.2. Air pollutants monitoring

All participants' home addresses and the locations of 5 air-quality monitoring stations in Taichung City that had been set up around the study area by the Taiwan Environmental Protection Administration (Taiwan EPA) were identified using the geographic information system (GIS) software in ArcGIS 9.3.1 (Environmental Systems Research Institute Incorporated, Redlands, California, USA). The distances between individual home addresses and the 5 monitoring stations were calculated to have a range from 0.6 to 5.9 km, as shown in Fig. 1. Hourly monitoring data on $PM_{2.5}$ and NO_x levels were collected and assigned to each subject based on the closest station to his or her home address for the 24-h exposure measurements during the study period. This study was conducted on weekdays from Tuesday to Thursday from September to November.

2.3. Noise exposure measurements

Each participant's noise exposure was measured continuously using a personal noise dosimeter (Logging Noise Dose Meter Type 4443, Brüel & Kjær, Nærum, Denmark) that was set to record 5-min continuous equivalent sound levels (Leq) at an exchange rate of 3 dBA and to calculate the time-weighted-averages (TWA) of noise doses. The range of 50–120 dBA was chosen to measure all subjects' noise levels with 5-min readings over 24 h. Because noise levels were determined to be below the detected limits at night, a value of 35.4 dBA (the $\sqrt{2}/2$ of the detected noise level limit of 50 dBA) was used to replace the undetected values for this study (Hornung and Reed, 1990). To investigate the current and time-lagged effects of noise exposure, 5-min exposure measurements were summarized into 60-min and 120-min time-moving-average segments for further analysis.

2.4. Ambulatory blood pressure monitoring

A portable, non-invasive, automated monitoring and recording system (DynaPulse model 5000A, Pulse Metric, San Diego, California, USA) was used to monitor each subject's ambulatory SBP and DBP over 24 h. The ambulatory blood pressure measurements were automated continuously every 30 min during the daytime (08:00–23:00) and every 60 min at night (23:00–08:00) to avoid interrupting sleep quality. The DynaPulse system can measure an individual's arterial pulsation signals via a non-invasive cuff device that transfers the arterial waveform to the estimated ambulatory blood pressure. The SBP and DBP readings generated by this system were validated against the measurements using a traditional mercury sphygmomanometer (Brinton et al., 1998a, 1998b). All participants' ambulatory SBP and DBP readings during the daytime, at night and over 24 h were used to investigate the transient and sustained effects of exposure to noise, $PM_{2.5}$ and NO_x before and after simultaneous adjustment.

2.5. Statistical analysis

The Shapiro–Wilk test was used first to determine the normality of the continuous variables, i.e., age, BMI, and 24-h noise exposure, hourly $PM_{2.5}$ level and hourly NO_x level measurements. Since none of these variables were normally distributed among participants (all p Values < 0.001 for the Shapiro–Wilk test), a 10-based logarithm transformation was applied to fit the normal distribution before the regression models were employed. Accordingly, the non-parametric Spearman correlation method was used to calculate the coefficients between each exposure and ambulatory blood pressure during the daytime, at night and over 24 h.

Additionally, to explore the linear associations between ambulatory blood pressure and exposure to noise, $PM_{2.5}$ and NO_x, smoothing splines (following the GAMM procedure, mgcv-package, R version 2.13.2, R Foundation for Statistical Computing, Vienna, Austria) (Wood, 2004, 2006) were used in this study.

Next, linear mixed-effects regression models were applied to investigate the associations between exposure to noise, $PM_{2.5}$ and NO_x and ambulatory blood pressure by controlling for important participant confounding factors (Littell et al., 1996). These regression models were selected to address the auto-correlation problem between the repeated ambulatory blood pressure measurements and to increase statistical power by combining information across study subjects. Linear mixed-effects regression models have both